FLOODS AND FLOOD CONTROL POLICIES
An Analysis with reference to the Mahanadi Delta in Orissa

Dissertation submitted in partial fulfilment
of the requirements for the Degree of
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I hereby affirm that the research for this dissertation titled **"FLOODS AND FLOOD CONTROL POLICIES: AN ANALYSIS WITH REFERENCE TO THE MAHANADI DELTA IN ORISSA"** being submitted to the Jawaharlal Nehru University for the award of the Degree of Master of Philosophy was carried out entirely by me at the Centre for Development Studies, Trivandrum.

Sadhana Satapathy

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Certified that this dissertation is the bonafide work of Mrs.Sadhana Satapathy and has not been considered for the award of any other degree by any University. This dissertation may be forwarded for evaluation.

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INTRODUCTION

The immediate motivation for the present study is the fact that, on a world scale, the frequency of floods has increased one and half times in the 1970's over that in the 1960's; and the intensity of floods has increased roughly two to three times over the same period (see Table 0.1). Thus floods have emerged as the second most important 'natural' disaster after droughts[1].

Table 0.1

Frequency & Intensity of Floods, Worldwide

Period	Frequency	Intensity	
	No. of occurrence per year	No. of people affected per year (in millions)	No. of people killed per year
1960's	15	5.2	2370
1970's	25	15.4	4680

Source: Tinker (1984), pp.9-10.

Such an increasing frequency and severity of floods implies that the total damage due to floods has been increasing. This is rather surprising in view of the fact that massive expenditure on flood control schemes has been incurred in different countries. Moreover, no theory has been put forward ascribing this phenomenon to changes in the rainfall pattern.

In fact, there has been a recent worldwide debate: is the increasing damage due to phenomena such as floods to be regarded merely as natural disasters? A major and influential point of view within this debate has emerged. It takes the position that floods are fundamentally a man-made phenomenon. The major target of attack of this view has been the kinds of flood control measures that have been undertaken in different flood-prone countries. In addition to flood control embankments, which have been the traditional means of flood control, the single most important modern measure of flood control has been the construction of large-scale storage reservoirs. It is this measure which has come under severe criticism. The large dams along with their embankments are referred to as structural control measures. There are two aspects of the arguments against such structural control measures. First, it is pointed out that certain adverse social/environmental effects of large river valley projects are not properly included in the cost; if included, they are likely to change the cost-benefit ratio significantly. Some of the adverse effects of such large dam projects are pointed out to be as follows: large scale displacement of human settlements without proper resettlement; significant destruction of forest area and/or submergence of cultivated land; inadequate understanding of the technology of large dams often leading to dam failures; loss of wildlife; increased incidence of water borne diseases - notably malaria and schistosomiasis; waterlogging; and salinity[2].

The second aspect of the argument against the structural control measures is the following: It is suggested that such measures are bound to be more or less completely ineffective and hence that the situation could not have been worse without such measures. Indeed such measures often accentuate the problem of flood: "There is now an increasing body of evidence that structural controls do little or nothing to reduce the ravages of floods. On the contrary, they exacerbate the problem by increasing the severity of flooding"[3].

From the point of view of the present study, the second aspect of the above argument becomes relevant and hence let us look at this a little more closely. How is it argued that structural control measures do almost nothing to check floods, but often make it worse? As regards large multi-purpose reservoirs with flood control as one of the objectives, it is pointed out that "... there is often a conflict between the need to keep reservoirs low for flood control purposes and keep them high in order to generate electricity and provide water for irrigation. The result is a 'trade-off' between the three competing demands with those who wish the reservoirs to be kept high invariably winning the day. The trade-off frequently proves disastrous"[4]. As regards flood control embankments, how these can not only prove ineffective but actually increase the severity of floods is explained as follows: "By containing a river within concrete embankments, one does not reduce the total volume of flood waters. One does, however, dramatically increase the river's rate of flow. When a flood occurs, the waters are literally propelled downstream. Inevitably the damage done in the flood plains downstream is correspondingly increased"[5]. This inherent limitation of embankments is said to be compounded by a number of external factors, such as deforestation in the catchment and soil erosion, which make the role of the embankments even more limited and can prove to be disastrous: "During heavy rainfall, the volume of water carried by rivers in deforested areas can be massive. The pressure put on flood control embankments is tremendous. Deforestation has another serious consequence. It causes severe erosion increasing the silt load of the rivers. Where a river is chenneiled through embankments that silt simply accumulates. The height of the river bed is thus raised until, eventually, it becomes higher than the surrounding land. Such silting up further increases the pressure on embankments, whose height must be raised year after year in order to prevent flooding. But raising the height of the embankments does not solve the problem indefinitely. In the long run, it can only increase the severity of the future floods. For when a breach occurs, the result is disastrous"[6]. Such structural control measures have the further consequence, it is suggested, of leading to intensified use of flood plains by making it 'appear' safe to settle on them.

Taking the above arguments as our starting point, it still remains to be seen whether the structural control measures have played <u>any</u> role at all in reducing floods and flood damage. If not, whether it has to do with the very nature of such measures or because there are autonomous factors at work which limit the effectiveness of such measures. Some of these factors are of course singled out in the above argument but, as we shall see, these autonomous factors interact in a complex way. In other words, it is through a systematic analysis that one would be able to see, precisely in what ways, the increasing severity of 'natural' disasters such as floods are indeed 'man-made'. To anticipate the conclusion of the present study, whereas in some respects the above argument holds good, in some other respects, it does not. For example, we shall see that the large dam project in our study area has in fact reduced the frequency and intensity of floods; that the conflict between flood control objective on the one hand and power and irrigation objectives on the other, is not inherent in a large scale multi-purpose project but is rather due to <u>changing</u> conditions of run-off in the upstream catchment of the reservoir; that the flood control embankments have played a negative role because of unplanned, haphazard nature of the construction and poor maintenance, and so on.

The empirical focus of the present study is the widespread damage due to floods in Orissa, which has been identified as one of the five chronically flood affected states in India[7]. Within Orissa, floods in the deltaic area of the Mahanadi river have been most important and with a long history. The recorded history (for the colonial period) of floods in the Mahanadi delta goes back to 1834, when there was a severe flood. There were floods almost every other year after 1834 with very large floods in several years in between such as 1855,1866,1872,1896,1926,1933,1937,1940,1955 etc.

The major form of flood control in the Mahanadi delta has traditionally been construction of flood control embankments on one or both sides of the river bank within the delta. This was done mainly through private initiatives by Zamindars to protect their respective estates. During the second half of the 19th century, the colonial government also took interest in the construction of embankments. Thus a thick network of flood control embankments had come into being in the Mahanadi delta by the time of Independence. The embankment system has been further extended after Independence.

But the construction of the Hirakud dam across the Mahanadi (in 1957), which was one of the first multi-purpose river valley projects after Independence, has been put forward as a significant flood control measure. In fact, the Hirakud Reservoir was first conceived as a means of flood control in the Mahanadi delta, since it was thought that the menace of floods had to be eliminated before planning for irrigation, etc.

The purpose of the analysis of the present study is to examine the role of flood control measures (particularly of the Hirakud Dam) and flood control embankments, in checking floods and flood damage in the Mahanadi delta. Such a concern of the present study with the efficacy/effectiveness of flood control measures can be said to have an immediate economic significance in the following way. The Mahanadi delta, like all deltaic regions, consists of very fertile alluvial plans; it is closely cultivated (rice being the major crop) and supports a large population. Because of limited perennial irrigation in the Mahanadi delta at present, the bulk of the cropped area is under the rice crop during the monsoon period, ie., during the flood season. Thus the area under monsoon rice accounts for 47% of the gross cropped area in the Mahanadi delta, and this constitutes 26% of the total area under monsoon rice for Orissa as a whole[8]. Hence, flood control in the Mahanadi delta becomes an important preconditioning for the stabilisation and growth of agricultural (food) production. This is in general true of all flood-prone deltaic regions, such as those of Eastern India. Therefore it becomes important to study the role of flood control measures so as to bring out the limitations of particular measures and the ways in which these measures may have failed to produce the desired effect.

The study is organised as follows. In Chapter One, we present an analytical framework which will provide us with a possible explanation for the phenomenon of increasing floods and flood damage even with substantial flood control measures. This will be preceded by a description of river system in general, and river systems and floods in the Indian context as well as a review of flood control policies and flood damage in India in the post-Independence period.

Chapter Two will seek to establish the trend in the frequency and intensity of floods as well as in the extent of flood damage in the Mahanadi delta.

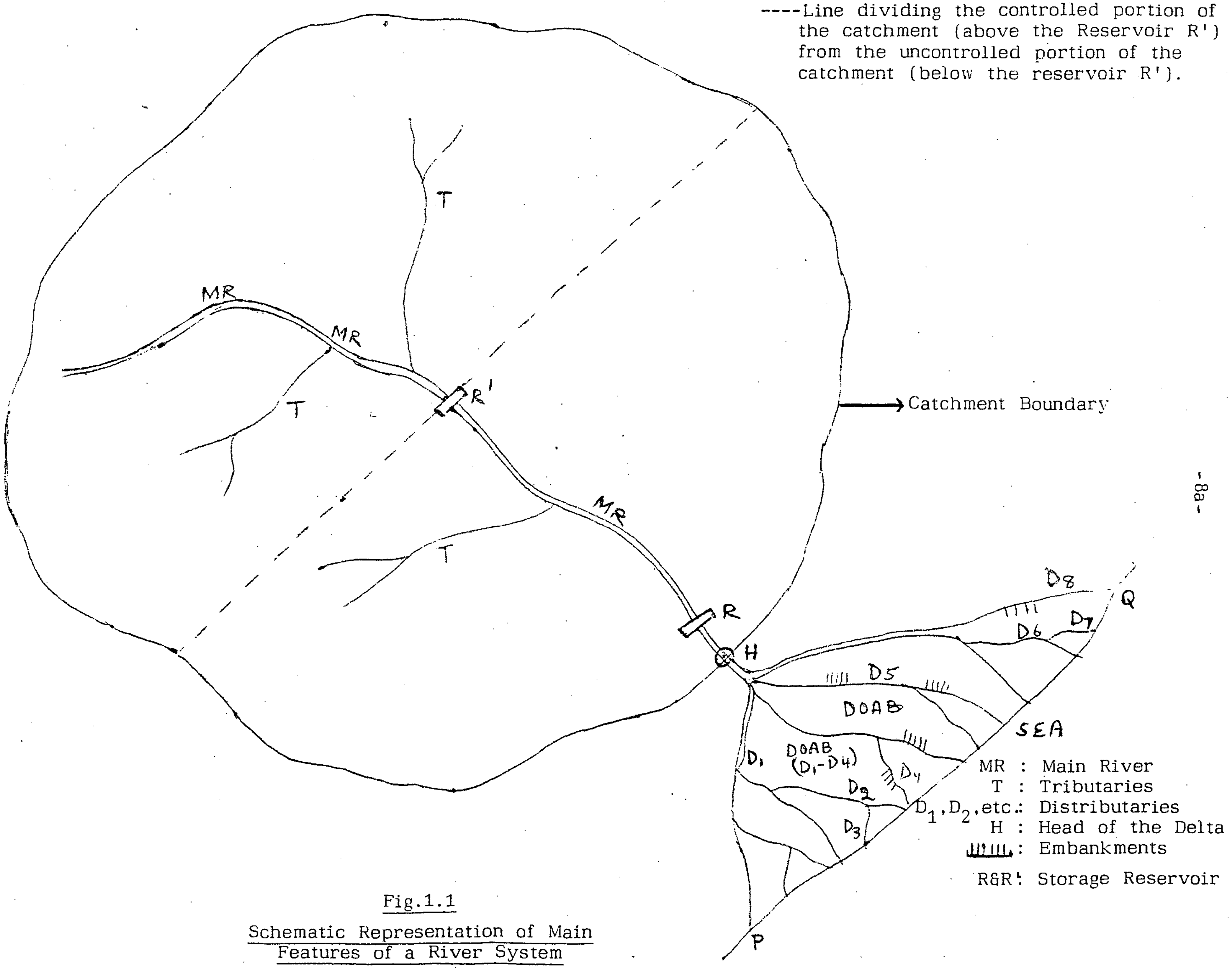
Chapter Three will focus on the role of the Hirakud reservoir, alongwith other conditions in the Mahanadi catchment in determining the frequency and intensity of floods in the Mahanadi delta.

Chapter Four will focus on the role of flood control embankments in the Mahanadi delta in containing the floods within the banks and hence in checking flood damage in the delta.

In the end, we shall pull together the main findings of the study and point out some larger implications of it.

NOTES

1. Tinker(1984), pp. 9-10.
2. See Goldsmith and Hildyard (1984), for a concise statement of the above points.
3. *Ibid*, p. 9
4. *Ibid*, p. 10
5. *Ibid*, p. 9
6. *Ibid*, p. 10
7. National Committee on the Development of Backward Areas (1981)
8. The Mahanadi delta is mostly comprised of Cuttack & Puri districts (see Chapter Four); the above figures are thus for these two districts taken together; Area under 'Winter Rice' is regarded as the rice area during the flood season. The above percentages have been calculated from the average figures for four years, namely, 1973-74, 77-78, 78-79 and 79-80 and are taken from Government of Orissa, *Economic Survey of Orissa*, 1980-81, Bureau of Economics and Statistics, pp. 113, 97, 101.



----Line dividing the controlled portion of the catchment (above the Reservoir R') from the uncontrolled portion of the catchment (below the reservoir R').

⟶ Catchment Boundary

MR : Main River
T : Tributaries
D_1, D_2, etc. : Distributaries
H : Head of the Delta
ШШ : Embankments
R&R' : Storage Reservoir

Fig.1.1

Schematic Representation of Main Features of a River System

CHAPTER ONE

FLOODS AND FLOOD DAMAGE: TOWARDS AN ANALYTICAL FRAMEWORK

Before coming to the analytical framework of the study, we shall first give a general descriptive account of the characteristic features of a river system and the phenomenon of river floods. The purpose of this is to clarify the meaning of certain technical terms and parameters which will be used in different parts of the thesis (see also Glossary of Selected Terms for this purpose). This will be followed by a brief account of the importance of river systems and river floods in the Indian context. We shall then make a close examination of the nature and extent of flood control measures undertaken in India after Independence and the trend in the extent of flood damage, in order to have a preliminary idea about the extent of effectiveness of such measures for India as a whole.

I

River System & Floods

A river is a natural stream of water of a fairly large size flowing in a definite course or chennel or series of converging and diverging channels. The natural purpose of a river is to drain the precipitation of a certain area. The area from which a river receives its water due to precipitation is called the catchment basin or drainage basin. Usually within a catchment area there are a number of relatively smaller river channels contributing their flows to the main river channel. These are called tributaries (see Fig.1.1) which together with the main river form a river system.

Usually, a river course traverses three types of topography, namely, the upper reach in the hilly regions, the middle reach in the alluvial plains and the estuarine reach near its outfall into the sea. A river, soon after entering the alluvial plain usually divides itself into a network of distributary channels (shown as D_1, D_2 etc in Fig.1.1) which fall independently into the sea or a lake. The alluvial tract of land enclosed between diverging branches of a main river and the sea is called the Delta of the main river, usually triangular in shape (represented by the area HPQ in Fig.1.1). The apex of this triangle is thus called the head of the delta (point 'H' in Fig 1.1). The delta of a river is usually extensively cultivated and supports dense agricultural population. Inhabited land between any two adjacent distributary channels is called a Doab (see Fig.1.1).

In the upper reaches, where the river flows through the mountainous terrain or undulating country there is generally no overflow of banks during high discharges (see Glossary) and the problem is confined to bank erosion or in a few rare cases to shifting of the course. It is in the middle and lower reaches, where the country is flat, that the rivers overflow their banks and cause innundation of low-lying lands. Thus the problem of floods is confined to the deltaic area of a river. This brings us to the question, what do we mean by floods? Is there any general definition of floods possible?

Defining a flood is difficult, partly because floods are complex phenomena and partly because they are viewed differently by different people. For our purpose, the definition of floods should incorporate the notions of both innundation and damage.

On the other hand, a narrow definition of a flood could run as follows[1]. 'A flood is a relatively high flow which overtaxes the natural channel provided for the run-off', but then so many channels have been artificially improved that the following definition is rather more appropriate: 'A flood is any high streamflow which overtops natural or artificial banks of a stream.' However, because the banks of a stream vary in height throughout its course, there is no single bankfull level above which the river is in flood and below which it is not in flood. Thus, a more general definition of floods is as follows: 'A flood is a body of water which rises to overflow land which is not normally submerged[2]. In this definition, innundation is explicit and damage is implied.

As we have seen above, floods occur mostly within the delta of a river and hence from the point of view of floods the volume of inflow of water per unit time at the head of the delta (point H in Fig.1.1) becomes an important variable. The delta channels of a river (distributaries) have the capacity of carrying a certain maximum volume of water per unit time entering the delta at its head. Innundation would normally occur if the actual rate of inflow exceeds this maximum.

Flood Control reservoirs or multi-purpose reservoirs (with flood control during the monsoon period as one of the objectives) can thus be constructed across the main river at any point above the head of the delta, given that a suitable site for the same exists. For example, in terms of Fig.1.1, it could be at the point R. In that case, the run-off of almost the entire catchment has to be intercepted. Hence the capacity of the reservoir has to be correspondingly large.

On the other hand, it could be constructed at some point upstream of the river course (such as R' in Fig.1.1). In this case, the run-off will be only for a part of the total catchment and hence the capacity of the reservoir can be correspondingly small. But at the same time, the run-off of that part of the catchment which lies below R' will remain uncontrolled.

While a reservoir at some point within the catchment seeks to check the run-off, flood-control embankments are constructed within the delta on one or both banks of the distributaries (as shown in Fig.1.1).

II

Flood Control Policies and Flood Damage in India

The average annual precipitation in India (1150 mm) is higher than that of every other continent in the world except that of South America and twice that of the average annual precipitation of Asia[3]. This is equivalent to about 400 million hectare meters (mham) of water. Out of this, after evaporation losses and conversion into soil moisture etc, as much as 135 mham has to flow down as surface water[4]. Thus India has a thick network of river systems which act as natural channels for carrying this enormous volume of surface water to the sea.

River System of India

The rivers of India can be grouped according to four regions[5]: 1) Brahmaputra Region, 2) Ganga Region, 3) North-west Region, 4) Central India & Deccan Region. The Brahmaputra region consists of rivers of Brahmaputra and Barak and the tributaries. It covers the states of Assam, Meghalaya, Manipur, Tripura, Nagaland etc. The Ganga region consists of the river Ganga and its numerous tributaries. It covers the state of Uttar Pradesh, Bihar, South and Central portion of West Bengal etc. The main rivers in the North West region are the Indus and its tributaries - the Jhelum, the Chenab, the Ravi, the Beas and the Sutlej - all flowing from the Himalayas. This region cover the State of Jammu and Kashmir, Punjab and parts of Himachal Pradesh, Haryana and Rajasthan. Finally, the important rivers in the Central India and Deccan region are the west-flowing rivers, the Narmada and the Tapti and the east-flowing rivers, the Mahanadi, the Godavari, the Krishna, the Subarnarekha, the Brahmani, the Baitarani, the Pennar and the Cauvery. This region covers all the southern states and the states of Orissa, Maharashtra, Gujarat and parts of Madhya Pradesh.

Floods and Flood Control Policies

Floods have been a regular feature in most of the above river systems as three-fourth of the average annual precipitation comes down in the monsoon months of June to September. States like West Bengal, Bihar, Uttar Pradesh, Assam and Orissa are known to be traditionally flood affected areas. The single most important traditional means of flood control in India, as in the fertile valleys of Egypt and China, has been the construction of flood control embankments with community/private initiative. The State also seems to have played a major role - through its local representatives - in the construction and maintenance of embankments to ensure a stable revenue from agricultural land. During the later part of the British rule, the same practice was continued with Government and private initiatives, partly as an adjunct to canal irrigation schemes. Thus, it has been estimated that upto 1947 about 5280 km of embankments existed along different rivers, giving protection against floods to about three million hectares[6].

After Independence, as part of the planned development strategy, planned expenditure on flood control began to be undertaken. During the period 1947-1954, in addition to the traditional methods of embankments, the technique of flood protection by moderation through flood space in multi-purpose reservoirs was decided as a matter of policy. This new way of thinking was reflected in the First Five Year Plan document published in 1952 which stated that "the problem of flood control is now always considered in conjunction with the construction of multi-purpose projects. The construction of large dams to store these flood waters is the most effective way of preventing flood damage'[7]. As a result, a few multi-purpose projects such as in the Damodar and the Mahanadi valleys were started during the First Plan.

In the wake of a spate of severe floods in different parts of the country during the monsoon of 1954, the then Union Minister for Planning and Irrigation & Power placed before the Parliament, two statements which were to form the basis of a comprehensive national policy on flood control. This initial policy statement conceived of a time-bound programme consisting of three phases. In the immediate phase, extending over a period of two years, intensive investigation and collection of data was to be carried out. Comprehensive plans could then be drawn up and designs and estimates prepared for short-term measures of flood protection. During the second phase, lasting for about six years, flood protection measures such as embankments and channel improvements were to be undertaken. There was an emphasis on such measures as, to quote the original statement, "this type of protection will be applicable to a major portion of India now subject to floods"[8]. The third phase was related to selected long-term measures such as the construction of storage reservoirs on tributaries of certain rivers and additional embankments, wherever necessary. Clearly this approach was different from the one followed during the first Five Year Plan which believed that large dams by themselves could solve the flood problem. At the same time, it was felt that the short-term and long-term measures taken together, could go a long way towards containing the flood problem. The subsequent official policy statements continued the same optimistic view while admitting that the problem of floods could not be completely cured. To quote from the "Statement on the flood control programme and flood situation in the country" which was presented before the Parliament in 1958, "the various flood control measures either executed or visualised should not lead to a wrong impression that complete immunity from flood damage is physically possible in some distant future. Any such illusion has to be dispelled and it has to be emphasised again ... that even the best known methods of flood control aim only at providing what may be called a reasonable degree of protection ... . There is, however, every hope that, with the completion of the immediate, short-term and long-term programmes, there will be substantial diminution in human distress and sufferings due to floods"[9].

Plan Expenditures on Flood Control and Flood Damage

With this background of the overall policy approach to the problem of flood control, we can now turn to look at the financial outlays on flood control on the one hand and actual flood damage on the other. This will be done for the period starting from the launching of the national policy on flood control (ie., 1954) till 1978, thus covering the five five-year plans.

Table 1.1

Actual Outlays on Flood Control Measures, India

(in Rs. Crores)

Plan/Period	Outlay on Flood Control	% of Total Plan Outlay
Ist Five Year Plan (1951-56)	13.8	0.70
IInd Five Year Plan (1956-61)	49.2	1.07
IIIrd Five Year Plan (1961-66)	86.0	1.00
Annual Plans (1966-69)	43.6	0.64
IVth Five Year Plan (1969-74)	171.8	1.08
Vth Five Year Plan (1974-78)	274.9	0.70
VIth Five Year Plan (1978-83)	1045.0	1.50
Total	1684.3	1.15

Source: Govt. of India, Report of the National Commission on Floods, Vol I, p.105, Govt. of India, Ministry of Irrigation, Report 1983-84, p.4

The total financial outlays by State and Central Governments on successive five year plans are given in Table 1.1. We find that the outlay on flood control has been steadily increasing over the successive five year plans in absolute terms. But, as a proportion of total plan outlay, it is almost constant around one percent. The above financial outlays, however, do not include the financing of large and medium multi-purpose river valley projects. Thus, the cumulative share of the Centre of the figures given in Table 1.1 comes to only Rs.45 crores till 1978.

Now, coming to the physical achievements, the cumulative gross storage capacity created through multi-purpose storage reservoirs comes to 9% of average annual flow of water for all the rivers in India[10]. In fact, for some of the flood prone rivers, the percentage is higher. For example, for the Indus it is 25%, for the Godavari, 14%, for the Krishna, 57%; for the Cauvery, 36%; for the Mahanadi, 13% etc.

On the other hand, the physical achievements for the direct measures for flood control which mainly mean flood control embankments, construction of drainage channels and improvement of river channels, are as follows: Between 1954 and 1978, a total length of 10,821 kms of embankments have been built as against an estimated 5280 kms of embankments which existed prior to 1954[11]. Again, a total length of 19,260 km of drainage channels and river channel improvement works have been completed. As a result of these direct measures of flood control, a total area of 10 million hectares is supposed to have been given a reasonable degree of protection out of an estimated 34 million hectares of area liable to floods.

Fig.1.2

Cropped Area, Non-Cropped Area and Total Area Affected by Floods in India, 1953-1980 .

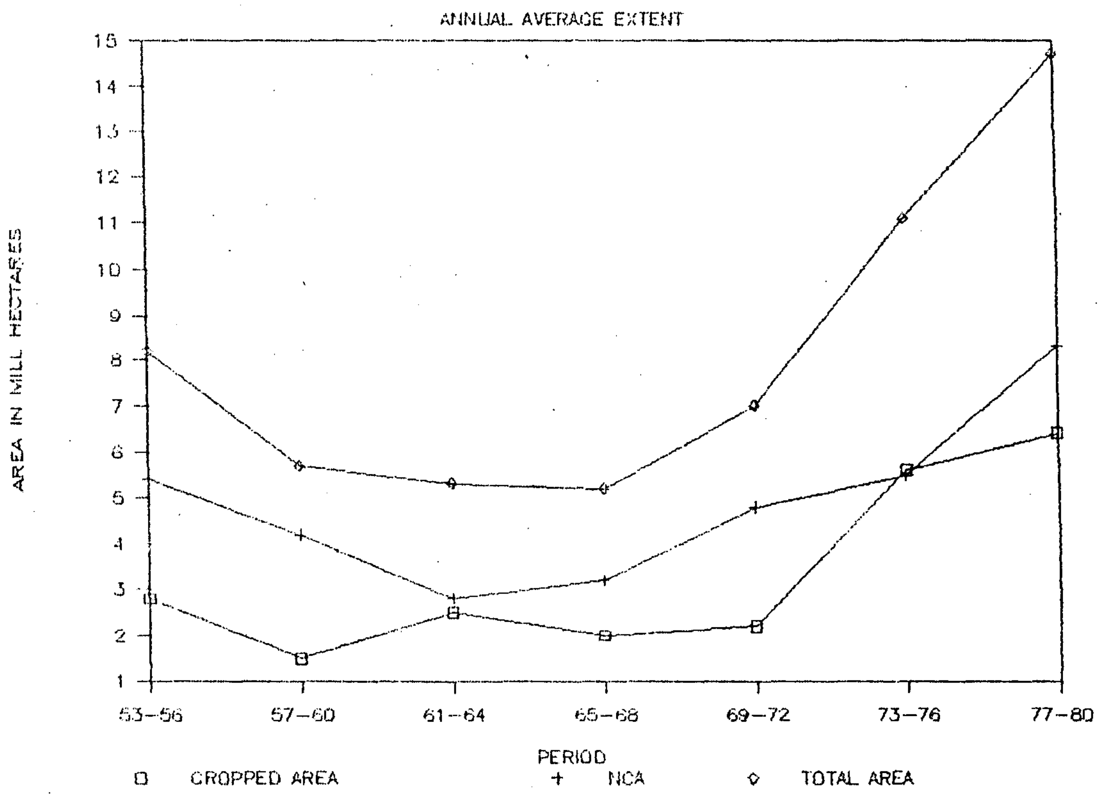
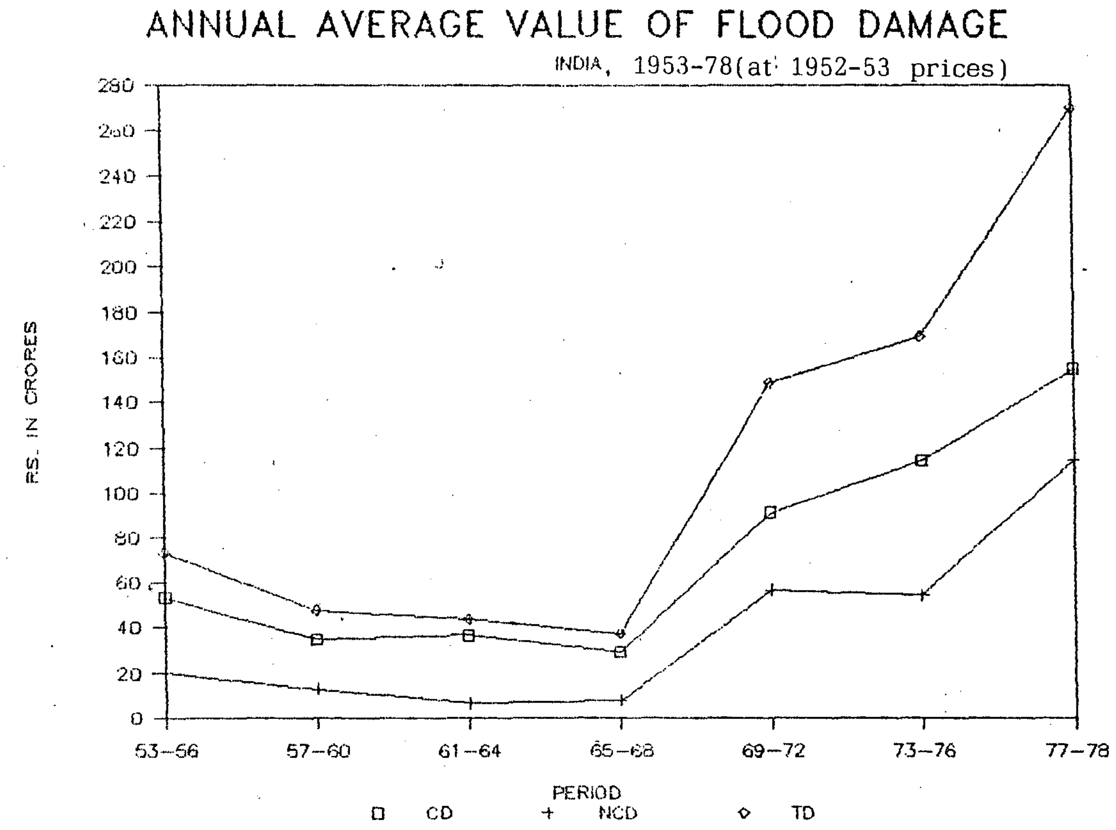


Fig.1.3



In fact, for some of the flood-prone states, the percentage of area liable to floods that has been given protection is higher than that for the country as a whole (about 33%): Andhra Pradesh (50%); Assam (41%); Bihar (37%); West Bengal (38%).

What has been the trend in the extent of actual flood damage over the period for which the above mentioned flood control measures were adopted? To what extent have they been effective? We now turn to take a look at the relevant data. We have data for the period 1953-1980. We find (see Table 1.2) that during this period, after some fluctuations in the extent of physical damage, there has been a steady increase in the same since 1965-68 (see also Fig.1.2). The monetary value of damage at constant prices thus shows that from an estimated damage of some Rs.73 crores per annum during 1953-56, it has gone up to Rs.148 crores by 1969-72 (see Table 1.3 and Fig.1.3).

Table 1.2

Annual Average of Area Affected by Floods, India

(in million hectares)

Period	Cropped Area Affected	% of total area affected	Non-Cropped Area	Total Area
1953-56	2.8	34.0	5.4	8.2
57-60	1.5	26.6	4.2	5.7
61-64	2.5	47.2	2.8	5.3
65-68	2.0	38.1	3.2	5.2
69-72	2.2	31.2	4.8	7.0
73-76	5.6	50.5	5.5	11.1
77-80	6.4	43.5	8.3*	14.7

*Average for 1977 & 1978 only

Source: (see overleaf)

Source: Govt. of India, Ministry of Energy and Irrigation (Dept. of Irrigation), National Commission on Floods, Report, Vol I, New Delhi, 1980, p.59;

Centre For Science & Environment, The State of India's Environment 1982 : A Citizens' Report, p.62.

Table 1.3

Annual Average of the Value of Flood Damage, India

(Rs Crores)

(at 1952-53 prices)

Period	Crop Damage	Non-Crop Damage	Total Damage
1953-56	53.3	19.8	73.1
57-60	35.0	13.0	48.0
61-64	37.0	7.0	44.0
65-68	29.5	8.2	37.7
69-72	91.6	57.1	148.7
73-76	114.6	54.6	169.2
77-78	154.8	115.1	269.9

Source: Govt. of India, Ministry of Energy and Irrigation (Dept. of Irrigation), National Commission on Floods, Report, Vol. 1, New Delhi, 1980, p.60.

The flood-prone area (or the area liable to floods) is defined as the maximum area damaged due to floods in any one year over a period and has been estimated by the National Commission on Floods. It has been found that the flood-prone area in the country has increased from about 25 million hectares at the end of 1960s to about 40 million hectares by the mid-70s[12]. This has been due to two reasons:

First, in the 1970s new states like Andhra Pradesh, Rajasthan, Madhya Pradesh etc., which were outside the traditionally flood affected areas, are also being subject to floods[13]. Second, new areas within the traditionally flood-prone states like U.P., Bihar and Orissa are getting flooded[14].

Such an increase in the extent of flood-prone areas as well as the extent of actual physical damage due to floods also means a heavy indirect cost in terms of flood relief. To give one example, the expenditure on flood relief during the Sixth Plan period was Rs.1190 croes, whereas the planned expenditure on flood control works was Rs.1045 crores[15].

Thus, we find that the extent of potential (as measured by the extent of flood-prone area) as well as actual damage due to floods shows an increasing trend for India and for the world as a whole. The important question is, how does one account for this? Could it be because the expenditure on flood control measures is not sufficient or because the nature of flood control measures is not appropriate? It is clear that, in order to throw light on these questions, a systematic analysis is called for. For this, it is necessary to have an analytical framework which incorporates some important underlying factors. In this framework, such factors are recognised as crucial in influencing the extent of flood damage directly or indirectly. We shall now present the outline of such an analytical framework.

III

Analytical Framework

It is obvious that abnormally high and concentrated rainfall in the catchment of a river is both a necessary and a sufficient condition for the occurence of any one flood. But the relationship between rainfall and extent of flood damage over time is neither simple nor constant once we hypothesise that there are a whole lot of mediating or intervening factors which shape or condition the nature of the relationship between rainfall and damage due to floods. Below we shall indicate in broad outline what these factors could be and how they have a dynamic impact on the above relationship.

For the purpose of the present analysis, we introduce two separate sets of such mediating factors. The first set of factors has to do with conditions in the catchment, whereas the second set has to do with the conditions in the delta. We shall begin by explaining the role of the first set.

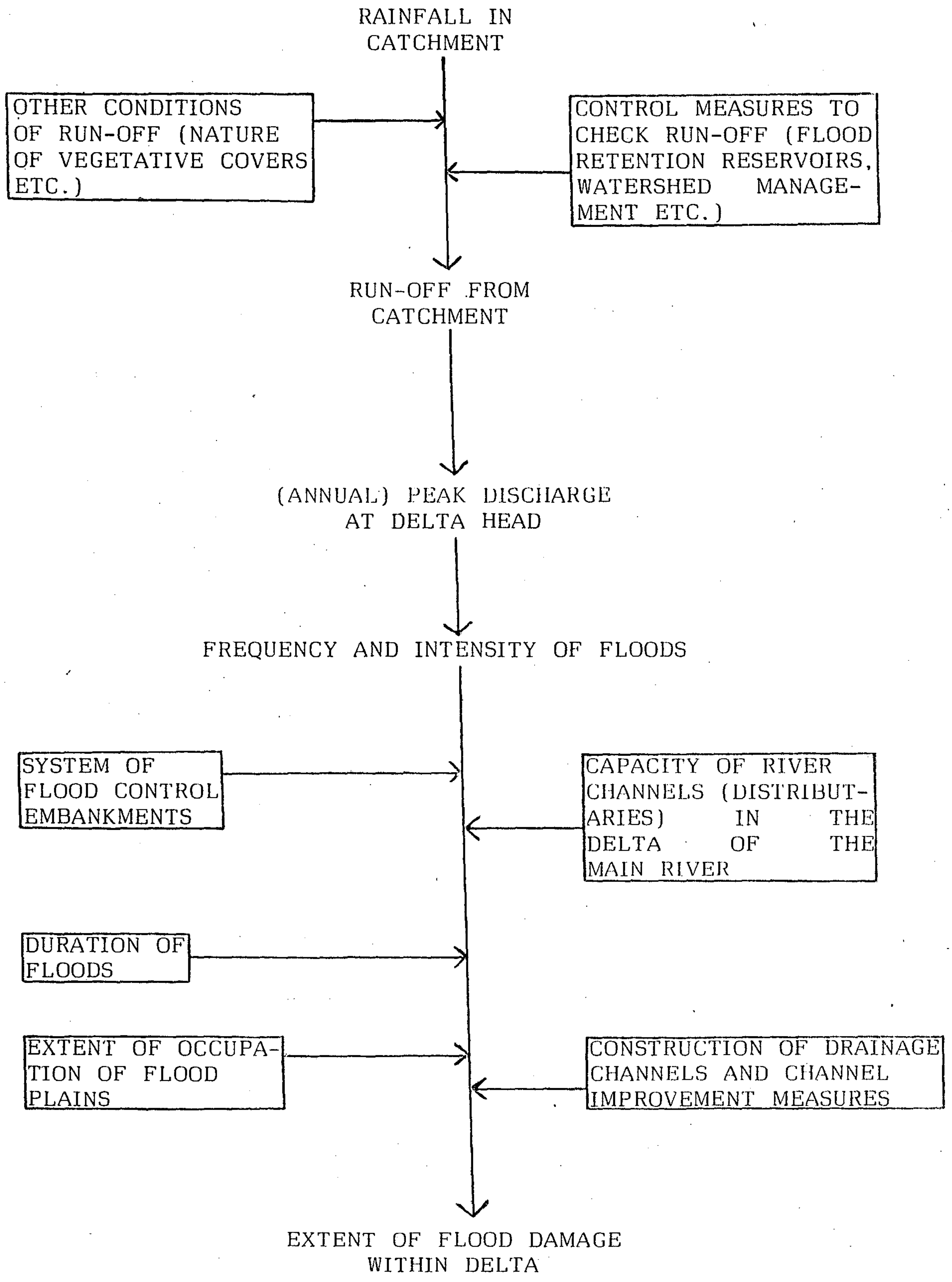
Rainfall and Run-off

Concentrated rainfall (usually during monsoon period) in the catchment of a river leads to substantial surface run-off. From the point of view of floods, what is important is not the total amount of surface run-off but the peak discharge at the delta head of a river. This, in turn, determines the frequency and intensity of floods depending on whether, and by how much, the peak discharge exceeds the capacity of the distributaries of a river within the delta. The first set of factors basically mediate the relation between rainfall and run-off. These include (1) the nature of vegetative covers in the catchment and (2) control measures to check run-off such as flood retention reservoirs (or multi-purpose reservoirs without any flood reserve but used for flood control during the flood season), watershed management in the form of intensive afforestation and soil conservation measures etc. Once we introduce such factors, we can think of a number of ways in which frequency and intensity of floods can vary without any change in the pattern of rainfall. For example, if extensive deforestation and loss of vegetative cover is occuring over time in the catchment area, this can lead to an increase in the proportion of run-off to rainfall, which can increase the peak discharge. Adequate watershed management, on the other hand, can counter this. Similarly, storage reservoirs can moderate the peak discharge by absorbing a part of the run-off and releasing it slowly. But if there is increased deforestation and hence soil erosion in the catchment lying above such a reservoir, this can lead to siltation of the reservoir and reduce its effectiveness. In this way the frequency and intensity of floods can increase or decrease even with an unchanging pattern of rainfall. In short, the first set of mediating factors have either a flood-intensifying or flood-moderating effect.

Flood Intensity & Flood Damage

Now, the relationship between the frequency and intensity of floods and the extent of flood damage is mediated by the second set of factors which operate within the delta and include 1) capacity of drainage channels (distributaries) of a main river, 2) construction of additional drainage channels and channel improvement measures to maintain or improve this capacity, 3) system of flood-control embankments, 4) duration of floods, 5) extent of occupation of the flood-prone area in the delta. These sets of factors can act in such a way that, even for a given frequency and intensity of floods, the extent of flood damage may vary. For example, even if the frequency and intensity of floods remains the same/decreases over time it can lead to greater/no less damage in case one or more of the following things occur: (i) if there is increased occupation of the flood-prone areas, or (ii) if the capacity of river channels is diminished because of siltation of the river bed, say due to increased soil erosion in the lower catchment below the storage reservoir, or (iii) if the embankment system is not maintained properly which leads to breaches or (iv) if the duration of floods (see Glossary) increases which increases the pressure on the embankments leading to breaches etc. It can be a combination of two or more of the above conditions as well. On the other hand, even if the frequency and intensity of floods increases over time, the extent of flood damage need not increase proportionately, if measures such as maintenance of the embankments with adequate height and strength, maintenance and improvement of the carrying capacity of the delta channels of a river, or restrictions on the occupation of the flood-prone area, etc. are undertaken. In effect, the second set of mediating factors can be said to have either a flood damage-intensifying or flood damage-moderating effect.

The above framework is schematically presented in the next page. Some of the above analytical points (such as the effect of vegetal cover on soil erosion and flood flow; the way in which the duration of flood can lead to greater damage for a given intensity of flood, etc) will be developed and illustrated in the course of the empirical analysis to follow.


RAINFALL IN CATCHMENT
OTHER CONDITIONS OF RUN-OFF (NATURE OF VEGETATIVE COVERS ETC.)
CONTROL MEASURES TO CHECK RUN-OFF (FLOOD RETENTION RESERVOIRS, WATERSHED MANAGEMENT ETC.)
RUN-OFF FROM CATCHMENT
(ANNUAL) PEAK DISCHARGE AT DELTA HEAD
FREQUENCY AND INTENSITY OF FLOODS
SYSTEM OF FLOOD CONTROL EMBANKMENTS
CAPACITY OF RIVER CHANNELS (DISTRIBUTARIES) IN THE DELTA OF THE MAIN RIVER
DURATION OF FLOODS
EXTENT OF OCCUPATION OF FLOOD PLAINS
CONSTRUCTION OF DRAINAGE CHANNELS AND CHANNEL IMPROVEMENT MEASURES
EXTENT OF FLOOD DAMAGE WITHIN DELTA

Since in India we have a vast network of river systems (as seen earlier) with very different conditions, as a starting point, the above framework of analysis is perhaps best applied to a single river system. In addition, since in the above framework, we incorporate the newer flood-control measures (such as multi-purpose storage reservoirs, extension of embankments etc) adopted since Independence as one of the mediating factors, the period of the analysis should cover a sub-period prior to the introduction of these measures. Thus, our empirical analysis to follow is with particular reference to the Mahanadi river system in Orissa - one of the five traditionally flood affected states, as mentioned earlier. Another reason for choosing the Mahanadi river is that the multi-purpose reservoir (Hirakud Dam) across the Mahanadi was one of the first multi-purpose river valley projects after Independence. Moreover, we have data for the Mahanadi river system on the more important mediating factors incorporated in the above framework, both for the pre-Dam and post-Dam periods. This would allow us to analyse the role of the changing conditions of such mediating factors, with the coming into operation of the Hirakud reservoir providing a suitable dividing line.

NOTES

1. Ward (1978), p.5.
2. Ibid, emphasis added.
3. Centre for Science and Environment, The Wrath of Nature: The Impact of Environmental Destruction on Floods and Droughts.
4. Ibid.
5. Govt. of India, National Commission on Floods, p.14 ff
6. Ibid, p.96
7. Cited in Ibid, p.97
8. Ibid, p.116
9. Cited in Ibid, pp. 98-99; emphasis added
10. Ibid, p.40
11. Ibid, p.119, 96
12. National Commission on Floods, p.46
13. Ibid, p.50
14. Centre For Science & Environment, The Wrath of Nature
15. Ibid.

CHAPTER TWO

ANALYSIS OF THE LONG TERM TREND IN THE EXTENT OF FLOOD DAMAGE AND IN THE FREQUENCY AND INTENSITY OF FLOODS IN THE MAHANADI DELTA

According to the analytical scheme presented above, the frequency and intensity of floods (as measured by the annual peak discharge at the head of the delta) and the extent of actual flood damage in the delta are the two dependent variables. Therefore, in this chapter, we seek to establish the long-term trend of these two variables to provide the basis for analysing the role of the two sets of mediating factors in influencing the trends in the two dependent variables.

As we have already said in the Introduction above, the present study focusses on the Mahanadi river in Orissa, which is the largest river of the state and most important from the point of view of floods. But we need to point out here that there could be a problem here since the data for the extent of actual flood damage is available mostly for the state of Orissa as a whole. Nevertheless, the trend in the extent of flood damage for Orissa as a whole can be said to reflect that for the Mahanadi Delta alone for the following reasons. First, we have district-wise break-up of damage due to floods in Orissa for three years, namely, 1964, 1980 and 1982 which show that damage in the Mahanadi Delta (which lies within the districts of Cuttack and Puri: see Inset, Fig.4.1) accounts for a substantial proportion of total damage for the state as a whole with respect to cropped area affected. For example, Cuttack and Puri accounted for as high as 82.5%, 82% and 70% of total damage in the above three years respectively. In any case, we have figures for annual peak discharge at the head of the Mahanadi Delta which can be used as a measure of the frequency and intensity of floods and hence as a proxy for potential damage (not for actual damage since, according to the analytical scheme above, actual damage is not a simple function of the frequency and intensity of floods; this will be brought out in the course of this Chapter).

Before we move into an analysis of relevant data, a word about the reliability of the state-level data for the extent of flood damage. It is true that the extent of flood damage as reported by the State Government is often overstated, since this forms the basis of the amount of the Central grant for flood relief. But from the point of view of our analysis, this would not matter since we are mainly concerned with the trend in the extent of flood damage; the absolute levels of damage for individual years are not relevant for our purpose. We have to assume, not unreasonably, that the extent of overstatement remains roughly the same over time.

I

Trend in the Extent of Flood Damage in the Mahanadi Delta: Pre-Dam & post-Dam Periods

It should be pointed out in the beginning that in analysing the trend in the extent of flood damage we take the year 1958 as the dividing line since it is from this year that a major flood control measure in the form of the Hirakud Reservoir was commissioned.

Now looking at the figures in Table 2.1, we find that the extent of cropped area affected shows mild fluctuations around an average of about 3 lakh hectares. As regards the monetary value of damage, it fluctuates around Rs.35 million (Table 2.2). Though there is no clear-cut increasing trend over the entire period, namely 1955-82, it is even more difficult to speak of a declining trend (see Figs. 2.1 & 2.2). In the above table, unfortunately, there are only three years before the Hirakud Reservoir came into force for which the data on the extent of damage are available. The annual average extent of cropped area affected for the above three year period (1955-57) works out to 1.66 lakh hectares. Comparing this with the post-Dam period, we find that the annual average of cropped area affected has always remained well above this figure (It may be mentioned here that 1955 was a year of fairly severe floods and thus the period 1955-57 was not exceptional in terms of absence of floods). The above observations more or less hold good for non-cropped area affected as well.

Table 2.1

Annual Average of Area affected by floods, Orissa, 1955-82

(in lakh hectares)

Period	Cropped Area	% of total area affected	Non-cropped Area	Total
1955-58	1.3	51	1.3	2.6
59-62	3.3	34	6.2	9.5
63-66	2.9	68	1.4	4.3
67-70	3.1	46	3.7	6.8
71-74*	4.4	49	6.5	10.9
75-78	2.4	76	0.7	3.1
79-82	2.6	-	-	-

(contd.. overleaf)

*Figures for the year 1972 has been excluded, since this shows an impossibly high figure (see footnote 2 to this Chapter).

Note: The above averages include years of no damage as well.

Source: Govt. of India, Ministry of Energy & Irrigation (Department of Irrigation), National Commission on Fllods, Report Vol.I,
New Delhi, 1980, p. 73; Govt. of Orissa, Department of Irrigation & Power, Flood Report of Orissa, 1980 & 1982.

Table 2.2

Annual Average of the Value of Flood Damage, Orissa (at 1952-53 prices)

(in million Rs.)

Period	Crop Damage	Non-Crop Damage	Total Damage
1955-58	28.2	7.1	35.3
1959-62	25.6	28.5	54.1
1963-66	6.9	0.8	7.7
1967-70	44.0	16.9	60.9
1971-74	78.9	42.2	121.1
1975-78	25.3	42.7	68.0

Source: Same as Table 2.1, p. 74.

Fig.2.1

Cropped Area, Non-Cropped Area and Total Area Affected by Floods in Orissa

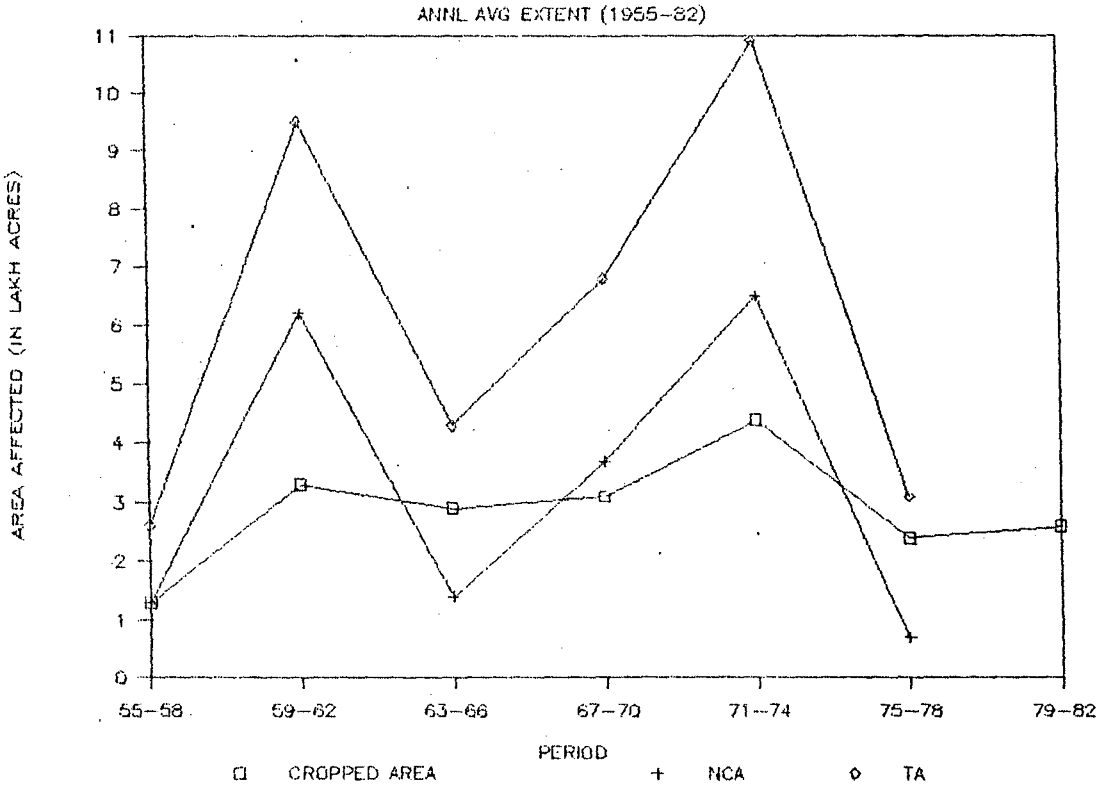
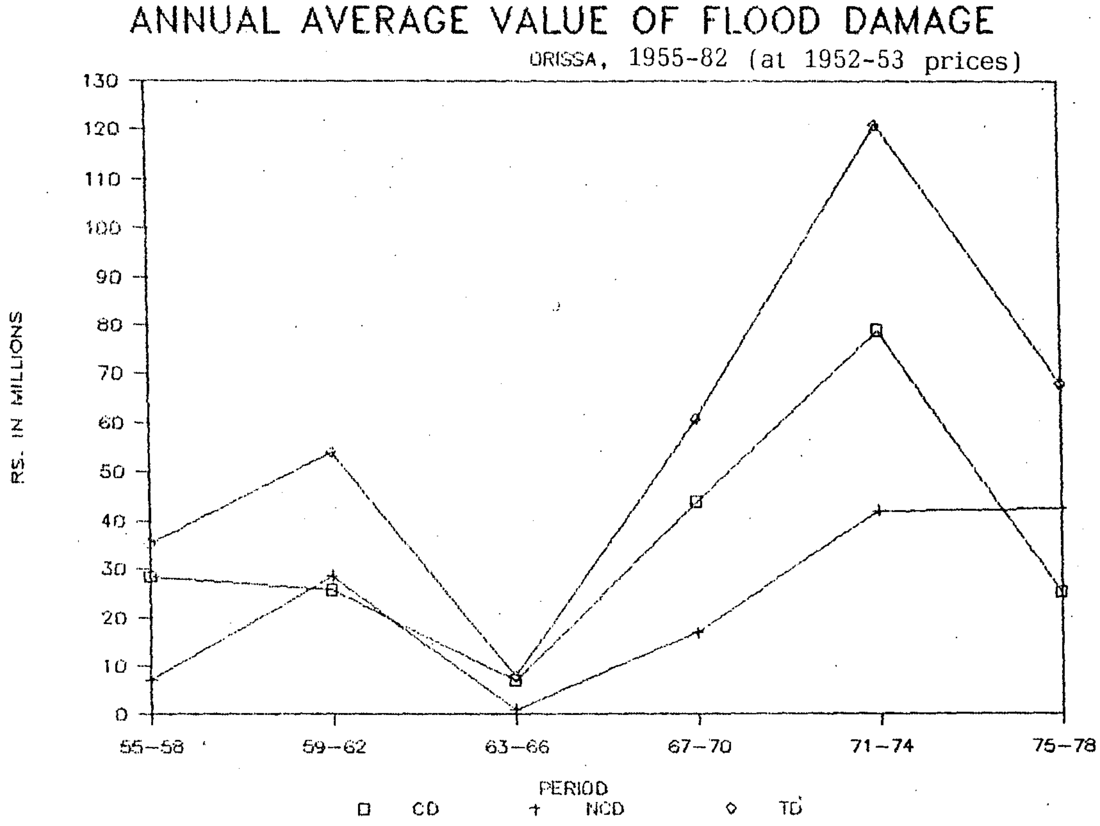


Fig.2.2



But we need to have data on the extent of flood damage for a longer period of time prior to 1958 (ie., pre-Hirakud Dam period, hereinafter referred to as pre-Dam period). There are some indirect estimates available but mostly for the extent of cropped area affected. Therefore, our analysis of the average extent of flood damage in the pre-Dam and post-Dam periods will have to be confined to cropped area only, which forms a significant proportion of the total area affected by floods (See Table 2.1).

Unfortunately, data on the extent of actual flood damage were not systematically collected before 1955 for Orissa. But the Sivaraman Committee, in its Report on the Benefits due to Complete Flood Protection by the Hirakud Dam Project, by analysing the annual peak discharge data for the Mahanadi over a period of 80 years upto about 1954, found out that a "normal flood" averages once in three years, a fairly "heavy flood" once in five years and an "abnormally heavy flood" once in twelve years. From this, it has been estimated that some 1.4 lakh hectares of cropped area are liable to floods in Cuttack and Puri districts, ie, in the Mahanadi Delta[1]. This figure can be taken as a kind of long-run annual average extent of cropped area affected during the 80 year period, upto 1954, taking floods of different magnitudes together. Now from the data on annual flood damage with respect to cropped area affected for Orissa (Table 2.1, above) for the period 1958-82 (ie. post-Hirakud Dam period, hereinafter referred to as post-Dam period), one can estimate the annual average extent of cropped area affected over the entire period (excluding those years in which there was no damage for calculating the average)[2]. Taking 70% of this state aggregate to represent the cropped area affected in the Mahanadi Delta alone, we get a figure of 2.16 lakh hectares which can be taken as a long-run annual average of cropped area affected during 1958-82 in the Mahanadi Delta in comparison with a figure of 1.4 lakh hectares for the pre-dam period as estimated by the Sivaraman Committee. Moreover, we have figures for the extent of cropped area affected for the three districts of Cuttack, Puri & Balasore for one year in the pre-dam period, namely 1926, in which there was a very large flood. This is reported to be 1.78 lakh hectares[3]. This suggests that there has definitely been no declining trend in the extent of flood damage in the post-Dam period.

Not only has the average extent of cropped area affected by floods increased in absolute terms, but also as a proportion of net sown area of Cuttack and Puri districts: it was some 13.5% in the pre-Dam period and increased to 18.4% in the post-Dam period[4].

Even if we allow for possible underestimation of cropped area affected in the pre-Dam period and over-estimation in the post-Dam period, it is possible to infer from above that there has not been any declining trend in the extent of flood damage: the latter has either remained constant or is likely to have increased.

II

Trend in the Frequency & Intensity of Floods in the Mahanadi Delta, Pre-Dam & Post-Dam Periods

What about the trend in the frequency and intensity of floods as measured by the annual peak discharge at the head of the delta? Has it correspondingly remained more or less constant or perhaps increased, as one would expect from the trend in the extent of damage as seen above?

Table 2.3

Distribution of Individual years across size-classes of Annual Peak Discharge at Delta Head, Mahanadi, pre-Dam (1931-57), & post-Dam (1958-84) Periods

Annual Peak Discharge (in lakh cusecs)	Period			
	1931-57 (pre-Dam)		1958-89 (post-Dam)	
	No. of years	% of total	No.of years	% of total
<9 (no flood)	6	22	15	56
9 - 10 (small/medium flood)	5	19	7	26
10 - 12 (large flood)	7	26	3	11
>12 (very large flood)	9	33	2	7
Total	27	100	27	100

Source: (see overleaf)

Source: Compiled from the data on Annual Peak Discharge for individual years given in Climatic Studies (for Agricultural Use) on Mahanadi Delta Command Area, in connection with the preparation of Mahanadi Delta Development Plan, Supt. Engineer, Drainage Masterplan Circle, Bhubaneswar, August 1985.

We have data on frequency and intensity of floods in the Mahanadi Delta for the period 1931-1984 in the form of an objective and reliable measure, namely, annual peak discharge (ie. the maximum rate of flow of water for any year) at the head of the delta (which is at Naraj: see Fig.3.1). This data has been used to construct the distribution of individual years across size classes of annual peak discharge for the pre-Dam and post-Dam periods separately (Table 2.3). Now, since it is known that the delta channels of the Mahanadi can safely carry a flow of 9 lakh cusecs[5] (Cubic feet per second), a peak discharge of anything less than 9 lakh cusecs corresponds to no flood; the intensity of floods is then proportional to any rate of discharge in excess of 9 lakh cusecs (though, as we shall see in Chapter Four, 9 lakh cusecs is not a static cut-off point, only above which floods occur, but this level of safe peak discharge changes depending on the changing capacity of river channels within the delta.

Since annual peak discharge data are available for 27 years (1958-84) in the post-Dam period, we have constructed the distribution of peak discharge across size-classes for 27 years (1931-57) in the pre-Dam period.

Looking at Table 2.3, we notice a number of striking changes as between the pre-Dam and post-Dam periods. For 1931-57, floods occured in 78% of the years, compared to

44% in the post-Dam period. Of the floods which occured, large and very large floods accounted for 59% of all years between 1931 and 1957, compared to only 18% for the post-Dam period. It is only the small and medium floods which account for a larger percentage of years in the post-Dam period, namely 26%, of all years compared to 19% for the pre-Dam period of 1931-57. Thus the composition (in terms of differing intensities) of floods has changed drastically: the share of large and very large floods has come down from 76% in the pre-Dam period to 42% in the post-Dam period; correspondingly, the share of small/medium floods has gone up from 24% in the pre-Dam period to 58% in the post-Dam period. As a result, the average intensity of floods has come down from 11.74 lakh cusecs in the period 1931-1957 to 10.69 lakh cusecs in the post-Dam period.

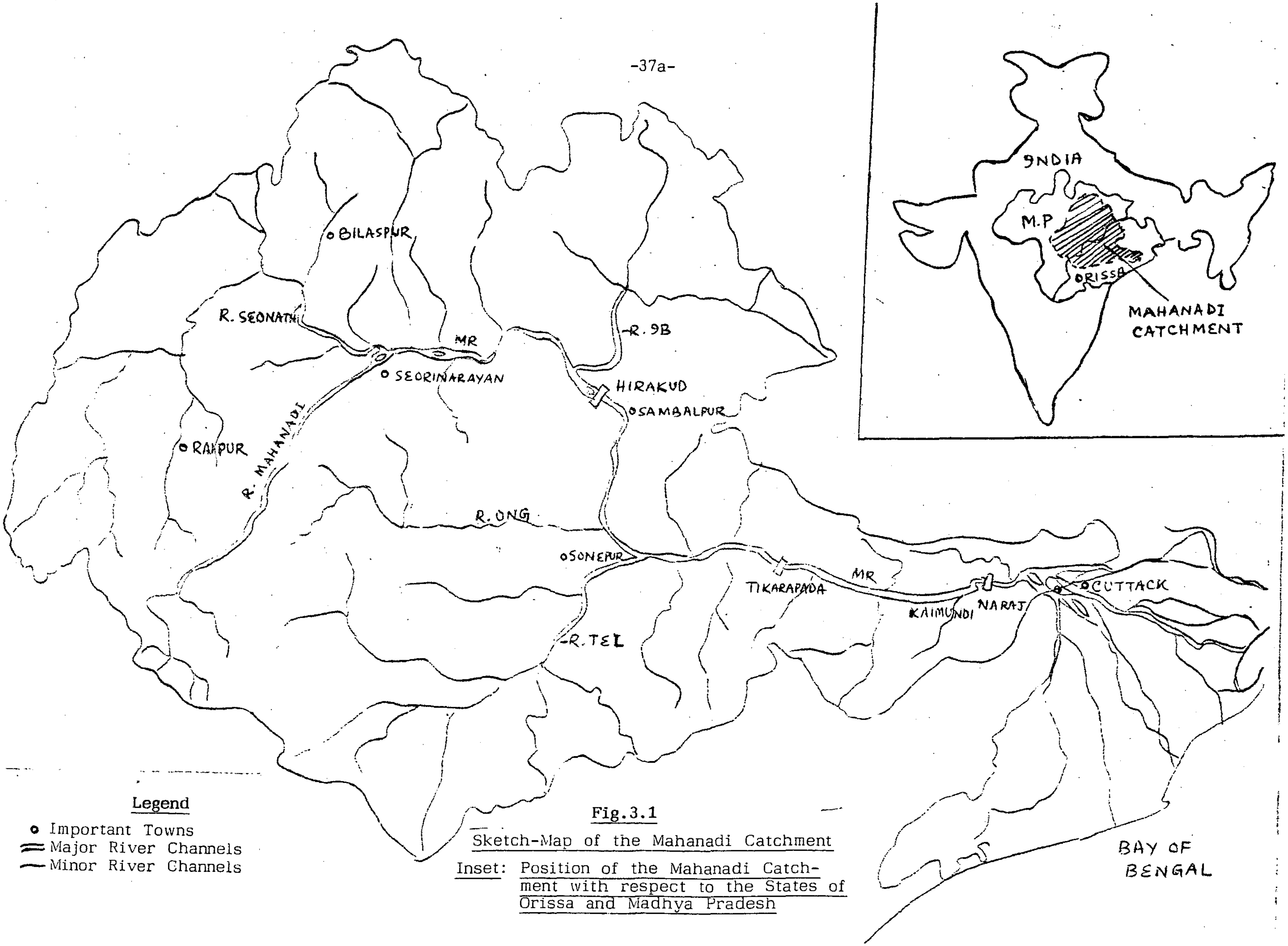
Now, from the above analysis of the trend in the extent of flood damage and in the frequency and intensity of floods, there are four specific questions which emerge. As we have seen above, the frequency of very large and large floods has come down in the post-Dam period. So the first question is: what has been the role of the Hirakud Dam in controlling such floods? But, we nevertheless find that there have been two instances of very large floods in the post-Dam period (see Table 2.3). Hence the second question is: under what conditions did such floods occur, inspite of the Hirakud Dam? On the other hand, we have seen that the frequency of low/medium floods has increased in the post-Dam period. So the third question is: How has this happened? The above three questions shall be taken up in Chapter Three.

But the most striking thing to note is that since the overall frequency of floods has come down in the post-Dam period and also the composition of floods has changed markedly away from very large and large floods and in favour of medium and small floods, one would have expected a corresponding marked decline in the average extent of damage per year (either including or excluding those years in which there was no damage due to floods). But this has not happened, as we have seen earlier in this Chapter. So, the fourth question that comes up is: How is it that reduced frequency and intensity of floods has not led to a corresponding decline in the extent of damage? Or, to put it differently, how is it that small/medium floods which dominate the composition in the post-Dam period seem to result in no less, if not greater, damage in the post-Dam period compared to large/very large floods which dominated the composition of floods in the pre-Dam period? This fourth question will be taken up in Chapter Four.

NOTES

1. Cited in Sovani and Rath (1960), p. 167.
2. We have also excluded the damage figure for 1972 which appears too high. For example, the extent of cropped area affected for Orissa as a whole is given as 12 lakh hectares; 70% of this works out to be 72% of the total cropped area of Cuttack and Puri districts.
3. Hubback (1926)
4. Figures of net sown area are the average of 1951-55 for the pre-Dam period and for the year 1978-79 for the post-Dam period. These are taken from Government of Orissa, Bureau of Economics & Statistics, Statistical Atlas of Orissa, 1954-55, 60-61 & 78-79.

5. This has been calculated on the basis of the rate of fall of the river and the depth of the river at several cross-sectional points of the distributaries of the Mahanadi: Hunter (1976), pp. 35-36.



Legend

- o Important Towns
- ═ Major River Channels
- — Minor River Channels

Fig.3.1

Sketch-Map of the Mahanadi Catchment

Inset: Position of the Mahanadi Catchment with respect to the States of Orissa and Madhya Pradesh

CHAPTER THREE

CONDITIONS OF RUN-OFF IN THE MAHANADI CATCHMENT: THE ROLE OF THE HIRAKUD DAM

The purpose of this chapter is twofold. First, we shall examine the role of the Hirakud Reservoir in controlling the floods in the Mahanadi Delta and point out the factors which limit its role in complete flood-control. Second, we shall examine the trend in the run-off coefficient (see Glossary) in the pre-Dam and post-Dam periods, and relate this to the process of deforestation in the catchment. We shall also examine here the extent of soil erosion in the catchment as a result of deforestation. Before going to the analysis proper, we shall describe briefly the course of the Mahanadi river through its catchment, the size of the catchment etc.

The Mahanadi rises in an insignificant pool in the extreme south-east of Raipur district in Madhya Pradesh (see Fig.3.1). In the first part of its course, it flows in a north and north-westerly direction for about 200 km, and drains the eastern portion of Raipur. About 13 km above the town of Seorinarayan in Bilaspur district, it receives its first major tributary, Seonath (see Fig.3.1). Beyond this confluence, after flowing for about 200 km in an easterly direction, the Mahanadi enters Orissa and is joined by the river Ib. Little lower down is the Hirakud Dam near Sambalpur town from where it turns and flows in a southernly direction upto Sonepur town where it receives the Ong. Thereafter, the river flows in a south-easterly direction and receives the Tel and comes across the Eastern Ghats. The Mahanadi then forms a series of rapids (See Glossary) and rolls down towards the outermost lines of the Eastern Ghats. This mountain line is pierced by a couple of lengthy gorges (such as Kaimundi) and finally pours down upon the plains from between two hills at Naraj, about seven miles west of the city of Cuttack. Below Naraj, it throws off numerous branches and ultimately falls into the Bay of Bengal[1]. Thus the length of the Mahanadi from its source upto Naraj is about 466 miles whereas its total length from its source upto its point of fall into the sea is about 535 miles. The catchment of the Mahanadi extends over an area of 51,000 square miles; about 60% of this lies in Madhya Pradesh and 40% in Orissa[2] (see Inset, Fig.3.1).

I

The Role of the Hirakud Dam in Flood Control: Achievements and Limitations

A significant policy measure has been the construction of the Hirakud Storage Dam to check the run-off and hence floods in the Mahanadi Delta. But this Dam was built at a point (9 miles west of Sambalpur Town: see Fig 3.1) at which the catchment area of the Mahanadi over the dam is 32,200 square miles (to be referred as upstream catchment) which is nearly 63% of the total catchment area. The Dam is supposed to control the run-off of this upstream catchment (some 19,500 sq.milles of which lie in M.P.); the catchment below the Dam (to be referred as downstream catchment) has thus an area of 18,800 sq.miles (37% of the total catchment area), almost all of which lie within Orissa. The run-off of this downstream catchment is hence uncontrolled.

Hirakud Dam was a major multi-purpose scheme of river valley development, with flood control, irrigation and power generation as three main objectives. According to the original project report, "The reservoir formed by the Dam will rise to 625 ft at which it will submerge an area of 1,35,000 acres. It will have a gross storage capacity of 5.3 m.a.ft (million acre ft) of which 1.2 m.a.ft will constitute dead storage to provide silt reserve for over one hundred years and a minimum working head for power generation. The live storage of 4.10 m.a.ft will provide 1.30 m.a.ft for purposes of irrigation and by judicious reservoir regulation 2.72 m.a.ft for flood control. Provision has been made for a further flood reserve of 0.70 m.a.ft (or 3.42 m.a.ft in all) five feet above the normal reservoir level. This may have to be used once in a century ... the Hirakud Dam will provide adequate flood protection to the delta from all but extraordinary floods. The additional reserve of 5 ft will afford almost complete protection even for floods of the magnitude of that of 1834"[3].

Though the monsoon run-off of the downstream catchment below the Dam was to remain uncontrolled as before, according to a later government report of an Expert Committee on flood control benefits due to the Hirakud Dam, the "Peak discharge of this uncontrolled area cannot raise the flood level beyond the gauge of 88.5 ft at Naraj. Damage by floods occurs in the delta area only when the flood level goes above 89 ft at Naraj. The max. reserve required for controlling the severest flood on record has been estimated as 3 million acre ft while maximum storage available at the Dam between the dead storage level and the full reservoir level is 4.5 m.a.ft. The flood reserve provided by the dam project is therefore, considered adequate to reduce all floods to gauge of 89' at Naraj and it is therefore forecasted that there will be no floods to cause damage in the lower regions"[4].

Thus the basic principle in operating the Hirakud Reservoir was that it would absorb the monsoon run-off from the upstream catchment till the peak flows from the downstream catchment passed over the delta, or at any rate the outflow from the Hirakud Reservoir would be such that this contribution plus the peak flows from the downstream catchment would not exceed the gauge level of 89 ft at Naraj corresponding to a safe peak discharge of 9 lakh cusecs into the delta.

There were two assumptions involved in putting the above principles successfully into practice. First, the peak discharge from the downstream catchment alone cannot exceed 9 lakh cusecs so as to cause damage in the delta. Secondly, that it is possible to predict (on the basis of the rainfall run-off relationship) the run-off and the peak discharge from the <u>downstream catchment alone</u>, 36 hours in advance (which is the time taken for water released from Hirakud Dam to reach Naraj, the head of the Delta). Then it could be decided how much water to release from the reservoir such that the flow at any point of time combined with the predicted flow from the downstream catchment 36 hours hence, would not exceed 9 lakh cusecs. It is important to keep these two assumptions in mind since these will be relevant in the context of our discussion later in this chapter on the role of the downstream catchment.

So the project was finally completed in 1957 and took effect from 1958 monsoon with a final gross storage capacity of 6.60 m.a.ft (with 1.87 m.a.ft dead storage capacity as silt reserve with 4.73 m.a.ft as live storage capacity). The originally planned additional flood reserve of 0.7 m.a.ft was subsequently dropped[5]. The capacity of reservoir at various levels in given in Table 3.1.

TABLE 3.1

Capacity of Hirakud Reservoir at different Reservoir levels

Reservoir Level (in ft.)	Gross Capacity (m.a.ft.)	Live Capacity (m.a.ft.)
590	1.87	....
595	2.24	0.37
600	2.61	0.74
605	3.15	1.28
610	3.73	1.86
615	4.31	2.44
620	4.93	3.06
625	5.76	3.89
630	6.60	4.73

Source: Bhanjadeo Committee Report, p.10.

Having briefly mentioned the original claims regarding the role of Hirakud Dam in complete flood control and the principle of operation of the reservoir, we shall now examine the actual performance of the reservoir and its limitations with respect to flood control.

The first thing to examine is whether the reduced frequency of large floods and very large floods in the post-Dam period (see Table 2.3 above) can be attributed to Hirakud Reservoir. For this we have data on what would have been the peak discharge at the head of the delta in the absence of the Hirakud Reservoir as against the actual peak discharge. This is presented in Table 3.2.

TABLE 3.2

Extent of Flood Moderation by Hirakud Reservoir, 1958-67

Year	Period of Flood	Estimated Discharge at Delta Head in absence of Hirakud Reservoir* (in lakh cusecs)	Actual Peak Discharge at Delta Head (in lakh cusecs)	Initial R.L. after Absorption (in ft.)	Maximum R.L. after Absorption (in ft.)	Volume Absorbed (in lakh acre ft.)
1958	15 to 25 July	14.12	11.95	609.3	618.3	16.6
1959	5 to 20 September	13.01	12.55	620.4	625.3	8.3
1960	14 to 23 August	14.07	12.65	608.7	619.7	14.9
1961	5 to 23 July	17.49	12.71	615.3	629.3	21.5
1962	3 to 18 September	12.16	13.01	616.0	627.8	16.7
1963	13 to 19 September	10.17	9.25	619.1	623.8	7.0
1964	5 to 8 July	13.44	8.98	592.2	603.6	9.8
1965	11 to 20 August	12.36	9.04	598.8	617.1	20.8
1966	24 to 29 August	14.46	8.20	600.8	612.6	21.9
1967	2 to 7 August	12.13	8.94	597.3	614.8	18.6

*This is estimated as follows: If the peak inflow in a certain year into Hirakud Reservoir was observed at, say, x hour on a certain day, then the observed discharge at delta head at (x+36) hour is taken as the estimated discharge at delta head in the absence of Hirakud Reservoir, since the time of travel of water from Hirakud to Naraj is about 36 hours.

Note: 1. Discharge data are for a place called Kaimundi which lies only 9 miles west of Naraj (see Fig.3.1) - the head of the Mahanadi delta. Hence the catchment area between Naraj and Kaimundi is negligible.

2. R.L. refers to Reservoir Level.

Source: Govt of India, Report of the Team of Experts on Operation of the Hirakud Reservoir during the Flood Season, June, 1976, p.32.

From Table 3.2, we find that, except for the year 1962, the actual peak discharge at delta head due to flood absorption by the Hirakud reservoir has been less than what would have been the discharge without such absorption, though it is only after 1962 that flood moderation by Hirakud reservoir has been able to bring the actual peak discharge to around 9 lakh cusecs - the safe discharge for the delta channels. Unfortunately, we do not have data of the kind presented in Table 3.2 after 1967.

In any case, though the Hirakud Reservoir has reduced the frequency of very large and large floods compared to the pre-Dam period, we still find that there have been three cases of large floods and two cases of very large floods out of a total of twelve cases of floods (in terms of peak discharge) in the post-Dam period (Table 2.3). It is with reference to this observed fact that we need to point out some factors which limit the role of Hirakud Reservoir in complete flood control in the Mahanadi Delta.

Conflict between Power, Irrigation and Flood Control Objectives

Two factors have played an important role in limiting the effectiveness of Hirakud Reservoir in controlling floods, especially in September.

Firstly, in order to provide for power generation during the dry season, the authorities have attempted to fill up the reservoir by end August, thus reducing the reservoir's absorptive capacities in September. As the Orissa Flood Enquiry Committee of 1960 commented: "The reservoir which as per the project planning was to be kept at 590' during July and August has been kept above 607' and this has meant reduction of flood storage by 1.5 m.a.ft. for floods occurring in July and August and upto say 15th of August. The project authorities have also felt the need to fill up the reservoir to 612 ft. by the 1st September to ensure a full reservoir for power generation. Thus the present flood reserve available in Hirakud is about 3 m.a.ft. for controlling floods occurring on or before the 1st September and the reserve is much less if the flood occurs in early part of September, and after the 15th of September, the flood reserve is uncertain."[6]

Secondly, inflows into the reservoir from end August onwards are now apparently much higher than before whereas inflows earlier during September were low/moderate:"... the data from 1926 onwards show that peak floods of the order of 9 lakh cusecs in the catchment above Hirakud during the early part of September occurred only in the year 1947."[7]

The effect of these two factors is brought out by Table 3.2 where we find that between 1958 and 1962, due to already high initial reservoir level before flood absorption, the extent of flood moderation was not satisfactory. In particular in 1959, when the period of flood was from 5th to 20th September, the initial reservoir level was already high at 620.40 ft.; the same was true for the years 1962 and 1963.

Though after 1962, the operation has been satisfactory because of relatively lower initial levels of the reservoir at the time of floods and their lesser magnitude, it is important to point out that one of the two very large floods which have occurred in the post-Dam period, namely in the year 1980, was entirely due to release from the Hirakud Reservoir which was forced because of high peak inflows from the upstream catchment in late September.[8]

Hence we find that a combination of reservoir authorities' anxiety to fill the reservoir by end August in order to provide for power generation during the dry season and the higher inflows in September can lead to dangerous situations as in 1980. The higher than anticipated inflows in September are possibly related to conditions of vegetative cover and the run-off of water in the upstream catchment. Reliable data on the vegetative cover separately for the upstream catchment of the Mahanadi are, however, not available. Nevertheless, we can indirectly infer something regarding loss of vegetative cover in the upstream catchment from the data on siltation of Hirakud Reservoir, which we will now discuss.

Problem of Premature Siltation

The next important factor which can limit the role of the Hirakud Reservoir is the problem of premature silting leading to loss of storage capacity, which we shall now discuss. As we have already seen, the Hirakud Reservoir has been provided with dead storage capacity for silt reserve, but the problem arises when the actual rate of siltation begins to affect the live storage capacity itself. Both of these seem to be happening in the case of Hirakud Dam.

There have been two cycles of hydrographic surveys conducted in the years 1979 and 1982 according to which the silt deposit in the reservoir is found to be 138.60 acre.ft/100 sq.miles/year[8a] and 143.10 acre.ft/100 sq.miles/year respectively as against 52.46 acre.ft/100 sq.miles/year as anticipated in the Revised Report of Hirakud Dam project 1953, which was based on actual silt survey for the period 1947-51, ie. the actual rate of siltation is more than double of the anticipated rate.

The loss of storage in different allocated storage as per the latest hydrographic survey (1981) results are as given in Table 3.3

TABLE 3.3

Extent of Loss of Dead, Live and Gross Storage Capacity of Hirakud Reservoir due to siltation

(in million acre-ft)

Type of Storage	Original Capacity	New capacity	Silt Deposited	Loss (%) per year
1. Dead Storage (below R.L. 590 ft)	1.88	1.23	0.65	1.27
2. Live Storage (R.L. 630 to 590 ft)	4.72	4.14	0.58	0.48
3. Gross Storage (R.L. 630 and below)	6.60	5.37	1.23	0.70

Source: Govt. of Orissa, Department of Science, Technology & Environment, Orissa Remote Sensing Application Centre and Hirakud Research Station, Application of Remote Sensing to Sedimentation Studies in Hirakud Reservoir, 1986.

From Table 3.3, we find that the rate of loss (% per year) has been 1.27%. It should have been no more than 1% per year, since normally the economic life-span of the storage reservoir is assumed to be 100 years. Let us explain this a little more. Suppose it has been found out on the basis of actual silt survey that siltation due to soil erosion in the catchment above the reservoir is of the order of say x acre ft/year; in that case, the dead storage (exclusively for silt deposit) has to be 100x acre ft, if the live storage capacity (over and above the dead storage capacity) is to remain intact for a period of 100 years. If the actual rate of siltation is anything greater than x acre ft per year, then obviously the dead storage capacity will be filled up in less than 100 years. Thus the loss of dead storage capacity at the rate of 1.27%/Year means that this capacity will be filled up in about 78 years (assuming the same rate of siltation over time). Even more seriously, what we find in the case of Hirakud reservoir is that siltation is eating into the live storage capacity as well at an average rate of 0.48% per year. As a joint result, the gross storage capacity (dead storage + live storage) is getting reduced at the rate of 0.7% per year (Table 3.3). Given these rates of loss of dead, live and gross storage capacities of the reservoir, the total reduction in the respective capacities of the reservoir upto 1985 (ie, 29 years) must have been some 36.8% (1.27% x 29) for dead storage, 14% (0.48% x 29) for live storage and 20.3% (0.7% x 29) for gross storage capacity.

The above results of the more conventional hydrographic surveys are seen to compare very well with the analysis of the capacity survey of live storage area of the Hirakud Reservoir by remote sensing technique (using LANDSAT imagery obtained from EROS Data Centre, U.S.A.) for the period Oct. 76 - June 77[9].

Such a high rate of siltation seems to be ultimately connected with loss of vegetative cover and soil erosion in the upstream catchment of the Mahanadi above the dam. According to Biren Pattanaik,Engineer-in-Chief, Irrigation, Orissa: "There is heavy deforestation in the catchment area. Before the construction of the dam, about 75% of the catchment in M.P. and Orissa extending over 62,500 sq.km. was densely wooded, and today the forest spread is less than 40% (25,000 sq.km.). Even the grass cover is vanishing at an alarming rate. If the afforestation of the catchment areas is not taken up immediately, the consequences will be serious. Sudden floods will occur and the high siltation will endanger the dam, reducing its effective life span"[10]

TABLE 3.4

Degradation of Forest in the Periphery of the Hirakud Reservoir

(in sq. km.)

Year	Open Degraded Forest	Closed Forest	Total Forest Area Surveyed
1972-75	373	709	1012
1980-82	462	581	1043

Source: Govt. of Orissa, Department of Science, Technology and Environment, Orissa Remote Sensing Application Centre, Monitoring Forests of Orissa by Remote Sensing, Bhubaneswar (date not mentioned).

The above is borne out by the Landsat Imagery of the forested area for a portion of the upstream catchment of Hirakud Reservoir, which shows degradation of forests. As Table 3.4 shows, closed forest (i.e., forest with adequate tree cover) accounted for 70% of the total forest area surveyed in 1972-75; this had come down to 56% by 1980-82.

That increased deforestation and soil erosion are major factors repsonsible for increased siltation is brought out by the interesting finding of the earlier mentioned Landsat data that the confluence of the Hirakud Reservoir with the Mahanadi was more choked with sediments than the confluence with the river Ib, the one major tributary of the Mahanadi directly discharging into the Hirakud Reservoir[11] (see Fig.3.1). And this difference in sedimentation between two parts of the reservoir is very likely to be due to intensive soil conservation measures taken up in the Ib subcatchment of Orissa about which a little description may be given. Out of the total catchment of 11,681 sq.km. of Hirakud lying in Orissa, 10,366 sq.km. is covered under the Ib sub-catchment and lie in the districts of Sambalpur and Sundergarh.

TABLE 3.5

Types of Soil Conservation Measures in the Priority Watershed of the Ib Sub-catchment

Soil Conservation Measures	Total Area treated upto 1984-85 (hectares)
1. Contour Bunding	37099
2. Stream Bank Erosion Control	1715
3. Gully Control	5500
4. Water Harvesting Structure	11520
5. Miscellaneous Tree Planting	19662
6. Pasture Development	1567
7. Afforestation	21155
8. Field Bunding	336
9. Sisal Plantation	469
Total	99023

Source: Same as Table 3.3.

The State Directorate of Soil Conservation have been undertaking several soil conservation measures in the priority watershed of the Ib subcatchment (See Table 3.5).

Though only about 10% of the total area of Ib subcatchment has been treated, these however are the problem areas where erosion was acute[12].

So far in this Chapter, we have examined the role of the Hirakud Reservoir in flood control and found how while on the one hand, the operation of Hirakud reservoir has successfully moderated potentially very large and large floods, at the same time, there have been more than a few cases of large as well as medium floods inspite of the Hirakud Reservoir. In this connection, we have pointed out some factors which limit the role of Hirakud Reservoir in complete flood control. In the rest of this chapter we shall examine the importance of the downstream catchment in further limiting the role of the Hirakud Reservoir.

As we have seen in Chapter Two (Table 2.3), medium/low floods dominate the composition of floods in the post-Dam period accounting for more than 50% of the total number of floods. The frequency of this category of floods has also increased in the post-Dam period. There is some evidence to suggest that even if the Hirakud Reservoir has moderated large floods and brought down the peak discharge below 9 lakh cusecs, the independent contribution from the downstream catchment has pushed up the peak discharge at the head of the delta to around 9 lakh cusecs and beyond. For example, in 1964, even though there was no outflow from Hirakud, more than normal rainfall in the downstream catchment in the month of August kept the peak discharge at Naraj around 7 lakh cusecs for a long time[13]. Similarly in the 1st week of August 1967, even though the peak inflow of 7.74 lakh cusecs into the reservoir was absorbed, there was a high flood of 8.5 lakh cusecs from the downstream catchment which kept the peak discharge at the delta-head just below the safe maximum discharge of 9 lakh cusecs. There is evidence for how a number of low/medium floods have been caused partly by the contribution from the downstream catchment (see Table 3.6). As Table 3.6 shows, the percentage contribution of downstream catchment to the annual peak discharge at the head of the delta (Naraj) was significant for a number of years..

So the downstream catchment seems to have played a role in producing a regime of medium/low floods following moderation of large floods by the Hirakud Reservoir. Such medium/low floods have their own problems in terms of damage in the delta (as we shall see in Chapter Four).

In addition, in some cases, even with moderation by the Hirakud Reservoir, the moderated outflow from the reservoir has combined with peak discharge from the downstream catchment to produce large floods. For example, during 1959, the highest flood which was negotiated at the reservoir was 9.6 lakh cusecs. This was moderated to 6.25 lakh cusecs below the reservoir. The moderation effect, however, didn't give much relief because the downstream catchment contributed as much as 5 lakhs cusecs[14]. The crucial importance of downstream catchment came out most prominently in the case of 1982 flood which has been the worst flood in the recorded history of the Mahanadi floods with a peak discharge of 15.80 lakh cusecs and which caused extensive damage. Significantly, this flood was caused entirely by the run-off from the downstream catchment alone, without any contribution from the reservoir (See Table 3.6).

Table 3.6

Contribution of Downstream Catchment to Annual Peak Discharge at Naraj, 1958-82

(in lakh cusecs)

Year	Annual Peak Discharge at Naraj	Contribution of Downstream Catchment to Peak Discharge at Naraj	Percentage Contribution
1958	9.37	2.6	36.0
1959	11.20	3.0	44.6
1960	11.32	4.4	38.9
1961	11.57	4.2	36.3
1962	N.A.	N.A.	N.A.
1963	9.20	3.5	38.0
1964	7.0	7.0	100
1965	N.A.	N.A.	N.A.
1966	N.A.	N.A.	N.A
1967	8.0	7.0	87.5
1968	7.5	3.5	46.8
1969	9.78	3.3	33.7
1970	N.A.	N.A.	N.A.
1971	7.42	3.0	40.4
1973	9.27	5.4	58.7
1974	7.57	2.6	34.6
1975	8.10	3.6	44.4
1976	9.34	4.5	48.2
1977	9.35	2.7	29.3
1978	9.85	8.9	89.8
1979	N.A.	N.A.	N.A.
1980	12.27	0	0
1981	N.A.	N.A.	N.A.
1982	15.80	15.8	100

Source: Govt. of Orissa, Irrigation & Power Department, Flood Reports of Orissa, various years.

Note: The contribution of the downstream catchment to the observed peak discharge at Naraj is calculated as follows: Suppose the annual peak discharge at Naraj was observed at x hour on a certain day. The contribution of the Hirakud reservoir to this peak discharge is then found out by the information on what was the outflow from Hirakud reservoir at (x-36) hour, since the average time of travel of water from Hirakud to Naraj is about 36 hours. This contribution of the Hirakud reservoir is then deducted from the peak discharge at Naraj to arrive at the net contribution of the downstream catchment.

II

Deforestation, Soil Erosion & Run-off Coefficient: Downstream Catchment, Pre-Dam & Post-Dam Periods

In this connection, it becomes important to see whether and why there are occuring any changes over time in the rainfall-run-off relationship in the downstream catchment. Before turning to a review of the evidence bearing on this question, we will deal with a theory of the rainfall-run-off relation, which emphasizes the importance of vegetative cover and soil characteristics of a catchment. Then we will review the evidence for some river catchments/watersheds in support of this theory, before coming to the evidence for the downstream catchment of the Mahanadi in particular.

Effect of Vegetal Cover and Soil Conditions on Flood Flow

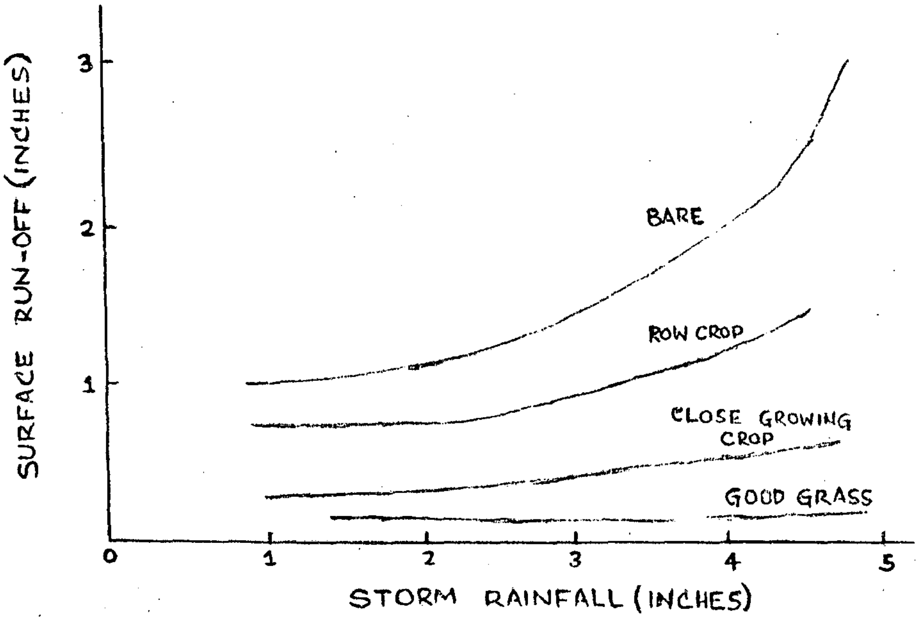
An important step in the understanding of the effect of surface cover on floods was the development of the so-called "infiltration theory" of run-off during the 1930's.

A pioneering paper entitled "The effect of Land Management upon Run-off and Groundwater" was presented by H.L.Cook to the U.N. Scientific Conference on the Conservation and Utilisation of Resources in 1949, in which he gave quantitative evidence regarding the effect of vegetal cover and soil condition on flood run-off.

Fig.3.2 shows average curves that demonstrate the wide range in surface run-off under various cover conditions on the same soil. An examination of these curves show that, on the average, a 3" storm rainfall produces 1.5" of run-off

Fig.3.2

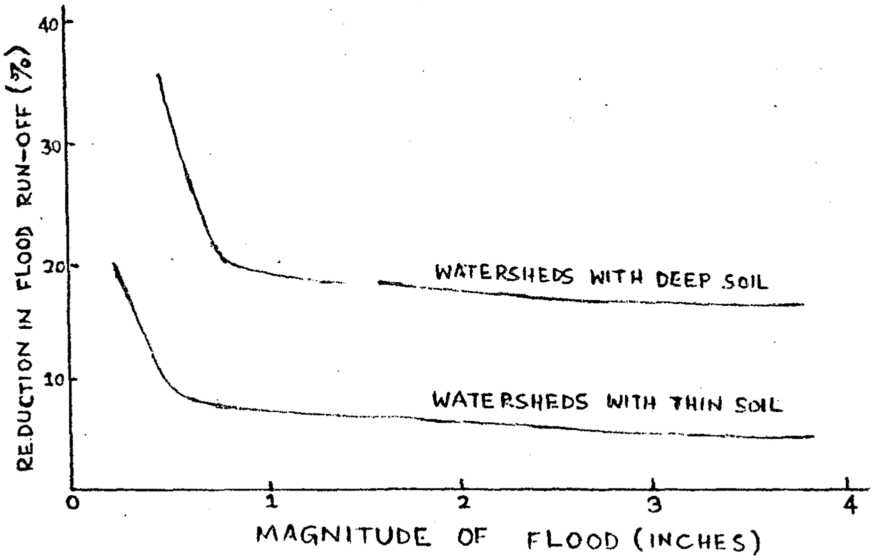
Effect of Vegetal Cover upon the Surface Run-off Caused by Individual Storms: Average Relationships at One Site



Source: United Nations, Methods and Problems of Flood Control in Asia and the Far East, prepared by the Bureau of Flood Control of the ECAFE, Bangkok, 1951.

Fig.3.3

Typical Curves Showing Average Reduction in Flood Run-off Attainable through Treatment of the Land, by Nature of Soil



Source: Same as Fig.3.2.

on bare land, 1" on land in row crops, 1/2" on land in close growing crops and negligible run-off on land in undisturbed permanent grass. It was results like these that led many to conclude that floods might be greatly reduced by reforestation or other changes in land use management.

As regard the quantitative estimates of flood reduction achievable through treatment of land and the role of the nature of soil in this, Cook, summarising the results of a large number of such estimates, produced the average curves as shown in Fig.3.3, showing the reduction of floods achievable through treatment of land; one for the watersheds with thin soils and the other for watersheds with deep soils.

It may be noted that the improvement of vegetal cover has a very decided influence on the reduction of floods of small magnitude and it is much more so for watersheds with deep soil, but the effect is less and less pronounced as the magnitude of flood increases (though still greater for watersheds with deep soil). Thus, if the average annual flood damage is composed mainly of small floods that occur more frequently, improvement of vegetal cover could be a very effective means of flood control[15].

Evidence in favour of how improvement of vegetal cover can reduce run-off is available on the basis of a number of experimental results of watershed treatment obtained for different regions of India[16].

(i) In a small watershed of 8.4 hectares near Agra, the annual run-off out of a total precipitation of 624 mm in 1962 was 54 mm which represents a percentage of 8.7. This watershed - which is situated in the ravines of the Yamuna and is under agriculture to the extent of 80 percent - was treated for soil and water conservation by appropriate physical and biological measures in the early Sixties. Observations made in 1981 showed that of a total of 863 mm of precipitation in that year the run-off amounted to only 8.5 mm which represents a percentage of just about one;

(ii) In an area in the North-Eastern hills which has slopes of around 40 percent it has been observed that while land under jhomming yields 6.45 percent of the rainfall as run-off, bamboo forests yield only 0.26 percent;

(iii) In the Shivalik region near Dehra Dun, run-off losses were reduced by a factor of 72 percent by placing bare fallow lands under natural grasses;

(iv) Observations made near Dehra Dun show that the infiltration of rainwater in the first three hours was 5.45 cm on a ploughed field while in a sal forest with good leaf litter it was as high as 20.7 cm;

(v) According to a study, 15 years of afforestation and protection to improve plant cover on a 1715-acre watershed showed that Summer floods were reduced by 92 percent and the duration of summer storm run-off increased by 500 percent.

Effect of Vegetal Cover on Sediment Flow[17]

In the above, we have seen the joint but independent effect of vegetal cover and the nature of soil on flood flow. But there is another important effect of vegetal cover, namely, on sediment flow via soil erosion in the catchment area.

TABLE 3.7

Extent of Soil Erosion and Run-off by Nature of Vegetal Cover for Experimental Plots in Nurpur, India

Vegetal Cover	Rainfall(inches)	Run-off(%)	Soil eroded (100 lbs/acre)
Grass	98.51	15.1	41.3
Grass	98.51	19.2	53.6
Grass & Scrub	98.51	9.4	45.1
Grass & Scrub	98.51	12.2	53.7
Bare	98.51	46.4	461.2
Bare	98.51	49.6	435.8

Source: Same as Fig.3.2, p.39

Experiments carried out at Nurpur, India on plots of 3,125 sq.cm. receiving natural rainfall during a period of 18 months show the results presented in Table 3.7.

While the results of observations on small experimental plots or small watersheds are suggestive, there are very few studies for large drainage basins. One such interesting study on the Tjijoetoeng Basin in Indonesia was for an area of 62,000 hectares for two comparable time points. Elaborate investigations of the river flow during the period October 1911 - September 1912, indicated the erosion then prevailing.

A similar investigation was repeated during the same period of 1934-35, the intervening period being known to be one during which there was substantial deforestation, etc. The result of this study is presented in Table 3.8, which shows that the rate of soil erosion had doubled.

TABLE 3.8

Deforestation, Soil erosion and Sediment Flow for the Tjijoetoeng River Basin in Indonesia, 1911-12 and 1934-35

	1911-12	1934-35
Total Rainfall (10^6 cu.m)	1791.7	1941.5
Total during wet monsoon	1550.9	1822.5
% in wet season	86.0	94.0
Maximum Silt Concentration measured (gm/li)	8.14	21.46
Total Silt removed (10^3 tons)	821	1790
Total during wet monsoon	804	1765
% in wet monsoon	98	99
Silt removed (tons/hectare)	13.2	28.9
Rate of erosion (mm/year)	0.9	1.9

Source: United Nations, Methods and Problems of Flood Control in Asia and the Far East, prepared by the Bureau of Flood Control of the ECAFE, Bangalore.

The available data for different river basins on the average rate of soil erosion (based on the silt load measurements of the streams and hence the total silt eroded annually) shows how it varies from basin to basin, apparently depending on the extent of vegetal cover, the nature of topography, soil, etc. This is presented in Table 3.9 and pertains to some time before 1951.

We see from Table 3.9 that for river basins located in the tropical or warm temperate zones where the virgin forests in the headwater region have remained unexploited such as the Irrawaddy, the Mekong, and the Mahanadi, soil erosion has been slight whereas soil erosion is moderate in the river basins where vegetal cover in the headwater area has been partly denuded such as the Damodar River. On the otherhand, very serious erosion has taken place in some of the Himalayan rivers such as the Brahmaputra and the Kosi, where the steepness of the topography, denudation of vegetal cover or occurrence of earthquakes and landslides seem to have greatly accelerated soil erosion. Another interesting case is that of the rivers of the loessial area like the Yellow river where the high erodibility of loessial soils has given rise to the high silt rate of the rivers which reaches, during floods, 50% by weight.

Now turning to the evidence for the run-off characteristics of the Mahanadi Catchment, whatever little indirect evidence we have, indicates some interesting changes over time in the conditions of run-off.

To start with, P.C.Mahalanobis had done an exhaustive statistical analysis of rainfall and floods for the three major rivers in Orissa: Mahanadi, Brahmani and Baitarani. The study period was 1872-1926. One part of this massive study which is of relevance here is the relation between the average rainfall in the Mahanadi Catchment and the average discharge (run-off) at the head of the delta (Naraj) for the above period. For each year in which there was flood, the percentage of average run-off to average rainfall

Table 3.9

Silt Load and Rate of Soil Erosion, Some River Basins, prior to 1951

River	Station	Drainage Area (sq.km)	Total Silt Run-off (in million tons)	Unit Silt Run-off (tons/sq.km)	Annual Thickness of Erosion (mm/Yr)	Remarks
Yellow (China)	Shenhsien	715,184	1890	2,640	1.76	(high)
Damodar (India)	Rhondia	19,900	20.4	1,420	0.95	(Moderate)
Irrawaddy (Burma)	Prome	367,000	300	820	0.55	(slight)
Kosi (India)	Chatra	61,600	174	2,820	1.88	(high)
Mahanadi (India)	Naraj	132,000	61.5	465	0.31	(slight)
Mekong (Indo-China)	Kratie	662,000	100	151	0.10	("")

Source: Same as Fig.3.2.

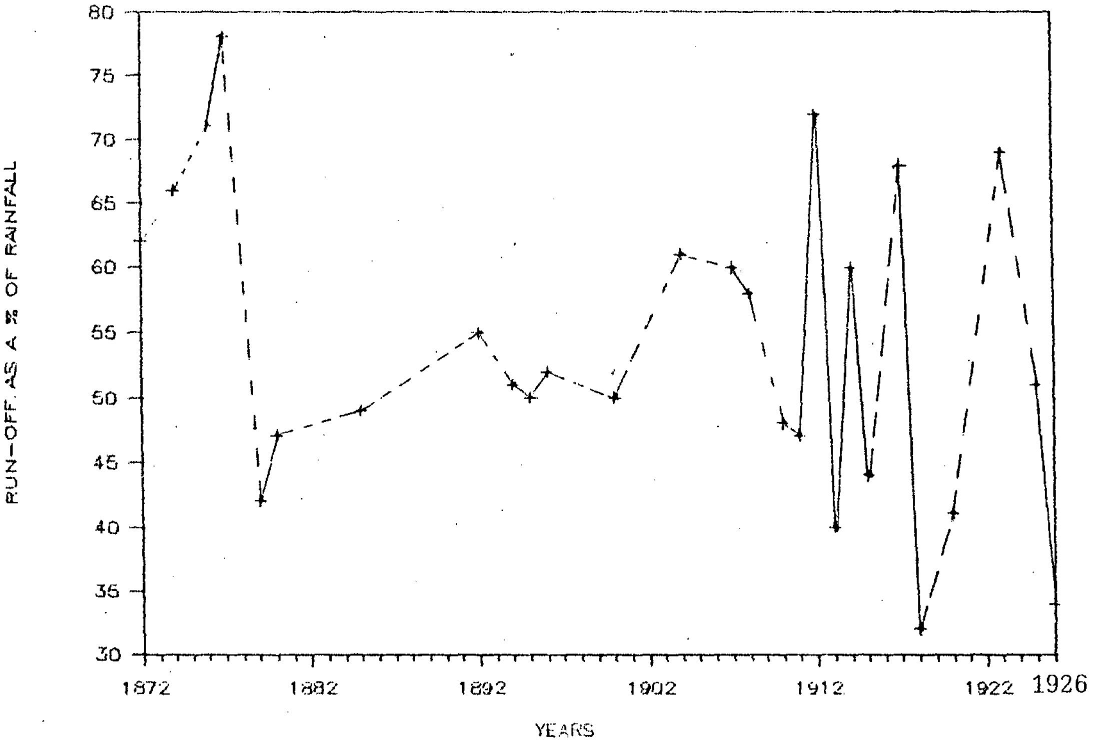
was worked out for periods of three to seven days before the date of flood. It is of interest to note that the percentage discharge quite clearly does not show any increasing trend over the period 1872-1926[18] (for any of the length of time for which average rainfall and average discharge was worked out, namely, from 3-7 days before the date of flood). The relevant graphs are presented as Figs.3.4(a)-3.4(e). Mahalanobis mentions that Mr.J.Shaw, Special Flood Officer, Orissa, in a typewritten note, remarked: "A point of interest in these run-off tables is that the percentage of run-off has not increased from 1872-1926, so there is no indication of increased run-off due to deforestation, extension of cultivation, etc. which is feared and justly so in other river catchments"[19]. We have done a similar analysis for the period 1927-1950 to examine the trend in the run-off coefficient for the entire Mahanadi Catchment. But we took the rainfall and run-off of the catchment for the monsoon period (June to September) for each year[19]a. This showed that there was no increasing trend in the run-off coefficient (see Fig.3.5).

The next suggestive evidence that there was no significant deforestation and soil-erosion in the Mahanadi Catchment till about 1951 comes from the data (pertaining to sometime before 1951) on the rate of silt discharge on Mahanadi at the head of the delta, as already presented in Table 3.9 above, which shows that it was insignificant.

Thus, while till about 1951, there was apparently no significant deforestation and soil erosion in the Mahanadi Catchment (downstream and upstream), we have some evidence to suggest that the run-off coefficient (for the downstream catchment) has increased afterwards possibly due to increased deforestation and soil erosion.

Fig.3.4(a)

Run-off as a % of Rainfall, Mahanadi Catchment, 1872-1926: Period of 3 days before Peak Discharge



Note: In Figs.3.4(a) to 3.4(e), the dotted lines indicate breaks in the series, corresponding to those years in which the peak discharge at Naraj was less than the 'safe' peak discharge of 9 lakh cusecs, and hence excluded by Mahalanobis in his estimation of the run-off coefficients.

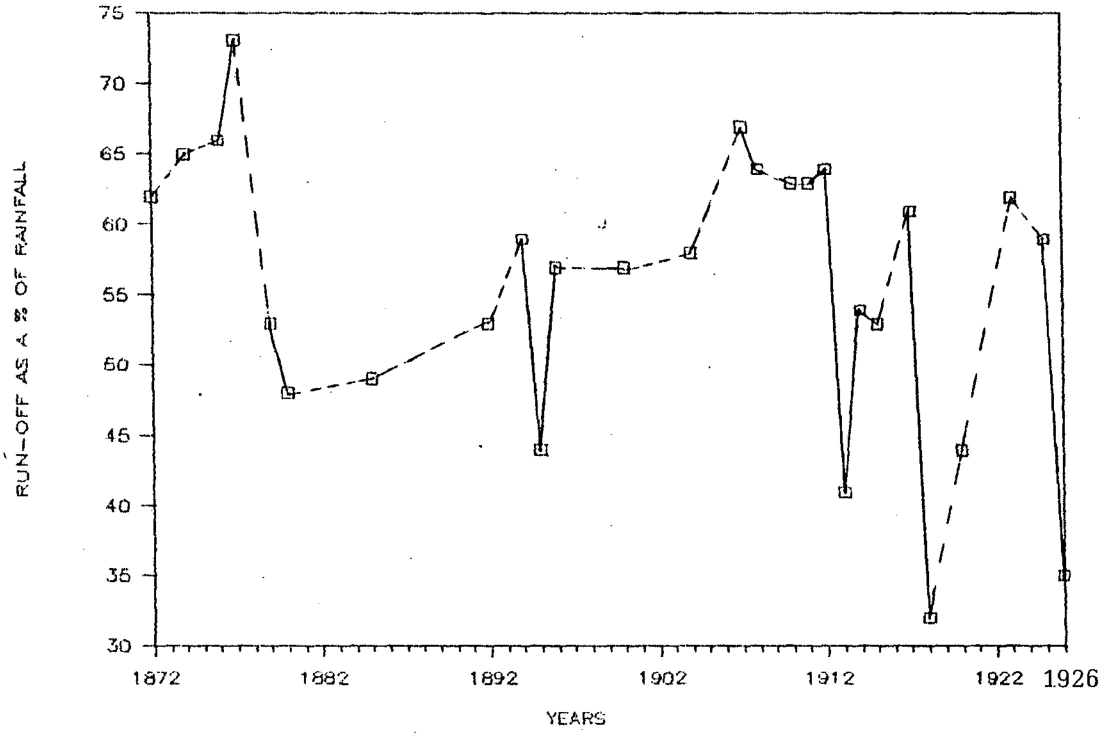


Fig.3.4(b)

Run-off as a % of Rainfall, Mahanadi Catchment, 1872-1926: Period of 4 days before Peak Discharge

Fig.3.4(c)

Run-off as a % of Rainfall, Mahanadi Catchment, 1872-1926: Period of 5 days before Peak Discharge

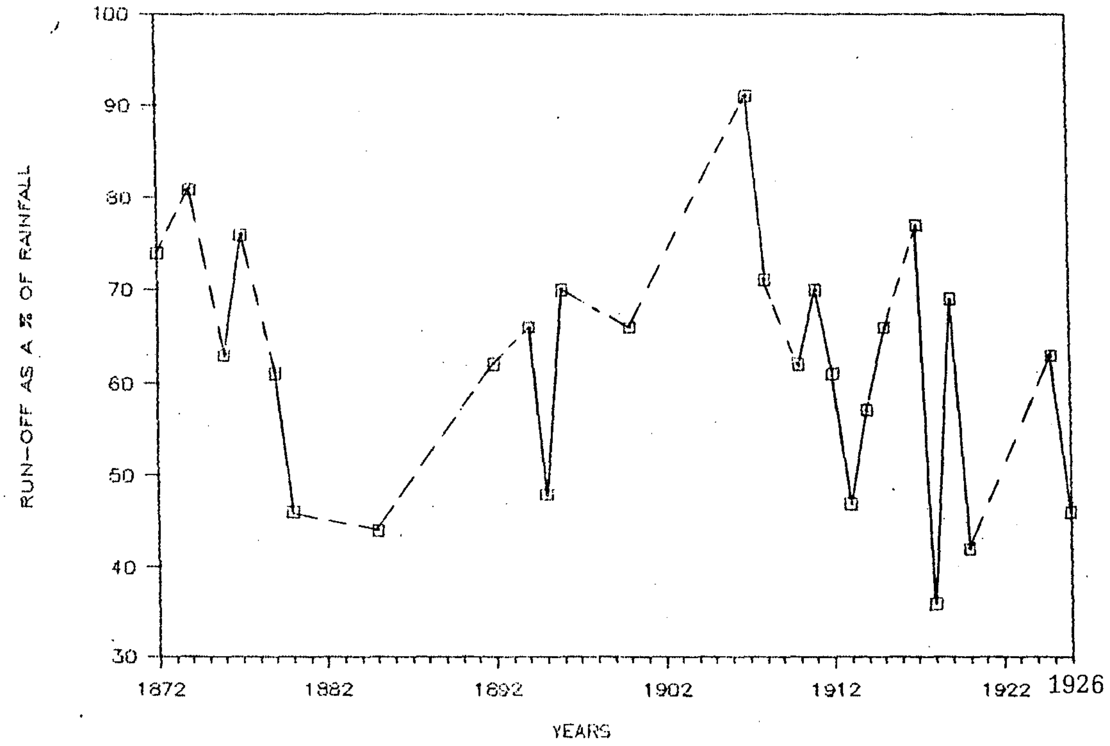


Fig.3.4(d)

Run-off as a % of Rainfall, Mahanadi Catchment, 1872-1926: Period of 6 days before Peak Discharge

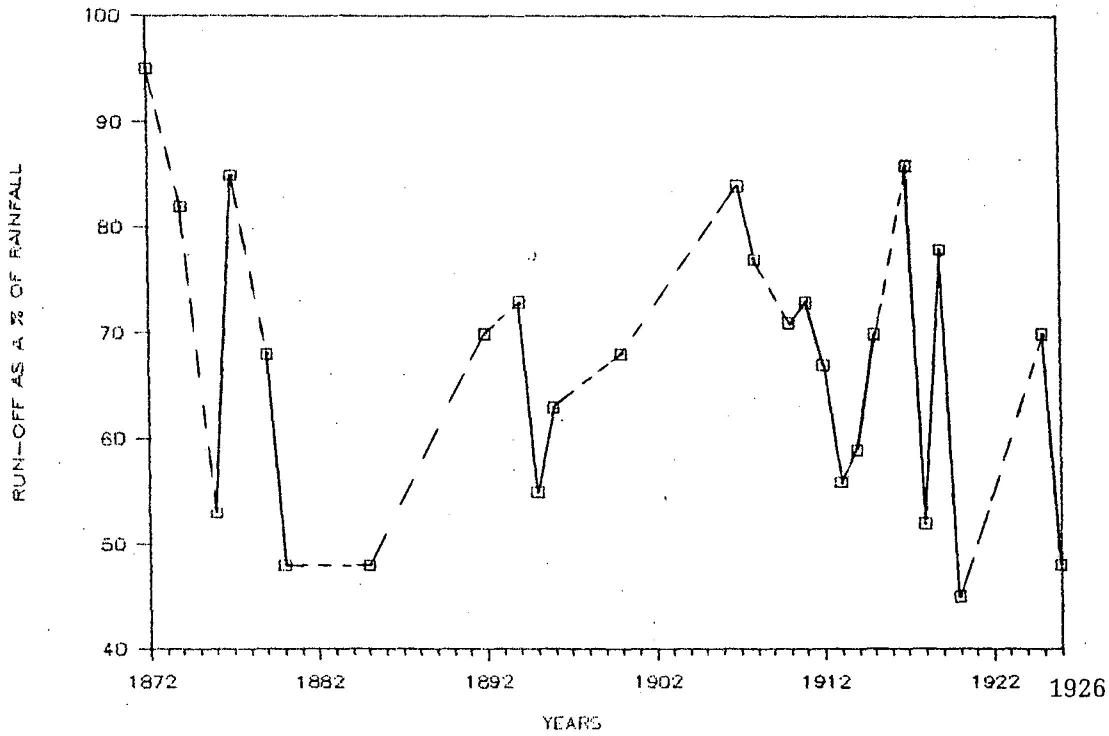


Fig.3.4(e)

Run-off as a % of Rainfall, Mahanadi Catchment, 1872-1926: Period of 7 days before Peak Discharge

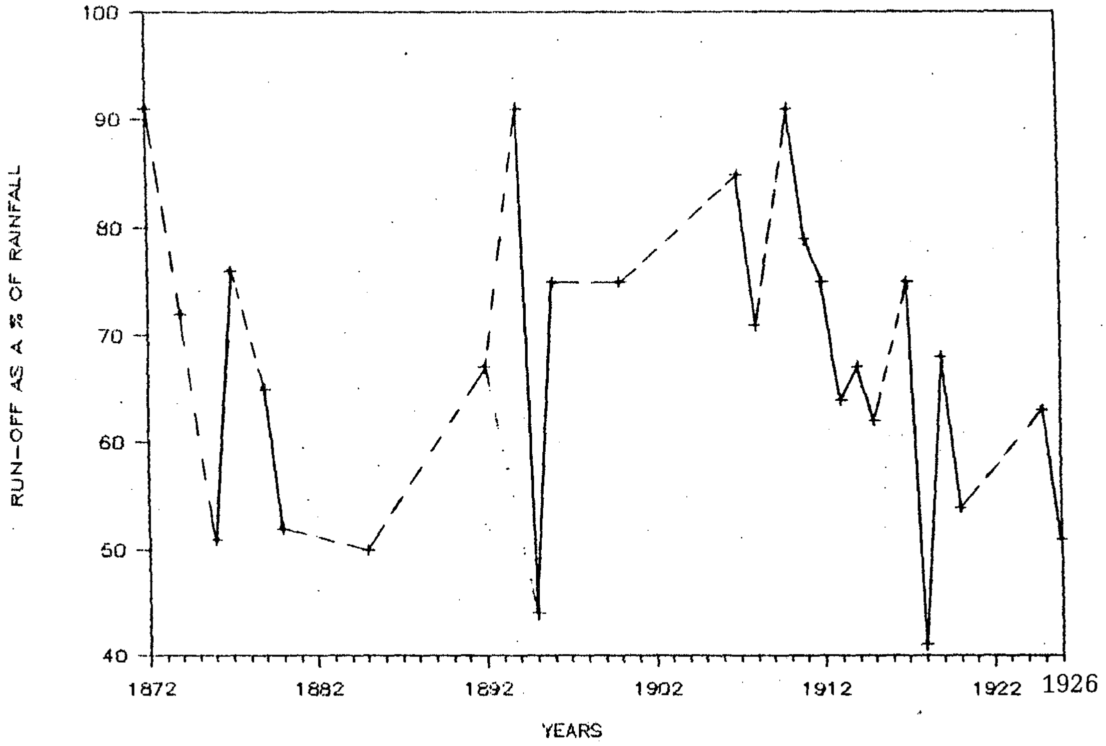
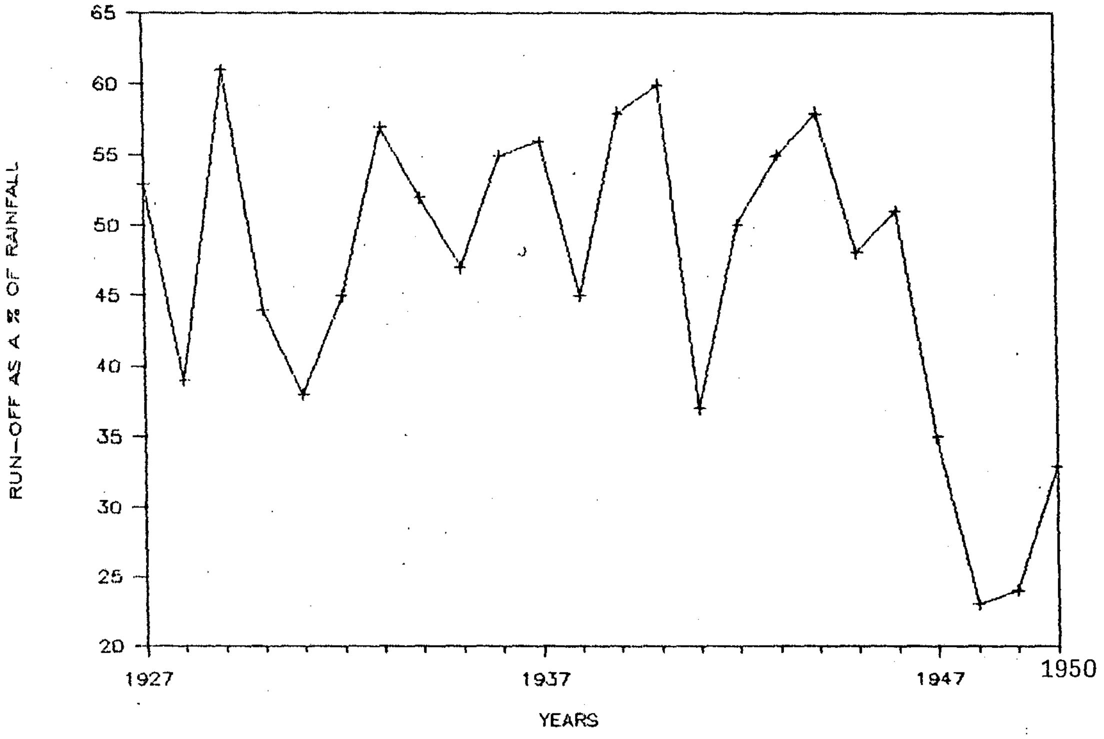


Fig.3.5

Run-off as a % of Rainfall, Mahanadi Catchment, 1927-1950: Monsoon (June-September) Period



An econometric analysis[20] of the relationship between net (of the contribution of Hirakud reservoir) annual peak discharge for the downstream catchment alone and a suitable rainfall index for the same, based on the data for 10 flood occurrences between 1960 and 1970 arrives at the following least-square estimates (postulating a non-linear dependence of net peak discharge, Y, on rainfall, X):

$$\hat{Y} = 0.365 + 0.310X + 0.045\, X^2$$

$$R^2 = 0.9817$$

It is true that the size of the sample is small, but it is striking to note what the above estimated equation suggests, namely that 1" of rainfall is producing nearly 0.66" of net discharge. Now referring back to Fig.3.2, this implies a very high run-off co-efficient corresponding to a thin vegetal cover in the catchment.

As regarding increasing deforestation in the post-Dam period, there are no data available separately for the downstream catchment of Mahanadi as such. On the other hand, the downstream catchment of the Mahanadi mostly covers the five districts of Orissa, namely, Bolangir, Dhenkanal, Kalahandi, Phulbani and part of Sambalpur. According to a study by the National Remote Sensing Agency of India, the forest area in these five districts accounts for nearly 40% of the total forest Area of Orissa (in 1975-76)[21]. Thus, we can assume that the trend in the area under forests for Orissa as a whole—for which Landsat data are available - should reflect that for the above five districts and hence for the downstream catchment of the Mahanadi as well. Now the Landsat data for Orissa for the area under different types of forests (see Table 3.10) shows that in 1972-75, total forest area was some 31.06% of the total geographical area of the state; at this time,

Table 3.10

Total Forest Area & Area under different Forest Types in Orissa, 1972-75 and 1980-82

(based on visual interpretation of Landsat Data)

(in sq.km.)

Period	Total Geographical Area	Closed Forest	Open Degraded Forest	Mangrove Forest	Total Forest Area	% of Geographical Area
1972-75	155780	37320	10829	234	48383	31.06
1980-82	" "	28812	10386	227	39425	25.31

Source: Govt of Orissa, Department of Science, Technology & Environment, Orissa Remote Sensing Application Centre, Monitoring Forests of Orissa by Remote Sensing, (date of publication not mentioned), p.4.

forests with adequate tree cover ('Closed forests') was already low at about 24% of the total geographical area. By 1980-82, the total forest area had come down to 25.31% of total geographical area and 'closed forests' constituted only 18.5% of the total geographical area (see Table 3.10).

The above shows how the rate of deforestation and degradation of forests has been high and increasing in Orissa (within which the downstream catchment of the Mahanadi lies) in the post-Dam period. But, unfortunately, we do not have the required data to analyse how this might have led to an increasing trend in the run-off coefficient in the post-Dam period for the downstream catchment.

On the other hand, we have more direct evidence of increased soil erosion in the downstream catchment as measured by the sediment load of the Mahanadi river at the head of the delta (Naraj). In Table 3.9 above, we had presented data on the amount of silt load and rate of soil erosion for the entire Mahanadi Catchment for sometime before 1951. From there, we find that the total silt load of the river at Naraj was of the order of 61.5 million tons per year. Since the downstream catchment constitutes some 37% of the total catchment area of the Mahanadi, the contribution of the downstream catchment to the total silt load of 61.5 million tons per year can be assumed to have been some 22.8 million tons per year (37% of 61.5 million tons). Similar studies on the sediment load of the Mahanadi at Naraj have been carried out for five years in the post-Dam period. Since in this period, the sediment flow from the upstream catchment is trapped by the Hirakud Dam, the figures for sediment load of the Mahanadi at Naraj can be said to represent the sole contribution of the downstream catchment. These figures show that the total sediment load at Naraj is some 29.8 million tons per year taking the average of the figures for five years (1980-1984)[22], compared to silt load of 22.8 million tons per year before 1951, as we have seen above.

Such an increased rate of soil erosion in the downstream catchment leading to an increase in the sediment load of the river has meant an increase in the river bed within the delta and a rise in the flood level with serious consequences, as we shall see in the following Chapter Four.

Overview

To conclude, in this Chapter, we have attempted to explain the reduced frequency of large and very large floods (but also two particular cases of very large floods in the post-Dam period) and increased frequency of small/medium floods in the post-Dam period compared to the pre-Dam period (Chapter Two, Table 2.3). We have seen that whereas the Hirakud Reservoir has successfully moderated potentially large and very large floods (particularly after 1962), there are limits to the role of the Hirakud Reservoir in complete flood control. First, the conflict between different objectives of the reservoir becomes sharp when the peak inflows from the upstream catchment come as late as September, the extreme case of this was the very large flood of 1980 which came in the second half of September and was caused entirely by forced release from the reservoir. Increased run-off from the upstream catchment following deforestation seems to have rendered inadequate the original live storage capacity which was designed on the basis of past trends in the run-off from the upstream catchment. Added to this is the problem of siltation which has threatened to reduce the original capacity of live storage of the reservoir. Such a higher rate of siltation than anticipated in the original project on the basis of actual silt survey is indicative of increased soil erosion in the upstream catchment.

The increased frequency of medium/small floods was seen as the joint result of flood moderation by the Hirakud Reservoir on the one hand and the contribution from the downstream catchment on the other; whereas the very large flood of 1982 was caused by the downstream catchment alone. We then pointed out the importance of the run-off characteristics of the downstream catchment. The indirect evidence on this indicated that due to deforestation etc. which seems to be taking place in this catchment area since the early 60's or so, the run-off coefficient seems to have increased. This could be crucial in perpetuating a regime of medium/small floods as well as in producing a very large flood in case of abnormally high rainfall in the downstream catchment, as had happened in 1982. This also shows the importance of afforestation and soil-conservation measures in the downstream catchment since such measures, as suggested by Fig.3.3 above, are particularly effective for checking small/medium floods whose frequency has increased in the post-Dam period, as seen earlier.

NOTES

1. The above description has been taken mostly from Govt. of India, National Commission on Flood, Report, Vol.I, p.24 and P.C. Mahalanobis, 1932, p.4.

2. Mahalanobis (1932), pp.12-13, 47.

3. Hirakud Dam Project, Vol.I: Report, p.18,20.

4. Sivaraman Report on Flood Protection Benefits, p.1, cited in Sovani & Rath (1960), p.164.

5. Govt of Orissa, Bhanjadeo Committee Report (1962), p.10.

6. Ibid.

7. In Ibid, Interim Report, 1959, p.52.

8. Govt of Orissa, Irrigation & Power Dept, Flood Report of Orissa (1980).

8a. Acre-ft is a cubic measure of volume. The rate of siltation is measured here as a certain volume per unit of the catchment area (in this case, 100 sq.miles) per unit time (in this case, one year).

9. Govt of Orissa, Orissa Remote Sensing Application Centre, Application of Remote Sensing to Sedimentation Studies in Hirakud Reservoir. The above data of the hydrological surveys have also been taken from this source.

10. Cited in "Siltation of Reservoirs", The Hindu, Special Report, Tuesday, May 5th, 1987.

11. Application of Remote Sensing to Sedimentation Studies in Hirakud Reservoir, pp.5-6.

12. Ibid.

13. Govt of Orissa, Flood Report of Orissa 1964, p.1,9.

14. Interim Report, Orissa Flood Enquiry Committee 1959, p.52.

15. The above discussion of Cook's results is taken from United Nations, Methods and Problems of Flood Control in Asia and the Far East, prepared by the Bureau of Flood Control of the ECAFE, Bangkok, 1951.

16. The following examples have been taken from B.B. Vohra, "Pre-eminent Water Source", The Hindu, Saturday, January 24, 1987, p 8.

17. This relies entirely on the U.N. Study mentioned in n.15 above.

18. Mahalanobis (1932), pp 225-228.

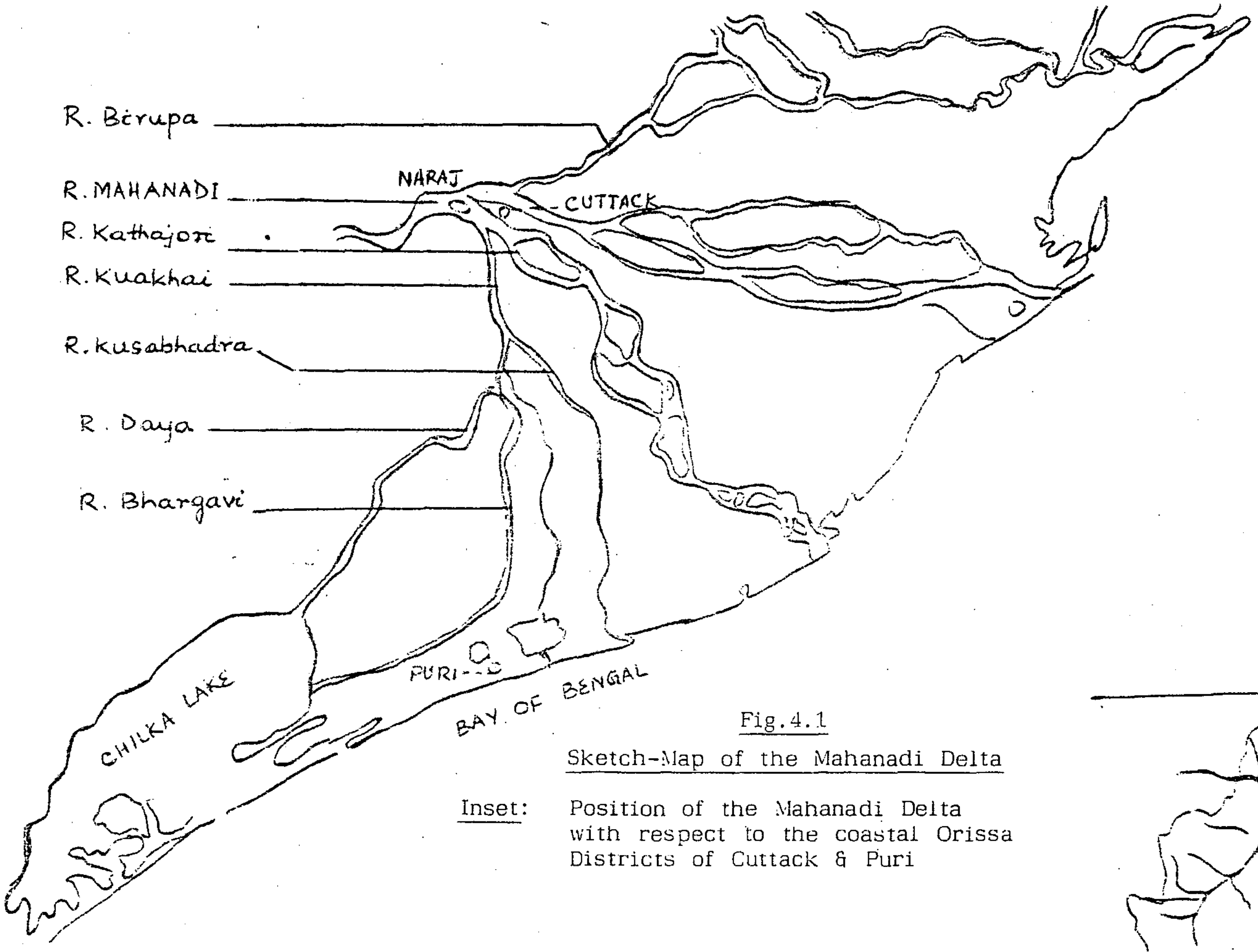
19. Ibid, p 228 (note)

19a. The rainfall data is for 81 raingauge stations situated in different parts of the Mahanadi Catchment: Both this rainfall data and run-off data are taken from Govt of India, Central Water & Power Commission, Hydrological Data of River Basins of India: The Mahanadi Basin (upto 1950), Delhi, 1952.

20. S.N.Sinha, "Forecasting Downstream Discharge for Operation of Hirakud Reservoir", unpublished paper (typescript), date not mentioned.

21. Govt of Orissa, Dept of Science, Technology & Environment, Orissa Remote Sensing Application Centre, Monitoring Forests of Orissa by Remote Sensing (date of Publication not mentioned), p.3.

22. Govt of Orissa, Delta Development Plan, Mahanadi Delta Command Area, Vol.IV: Geology, Geomorphology and Coast Building, Engineer-in-Chief (Irrigation), 1986, p.53.



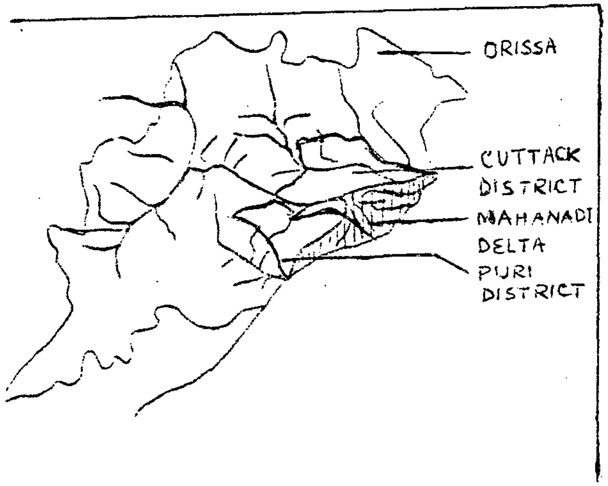


Fig.4.1

Sketch-Map of the Mahanadi Delta

Inset: Position of the Mahanadi Delta with respect to the coastal Orissa Districts of Cuttack & Puri

CHAPTER FOUR

CONDITIONS OF FLOOD DISCHARGE IN THE MAHANADI DELTA: THE ROLE OF FLOOD CONTROL EMBANKMENTS

We have seen (Chapter Two) that small/medium floods have come to dominate the composition of floods in the post-Dam period compared to large/very large floods which dominated the compsition of floods in the pre-Dam period. Consequently, the average magnitude of floods has come down in the post-Dam period. The purpose of this Chapter is to see how this has not led to a corresponding decline in the average extent of damage in the post-Dam period. In effect, here we shall analyse those conditions in the Mahanadi Delta which influence the relationship between a certain magnitude of flood (annual peak discharge into the delta) and the extent of damage caused by it. Before coming to the analysis, we shall give a brief description of the delta.

As we have seen, the Mahanadi enters the plains at Naraj, seven miles west of the city of Cuttack (see Fig.3.1). At Naraj the river divides, the main stream called the Mahanadi flowing east towards the sea and a large branch called the Kathajori turning off towards the south partly through the district of Puri. The Mahanadi next gives out a large branch (called Birupa) on the left, little below Cuttack, while four miles below Naraj, opposite Cuttack City, the Kathajori sends out a big channel called the Kuakhai on the right. Kuakhai then branches off into several smaller distributaries such as Daya, Bhargavi and Kushabhadra; same is true of Kathajori, the main channel of the Mahanadi and the Birupa. These delta channels together form a thick network (see Fig.4.1) with several fertile tracts of land between adjacent channels. The total area of the Mahanadi delta is estimated to be about 3100 sq.miles of which about 1400 sq.miles lie in Puri district and 1700 sq.miles in Cuttack district (see Inset, Fig.4.1).

We start with the data on the magnitude of flood and the corresponding extent of damage (Cropped area affected) for a number of years to see whether or not the extent of damage is a simple, increasing function of the magnitude of flood, as one would expect (other things remaining the same).

I

Relationship between Intensity of Flood and the Extent of Flood Damage: The Role of the Duration of Flood

There are three striking things to be noted from the following Table 4.1. First, there have been several years (1964,67,68,70,71,74,75) in which flood damage has occured even with a peak discharge of less than 9 lakh cusecs at the delta head, whereas the safe carrying capacity of the delta channels of the Mahanadi is regarded as 9 lakh cusecs, as we have seen earlier. Second, even with comparable levels of peak discharge (ie. magnitude of floods), the extent of damage has been different for different years (the above years of less than 9 lakh cusecs and 1976 & 1977). That is, the same magnitude of flood has resulted in different extent of damage. Third, a flood of smaller magnitude has sometimes led to a greater extent of damage than a flood of a relatively larger magnitude, e.g. 1866 compared to 1855; 1964 compared to 1976; 1967 compared to 1977; 1968 or 1971 or 1975 compared to 1969,1977 or 1978.

Table 4.1

Relation between Magnitude of Flood and Extent of Damage, Mahanadi Delta, Selected years

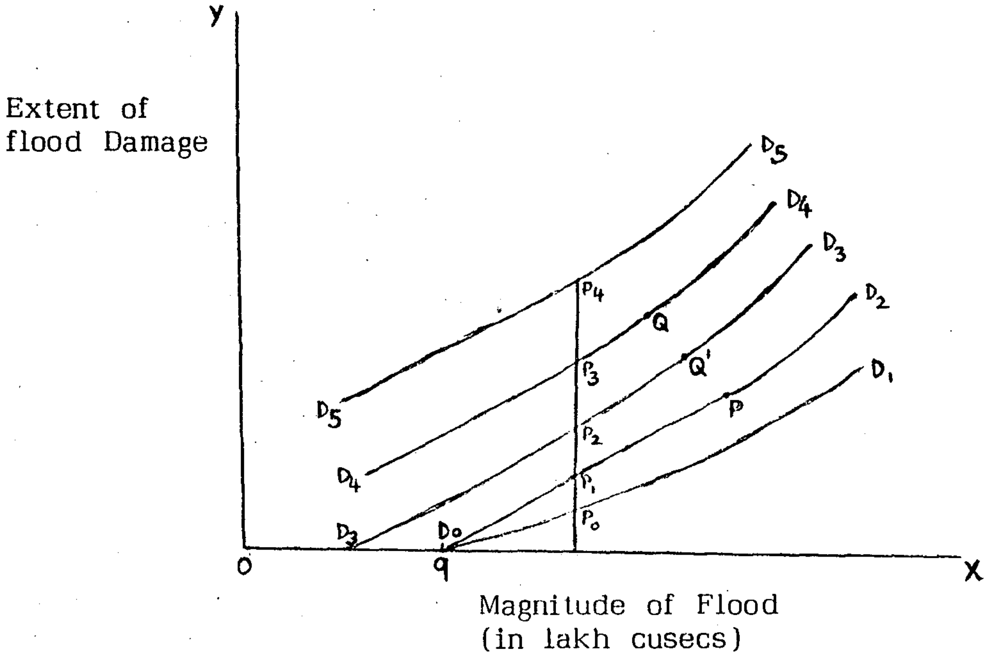
Year	Magnitude of Flood (in lakh cusecs)	Duration of Flood (in no.of days)	Extent of Cropped Affected (in lakh hectares)
1855	15.44	shorter than in 1866	less than in 1866
1866	12.46	longer than in 1855	more than in 1855
1964	7.0	15	1.12
1967	7.75	5	1.89
1968	7.47	7	2.59
1969	9.78	2	1.96
1970	8.18	4	2.24
1971	7.43	9	3.29
1974	7.56	3	0.84
1975	8.11	5	2.94
1976	9.34	1	negligible
1977	9.35	2	1.33
1978	9.85	2	2.31

Source: W.W.Hunter, A Statistical Account of Bengal, Vol.XVIII: Cuttack & Balasore, p.52; Climatic Studies(for agricultural use) on Mahanadi Delta Command Area; National Commission on Floods, Vol.1, p.73; Govt. of Orissa, Annual Flood Reports, relevant years.

What is this crucial parameter which determines the above kinds of relationship between the magnitude of flood and extent of damage? From the available evidence, it is clear that this crucial parameter is the duration of floods, which is the length of time for which a certain rate of peak inflow into the delta is more or less maintained at that level. For example, from the comparative case of 1855 and 1866 floods, though the magnitude of 1855 flood was greater, because of its shorter duration the extent of damage was less. As Hunter, writing in 1877 or so commented: "In 1855 the floods were deeper, although from the shorter period of their continuance they didn't do so much harm'[1]. Again, in 1964, the peak discharge was only 7 lakh cusecs. According to the Flood Report for this year, "...eventhough the gauge at Naraj did not exceed the danger level, severe damage occured in the delta due to the protracted nature of the flood... the gauge at Naraj remained mostly between 85' to 87' for a total period of 15 days. The discharge at Naraj was on an average 7 lakh cusecs during this long period..."[2]. Similarly, in 1967, there was substantial damage eventhough the peak discharge was less than 9 lakh cusecs, which was because of the fact that a peak discharge of between 7 and 9 lakh cusecs persisted for five days[3]. Similarly, in 1968 and 1971 for example, the extent of damage was greater than say, in 1978 though the intensity of floods was much smaller in the former two years: this was apparently because of the much longer duration of floods in these two years (see Table 4.1). Again, in 1976 and 1977, even with almost the same intensity of floods, there was significant damage in 1977 due to a longer duration of floods, etc. Thus, the duration of flood emerges as a crucial parameter in the relationship between magnitude of flood and extent of damage.

Fig 4.2

Family of Flood Damage Curves



The above can be diagrammatically represented as in Fig.4.2. In this figure, Y-axis measures the extent of flood damage whereas X-axis measures magnitude of flood. In the diagram, the extent of flood damage is an increasing function of the magnitude of flood, represented by an upward-sloping curve. But the position of such a curve depends on the average duration of flood: any given damage curve is thus drawn for floods of a given duration. As the average duration of floods increases, the curve shifts upwards, so that we get a family of flood damage curves in Fig.4.2, for varying average duration of floods. We shall see a little later why such a shift takes place as the average duration of floods increases, but there are three important things which the family of flood damage curves are supposed to represent. First, at a certain low average duration of floods, the damage curves (such as D_0D_2) touch the X-axis at a magnitude of flood of 9 lakh cusecs which means that there is zero damage for a magnitude of flood of 9 lakh cusecs or less (since this is supposed to be the safe carrying capacity of the Mahanadi delta channels, as we have seen). But as the average duration of floods increases beyond a certain point, flood damage begins to occur at even less than 9 lakh cusecs (corresponding to damage curves such as D_3D_3, D_4D_4, D_5D_5 etc). Second, for any given magnitude of flood, the extent of damage increases as the average duration of flood increases (represented by points such as P_0, P_1, P_2, P_3, P_4 etc). Third, a relatively smaller magnitude of flood but of a sufficiently longer duration can lead to a greater extent of damage than a larger flood of a shorter duration (Point Q can lie above point P; how much above would depend on the difference in the average duration of flood between the smaller and the larger floods). It is to be noted that the data presented in Table 4.1 above show the above three features.

II

Average Duration of Floods in the Pre-Dam and Post-Dam Periods

If the above parametric role of the average duration of floods is true and since the main purpose of this Chapter is to see how low/medium floods in the post-Dam period have led to no less/greater damage than the large/very large floods on the pre-Dam period, the next question to ask is: what has happened to the average duration of floods in the post-Dam period relative to the pre-Dam period, since this might explain the observed trend in the extent of flood damage, say through an increase in the average duration of floods in the post-Dam period. We shall examine the available evidence on this (which, as we shall see now, suggests that the average duration of floods has indeed increased in the post-Dam period, though the average magnitude of flood has reduced, as already seen in Chapter Two).

As regards the pre-Dam period, we have historical reference to the short duration of large and very large floods which dominated the composition of floods in this period (Table 2.3). A. Cotton, in his report on the Mahanadi river, says that the flood of 1855 which is the most severe flood on record, "... continued nearly at the same level for 12 hours; the longest in the Godavari nearly at one height for 10 days; that of the Ganges for 40 days, (thus) the characteristic of Mahanadi flood is said to be 'immensity of volume, brevity of period"[4]. On the other hand, in the post-Dam period, small/medium floods (as well as floods of less than 9 lakh cusecs which, as we have seen, cause damage) dominate the composition of floods following moderation of large/very large floods by the Hirakud reservoir. We shall see later how such small/medium floods inevitably have a typically longer duration.

The data on duration of floods for 31 years (1920-50) in the pre-Dam period and 26 years (1958-84) in the post-Dam period has been presented as frequency distribution of these years across low (0-1 day), medium (2-3 days) and long ($\geqslant$ 3 days) duration classes (see Table 4.2). We find that the proportion of short duration floods has come down in the post-Dam period whereas the proportion of both medium and long duration floods has increased. As a result, the average duration of floods has increased from 1.61 days in the pre-

Table 4.2

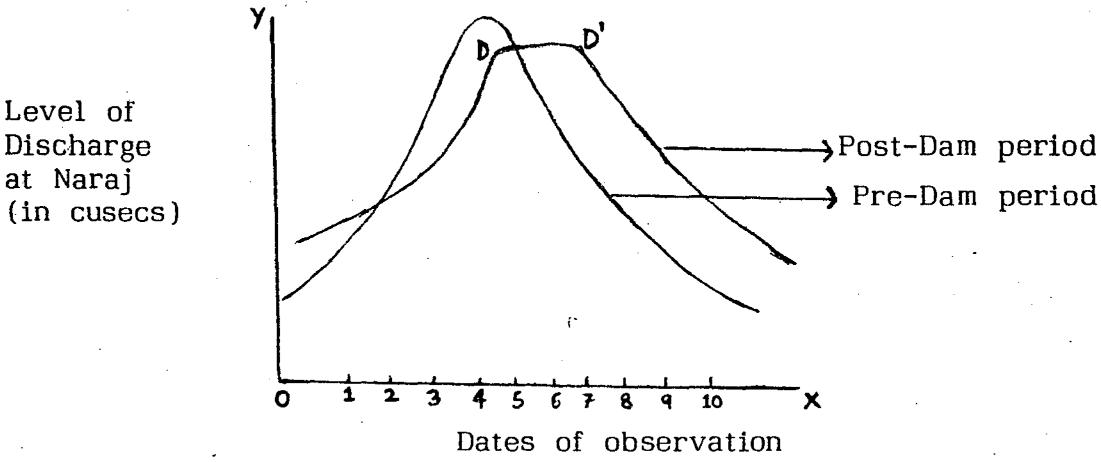
Frequency Distribution of different years by Classes of Duration of Flood in each year, Pre-Dam and Post-Dam periods

Duration (in no.of days)	Pre-Dam (1920-50)		Post-Dam (1958-84)	
	No.of Years	% of total	No.of Years	% of total
0 - 1	20	64.5	8	30.8
2 - 3	7	22.6	8	30.8
≥3	4	12.9	10	38.5
Average	1.61 (31 years)		3.17 (26 years)	

Source: Tabulated from the data on the duration of floods for individual years in Govt of India, Central Water & Power Commission, Hydrological Data of River Basins of India: The Mahanadi Basin (upto 1950), Delhi, 1952, pp 586-620 (for the pre-Dam period) and Govt of Orissa, Annual Flood Reports, various years (for the post-Dam period).

Dam period to 3.17 days in the post-Dam period. Such an increase in the average duration of floods in the post-Dam period can be represented through a simple diagram (see Fig.4.3). In the Y-axis, we measure the level of discharge at the head of the delta and in the X-axis, the dates of observation of this discharge during the flood season. The average curve showing the changes in the level of discharge over time (known as the flood hydrograph) is drawn for the pre-Dam and post-Dam periods. Though the peak discharge for the post-Dam period lies below that for the pre-Dam period (corresponding to a lower average intensity of floods in the post-Dam period), the peak discharge remains more or less at the same level for more than three days in the post-Dam period (shown by the horizontal section DD' in the flood hydrograph for the post-Dam period), whereas for the pre-Dam period it starts falling fairly steeply (corresponding to an average duration of floods of just more than a day in the pre-Dam period).

Fig 4.3
Average Flood Hydrographs,
pre-Dam and post-Dam periods



Thus, in general, we can say that, as between the pre-Dam and post-Dam periods, large/very large floods of a short duration have been replaced by small/medium floods of a longer duration. In terms of Fig.4.2, this can be represented as a movement from point P to, say, point Q'. (Since the average magnitude of flood has not come down all that much in the post-Dam period, as seen in Chapter Two, the movement cannot be from P to, say, P_2 which would have meant a decrease in the average extent of flood damage in the post-Dam period). The above can explain why the average extent of damage has not come down - and in fact might have gone up - in the post-Dam period.

Role of Flood Control Embankments

Given that the average duration of floods has increased in the post-Dam period, there are two further questions which need to be asked now: First, how has the average duration of floods increased? Second, how has an increased duration of floods led to an increased/no less damage in the post-Dam period (that is, what factors underlie the upward shift of flood damage curves, in terms of Fig.4.2 above)? In order to answer these questions, we have to describe the pre-existing system of flood protection in the Mahanadi delta in the form of flood control embankments which, as we shall see, play a crucial role. The available data on this for different time points in the pre-Dam period are presented in Table 4.3-4.5.

From Table 4.3, we find that as early as 1872, nearly 50% of the total length of delta channels of the Mahanadi had flood control embankments; 25% of these embankments (in terms of length) were privately managed by Zamindars of the respective estates, the rest being Government embankments. Thus, the data for 1905 shows that some 53% of the total deltaic area of the Mahanadi was protected by means of flood control embankments (Table 4.4). There was an expansion of the embankment system and consequently the extent of area

Table 4.3

Extent of Embanked River Banks, Mahanadi Delta, 1872

(in miles)

District	Length Embanked G	Length Embanked Z	% of total	Length not embanked	% of total	Total length of channels measured
Cuttack	510 (67)	248 (33)	49	790	51	1548
Puri	360 (88)	48 (12)	49	423	51	831
Total	870 (75)	296 (25)	49	1213	51	2379

Source: W.C.Taylor, Report on the Embankments of Orissa, Calcutta: Bengal Public Works. Dept. Press, 1872.

Notes:

1. G - Government Embankments, Z - Zamindari Embankments.
2. Figures in brackets represent percentage of total length of embankments in each case.

protected increased from 1,327 sq.miles in 1905 to some 1,822 sq.miles in 1940 which was as much as 80% of the total area liable to floods (Table 4.5, sum of first three rows).

Thus, we find that, by the time the Hirakud reservoir came into the picture, there was already existing a fairly extensive system of flood protection in the Mahanadi delta in the form of flood control embankments. We are, however, actually interested in identifying the problems or the limitations of the method of flood prevention through a system of embank-

Table 4.4

Extent of protected Area in the Mahanadi Delta due to Flood Control Embankments, 1905

(in sq. miles)

Total Deltaic Area	2,525
Area protected	1,327
% of total Deltaic Area	53

Source: A.S.Thomson, Rivers of Orissa cited in P.C.Mahalanobis, Rainfall and Floods in Orissa, p.62.

Table 4.5

Extent of Fully Protected, Semi-protected and Unprotected Areas, Mahanadi Delta, 1940

(in sq. miles)

1. Area Protected from all Floods and Irrigated (Fully Protected)	641(28.0)
2. "" "" but not Irrigated (Fully Protected)	456(19.8)
3. Area protected from low floods (semi-Protected)	725(31.6)
4. Area open to all Floods (Unprotected)	475(20.6)
5. Total Area Liable to Floods (Totals of 1 to 4 above)	2,297(100.0)
6. High ground, jungles etc. not ordinarily flooded	278

Source: J. Shaw (Executive Engineer, Floods and Drainage Division), Interim Report of the Orissa Flood Advisory Committee, 1939-40, Appendix VI, cited in Mahalanobis, Rainfall and Floods in Orissa, p.64

Note: Figures in brackets represent percentage of total area liable to floods.

ments of the kind we find in the Mahanadi delta. We shall now turn to a discussion of these problems.

First, the consequence of the partial nature of effective protection was that it only transferred the threat of flood to unprotected or inadequately protected (semi-protected) areas which together made up, in 1940, nearly 52% of the total area liable to floods in the Mahanadi delta (Table 4.5). As H.A.Gubbay, Superintending Engineer, Orissa Circle, commented in 1920: "In protecting deltaic areas from flood by means of marginal embankments, it necessarily follows that the unprotected areas are subjected to increased inundation..."[5]. Again, the Orissa Flood Committee of 1928 commented: "Every sq.mile of country from which spill water is excluded means the intensification of floods elsewhere; every embankment means the heading up of water on someone else's land ... the most insistent demand made to us by the inhabitants of the semi-protected and unprotected areas is for the complete abolition of the Canal system and the throwing open of the fully protected areas to the spill of the rivers. They argue that the effect of this protection is to intensify the floods in the remainder of the country..."[6]. This shift of the flood threat becomes particularly serious from the point of view of flood damage because of the inadequate strength, and hence vulnerability, of the embankments in the 'semi-protected' area, as we shall see below.

The second general problem with the system of embankments was that most of them came up in an unplanned, haphazard manner, without adequate attention to quality and were mostly poorly maintained. This seems to be true not only of private (Zamindari) embankments but also for government ones. As the National Commission on Floods has observed: "The term 'zamindari' embankments connotes small bunds, dykes and levees put up by Zamindars... as localised individual efforts primarily to protect their lands and properties against floods in specific areas... These were usually constructed in isolated places and without much technical know-how. The result was a haphazard growth of local bunds built over the centuries concentrated mainly in the four states of West Bengal, Orissa, Bihar and Uttar Pradesh ... Due to lack of resources and planning these stray works were generally sub-standard and not capable of withstanding the pressure of recurring floods. Not being systematically or scientifically planned, for want of adequate records of flood heights, the embankments suffered several breaches. The standard of their maintenance which was the responsibility of the Zamindars was very often poor. Such lack of planning, by and large, equally applies to some embankments constructed under some relief programmes of the Government like test relief embankments, etc."[7]. Such haphazard nature, poor design and maintenance was also true of the embankment system particularly in the 'semi-protected' area in the Mahanadi delta. As the Orissa Flood Committee of 1928 observed: 'The whole system of embankments in these areas seems to have grown up without any reasoned plan underlying it: Some of the embankments have been constructed and maintained by government, some by the Zamindars. These are marginal embankments running along the banks of the rivers, and ring bunds, completely enclosing villages and estates. They have come into being solely in the interest of the particular area to be protected, and with complete disregard of their effects upon the other areas. The river, shackled in one direction, bursts its bund elsewhere; fresh shackles are applied at the new danger point which necessitates the strengthening of the original defences and the institutions of the new ones which would otherwise not have been required.

The whole arrangement can only be described as chaotic. There is not, to the best of our knowledge, a single embankment in the semi-protected area which can be regarded as really safe... There has been nothing in our tour which has struck us as more pitiable than the position of the people sheltering behind some of these illusory defences."[8]

The third general problem which is somewhat inherent in the method of flood prevention through embankments is that it could lead to silting of the river bed. As a result, there occurs a progressive rise in the level of the river bed and hence the high flood levels also go on increasing and exceed those of the previous years for the same discharge. This has two consequences: on the one hand, this necessitates continuous raising of the embankments which therefore cannot be maintained properly beyond a point. Secondly, there occurs a continuous lowereing of the level of the protected area relative to the peak flood level as well as to the unprotected area. This, in turn, could lead to the problem of drainage congestion in the protected area behind the embankments which can destroy the standing crops completely in case of flood due to a breach in the embankments. The Orissa Flood Committee of 1928 has described different aspects of the above problem quite forcefully as follows:

"It must be clearly grasped that, in a deltaic area there must be flooding; it is nature's method of land formation, any effort to prevent it are doomed to failure from the outset. It might, for example, be suggested that every river should be embanked from both sides from the point where it leaves the hills to the sea; the result would merely be that it would deposit silt in its bed, the bed would rise, the floods would rise and the embankments have to be raised to correspond, until eventually these embankments would reach a size at which they could no longer be maintained. They would then burst, probably to the complete destruction of the country in the vicinity which would have become lower and lower relatively to the level of water in the river. Much the same phenomenon occurs when isolated areas are protected by embankments; the land around, subjected to an increased spill, tends to rise, the height of the flood is increased, one proprietor raises his embankments, the others are bound to follow suit or be drowned out and thus the vicious circle goes on until, in many cases, the protected areas behind them is infinitely worse-off than is the unprotected areas outside"[9].

Thus, an extensive system of flood control embankmemnts in the Mahanadi Delta was inherited from the past. That such a system had a much greater importance in the Mahanadi delta than other river deltas in the country is brought out by the fact that by 1947, according to one estimate by the Central Water Commission, out of about 5,280 kms of embankments in all rivers of India, those along the Mahanadi alone were some 1,209 kms. This was 23% of the total length of embankments whereas the protected area in the Mahanadi delta was less than 15% of the total protected area in the country[10]. But, more importantly, the whole system has been taken over without any major qualitative change, that is, with all the problems of such a system mentioned above: according to the National Commission on Floods, till about 1980, the Orissa State Government didn't have any comprehensive plan to replace, supersede or remodel the existing embankments[11]. This means that the above

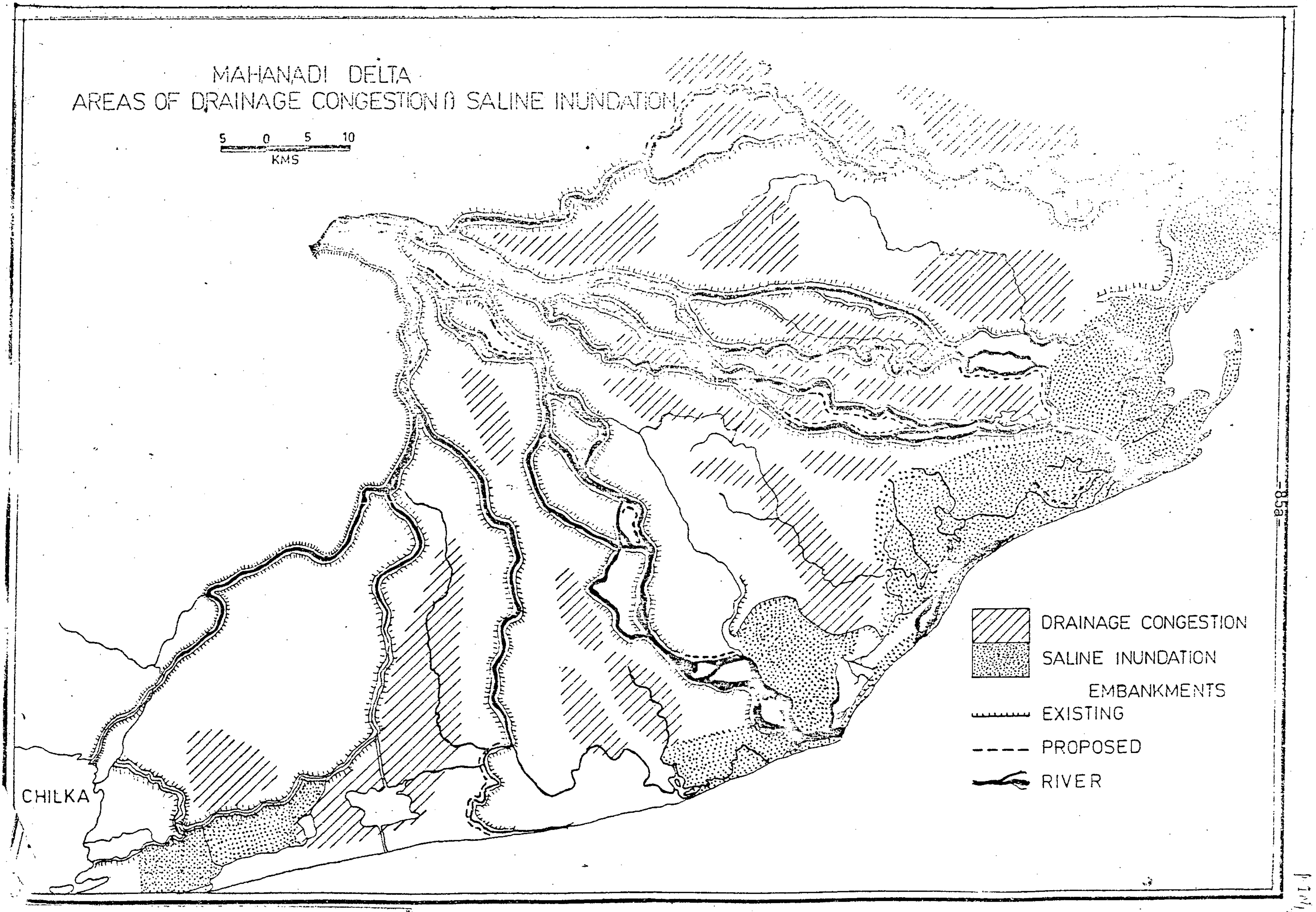

MAHANADI DELTA
AREAS OF DRAINAGE CONGESTION & SALINE INUNDATION
5 0 5 10
KMS
CHILKA
DRAINAGE CONGESTION
SALINE INUNDATION
EMBANKMENTS
EXISTING
PROPOSED
RIVER

Fig.4.4

mentioned problems associated with the embankments system, such as partial protection, poor maintenance, etc. have more or less persisted into the post-Dam period. The problem of drainage congestion in the Mahanadi delta seems to be fairly acute (see Fig.4.4): Out of 2,297 sq.miles of area liable to floods in the Mahanadi delta, an area of nearly 500 sq.miles[12] (22%) is liable to drainage congestion. According to another recent estimate, the area subject to drainage congestion in the Mahanadi Delta formed 38% of the culturable command area[12a]. In fact, given the further expansion of the embankment system in the post-Dam period, some problems like siltation of the river bed seems to have been aggravated (as we shall see later). It is against this background of the inherited embankment system (and the related problems) that we can see how an increased duration of floods along with some other factors have led to no less/greater flood damage in the post-Dam period. We now come back to the questions of how the average duration of floods has increased, and how this has resulted in no less/greater damage, in the post-Dam pereiod. We shall also discuss two other sets of contributing factors.

Increased Duration, Pressure on Embankments and Flood Damage

We start with the question: how has the average duration of floods increased in the post-Dam period? Basically, following moderation of large/very large floods by the Hirakud reservoir, the frequency of low/medium floods has increased, partly due to contribution from the downstream catchment, as we have seen in Chapter Three. Such a regime of low/medium floods or maintaining a peak discharge of just around 9 lakh cusecs (supposed to be the safe carrying capacity of the Mahanadi delta channels) is achieved by distributing the peak discharge over a longer period of time so as not to allow the peak discharge to rise above a certain level. This necessarily results in prolonging the period for which the peak discharge stays around 9 lakh cusecs or so. As the Third Interim Report of the Orissa Flood Advisory Committee (1942) put it: "The operation of the Hirakud Dam, as envisaged at present, is to moderate the floods by holding up water in the reservoir from the upper catchment area until the peak flood water from the uncontrolled portion of the catchment area has flown down to the sea. Obviously the moderation of flood by the Hirakud Dam will mean that the gauge at Naraj will be kept below or at RL89 ft. (which means discharge of 9 lakh cusecs). The total discharge of the Mahanadi will not be allowed to rise above a certain level by distributing it over a longer time than hitherto by the moderating operations of the Hirakud Dam. This means that the water level of the Mahanadi will be maintained at Naraj at R.L. 89 ft. for a longer time than hitherto because of the Hirakud Dam"[13].

How has this increased duration of floods of a low/medium intensity or of a peak discharge of 9 lakh cusecs or less led to no less damage in the post-Dam period (as can be seen from Table 4.1, there are as many as six years in the post-Dam period in which there was significant damage even when the peak discharge was less than 9 lakh cusecs)? It is here that the inherited system of flood control embankments comes into the picture. The Third Interim Report of the Orissa Flood Advisory Committee (1942) had commented. "The embankments in Orissa if exposed to flood for a prolonged period, percolate in many places and there is a chance of earth slips and breaches. A flood height of 89' at Naraj (corresponding to a discharge of 9 lakh cusecs) for more than three days may be taken as indicating percolation danger."[14]. Thus, an increased duration of floods means prolonged pressure on the embankments. Now, we have seen that the embankments were mostly badly maintained in the pre-Dam period. In the post-Dam period also, there has been no comprehensive plan for the proper maintenance of embankments. For example, the team of experts appointed by the Government of India to advise on the operation of the Hirakud Reservoir during the flood season were commenting as late as in 1976 in their Report: "There doesn't seem to be any satisfactory criteria for the design of the embankments... The strengthening of embankments should be taken up immediately and carried out in the order of their vulnerability"[15]. In fact according to the list of vulnerable points in the flood embankments of Orissa released by the Board of Revenue, in 1986, there were as many as 140 embankments in the Mahanadi Delta with at least one vulnerable point: altogether there were 331 such points in these 140 embankments, which on an average works out to one vulnerable point for every 4.2km length of embankment[15a]. Given such poor maintenance of the embankment system, increased pressure on the embankments due to increased duration of floods leads to breaches in the embankments. Even in the absence of breaches, floods of a long duration can be transferred to the unprotected area and cause damage there. For example, in 1964, the peak discharge was only 7 lakh cusecs but remained more or less at that level for 15 days. As a result, according to the Flood Report for that year, "In the lower delta where there are no embankments extensive damage occured due to continuous spilling of flood water"[16].

There is a second set of factors which lead to increased pressure on embankments, besides an increased duration of floods. First, there is evidence for significant expansion of the embankment system in the post-Dam period. According to one estimate, 370 km of embankments have been constructed between 1954 and 1978 which is 30% of the total length of embankments existing prior to 1954[16a]. According to another estimate the length of the embankments in the Mahanadi delta meant for flood control increased by about 250 kms roughly between 1975 and 1986[16b]. This along with increased soil erosion in the downstream catchment (as seen in Chapter Three) seems to have led to silting of river channels and hence a fall in the safe carrying capacity of the delta channels of the Mahanadi (This is perhaps reflected in the fact that flood damage is occuring even at a peak discharge of less than 9 lakhs cusecs, which was earlier considered safe). This in turn leads to a continuous rise in the flood levels even with the same discharge. As the Flood Report of 1967 said: "A number of embankments have been constructed on either side of the deltaic rivers since 1962 and the bed levels of the rivers in the delta have increased owing to silting. Therefore there is progressive increase in flood levels in different gauges of the rivers."[17]. The above has been brought out by a comparative analysis of the peak gauge levels of three distributaries of the Mahanadi flowing through the southern portion of the delta, namely, Kushabhadra, Bhargavi and Daya (see Fig.4.1) along which new embankments are known to have been constructed. It has been seen that the peak flood levels have been showing an increase (progressive) from 1961 to 1964 to 1967, even though the peak flood discharge at Naraj in 1961 was 12 lakh cusecs and in 1964 and 1967 around 8 lakh cusecs[18]. Again, in 1976, the team of experts appointed by the Government of India, said: "After the Hirakud Reservoir came into operation, with a view to introduce irrigation in the earlier flood-prone areas, embankments were extended towards the sea and several islands in the flood zone were taken out of the flood zone and brought under irrigation, resulting in the obstruction of the waterway and consequent rise in flood level"[19]. Such an increasing flood level makes the embankments more and more inadequate; along with an increased duration of flood, this would mean prolonged pressure on the already poorly maintained embankment system.

Increased Flood Plain Occupancy

There is a third factor which, in an important way, seems to have led to greater actual flood damage following breaches in the embankments due to the above two factors. It is the increased flood plain occupancy following moderation of large/very large floods by the Hirakud reservoir and further expansion of emabnkments. As the team of experts appointed by the Government of India commented: "On account of lower flood levels prevailing in the post-Hirakud conditions, the towns and villages below Hirakud have encroached into the earlier flooded areas... Due to the gradual construction of more and more embankments on downstream channels for reclamation of the delta area and consequent encroachment in the flood plains, flood damages are now reported to occur at much lower levels."[20]

We have attempted to verify whether the rate of occupancy of flood-prone areas in Cuttack and Puri districts has been higher in the post-Dam period. This has been done in a very rough way by looking at the data on the level of population density and the annual percentage increase in it between 1951-61 (ie. mostly the pre-Dam period) and between 1961-81 (ie. post-Dam period). The relevant data are available at the level of Police Stations (which, in size, is between a tahsil and a Revenue Block), which have been classified (according to the status of flood protection enjoyed by it) into three classes: fully protected (ie, where there are both canals and strong embankments which can withstand large floods or small/medium floods of long duration), semi-protected (ie, where there are only flood embankments which are quite vulnerable) and unprotected (ie, where there are no embankments). This classification of Police Stations is based on the maps of police stations given in the Administrative Atlas of Orissa and is admittedly rough. This is because, a policy station may contain villages which are fully protected, semi-protected or unprotected. Again, the entire area of the districts could not be included, because some police stations could not be classified as above because of lack of information. The relevant data are presented in Table 4.6 and 4.7.

We find that, for Cuttack district (see Table 4.6) even by 1951, all the semi-protected areas had a much higher level of population density than the unprotected areas; for some semi-protected areas (Dharmasala, Patkura, Tigiria), it was higher than the population density of the district as a whole. This is maintained subsequently. Of course, the population density of the semi-protected areas has been lower than that for the fully protected areas. As regards

Table 4.6

Level of and change in Population Density for Fully Protected (F), Semi-Protected (SP and Unprotected (UP) Areas, Cuttack District, 1951-81

Police Stations	Status of Protection from floods	Population Density (per sq.km) 1951	1961	1981	Annual % increase in Population density 1951-61	1961-81
Salepur	FP	332	433	612	3.0	2.1
Mahanga	"	371	437	641	1.8	2.3
Tirtol	"	230	269	411	1.7	2.6
Jagatsinghpur	"	292	332	611	1.4	4.2
Balikuda	"	379	439	453	1.6	0.2
Jajpur	"	314	401	469	2.8	1.7
Kendrapara	"	318	386	399	2.1	0.2
Patamundai	"	190	227	281	1.9	1.2
Banki	SP	161	195	435	1.5	6.2
Dharmasala	"	352	417	625	1.8	2.5
Barchana	"	165	188	292	1.4	2.8
Patakura	"	329	385	533	1.7	1.9
Mahakalpara	"	139	165	310	1.9	4.4
Athgarh	"	210	258	358	1.3	1.9
Ersama	UP	140	180	287	2.9	3.0
Narsinghpur	"	87	107	148	3.4	1.9
Cuttack District		231	280	415	2.1	2.4

Source: Census of India, 1961 Vol.XII-Part IX-B: Orissa Administrative Atlas, pp 15, 55; Census of India, 1951, Orissa, Part II-A: Tables, pp 40-44, 46-50; Census of India, 1981, Series 16, Orissa, Part II-A, General Population Tables, pp.40-43; 58-60.

Table 4.7

Level of and Change in Population Density for Fully Protected (FP), Semi-protected (SP) and Unprotected (UP) Areas, Puri District, 1951-81

Police Station	Status of protection from floods	Population Density (per sq.km)			Annual % change in Population Density	
		1951	1961	1981	1951-61	1961-81
Delang	FP	277	306	431	1.0	2.0
Pipli	" "	278	328	485	1.8	2.4
Nimapara	" "	263	313	465	1.9	2.4
Balipatna	" "	325	372	557	1.4	2.5
Balianta	" "	321	356	548	1.1	2.7
Gop	SP	190	221	339	1.6	2.7
Kakatpur	" "	214	261	417	2.2	3.0
Khurda	" "	189	213	310	1.3	2.3
Nayagarh	" "	201	257	375	2.8	2.3
Satyabadi	" "	267	304	437	1.4	2.2
Banpur	UP	127	146	234	1.5	3.0
Ranpur	" "	111	131	197	1.8	2.5
Khandapara	" "	144	175	242	2.2	1.9
Daspalla	" "	43	50	76	1.6	2.6
PURI DISTRICT		150	177	287	1.8	3.1

Source: Census of India, 1961, Vol.XII- Part IX-B: Orissa Administrative Atlas, pp 15,55; Census of India, 1951, Orissa, Part II-A: Tables, pp 40-44, 46--50; Census of India, 1981, Series 16, Orissa, Part II-A, General Population Tables, pp.40-43, 58-60.

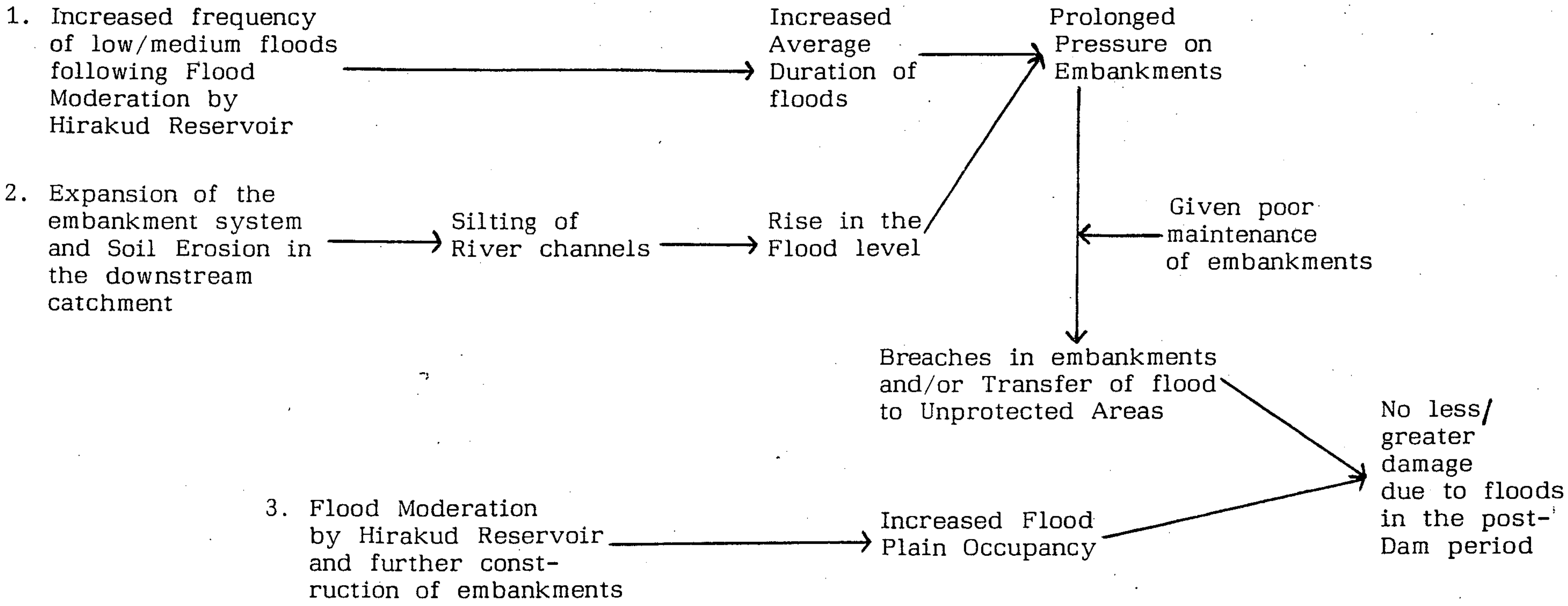
changes in the population density, we find that the annual percentage increase in population density has in fact been higher during period 1961-81 (post-Dam) than during 1951-61 (pre-Dam). This is true for all (except Athagarh) semi-protected areas. In fact, in a number of cases (Banki, Barchana, Dharmasala, Mahakalpara), the rate of increase has been higher than that for the district as a whole as well as that for some fully protected areas during 1961-81.

Coming to Puri district, we find (see Table 4.7) almost the same pattern. In all semi-protected areas the population density was higher than that for the unprotected areas as well as that for the district as a whole in 1951. Again in all semi-protected areas the annual percentage increase in population density has been higher for the period 1961-81 than for the period 1951-61; the same is even true of all (but Khandpara) unprotected areas.

The above can be taken as a rough indication of increasing occupancy of flood-prone areas, particularly in Puri district where the embankment system is known to be quite weak[21]. Lack of more disaggregated data prevents us from probing this further.

The mode of operation of the above three sets of factors can be schematically presented (see next page). To conclude, in this chapter, we have attempted to see how, even with a fall in the average magnitude of floods in the post-Dam period (following the greater incidence of small/medium floods in this period), the average extent of damage has not come down. This has been explained in terms of three sets of factors: First, an increase in the average duration of floods in the post-Dam period; Second, an increase in the flood

Conditions in the Mahanadi Delta affecting the extent of flood damage in the post-Dam period



level following siltation of river bed; these two factors have exerted an increased pressure on a pre-existing embankment system in the Mahanadi Delta which has been inherited with certain characteristics (such as partial nature of protection; poor maintenance etc) and effects (such as siltation of river bed; drinage congestion of the protected area, etc). In fact, with a further expansion of embankments in the post-Dam period, some of the above problems have become more acute. As a result, there have been breaches in the embankments and/or transfer of floods to unprotected area. This, coupled with the third factor of increased occupation of earlier flood-prone areas (due to flood moderation by the Dam as well as further construction of embankments) seems to have led to no less/greater damage in the post-Dam period. We can see that, in all this, the embankment system has played a crucial negative role.

NOTES

1. Hunter, A Statistical Account of Bengal, Vol.XVIII, Cuttack and Balasore, p. 52.

2. Govt. of Orissa, Irrigation & Power Department, Flood Report of Orissa, 1964. p.1.

3. Govt. of Orissa, Irrigation & Power Department, Report on the Flood in the Mahanadi Basin, Aug.1967, Statement No.2.

4. A, Cotton, Report on the Mahanuddy River. Calcutta: Military Orphan Press, 1858, p.6.

5. H.A.Gubbay, Report on the Contour Survey of the Flooded Tract of Orissa. Patna: Superintendent, Govt. Printing, Bihar and Orissa, 1924, para.20.

6. Report of the Orissa Flood Committee, 1928, Patna: Superintendent, Govt. Printing, 1929, paras 36,37.

7. National Commission on Floods, Report, Vol.I, March 1980, p.124.

8. Report of the Orissa Flood Committee, 1928, paras 39,40.

9. Ibid, para 17.

10. National Commission on Floods, Report, Vol.I, p.96. The extent of protected area for the Mahanadi Delta has been taken from Table 4.4 in the text. The total protected area in the country is as given in the above source.

11. Ibid, p.129.

12. From the data given in the National Commission on Floods, Report, Vol.I, p.173.

12a. Govt. of Orissa, Delta Development Plan, Mahanadi Delta Command Area, Vol.IV: Geology, Geomorphology and Coat Building, 1986. p.25.

13. Sovani & Rath (1960), p.166.

14. Cited in Ibid.

15. Govt. of India, Report of the Team of Experts on the Operation of the Hirakud Reservoir during the flood season, June 1976.

15a. Govt. of Orissa, Board of Revenue, Orissa (Special Relief Branch), List of Vulnerable points in Flood Embankments of Orissa, 1986.

16. Govt. of Orissa, Irrigation and Power Dept., Flood Report of Orissa, 1964, p.1.

16a. Govt. of India, National Commission on Floods, Vol.I, pp.119, 96.

16b. Govt. of Orissa, Report of the 1975 Flood Enquiry Committee, Board of Revenue, Orissa; Govt. of Orissa, Delta Development Plan, Mahanadi Delta Command Area, Vol.VI: Hydrology and Flood Control Scheme, 1986, p.116.

17. Govt. of Orissa, Irrigation and Power Dept., Report on Flood in the Mahanadi Basin, August 1967, p.1.

18. Ibid. pp.18-24.

19. Govt. of India, Report of the Team of Experts, p.52.

20. Ibid. pp.50-51, 91.

21. Govt. of Orissa, Delta Development Plan, Mahanadi Delta Command Area, Vol.II: Socio-economic Bench-mark Studies, Engineer-in-Chief (Irrigation), 1986, p.181, Table.86.

SUMMARY & CONCLUDING REMARKS

It is now time to summarize the main findings of the study and point out some of the more significant conclusions which seem to emerge.

We started off by noticing that in India, as for the world as a whole, the extent of flood damage has been showing an increasing trend between 1954 and 1982. This has happened even though, during this period, systematic measures for flood control in the form of multi-purpose storage reservoirs, flood-control embankments, channel improvements etc have been undertaken in India under the successive Five Year Plans. This was the immediate context of the study. In order to understand how this might have come about, we suggested an analytical framework. In this framework, a distinction was made between frequency and intensity of floods (as measured by the peak rate of inflow of water into the delta) and actual flood damage within the delta.

The relation between the rainfall in the catchment and frequency and intensity of floods at the head of the delta was thought to be mediated by one set of factors, such as flood control measures in the catchment to check the run-off (like storage-reservoirs, watershed management in the form of afforestation and soil conservation measures etc) as well as the nature of vegetal cover in the catchment (which is known to have a crucial effect on soil erosion and flood flows). The relation between intensity of floods and actual flood damage was thought to be mediated by a second set of factors, such as the capacity of delta channels, the quality of the system of flood control embankments, adequacy of measures like channel improvement, maintenance of embankments, average duration of floods, restrictions on the occupation of flood-prone areas in the delta, etc.

We attempted to apply the above framework to the specific case of the Mahanadi river system in Orissa where the Hirakud Dam came into force in 1958 with a multi-purpose reservoir. In the empirical analysis, the objective was to attempt a comparative study of conditions before and after 1958 (ie. pre-Dam and post-Dam periods).

First, an analysis of frequency and intensity of floods revealed that the overall frequency as well as average intensity of floods had come down in the post-Dam period; the fall in the average intensity of floods was because of a lower incidence of large and very large floods in the post-Dam period and, secondly, that the incidence of low/medium floods had increased in the post-Dam period.

We then went on to examine the role of the Hirakud reservoir in bringing down the frequency and intensity of floods. We found that, on the whole and particularly after 1963, the Hirakud reservoir has in fact had a major flood-moderating effect, in the sense that without the reservoir, the incidence of large/very large floods would have been greater. At the same time, we noticed that there were a number of factors which tended to limit the effectiveness of Hirakud Dam. First, a much higher rate of siltation of the reservoir has occured than what was expected. This threatens not only to reduce the life-span of the reservoir but also the live storage capacity of the reservoir, if the observed rates of siltation are maintained. This can only reduce the potential flood-absorbing capacity of the reservoir during the flood season. Such a high rate of siltation was seen to be due to increased soil erosion as a result of increased deforestation in the upstream catchment for which some evidence was presented. Second, any large inflows of flood water from the upstream catchment as late as September - which seems to be happening more often than before - means that a part of the reservoir capacity had already been filled up by this time for meeting the power and irrigation requirements till the next monsoon. This has infact often led to forced release of flood water from the Hirakud reservoir, keeping the safety of the dam in mind. An extreme consequence of such forced outflows from the Hirakud reservoir was the very large flood of 1980 in the Mahanadi Delta when the entire peak discharge at the head of the delta was due to the release from the Hirakud reservoir. The third limiting factor is inherent in the very location of the reservoir: it is located at a point at which it controls the run-off of only a part of the total catchment of the Mahanadi. Thus the run-off of the catchment below the dam is completely uncontrolled. In fact, the very large flood of 1982 was caused entirely by the run-off from the catchment below the dam, ie, without any contribution from the reservoir. Finally, the increased incidence of low/medium floods in the post-Dam period was seen to be mainly due to contributions from the downstream catchment to the outflows from the Hirakud reservoir (for which we have presented the evidence).

Given this importance of the downstream catchment, we also looked at how the other conditions of run-off (such as the nature of the vegetal cover) have changed between the pre-Dam and post-Dam periods. For the pre-Dam period, we found on the basis of direct evidence that there was no increasing trend in the run-off coefficient from 1872 till 1950.

From this it was inferred that there was no major deforestation and hence soil erosion for the entire Mahanadi catchment in the pre-Dam period. Some direct evidence for relatively low rate of soil erosion till 1951 or so for the entire Mahanadi catchment was presented. As regards the post-Dam period, some evidence for increased deforestation in the upstream catchment was presented as we have said above. Increased soil erosion in the upstream catchment in the post-Dam period was of course indicated by a much higher rate of siltation of the Hirakud reservoir than was expected on the basis of actual siltation data for the pre-Dam period. As regards the downstream catchment, direct evidence for increased deforestation in the post-Dam period was presented. Increased soil erosion in the downstream catchment due to increased deforestation was indicated by the data on sediment load of the Mahanadi river which seems to have increased compared to the pre-Dam period. (Unfortunately, how such increased deforestation and soil erosion both in the upstream and downstream catchment might have led to an increasing trend in the run-off coefficient in the post-Dam period could not be done to lack of suitable data on rainfall and run-off separately for the upstream and downstream catchments. This can be said to be a major gap in the analysis.)

While the above factors have limited the effectiveness of the Hirakud reservoir in complete flood control, it is after all true that the average intensity of floods has come down in the post-Dam period. But the data on actual flood damage showed that there has not occured a corresponding decline in the average extent of cropped area affected in the post-Dam period. This led us to an examination of the role of the second set of mediating factors (operating within the delta), in order to account for the above non-correspondence between the average intensity of flood and the average extent of damage. Here we established that mainly low/medium floods of a relatively longer duration in the post-Dam period have replaced mainly large/very large floods of a relatively shorter duration of the pre-Dam period. As a result, the average duration of floods has increased even though the average intensity has come down in the post-Dam period. This, coupled with an increase in the flood level due to siltation in the river channels within the delta (as a result of increased soil erosion in the downstream catchment), has meant an increased pressure on the ill-planned system of flood contrtol embankments inherited from the past. There has occured a further expansion of the system without adequate maintenance in the post-Dam period. As a result, there have been breaches in the embankments which have affected the semi-protected areas and/or led to flooding of unprotected areas. This, coupled with increased occupancy of the semi-protected areas (for which some rough evidence was presented), has meant greater/no less damage in the post-Dam period.

We would now like to make the following concluding remarks from the above analysis. First, the full realisation of the benefit of complete flood-control by the Hirakud Dam seems to depend on adequate supporting investments in the form of regular maintenance and further strengthening of flood-control embankments and a comprehensive drainage scheme in the Mahanadi Delta. In addition, sufficient afforestation and soil conservation measures in the downstream catchment of the Mahanadi are necessary in order to check the problem of increased soil erosion. This can reduce the sediment load in the river flow and hence the siltation of the river bed.

As we have seen, another important factor which has limited the role of the Hirakud reservoir in complete flood control is the much higher rate of siltation than was expected. This effectively means that the useful life-span of the reservoir is diminished. What this crucially means is that a suitable dam site-which can be seen as a valuable, non-producible asset - is being exhausted. It may then be impossible to find an equally suitable site for constructing another dam.

There may, of course, be another site for constructing a large or a medium sized dam. For example, Tikarpada (see Fig.3.1) is regarded as a highly suitable site for damming the Mahanadi which, together with Hirakud, is seen as the ultimate answer to the flood problem in the Mahanadi Delta. This is because at Tikarapada (which lies only a few miles above Naraj, the head of the delta: see Fig.3.1), the run-off of almost the entire downstream catchment of the Mahanadi can be intercepted. But, if the process of increased deforestation and soil erosion in the downstream catchment (as the available evidence suggests) goes on unchecked, the proposed dam at Tikarpada is sure to face the same problem of siltation. In addition, if such increased deforestation is also changing the rainfall-run-off relationship in the downstream catchment, then planning for the live storage capacity of the reservoir at Tikarpada will also become difficult.

Afforestation and soil conservation measures have of course been in operation since the Third Five Year Plan in the catchment of a number of river valley projects, including the upstream catchment of the Mahanadi. But, as our data show, such measures seem to have been inadequate/ineffective in checking increased deforestation, though the rate of soil erosion, and hence siltation of some reservoirs, is believed to have come down in the last ten years or so[1]. In any case, the amount of central investments in such measures have not been significant, flood control being treated as a state subject.

In fact, the thrust of flood control policies followed by different state governments in successive Five Year Plans has been mainly on construction of flood control embankments, besides multi-purpose reservoirs mostly without any exclusive flood control reserve. For example, upto 1954, there existed about 5,280 km of embankments along different rivers; between 1954 and 1978, another 10,821 km of embankments have been added[2]. The point that seems to emerge from the present study is not that such structural control measures are ineffective by their very nature; it is rather to point out that, there are complex factors (and changing conditions) at work which tend to <u>intensify</u> the flood conditions and flood damage. This, in turn, limits the <u>effectiveness</u> of such structural control measures in minimising the extent of damage.

Given the vast network of river systems in India, the results of our analysis for the Mahanadi river system cannot of course be generalised. On the other hand, the purpose of the present study was to focus on a single river system to see the complex factors and processes of change at work so as to pose certain questions. It is with such a broad framework of questions that similar studies for other river systems can be carried out to test for the generality of the results of the present study.

NOTES

1. The Hindu, 'Siltation of Reservoirs', Special Report, 5 May, 1987

2. Govt. of India, National Commission on Floods, Vol.I, pp.96, 119.

GLOSSARY OF SELECTED TERMS

Annual Peak Discharge - Discharge refers to the rate of flow of water observed at a point of time. This can be measured at any point along the course of a river. The unit of measurement is cubic feet per second (cusec) or cubic metre per second (cumec).

Annual Peak Discharge refers to the maximum discharge observed during a year. Usually this is measured at the head of the delta (see this Glossary for explanation), as this is relevant from the point of view of floods in the delta.

It should be noted that what is actually recorded are the height markings of the gauge maintained at a recording station (usually at the delta head) and the discharge is calculated from the observed gauge height according to a certain formula.

Catchment Basin (also Drainage Basin) of a River - An Area from which water drains to a particular location such as a main river system. The shape of a catchment varies from basin to basin - it can be fan-shaped, saucer-shaped or circular.

Delta of a River - This refers to a nearly flat plain of alluvial deposit enclosed between the diverging branches (distributaries) of the mouth of a river and the sea, typically triangular or deltoid in shape as the name suggests.

Delta Head - The head of the Delta is the point at which a river enters the alluvial plain, before its distributaries branch out into the delta area.

Distributary - A branch of a river flowing away from the main stream and not rejoining it (opposed to Tributary; see below).

Doab - An area of land lying between two distributaries of a river.

Duration of Flood - The length of time for which annual peak discharge at the delta head remains above or close to the safe peak discharge. The safe peak discharge depends on the capacity of the delta channels of a river (see Frequency of Floods in the Glossary).

Flood - A flood is a body of water which rises to overflow land which is not normally submerged.

Flood Plain - Relatively level part of a river valley adjacent to the river channel, formed over time from sediments deposited by the river during periods of flooding.

Frequency of Floods - If the delta channels of a river are capable of carrying a discharge of, say, x lakh cusecs, then the frequency of floods over a period is the number of years in which the annual peak discharge exceeds this safe peak discharge of x lakh cusecs.

Gorge - A narrow cleft with steep, rocky walls, through which a stream runs.

Intensity (Magnitude) of Floods - This is measured in terms of Annual Peak Discharge (see above) at the Delta Head (see above) and is proportional to the excess of the peak discharge in a year over the safe peak discharge as determined by the capacity of delta channels.

Rapids - A part of a river where the current runs swiftly.

Run-off - That part of rainwater which drains or flows off, from a certain catchment area into the main river channel after allowing for evaporation and evapo-transpiration. The absolute amount of run-off depends on the size of the catchment. It is measured usually in acre-ft. or cubic.ft and for a period of time such as a whole year (annual run-off) or the monsoon months (monsoon run-off), etc.

Run-off Coefficient - Whereas the absolute amount of run-off depends on the size of the catchment of the main river channel, the proportion of run-off to rainfall depends on the nature of vegetal cover, soil condition etc. of the catchment. This proportion is called run-off coefficient. This coefficient can be for an entire year, or for the monsoon period, or for a few days.

Tributary - A stream contributing its flow to a large stream or other body of water.

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