Section 4

DOWNSTREAM POPULATIONS & ENVIRONMENT

Chapter 15

DOWNSTREAM SETTLEMENTS & POPULATION

15. DOWNSTREAM SETTLEMENT AND POPULATION

15.1 POPULATION NUMBERS AND PROJECTIONS

Immediately below Grand Falls the Tana River runs through Tharaka-Nithi District, with Meru and Tharaka peoples practising small scale agriculture together with livestock. To the south, the Tana river forms the boundary with Mwingi District. The river then borders Isiolo district with a mixed population of Boran and Somali pastoralists adjacent to the river, before entering the lower Tana basin proper. In Isiolo District the Tana flows adjacent to Garbatulla Division with an estimated 1996 population of about 15,000, of which a proportion will concentrate around Kinna, away from the Tana where amenities and security are improved. On an area proportional basis, the population of Isiolo District that falls within the Tana Basin is projected at 9,600 by 1996 (see Annex). However, people from a wider area are more or less completely dependant on the Tana River during dry seasons.

The major part of Tana River basin is covered by two districts, Tana River and Garissa, and although Garissa District extends beyond the actual river basin, virtually the entire district population depends to some extent on the river and on the riverine flood plain corridor, especially during the dry season. The rural population projection for 1996 for the two districts, plus those parts of Kilifi and Lamu falling within the Tana River basin, is estimated as 350,535 (Table 15-1). This is expected to have increased to 452,152 at the possible time of impounding and start of commissioning (year 2005). The majority of the population in Garissa is of Somali origin (referred to as Ogaden in the Census), the population of Tana River is recorded as being predominantly Orma and Pokomo (Table 15-2).

Table 15-1 Population Projections: Tana River and Garissa Districts together with those parts of Kilifi & Lamu falling within the Tana River Basin.

District	1989	1996	2005
Garissa	134,597	138,759	144,300
Tana River	137,987	182,705	262,118
Lamu	7,020	11,140	20,169
Kilifi	13,608	17,931	25,565
Total	293,212	350,535	452,152

Source: 1989 CBS data at sublocation level projected forward on basis of 79-89 rates of change

Table 15-2 **Major Tribal Groupings in Tana River and Garissa**

	Tana River	Garissa
Somali	1%	84%
Pokomo	37%	< 1%
Orma	33%	< 1%
Degodia	< 1%	3%

Figures as % of total district population.

Table 15-2 is clearly a simplification of the actual situation as the tribal groupings used in the National Census do not, for example, distinguish between the Orma and Wardei and the populations are better described in conjunction with their specific economic activities in the following sections. However, it is possible to give a rough breakdown of the total rural population groupings relying to a greater or lesser extent on the river downstream of the proposed reservoirs. Table 15-3 lists population projections for those areas adjacent to the Tana River downstream of the proposed reservoirs together with estimates of the proportion either partly or entirely dependant on the river.

By the year 2005, close to the year of impounding and commissioning, the downstream population dependant on the Tana River will be in the region of 555,000.

Table 15-3 Estimates of Downstream Ethnic Groups and Rural Populations, either partly or entirely dependant on the Tana River: Projections for 1995

District / Division	Main Ethnic Group	Census 1989	Population projections 1996	2000	2005	Est. % dependence on Tana	Est. 2005 dependence on Tana River
Tharaka-Nithi / Tharaka	Meru / Tharaka	74,929	91,500	102,600	118,400	50%	59,200
Mwingi / Kyuso	Kamba	103,32,5	126,800	142,600	165,100	20%	33,000
Isiolo / Garbatulla	Boran	11,188	15,400	18,400	23,100	50%	11,600
Garissa	Somali	134,579	138,700	141,200	144,300	100%	144,300
Tana River	Pokomo / Orma	137,696	182,300	214,000	261,600	100%	261,600
Lamu	Orma	7,020	11,100	14,500	20,200	100%	20,200
Kilifi		13,608	17,900	21,000	25,600	100%	25,600
TOTAL		386,680	483,100	551,800	653,600		555,500

15.2 AGRICULTURALISTS

The largest group of agriculturalists within the Tana River flood plain are the Pokomo. Their economic activities and cultural values are all tied to the behaviour of the river and its flooding regime. Up to 1961 they lived in villages on the river bank but after the bad floods in that year the villages were moved to higher ground away from the river.

There are thirteen subgroups of the Pokomo people, all Bantus, but the group can be roughly divided into the 'Upper' or 'Watu'wa djuna' and 'lower' or 'Malachini' Pokomo; the dividing line being regarded as around the village of Mwina. The latter include the Mwina, Ngatsana, Yunda, Ngao and Kilindi. All are sedentary and reside in villages.

They are basically agricultural people cultivating rice, maize, and other food and tree crops along the riverine plain. They traditionally practise flood recession farming relying on the twice yearly floods in May-June and November-December which used to be fairly regular with failure only 2 or 3 years in ten. There is no strict division of work between men and women although the former generally do the clearing, provide household security and do fishing. They also employ labour to work on their farms. Much of the field work is done in tradition 'Sindiko' groups where cultivation and weeding is done on all individual plots communally.

If there is a failure of the floods, then the Pokomo are particularly susceptible to food shortages. They keep few livestock and therefore cannot sell small stock as a source of income to buy food. Nor is there the alternative food source such as meat or milk.[1].

Generally the Pokomo have had insufficient food since 1989 and have increasingly relied more on traditional foods from the riverine forests. It is reported that most children under five years are malnourished and 30% of the children suffer from Kwashiorkor or Marasmus. A number of relief food programmes have been operating in the area.

Most villages are on the west side of the river, due to insecurity on the east, although the Tana River District boundary runs parallel to the river approximately three miles east of the river itself. This boundary does not appear to be recognised by some groups and there is a general feeling that if the Somalis want to develop irrigation in Garissa district they would be able to do this on traditional Pokomo land on the east bank. This would appear to be a difference of opinion that needs to be settled before further development takes place.

There are two other agricultural groups besides the Pokomo. The Wasonya are found along the river between Bura and Garissa. They are akin to the Orma and are Muslim. They grow maize, bananas and sugar cane, tend bees for honey, and fish, but unlike the Pokomo also keep cattle. They do not hunt for meat.

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[1] A previous study noted that 0.6% of household kept cattle, 2.3% sheep, 9.0% goats and 20.3% poultry.

The second group are the Malakote found between Garissa and Hola, akin to the Pokomo in language but again Muslim in their religion. They also cultivate rice and maize and keep cattle.

In addition to the Orma, there is another semi nomadic group of people called the Wanyoyaya or the Korokoro, who are found in the area between Mbalambala and Garissa. They are Hamitic, related to the Orma and Somali and are Muslim. They have manyattas close to the river and grow bananas and maize on flood irrigation. They also keep cattle which are on the flood plain during the dry season and out in the rangelands away from the river during the wet season.

15.3 PASTORALISTS

After leaving Meru District the Tana borders Isiolo District for 40 km on its northern bank although a portion of this is taken up by the Bisanadi National Reserve. The area, which corresponds to Range Unit No. 1 of Garbatulla Division is used by the Boran people for seasonal grazing, although after banditry problems and four major droughts over 40 years they have less stock, and lead a more sedentary lifestyle away from this area. The area is under-utilised. With less poaching the area is grazed by elephants which should reduce the bush to the benefit of the grazing. The Boran prefer to go to the Kinna - Bisandani area in the dry season when there is less Tsetse. The population of the area is estimated at around 25,000.

The Boran are becoming more sedentary and run their livestock on a basis of Awicha and Fora herds. The Awicha herd is composed of the productive animals - those that that are milking, have just calved or are about to calve, suckling stock, one or two bulls for service and possibly some animals destined for sale. The herd stays close to the homestead and returns there to the boma and water each night. The fora herd is composed of non-lactating, castrated cows due for service, young stock over a year old, castrated males and other males for breeding. This herd moves far from the homestead in search of grazing; often the fora herds of several homesteads in an ola combine to form one large herd. This herd leaves the proximity of the homestead and grazes far away providing water is available.

The Orma are the largest pastoralists ethnic group on the Tana and are closely associated with the Wardei and the Somali. They live exclusively in Tana River District. The Orma are Hamitic - Cushitic people derived from south west Ethiopia, and are sometimes known as the Southern or Tana Galla. They are related to the Oromo speaking Arssi, Macha, Boran and Gabbra. They live largely away from the riverine flood plain, and are concentrated in the lower third, less arid area of the district.

They are renowned for their affinity to their cattle, and they also keep goats, sheep, camels and donkeys. The livestock herding pattern is similar to the Boran, with a 'manyatta' milking herd and a 'urene' transhumant herd. They have been known to cultivate crops for a long time, particularly in bad seasons when livestock have been lost, and currently this practise is increasing as they become more sedentary along the

Hirimani, Galole and Kokani laghas that provide seasonal flooding with drainage water down from the hills of Ukambani.

The Wardei were originally Orma who were taken away by and subsequently bred with the Somali. They moved back into the area two decades ago, but are treated with suspicion by the Orma.

As the pastoralists enter more into agriculture it is inevitable that they will encroach on the economic and spatial domain of the Pokomo farmers. Already this causes some tension between the two groups especially in the area of the river. This is likely to increase in future years.

The Orma in particular are being pressurised through the loss of land to commercial ranches, national parks, village irrigation schemes, and the increasing pressures on land along the river, were traditional drinking access areas - 'Malka' are settled by the Pokomo. In addition a recent move of Somali herds into the north of the District has created friction.

The only true pastoralists in the area are the Somali, who have a basic diet of meat and milk, and rely totally on their herds for food and cash. They do however need access to the Tana for the watering of livestock.

The pastoralists of Garissa District are Somali, and once grazed over several districts in their migrations which led to many clashes over the use of resources. They are now largely restricted to the District, and are under considerable pressure, from alternate agricultural use of the river bank and flood plain areas, degradation of large areas of the District by refugee camps, the presence of Tsetse in the eastern divisions, and the lack of water in many areas.

15.4 TANA DELTA POPULATION

The delta has a mix of ethnic groups - Pokomo, Orma, Wardei and some Luos and Luhyas, the latter two involved in commercial fishing and a mixture of economic activities estimated as 49% farmers, 47% pastoralists, 2% fishermen and 2% other vocations.

Although the pastoralists are perhaps at a slight advantage; generally, all peoples in the basin are the poorest of the poor having low standards of housing and nutrition. General health conditions are poor with malaria, tsetse, bilharzia and water borne diseases widespread. Health facilities are generally poor and inadequate. School enrolment is low and there are not many skilled workers. Generally institutional development is poor. Even with good flooding of the river, the agriculturalists were often on the edge of food shortages, January being a particularly bad month with fish, and wild fruits and vegetables eking out a precarious existence before the harvest of the December planted crops. Food surplus are virtually unknown in the Pokomo villages, evidenced by the lack of granary structures.

15.5 ARCHAEOLOGICAL, CULTURAL AND HISTORICAL SITES

Archaeological, Cultural and Historic sites in the downstream area were covered by the Initial Environmental Assessment report. It is not expected that dam construction will impact these sites.

15.6 DOWNSTREAM URBAN CENTRES

The population of down stream urban centres is estimated at around 70,000, increasing to about 149,000 by the time commissioning occurs. If the Bura and Hola irrigation schemes are revived, it is possible that there will be an additional peri-urban population increase of 40,000 to 50,000, bringing the total urban and peri-urban population to about 200,000.

This population relies entirely on the river for water supplies, either through direct river extraction or through recharge of groundwater. The water quality, in particular the high turbidity, is already resulting in very high treatment costs for the Garissa water supply. During construction and impounding the physical water quality parameters, sediment load, colour and turbidity will all deteriorate as disturbance of the river channel and surrounding areas increases. Following commissioning the expected decrease in primary alluvial sediment load from the upper catchment, as a result of entrapment, will be negated by the time the flow has reached Garissa, as a result of erosion of the channel bed below the dam site.

Table 15-4 Large and Medium Urban Population Centres

Urban			Population Projection		
Centre	1989 Census	Growth Rate	1996	2000	2005
Garissa	31,319	8	53,700	73,000	107,300
Hola	9,508	5.75	14,100	17,600	23,300
Garsen	3,186	11.52	6,800	10,600	18,200
Total	44,013		74,600	101,200	148,800

In terms of dissolved chemical constituents, in particular Nitrates and Phosphates, with or without reservoir construction, unless there are major improvements in the treatment of waste water and other effluents in the middle and upper catchments there will be a serious decline in water quality for downstream consumers.

The effect of the reservoir will be to compound any upstream problems. During the initial period of impounding and during the early period of commissioning, there will be major releases of organic nutrients from the soil and decaying submerged vegetation. There will therefore be an immediate decline in downstream water quality, with directly increased costs in terms of treatment of potable water, to standards safe for domestic supply, for the downstream urban centres.

The effects of the changes in river bed levels (see Chapter 16) are likely to have significant effects on the population in the Garissa area. In the long-term, there will be a decrease in river bed level and a resulting change in the river water level as the river bed stabilises to a new level. This will have important implications for the recharge of groundwater supplies and for the extraction of water from the river for domestic and irrigation usage, since many of the pumps used are likely to require upgrading. In addition, the higher river banks will result in increased erosion and a consequent loss of land immediately in the vicinity of the river banks - with obvious implications for any infrastructure in these areas (e.g. the main road bridge at Garissa, and pumping facilities for irrigation).

In the shorter term, however, some the material eroded upstream of Garissa will initially be deposited in the Garissa area. River morphology simulations (see Chapter 16) indicate that within the 34 year time period of these simulations there will be an increase in the water levels at Garissa, of up to about 2.5 metres. The implications of this are:

- Increased flooding in and close to Garissa, both in terms of the frequency of flooding and the depth (severity) of flooding;
- Ultimately, a requirement to construct a new bridge at Garissa that takes the changed river morphology and flooding into account. This is also likely to require changes to the main road running through Garissa town.
- Either construction of flood defences, or re-locating of an unknown number of buildings in Garissa town.
- Initiation of a system for long-term planning in Garissa town that takes the likely changes to the Tana River morphology and flooding into account.

Chapter 16

RIVER HYDROLOGY & MORPHOLOGY

and

RESERVOIR INMPOUNDMENT PERIOD

16. RIVER HYDROLOGY AND MORPHOLOGY, AND RESERVOIR IMPOUNDMENT PERIODS

16.1 INTRODUCTION

This section is based on the results of specific studies carried out on to establish the nature of the "normal" patterns of flooding on the lower Tana, and the likely impacts of the proposed dams on the morphology of the Tana below Grand Falls. A consistent daily discharge set was established, and then used to analyse normal flooding patterns. From these analyses the patterns of flood release required at Grand Falls to sustain the normal pattern of flooding at Garissa, were determined.

By the nature of reservoirs, sediment is trapped in the reservoir itself, denying sediment to the reach downstream, whilst at the same time river flows downstream of the reservoir are also modified. These alterations lead to changes in the morphology of the river. The typical impact of reservoirs is to cause degradation of the river bed downstream. Degradation continues until a new equilibrium is established. This may take decades to achieve, or in some cases centuries. To predict downstream morphological impacts of reservoirs it is now common to use numerical models which simulate the movement of water and sediment in the river.

A tributary of the Tana River, the Kathita, enters the proposed reservoir a short distance upstream of the proposed dam. It has been suggested that sediment from this catchment could be diverted so that instead of entering the reservoir it is re-routed to the river downstream. This would enhance the sediment load in the river downstream and so reduce the morphological impact of the reservoir. This option was investigated using the numerical model.

The data and methods employed to establish a consistent daily discharge set for the Lower Tana are described in sections 16.2 and 16.3. The detailed analysis of the discharge data to characterise the normal pattern of flooding at Garissa and corresponding floods at Grand Falls are described in section 16-4. Section 16.5 describes additional rainfall analyses performed to assist in the evaluating the relationship between flooding at the two sites, whilst Section 16-6 discusses these results. Sections 7 to 9 examine potential changes in river morphology. Following a discussion of these findings in section 16.10, sections 16.11 and 16.12 comprise conclusions and recommendations for further work.

16.2 HYDROLOGICAL DATA

The consultants visited Nairobi in July 1995 and met with staff of the Ministry of Water Development (MOWD), Kenya Meteorological Department (KMD) and the Tana and Athi Rivers Development Authority (TARDA). Following these discussions several visits were made to the MOWD in order to collect gauging and stage data for gauging stations on the lower Tana River. Stage data were provided for six stations; 4F13, 4G01, 4G06, 4G08, 4G09 and 4G10. No reference to station 4G06 can be found in any of the reports contained in the reference list and it is assumed that the stage data may in fact relate to station 4G04, Hola. Stage data for one further key station, 4G02 at Garsen, were subsequently collected from MOWD. The location of these gauging stations is shown on Figure 16.1.

Current mater data were provided for station 4F13, Grand Falls. Data for stations 4G01, 4G02, 4G08 and 4G10 were subsequently collected from MOWD. Details of the data collected are given in Table 16.1.

Figure 16-1 Location of Gauging Stations on the Lower Tana

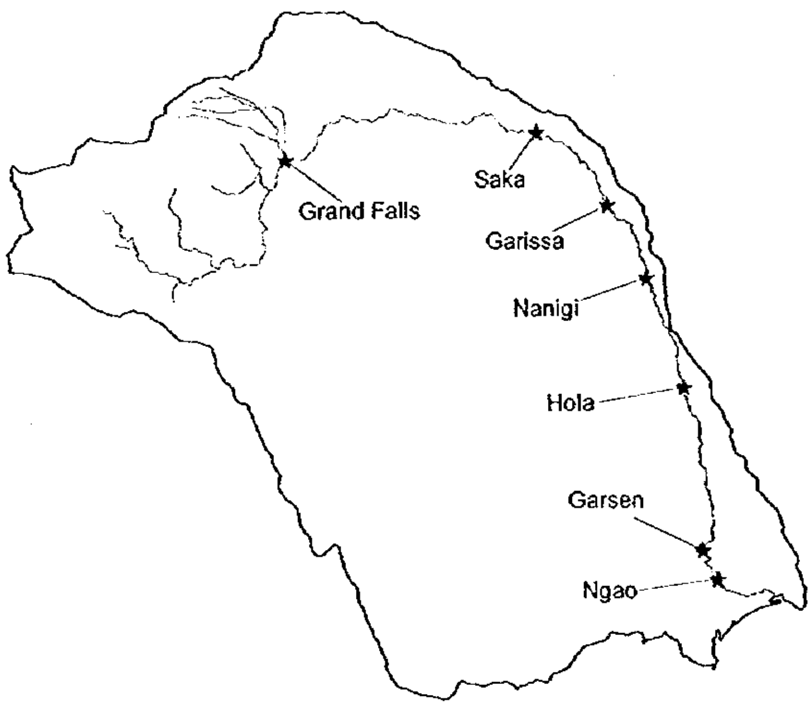


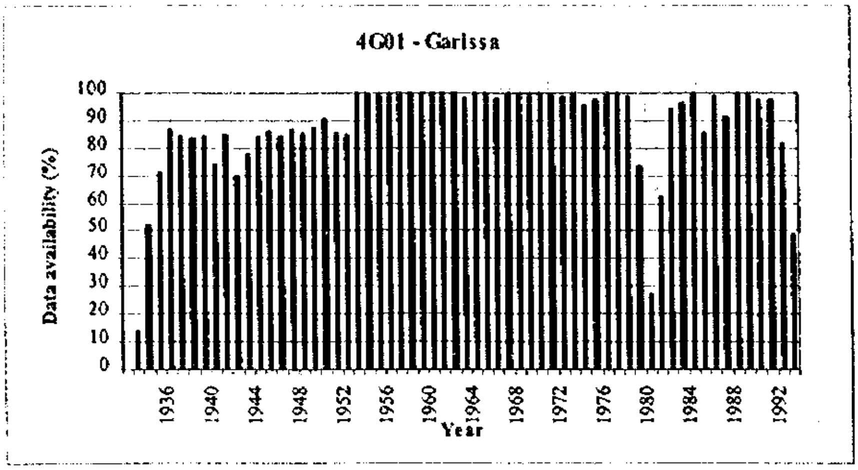
Table 16-1 Gauging and stage data collected from MOWD, July 1995

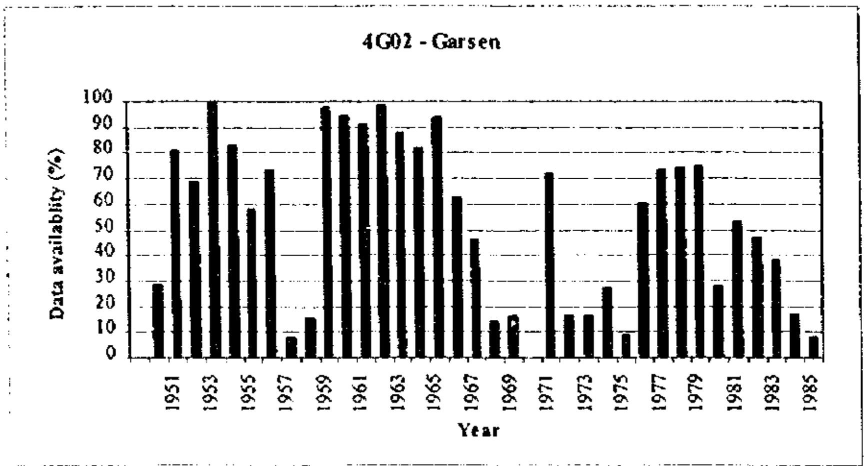
Station Number	Station Name	Period of Gaugings	Period of Stage Data
4F13	Grand Falls	07/62-01/81	1962 - 1993
4G01	Garissa	03/44 - 03/95	1933 - 1993
4G02	Garsen	03/46 - 11/91	1950 - 1985
4G04	Hola	None available from MOWD	
4G06	?	None available from MOWD	1966 - 1974
4G08	Nanigi	10/74 - 09/79	1973 - 1985
4G09	Ngao	None available from MOWD	1973 - 1985
4G10	Saka	02/84 - 05/85	1983 - 1985

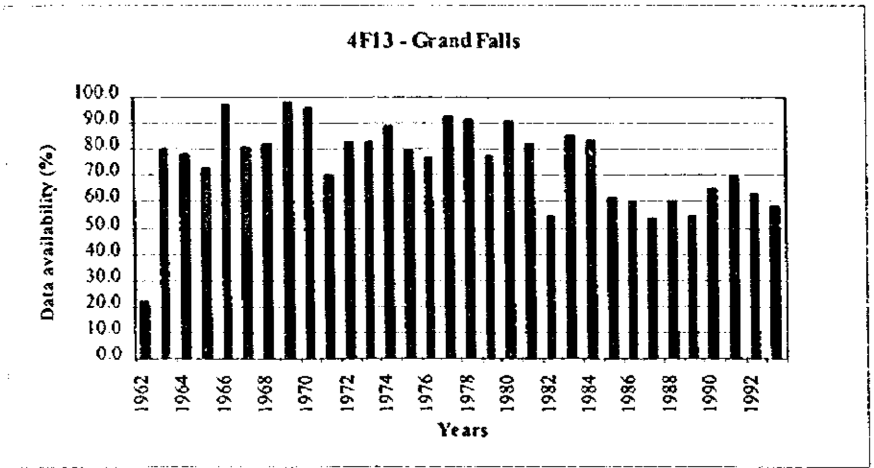
Stage data are observed manually either once or twice a day at each gauging station, with twice daily readings being more common in the two wet seasons. However, at all stations there are frequent gaps in the data, and there are only a few years with complete data. Figure 16.2 illustrates data availability at each station, with the figure showing the percentage of days in each year having at least one observed stage reading from which daily mean flow may be computed. Data availability is best at Garissa, perhaps because the station is close to a large town, and there are 11 complete years out of 61, with a further 21 having greater than 95 percent daily data available (equivalent to less than 18 days missing observed stages in a year). The key record at Grand Falls has only 3 nearly complete years out of 32 (i.e. greater than 95 percent daily data availability), and Garsen has only 4 nearly complete years out of 35, and 1970 is missing completely at this station. The earlier current meter data recorded at the gauging stations with longer records were provided in imperial units. These data were converted to metric format before proceeding with any analysis.

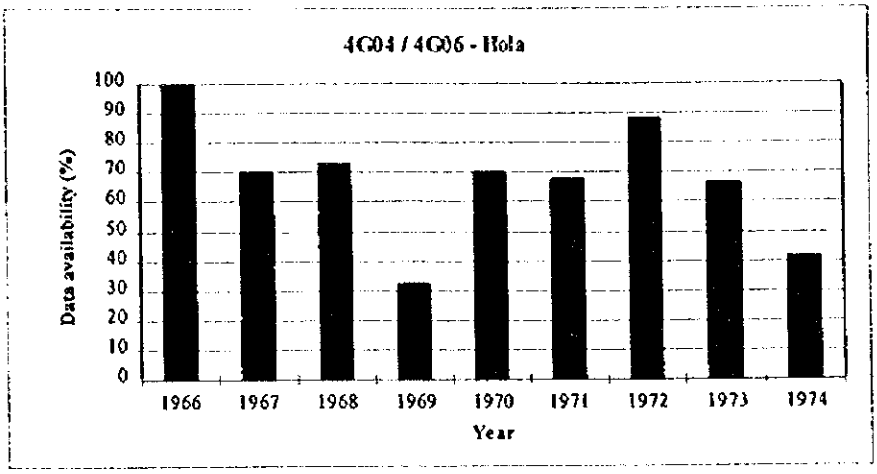
In addition to the stage and gauging data, daily rainfall records for approximately 200 to 300 stations in and around the Tana catchment collected by the KMD were obtained. These data were provided in several formats, some of which required processing before any analyses could be performed. Further details of the rainfall data used in the study are given in Section 16.5

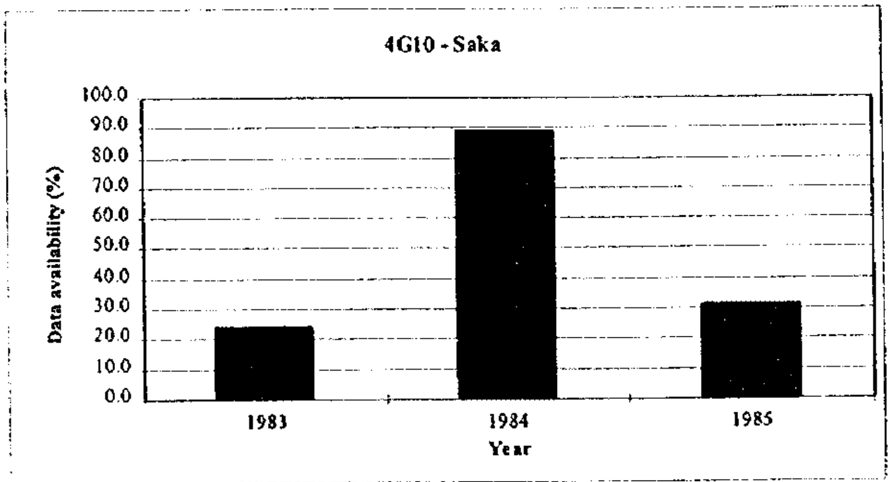
Figure 16-2 Availability of daily mean flow data for each gauging station

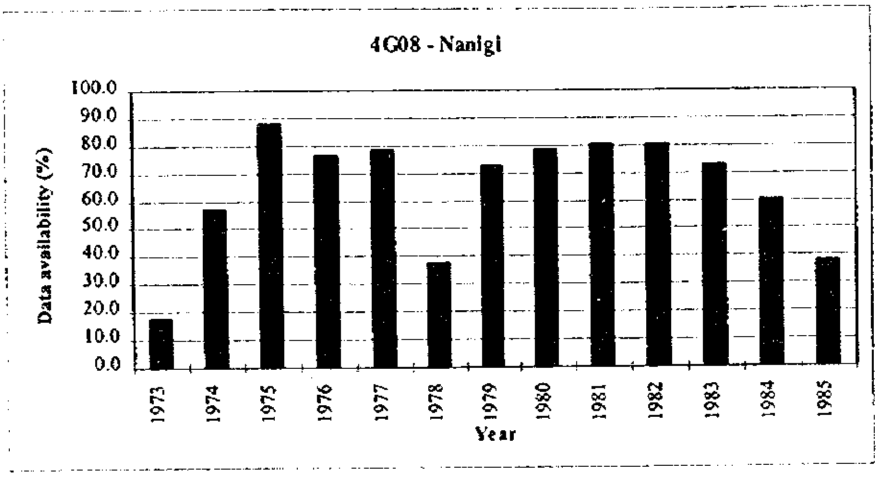







4G04 / 4G06 - Hola
Data availability (%)
100
90
80
70
60
50
40
30
20
10
0
1966
1967
1968
1969
1970
1971
1972
1973
1974
Year


4G10 - Saka
Data availability (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1983
1984
1985
Year


4G08 - Nanigi
Data availability (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
Year

16.3 RATINGS AND DISCHARGE CONVERSION

16.3.1 Review and fitting of rating curves

The existing rating curves used to derive flow from stage at each of the five stations for which current meter gaugings were collected were reviewed through an assessment of the goodness of fit with the gauging data detailed in Table 16-1. The ratings were taken from DHV (1986) and Nippon Koei (1995a) which, apart from minor discrepancies and difference in units, are broadly in agreement. These curves were fitted by MOWD except in the case of Saka for which curves were fitted by consultants involved in a previous study (DHV, 1986).

Following this review new ratings were fitted to the gauging data of each station. The gaugings were first assessed for any possible shifts in the relationship between stage and discharge and split into what appeared to be periods during which this relationship remained consistent. Outliers were inspected carefully to assess whether any errors may have occurred in the transcription of the data. Rating curves were then fitted to each of the periods of gauging data using the automatic fitting procedure on the Institute of Hydrology's HYDATA hydrological database and analysis software. Curves were fitted with between one and three parts with the goodness of fit judged partly by an automatically computed error function, and partly subjectively by an experienced hydrologist.

The new HYDATA ratings were plotted against the existing MOWD curves and the gauging data. For each station and each rating period the old and new curves were compared and a decision taken on which curve to use to convert the stage data to flows. In most cases the HYDATA rating curves appear to fit the gauging data provided more closely than the existing MOWD curves. In a minority of cases the HYDATA and MOWD curves are virtually identical. For consistency it was decided to select all the new HYDATA ratings for the conversion of stage data to discharge.

Details of the review, fitting and comparison of rating curves are given in Annex 16.

16.3.2 Conversion of stage to discharge

The stage data provided by MOWD were converted to discharges using the new HYDATA rating equations described in Annex 16. The conversion was made difficult by variations in the raw stage data, with some days having two stage readings, some just one and others none at all. A program was written to convert the raw stage data and to produce a single value of discharge for each day of record. On days with two stage readings each was converted to discharge and the mean taken. The resulting set of daily discharges are plotted in Annex 16.

The daily discharge series were carefully checked for any anomalies or suspected errors. Two types of anomaly were apparent. The first, single days of high or low values inconsistent with adjacent values, were easily checked by examining the stage data. In most cases the cause of these errors were obvious and could be amended. The second type of anomaly comprise periods of apparently constant discharge. In these cases examination of the raw stage data revealed that level had indeed been recorded as constant for a number of days. These periods of data were therefore not amended *although they were suspected to be erroneous.*

As a check on the daily discharges the values were summed to produce monthly totals and the mean monthly flow found. Complete months of record were compared with the values given as the "reference stream flows" in Nippon Koei (1995a). This was only possible for the flow series for Grand Falls and Garissa. The two sets of data agree well with divergences as expected according to differences between the MOWD and HYDATA ratings. In most cases the discharge values estimated from the HYDATA ratings curves are slightly lower than those from the MOWD curves. Scatter plots comparing the monthly flows are presented in Annex 16.

16.4 FLOOD EVENT ANALYSIS

16.4.1 Objective

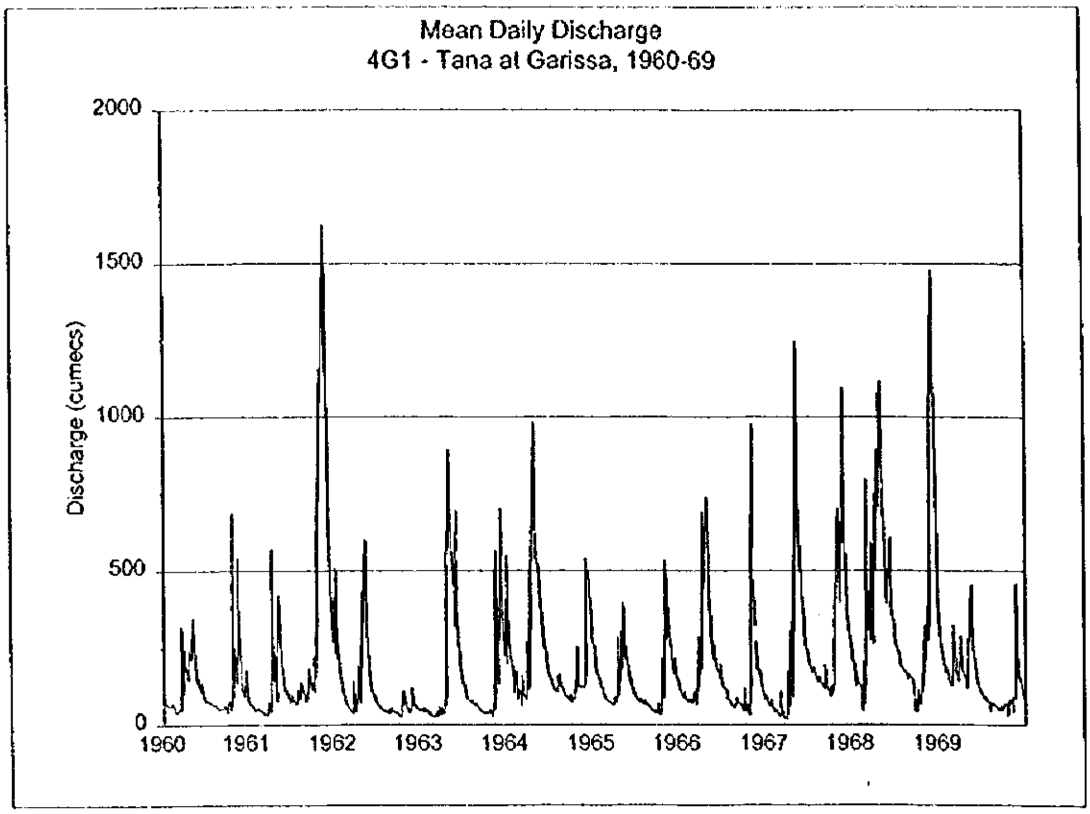
The daily discharge series at Garissa was analysed in order to establish the characteristics of flooding at Garissa. Floods were characterised in terms of their duration, peak flow and total volume. The objective of this analysis was to produce an estimate of the "normal" flood at Garissa. The daily discharge series at Grand Falls was also analysed in order to isolate the flow pattern corresponding with the "normal" flood downstream at Garissa. This flow is indicative of the release required at Grand Falls to sustain an acceptable pattern of flooding at Garissa.

The available daily discharge series at Nanigi and Garsen were also analysed in order to examine the relationship between flooding at Garissa and that downstream.

16.4.2 Pattern of flooding at Garissa 1960 to 1993

The daily discharge series at Garissa from 1960 to 1993 was examined in order to establish the pattern of flooding. There is a marked seasonal pattern of river discharge with floods occurring in general during two distinct wet seasons in each year, the first during April and May and the second in November and December. Daily discharges between 1960 and 1969 are shown in Figure 16-3 whilst those for the entire period are plotted in Annex 16.

Figure 16-3 Mean Daily Discharge at Garissa: 1960-1969



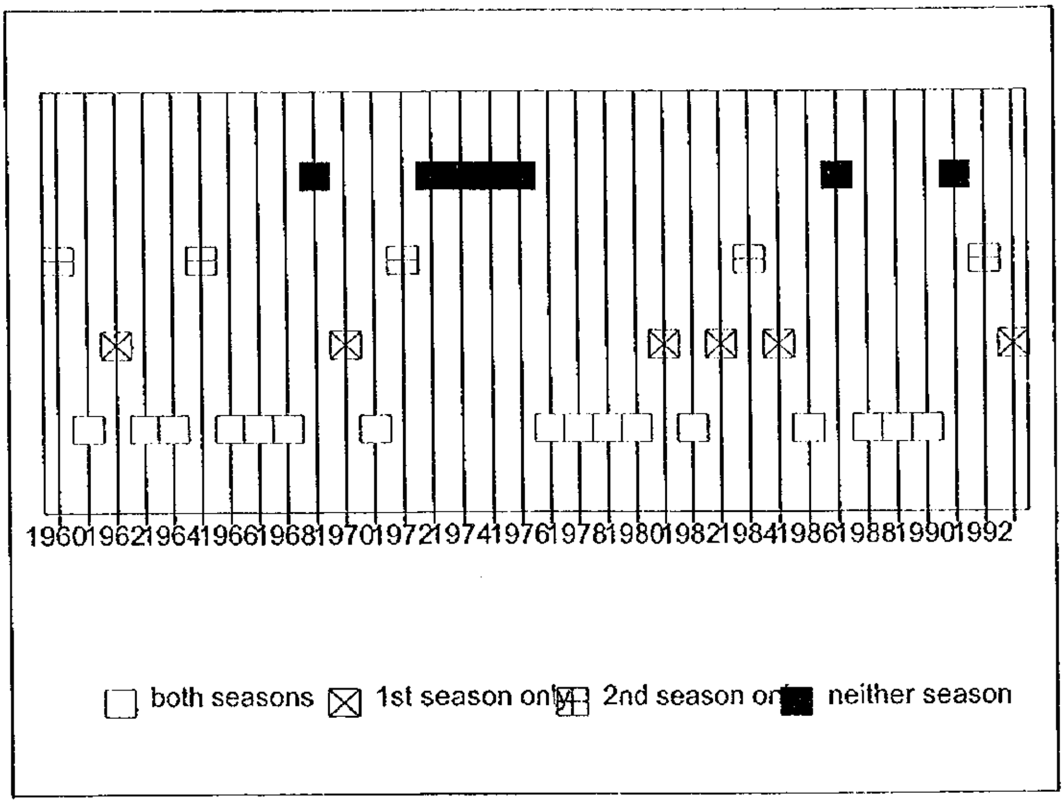
See Annex 16 for the complete discharge series.

In around half of the years between 1960 and 1993 floods greater than 500 m^3s^{-1} occurred in both wet seasons. In the majority of other years floods greater than 500 m^3s^{-1} occurred in one or other of the two wet seasons. However, in seven out of the 34 years there were no floods above this threshold and out of bank flow presumably did not occur. In probabilistic terms, and on the basis of this period of record, there is an 80% chance that a flood over 500 m^3s^{-1} will occur at least once in a year. The chance that floods will not occur in one or other of the two wet seasons is around 0.5 in any one year.

There appears to be a degree of clustering in the pattern of flooding between 1960 and 1993 (see Figure 16-4). During the 1960's there were floods greater than 500 m^3s^{-1} in almost all of the wet seasons. In contrast, floods were significantly lower during the early and mid 1970's. For four years between 1973 and 1976 there were no floods greater than 500 m^3s^{-1} at all. Following a period of higher floods in the late 1970's the pattern of flooding has become more erratic. Since 1981 floods greater than 500 m^3s^{-1} have occurred in only one season or not at all in 8 out of 13 years.

The pattern of flooding in the first wet season is slightly different to that in the second. There is a slight tendency for flood peaks to be greater in the first wet season, with this being the case in 22 out of the 34 years considered. This is supported by the flood frequency curves shown in Figure 16-5 which show the return periods associated with recorded flood magnitudes separately for the two wet seasons. At low return periods (less than 2 years), in other words the most frequent occurrences, flood peaks are higher in the first wet season. However, the flood peaks of more infrequent events, with return periods of more than 2 years, are higher in the second wet season. The highest flood peaks recorded in each of the two seasons are extremely similar. Peak floods of around 1,600 m^3s^{-1} occurred in April 1988 and in November of both 1961 and 1984.

Figure 16-4 Patterns of Floods greater than 500 cumecs, Garissa 1960-1993.



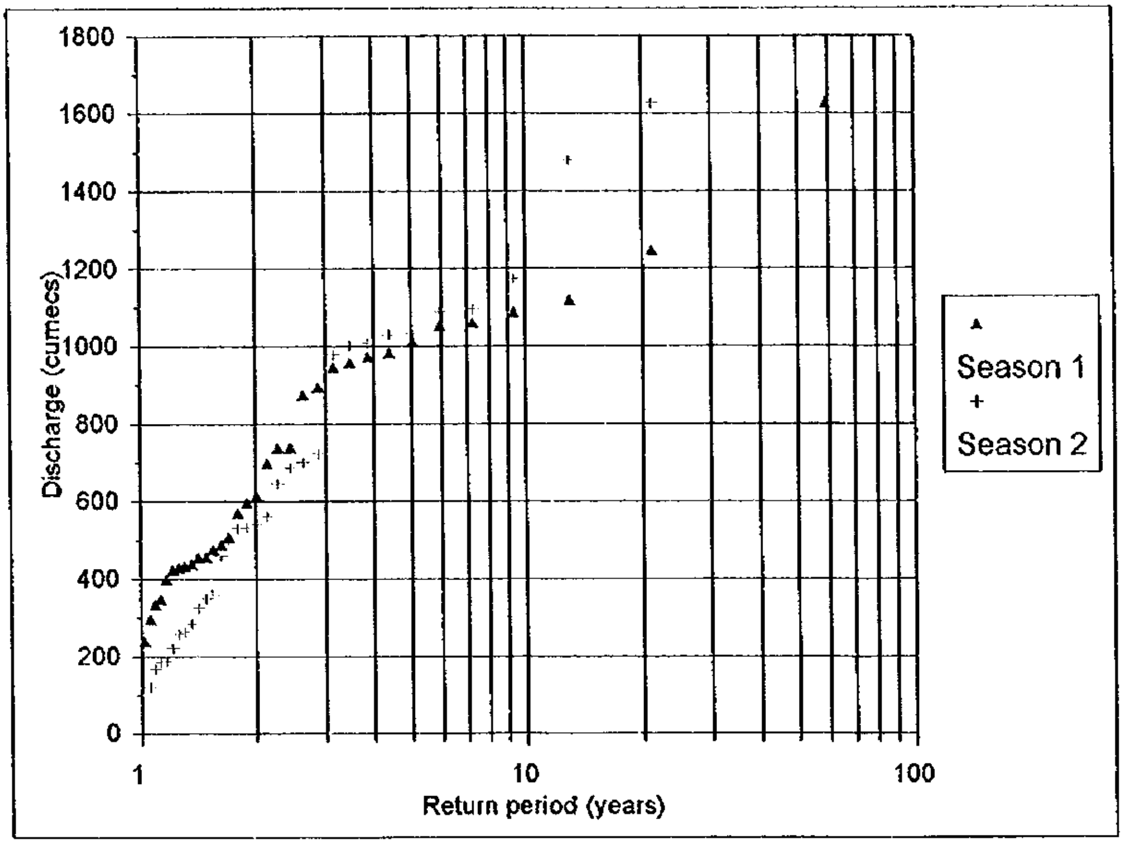
16.4.3 Assessment of the "Normal" flood at Garissa

Prior to any analysis it was important to establish a definition to describe the "normal" flood, or pattern of flooding, at Garissa. Ideally the flood should be defined in terms of a probability of occurrence, best described by a return period. The normal flood might, for instance, be selected as that which occurs on average once a year, with a return period of about 2 years.

Previous studies have preferred to describe the normal pattern of flooding at Garissa in terms of magnitude and duration. The consensus normal flood has a duration of 5 days during which mean daily discharge is over 500 m^3s^{-1}. This is assumed to represent the discharge required for out of bank flooding to occur at Garissa and to inundate the floodplain both upstream and downstream for a period sufficient to maintain the environment and level of economic activity currently supported by the river regime.

This definition, although strictly describing a requirement for flooding rather than a natural pattern, is particularly useful because it places certain constraints on the assessment of the normal flood at Garissa. These are, firstly, that the flood results in out of bank flow at Garissa and, secondly, that the floodplain both upstream and downstream is inundated to a defined extent and period of time.

Figure 16-5 Flood Frequency Plot: Seasonal Maxima at Garissa

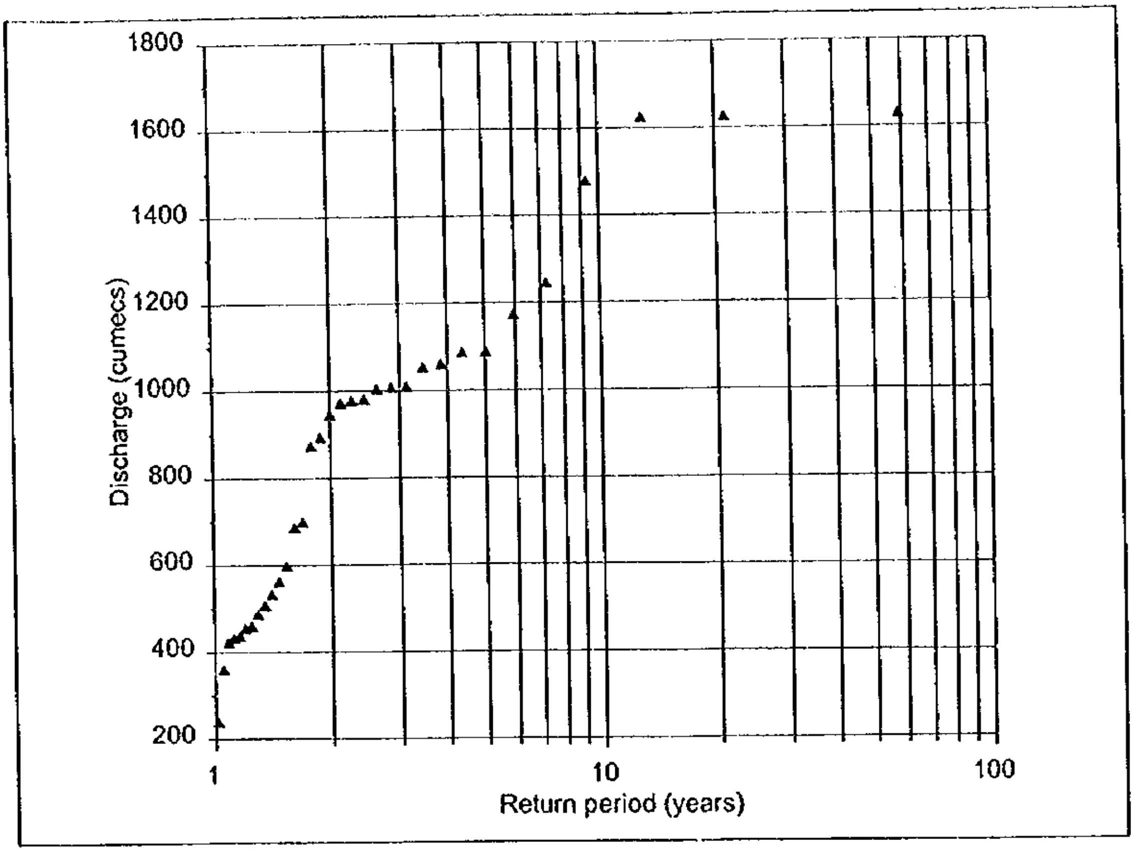


In the present study it was assumed that these criteria must be satisfied by the normal flood at Garissa. Following a review of the work performed as part of previous studies, the discharge value of 500 m^3s^{-1} was accepted as the threshold above which out of bank flow is likely to occur at Garissa. This value was identified from a change in slope in the rating curve for Garissa gauging station and from a comparison of bank height and river water levels using the RIVMOR morphological model (Delft Hydraulics, 1994). It is also reported that this value agrees with local records (Nippon Koei, 1995b).

A check on the estimated threshold value of 500 m^3s^{-1} for out of bank flow was made by comparing water depths and channel cross sections published by DHV (1986). The results of a series of gaugings include the following water depths and discharges:

Date	Water Depth (m)	Discharge (m^3s^{-1})
17/05/85	3.83	490.0
23/05/85	4.85	683.0
27/05/85	4.01	539.0

Figure 16-6   Flood Frequency Plot: Annual Maxima at Garissa



The nearest channel cross section (at km 510, with Garissa at km 509) indicates that bankfull height is around 3.5-4.0 m. Given the above gaugings this appears to confirm that out of bank flooding will occur with a flow of around 500 m^3s^{-1} at Garissa.

A further check was performed in order to examine whether, given this threshold of 500 m^3s^{-1}, out of bank flooding is a 'normal' phenomenon. The annual maximum series of flood peaks (the largest flood peak recorded in each year) was extracted from the daily discharge series at Garissa and plotted against return period (see Figure 16.6). The flood with peak of, or greater than, 500 m^3s^{-1} has a return period of around 1.3 years. Given that the out of bank flooding is likely to occur, on average, nearly once a year it is fair to describe this pattern of flooding as normal.

However, in order to characterise the range of out of bank flooding which occurs at Garissa it was necessary to take account of not just the minimum flood over the 500 m^3s^{-1} threshold but of all events with daily discharge above this value. This set of flood events is best characterised in terms of a median flood describing the middle value of flood duration, peak and total volume when these are ranked from largest to smallest. The median is an appropriate choice to represent the pattern of flooding because exactly half the events analysed are greater than it and exactly half are smaller. In probabilistic terms the median flood, with return period 2 years, has a 0.5 chance of occurring in any year. The mean flood is a poorer representation due to the skewed nature of the distribution of flood characteristics. It has an estimated return period of 2.33 years and is greater in magnitude than more than half of recorded events.

The working definition of the normal flood assumed in this study is therefore given by:

> **The median flood of those events resulting in out of bank flooding at Garissa and which inundate the floodplain both upstream and downstream for a period sufficient to maintain the environment and level of economic activity currently supported by the river regime.**

This was calculated as:

> **The median of floods with at least one day's flow of over 500 m3s-1.**

16.4.4 Estimation of the median flood at Garissa

The series of daily discharges at Garissa from 1963 to 1993 was analysed to isolate all flood events with at least one day of flow greater than 500 m^3s^{-1}. Given that it was important that concurrent flow records were also available for Grand Falls during each event the start date was determined by the availability of data for this latter station.

The discharge data extracted comprised all flood events with flow greater than 500 m^3s^{-1} at Garissa along with the ten days prior to the onset of the flood. Concurrent records were extracted for Grand Falls. Linear interpolation was used to infill a small number of single missing days of data at Garissa. Given the more incomplete state of the discharge data for Grand Falls periods of up to 3 days were infilled by the same method. Events with significant infilling or remaining missing days of data were not included in further analysis due to the high degree of uncertainty over the true daily discharge values. Where the daily discharge during a single event dropped slightly below 500 m^3s^{-1} these days were included in the analysis. Only 6% of all flows included in the analysis were less than 500 m^3s^{-1}.

Each flood event at Garissa was characterised in terms of its duration (number of days with flow greater than 500 m^3s^{-1}), peak flow and total flood volume. The characteristics of the 52 flood events examined are given in Annex 16 and are summarised in Table 16-2.

Table 16-2 Summary characteristics of flood events at Garissa greater than 500 m^3s^{-1}

	Duration (days)	Peak Flow (m^3s^{-1})	Total volume (MCM)
Maximum	47.0	1631.5	3208.6
75% percentile	18.0	1007.6	1043.7
Median	**6.5**	**784.8**	**394.2**
25% percentile	3.0	667.8	184.7
Minimum	1.0	504.7	47.6

The median event from the 52 analysed has duration 6.5 days, peak flow of 784.8 m^3s^{-1} and total volume of 394.2 MCM. These characteristics were assumed to represent the "normal" flood at Garissa.

For comparative purposes it is worth noting the characteristics of the mean flood. This has duration 11.2 days, peak flow of 841.4 m^3s^{-1} and total volume of 708.6 MCM. The characteristics of the mean flood are higher than those of the median flood because of the skewed nature of the distribution of flood characteristics. The mean flood is less representative of the normal flood than is the median flood because it has a longer duration, higher peak and greater total volume than more than half of the events analysed.

The median flood resulting from this analysis compares well with the normal or required flood at Garissa specified in previous studies. The normal flood given in Nippon Koei (1995a) has duration 7 days, peak flow 600 m^3s^{-1} and total volume 345.6 MCM for the period during which discharge is greater than 500 m^3s^{-1}.

16.4.5 Comparison of floods at Garissa and Grand Falls

Having estimated the median flood at Garissa the next stage of the analysis involved comparing the concurrent discharge records of Garissa and Grand Falls in order to establish the relationship between flooding at the two sites. Of the 52 events analysed in the estimation of the median flood at Garissa only 34 were suitable for inclusion in this comparison, the remainder having insufficient or too much infilled data at Grand Falls. Some of the long duration floods at Garissa were disaggregated where it was clear that they represented a sequence of flood events that could be analysed separately.

The flow records at the two sites were compared graphically for each of the 34 flood events. From this comparison it was evident that the relationship between flooding at Grand Falls and that at Garissa is not constant. There appear to be four distinct types of flood, each one characterised by differences in the relationship between discharge at the two sites. Each of the four categories is illustrated graphically in Figure 16-7 and summarised below.

Type	Characteristics	No.of events
A	Flood attenuates as it moves downstream. Peak flows and total volume significantly less at Garissa than at Grand Falls.	11
B	Massive flooding at Grand Falls with much greater attenuation than in type A. Flood at Garissa appears insignificant in comparison.	5
C	Little change in flood as it moves downstream. Flood at Garissa very similar in terms of peak and/or volume to that at Grand Falls.	11
D	Flood increases as it moves downstream. Peak flows and total volume significantly more at Garissa than at Grand Falls.	6

Of the 34 flood events analysed 11 were identified as type A, 5 as type B, 11 as type C and 6 as type D. The distribution of each type of event over the period 1963 to 1993 is shown in Figure 16-8. It is noticeable that type B floods appear to have been confined to the 1960s and early 1970s. The apparent lack of other events in the 1980s and 1990s is due to the patchy nature of the flow records for Grand Falls over this period.

On the basis of this evidence it appears that type B floods are no longer a feature of the current flood regime of the Tana. There is also some doubt over the validity of these events. In one example (December 1963) losses between Grand Falls and Garissa were estimated to be 80%. Given this uncertainty, and given that flows at Garissa were less than 500 m^3s^{-1} for many type B events, these type B events were excluded from any further analysis.

The remaining 30 floods events at Grand Falls were characterised in terms of their duration, peak flow and total volume. The lag time between flooding at Grand Falls and Garissa was also estimated. These details are listed in Annex 16.

The events with characteristics at Garissa which were relatively similar to those of the median flood were selected in order to establish whether they were linked to a consistent pattern of flooding upstream at Grand Falls. No consistency was evident with three of these events falling into category A and two each into C and D. The most similar event to the median flood in each of the three cases was examined in order to isolate the different patterns of flooding at Grand Falls which could give rise to a median type-flood at Garissa. Details of these three events are given in Table 16-3 and are shown in Figure 16-9.

Figure 16-7   Types of Flood Identified from Flood Event Analysis

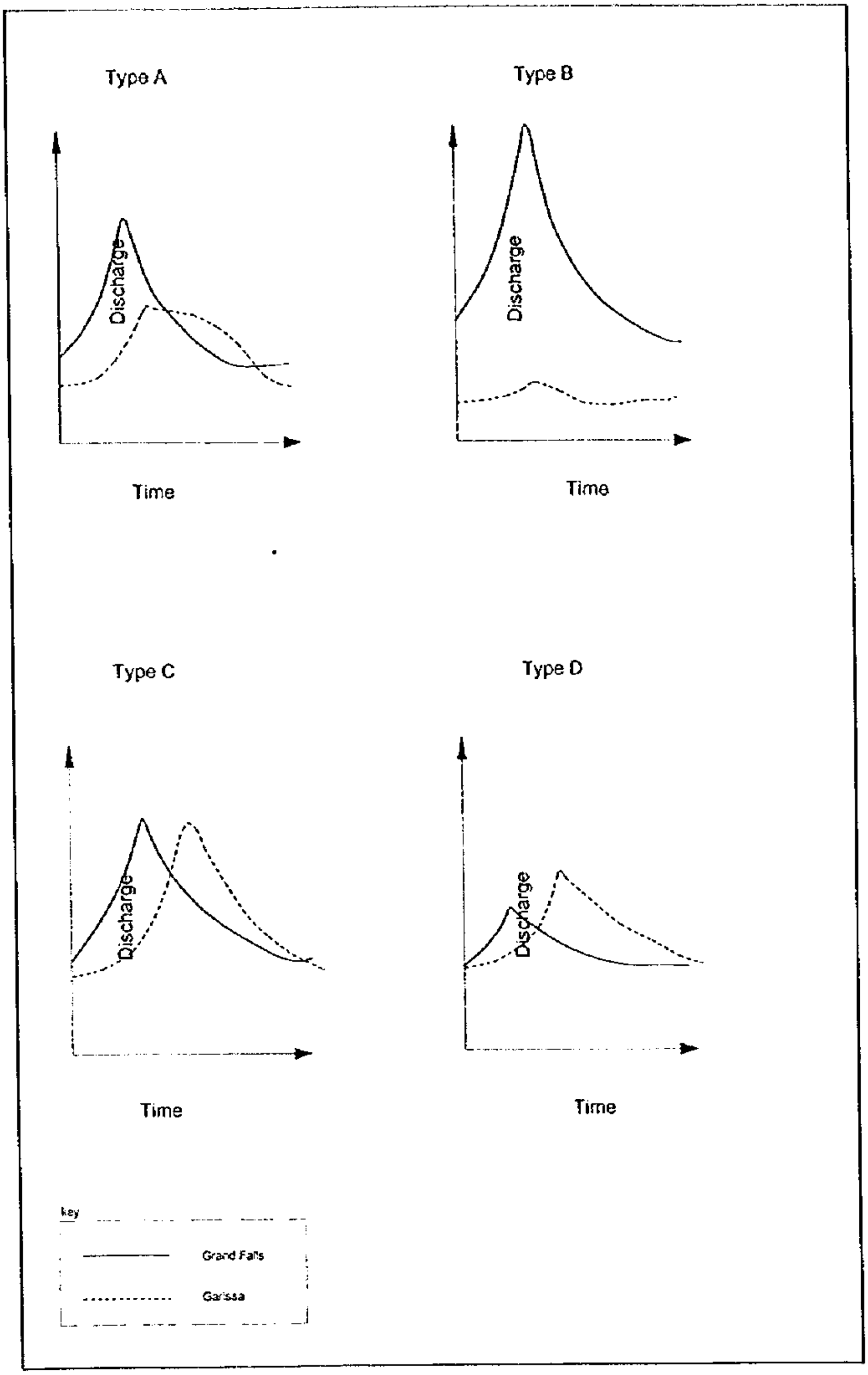


Figure 16-8 Distribution of Flood Events Analysed

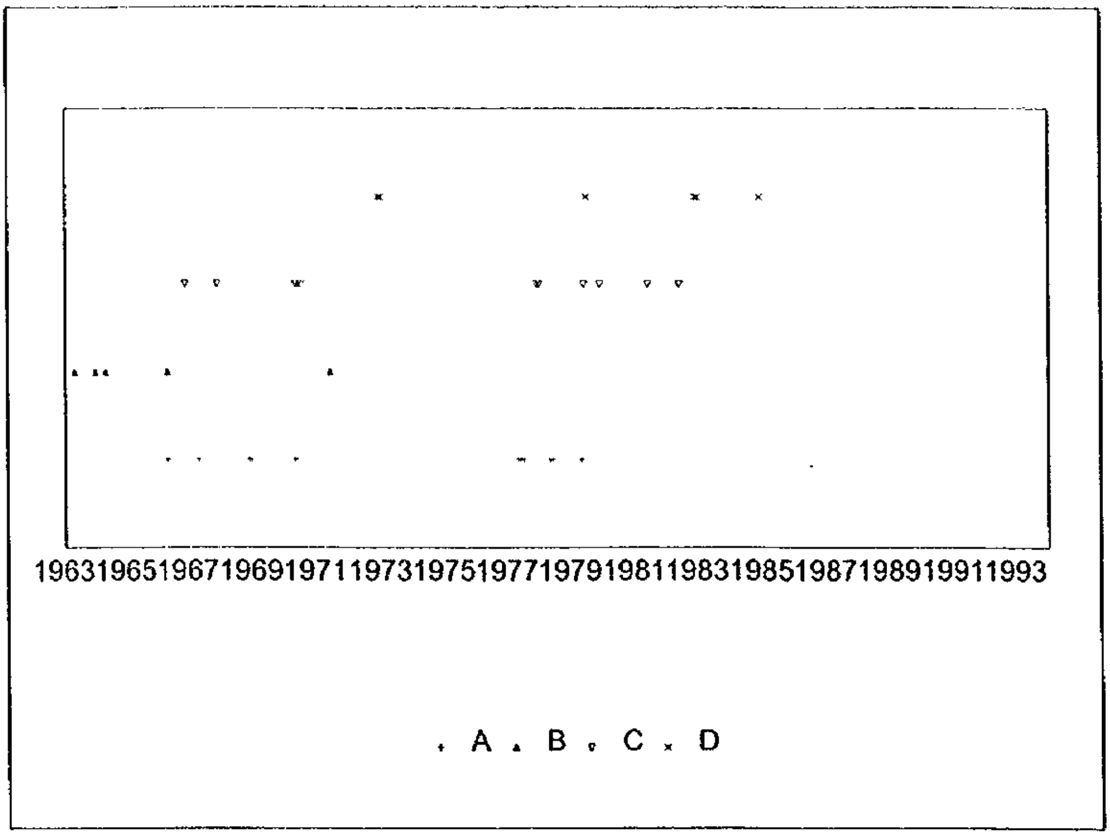
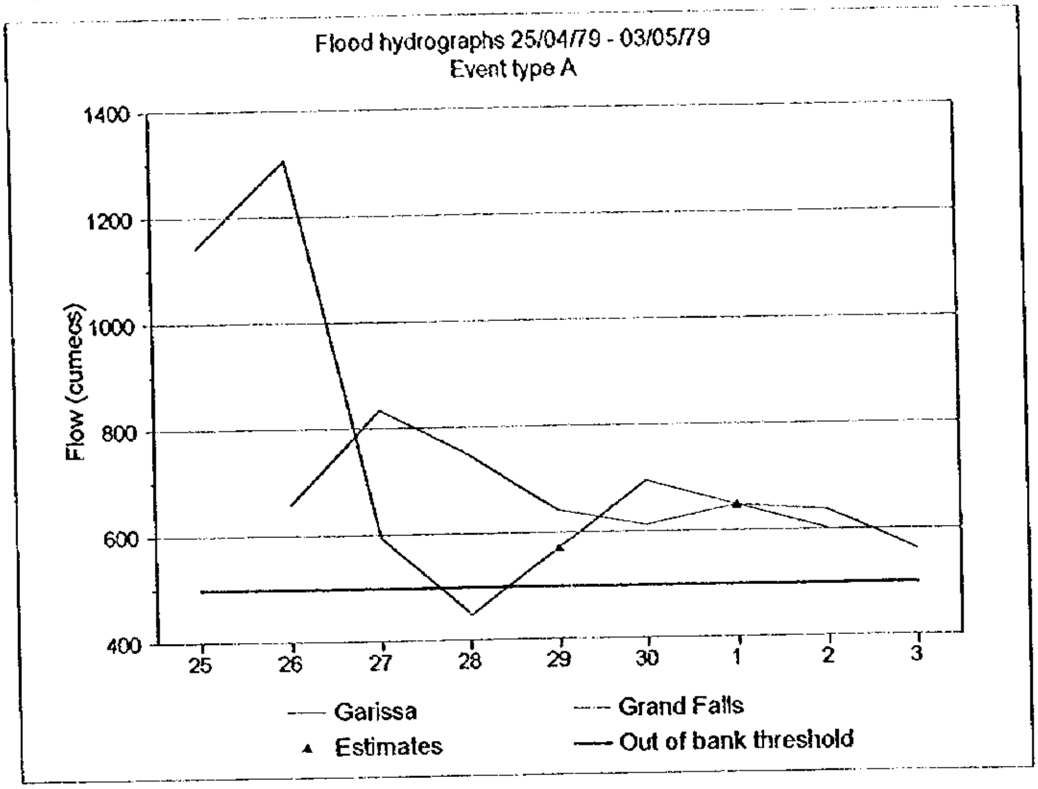


Figure 16-9 Flood Hydrographs of Median Type Events:



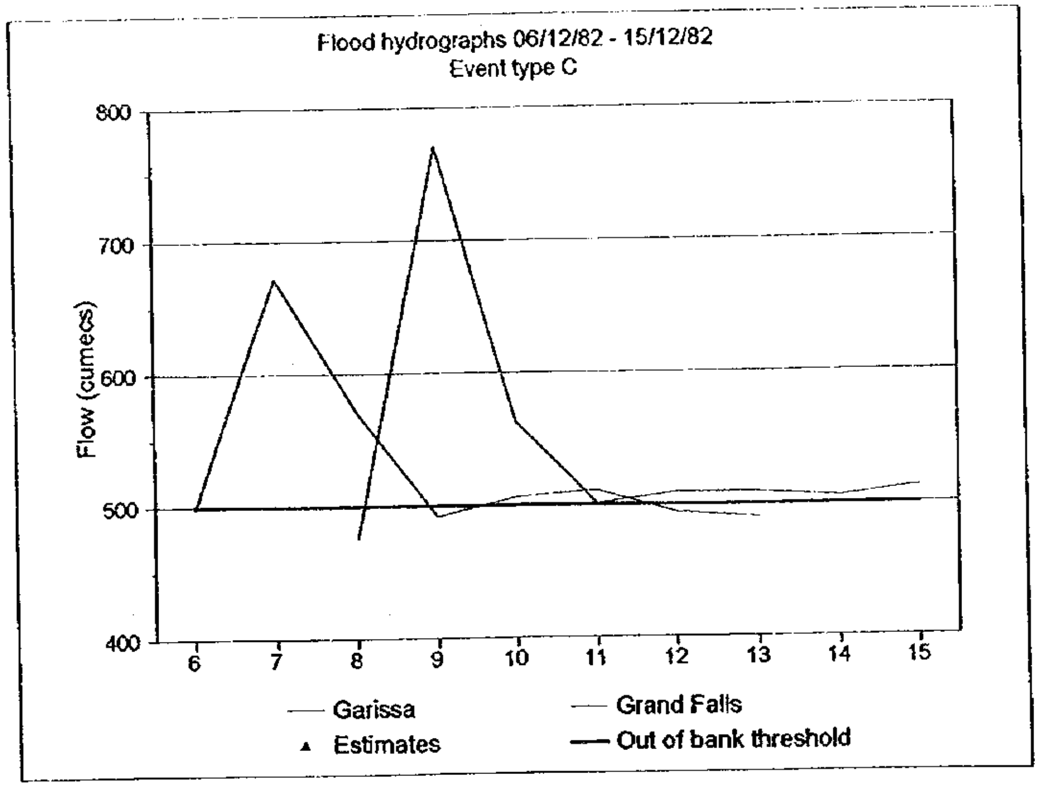


Figure 16-9 (continued)

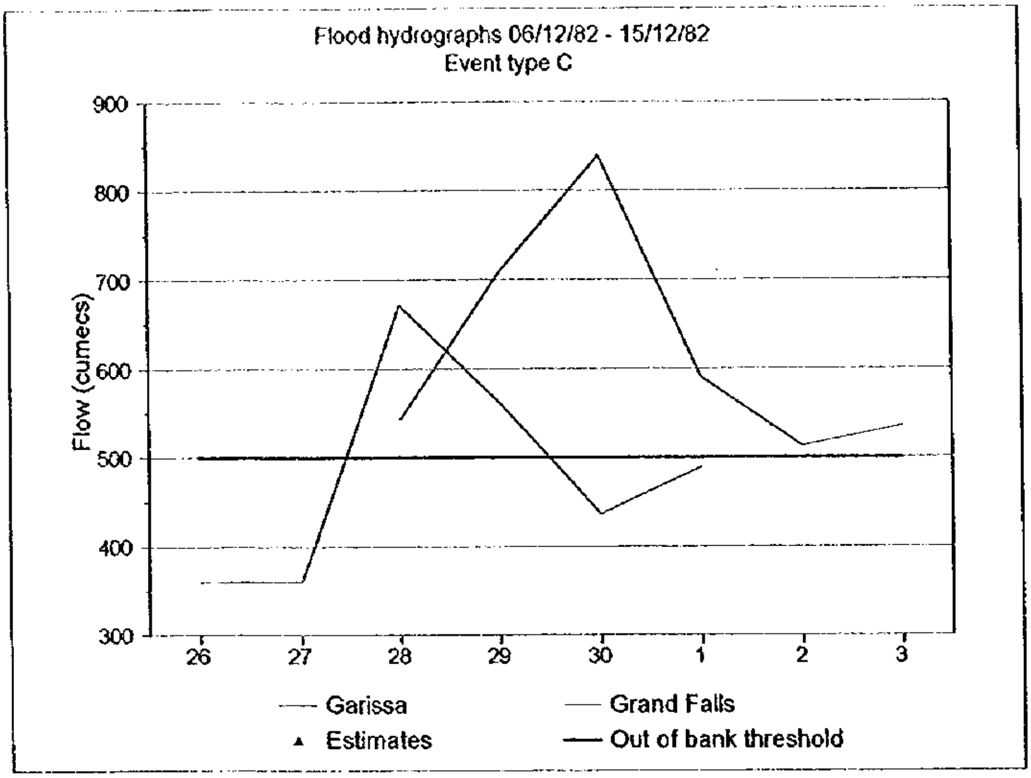


Table 16-3 Characteristics of events relating to median-type floods at Garissa

	Grand Falls				Garissa (median type floods)			
Type & date	Peak (m^3s^{-1})	Dur^n (days)	Volume (MCM)	Lag (days)	Peak (m^3s^{-1})	Dur^n (days)	Volume (MCM)	Losses
A 26/4/79	1306.2	8	518.8	1	835.4	8	461.8	11.0%
C 9/12/82	679.1	8	358.1	2	770.9	8	374.7	-4.6%
D 28/11/82	671.9	6	243.8	2	840.0	6	322.5	-32.3%

There is clearly no single flood at Grand Falls which will give rise to the normal flood at Garissa. The flood hydrograph may either attenuate, as in case A, be supplemented by additional runoff, as in case D, or undergo little change, as in case C. In order to improve the definition of these three relationships, all events in each category were analysed and the median of each type was estimated. The results of this analysis are presented in Table 16-4.

Table 16-4 Characteristics of Median floods in each of types A, C and D

	Grand Falls				Garissa (median type floods)			
Type	Peak (m^3s^{-1})	Dur^n (days)	Volume (MCM)	Lag (days)	Peak (m^3s^{-1})	Dur^n (days)	Volume (MCM)	Losses
A	1460.1	10	717.3	2	1002.7	10	615.8	19.6%
C	1039.5	8	448.4	1	864.7	8	473.0	3.1%
D	671.9	8	358.1	1	840.0	8	387.3	-8.3%

The median events at Garissa for each of types A, C and D are larger than the overall median (or normal) event specified in section 16.4.3. This is due to the fact that many of the original 52 events excluded due to lack of data at Grand Falls were small magnitude, short duration events.

The information in Table 16-4 allows the estimation of the flood at Grand Falls relating to the normal flood at Garissa for each of categories A, C and D. This is assumed to be a better estimate than relying on the relationship presented by Table 16-3 which is based on a single flood event.

The normal flood at Garissa, having peak flow 784.8 m^3s^{-1}, duration 6.5 days and total volume 394.2 MCM, is estimated to correspond with the floods at Grand Falls specified in Table 16-5 and presented graphically in Figure 16-10. Peak flows are estimated from the ratio of peaks at the two sites and volumes from the losses between the two sites, both of which are specified in Table 16-4. On the evidence of the events examined in this analysis the duration of flooding at both sites appears to be the same.

Figure 16-10 Flood Hydrographs at Grand falls relating to "Normal" floods at Garissa

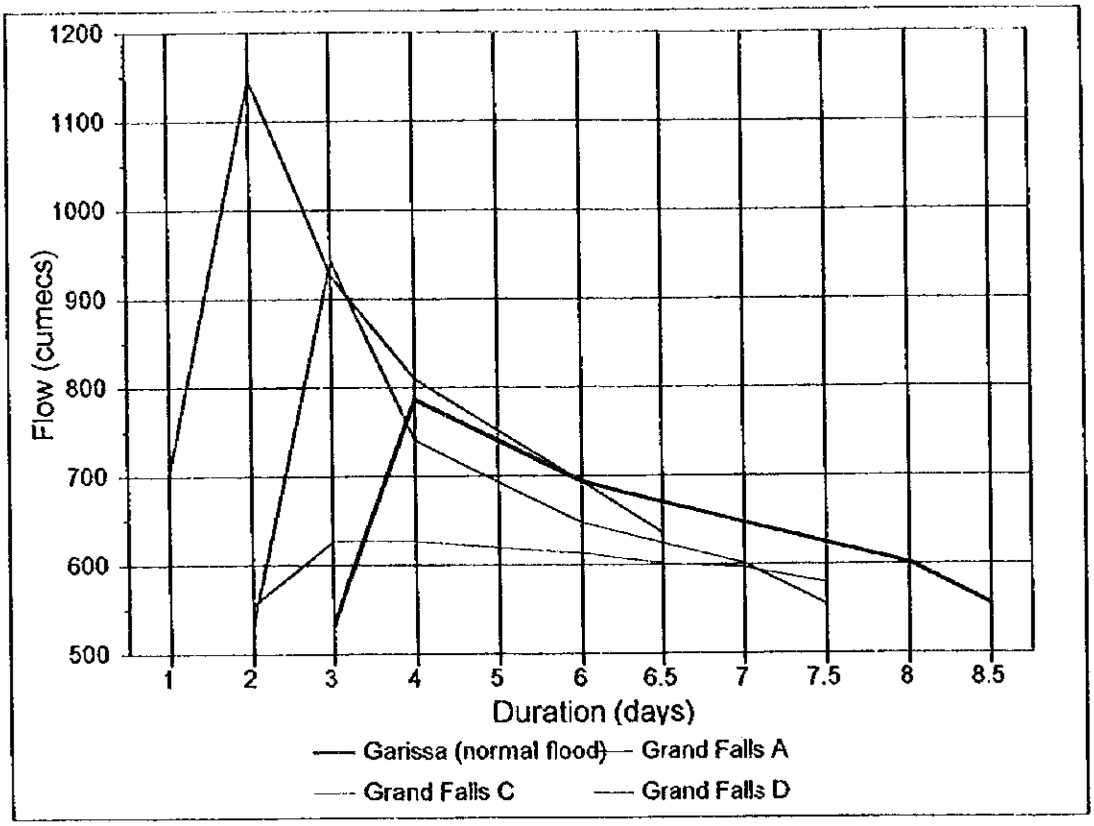


Table 16-5 Flood characteristics at Grand Falls corresponding to the normal flood at Garissa

Flood Type	Peak (m^3s^{-1})	Duration (days)	Volume (MCM)
A	1145.8	6.5	490.3
C	943.4	6.5	406.8
D	627.7	6.5	364.0

The values listed in Table 16-5 can be viewed as estimates of the release required from Grand Falls to ensure the normal flood at Garissa. Although these values are only estimates they are important in that they indicate that the release required at Grand Falls is not the only variable determining the flood response at Garissa but that other factors are also involved. These other factors can apparently make a considerable difference between the release required at Grand Falls, with that estimated for type D flood conditions only 75% of the total volume of the release in a type A flood.

In flood types C and D it is evident that flow downstream of Grand Falls is supplemented by additional runoff from the Lower Tana catchment. The differences between runoff generation in each of the three flood types were investigated further through an analysis of rainfall. This is described in Section 16.5.

16.4.6 Pattern of flooding downstream of Garissa

The analysis of flooding downstream of Garissa was based on fewer events due to the scarcity of data for gauging stations on the lower Tana. Events were examined where reasonably complete daily discharge series were available for the gauging stations at Nanigi and Garsen. The short daily discharge series available for Saka does not contain data that are concurrent with any of the flood events analysed at the other stations and was therefore not included in this analysis.

Despite the shortage of data, the analysis was able to reveal the general pattern of flooding at Nanigi and Garsen. Flood hydrographs show significant attenuation as the flood moves downstream from Garissa (Figure 16-11). The recorded peak flows and total volumes are lower at Nanigi, 79 km downstream of Garissa, and still less at Garsen, a further 300 km downstream. The lag time between the onset of flooding at Garissa and Nanigi is less than one day but appears to be at least four or five days from Nanigi to Garsen.

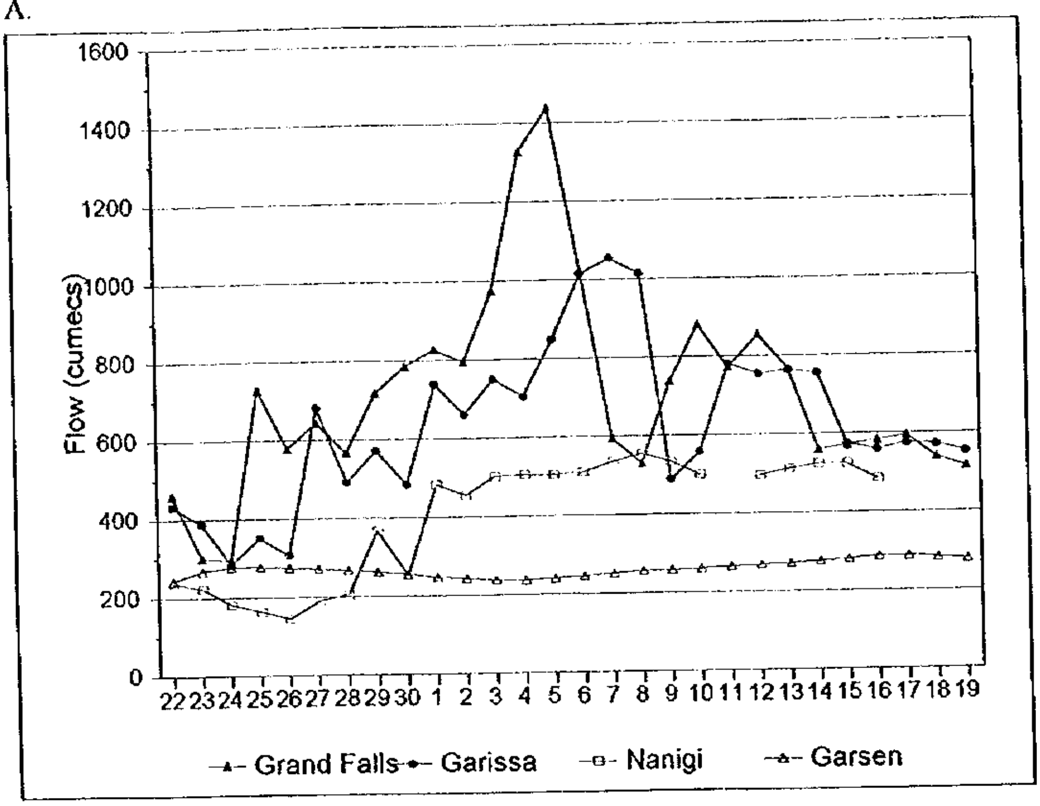
Flood discharges at Nanigi typically peak at 400-550 m^3s^{-1} and remain at this level for an extended period rather than receding quickly as do flood peaks upstream at Grand Falls and Garissa. Losses between Garissa and Nanigi during flood events are in the range 20-50% with a mean of 37%. Flood hydrographs at Garsen are further attenuated with an extremely gradual rise to peak flows which level out at around 200-300 m^3s^{-1}. Losses between Garissa and Garsen are in the range 40-70% with a mean of 60%.

Given these figures, the normal or median flood at Garissa may be expected to give rise to a flood downstream at Nanigi with peak of around 400 m^3s^{-1} and total volume of 250 MCM. The flood at Garsen would have a peak of around 200 m^3s^{-1} and an estimated total volume of 150 MCM. It was not possible to examine the actual response at Nanigi and Garsen following a median-type event at Garissa due to the lack of concurrent data for any such event. These estimates are therefore speculative and need to be treated with caution.

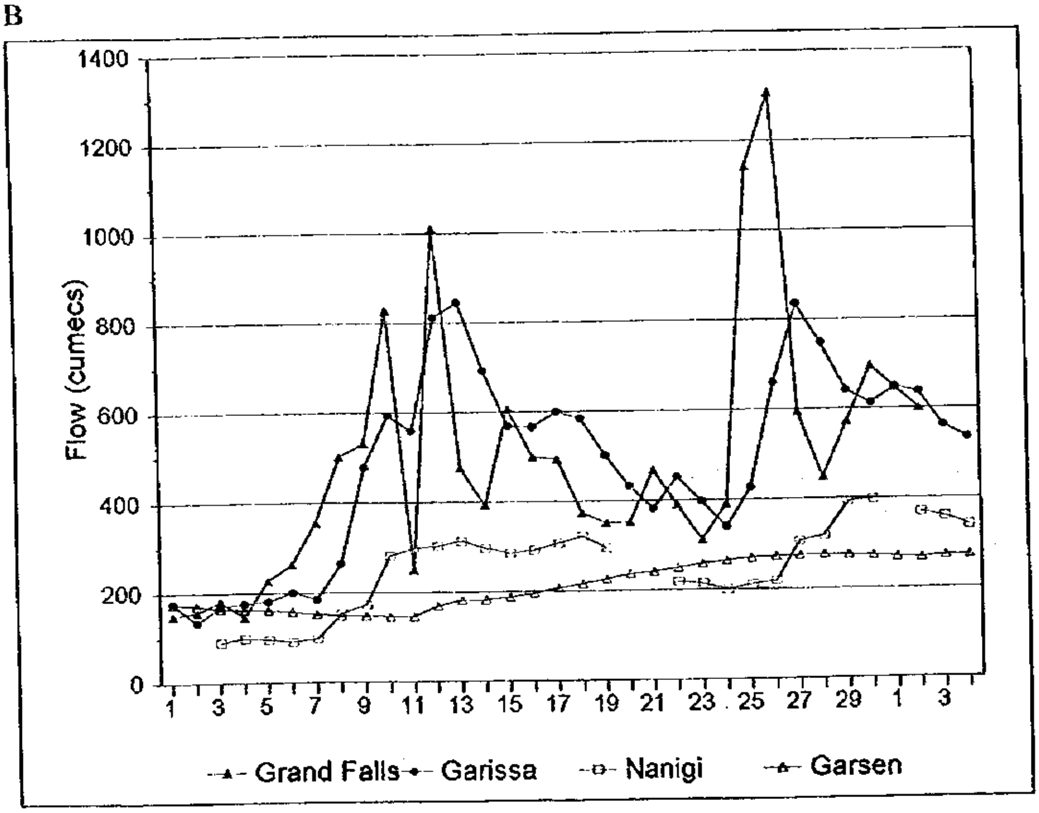
The pattern of flooding at Nanigi and Garissa does not appear to be affected by the relationship between flooding at Garissa and Grand Falls. The attenuation of floods downstream of Garissa appears to occur in a similar fashion irrespective of whether a flood is classed as type A, C or D upstream.

Figure 16-11 Flood Hydrographs showing attenuation of flows downstream of Garissa. A: 22/04/77 - 19/05/77, and B: 01/04/79 - 04/05/79.

A.



B



16.5 RAINFALL ANALYSIS

16.5.1 Objective

Daily rainfall data from selected stations were analysed in order to assess the extent to which variations in the relationship between floods at Grand Falls and Garissa relate to runoff generated by rainfall in the Tana catchment below Grand Falls. The rainfall preceding flood events of type A, C and D was examined in an attempt to characterise the rainfall corresponding with each type.

16.5.2 Selection of rainfall data

As described in earlier, rainfall data were provided for between stations in and around the Tana catchment. The great majority of these lie in the headwaters of the catchment upstream of Grand Falls or in areas draining through laghas to the Tana downstream of Garissa. Only a small number of stations lie in the area of interest draining to the river between Grand Falls and Garissa. Daily rainfall data was extracted for 14 stations lying in this area of the Tana catchment. These stations are listed in Table 16-6 whilst their locations are shown in Figure 16-12.

Daily rainfall was extracted for each of the flood events analysed previously. This included rainfall during and for a ten day period before each event. During most of the events the rainfall records of one or more stations was missing. For ease of comparison the rainfall stations were put into one of five groups according to their location; Nyambene Hills, Nyambene foothills, in the Tana valley downstream of Grand Falls, Garissa, and on the Tana upstream of Garissa. There was only a single station in each of the latter two groups. In the other three groups the mean daily rainfall of the individual sites was found and assumed to be representative of those areas.

The daily rainfall of 28 events was examined. Only two of these events had rainfall records for all of the five areas. This was largely due to the unavailability of records for station 9039001, the site upstream of Garissa. This site was largely excluded from the analysis described below. Half of the events had complete records for the other four sites whilst the remainder had data only for the Nyambene Hills and Garissa.

Figure 16-12 Locations of rainfall stations used in analysis of rainfall preceding flood events of types A, C & D

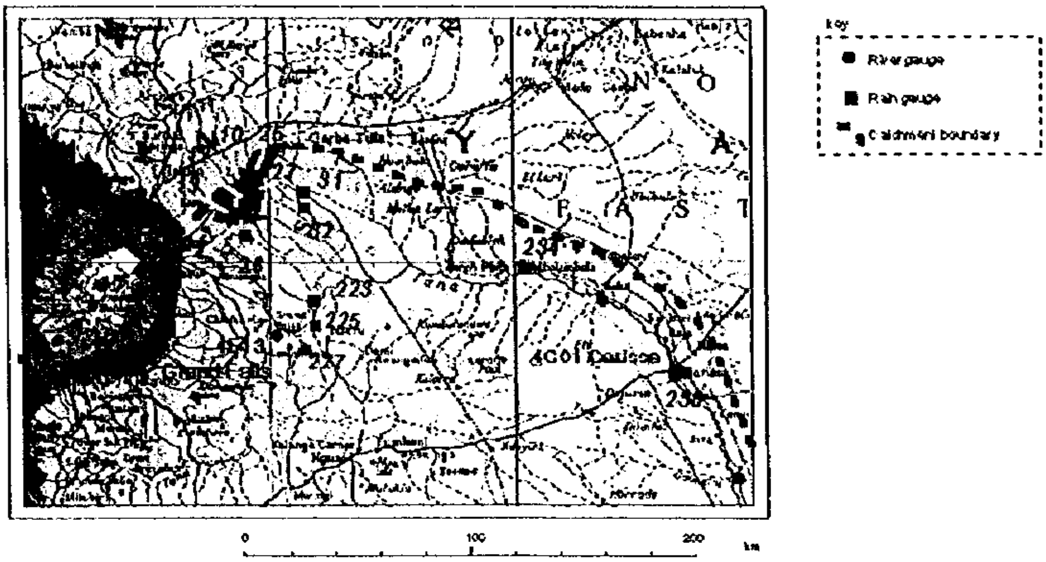


Table 16-6 Details of rainfall data used in the analysis

No	ID	Name	Area	Alt (m)	Long	Lat	Period
10	8937041	Lare, Meru	NH	2796	37.93 E	0.33 N	1957-90
12	8937059	Maua Nyambene Hills	NH	1738	37.93 E	0.23 N	1959-90
13	8937060	Meru Mucii Mukuru	NH	2050	37.85 E	0.18 N	1960-90
24	8937086	Atheru Gaiti Coffee	NH	1410	37.97 E	0.20 N	1974-90
25	8937089	Kathanga Primary School	NH	1935	37.98 E	0.43 N	1974-90
26	8937091	Akachiu Chief's Camp	NH	1542	37.95 E	0.18 N	1974-90
27	8937092	Atheru Ruujine Coffee	NH	1410	37.97 S	0.37 N	1974-90
30	8938001	Kinna Scheme Isiolo	NF	754	38.20 E	0.32 N	1957-90
31	8938005	Rapsu Scheme	NF	722	38.22 E	0.28 N	1973-87
223	9038020	Usueni Dispensary, Kitui	ds GF	443	38.20 E	0.15 S	1974-87
225	9038024	Nzanzeni Primary School	ds GF	508	38.20 E	0.22 S	1974-87
227	9038026	Kaivirya Primary School	ds GF	607	38.15 E	0.32 S	1974-87
233	9039000	Garissa Met Station	Gar	138	39.63 E	0.48 S	1957-90
234	9039001	Garissa Balambala Police	us Gar	205	39.07 E	0.03 S	1982-90

Key to areas: NH - Nyambene Hills, NF - Nyambene foothills, ds GF - downstream of Grand Falls, Gar - Garissa, us Gar - upstream of Garissa

16.5.3 Analysis of rainfall events

The rainfall events were characterised in terms of their duration, total rainfall, mean daily rainfall and maximum daily rainfall. Events were grouped according to the flood types they correspond with. A list of the characteristics of the events analysed is given in Annex 16.

The median characteristics of rainfall events in each area for each type of flood were estimated. The median was estimated firstly only from those events for which data was available for each of the four areas ("common" events). Unfortunately this halved the number of events under analysis. In particular the number of type C and D events was dramatically reduced so the decision was made to examine the rainfall of these two groups together. In order to examine whether there were differences between the rainfall of type C and D flood events it was therefore necessary also to estimate the median characteristics from all the available data for each site, although no longer comparing like with like.

The characterisation of rainfall events in this way resulted in a large array of summary statistics. The median characteristics for each area of the catchment during each type of flood event are given in Annex 16. A descriptive summary is provided below.

Type A floods are characterised by heavy rainfall on the Nyambene Hills, with median daily rainfall of around 35 mm and total rainfall of around 200 mm. Rainfall on the foothills and in the valley downstream of Grand Falls is low, with daily rainfall of 4-8 mm and totals during the event of around 15-20% of that falling on the Nyambene Hills.

Type C and D flood events have a lower median rainfall on the Nyambene Hills by 50 mm compared with type A. Daily rainfall intensities are also less with a median of under 30 mm/day. Rainfall in the river valley below Grand Falls is higher being around 50% of that on the Hills and with daily intensities of 15 mm/day. Rainfall on the Nyambene foothills is also slightly higher than during type A events, with total event rainfall of 20-30% of that falling on the Hills themselves.

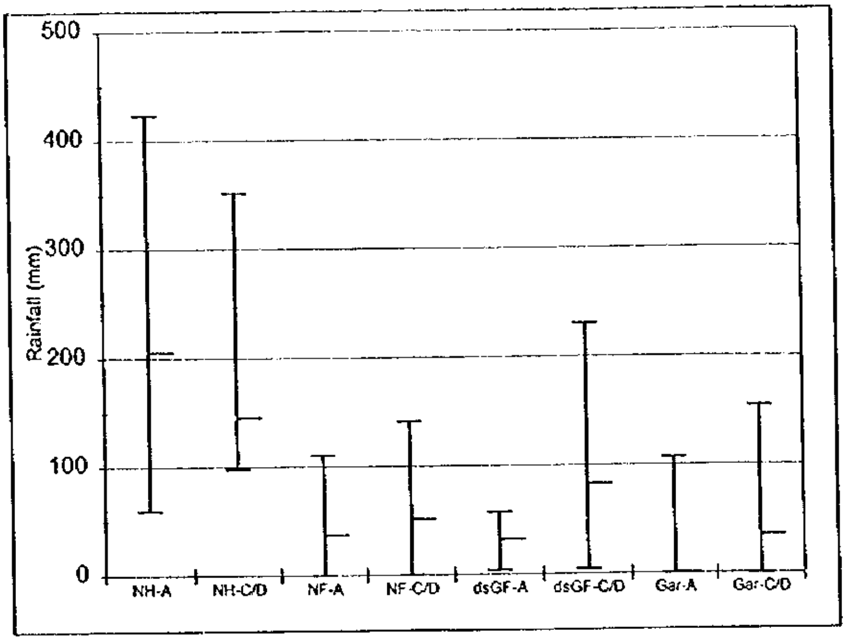
There are also differences between the rainfall of events of types C and D (although it should be noted these results are not based entirely on "common" rainfall data). During type D events rainfall is heavier at all sites than during type A events. Median total rainfall downstream of Grand Falls and on the Nyambene foothills is 60% and 35% respectively of that falling on the Nyambene Hills. Daily rainfall is 12-25 mm at these sites during these events but is relatively low at 32 mm on the Hills themselves. Type C events show less extreme patterns of rainfall than during type D events, but rainfall is still heavier downstream of Grand Falls and lower on the Nyambene Hills than during a type A event.

These differences between the median rainfall characteristics of rainfall events associated with flood types A, C and D are also borne out by an examination of the range of rainfall (total rainfall and mean daily intensities) in events of each type. Figure 16-13A shows the range (maximum to minimum) and median of total rainfall in each area during common events of type A and types C/D. Figure 16-13B shows the pattern of mean daily rainfall in the same fashion. The ranges of both total and mean daily rainfall are higher during type C/D events than type A events in all areas other than the Nyambene Hills. In contrast, the range of mean daily rainfall in the Nyambene Hills is significantly higher during type A events whilst the total rainfall in this area covers a wider range in type A events than in type C/D events.

This general pattern of rainfall variations during the different types of event is shown in Figure 16-14 which presents the rainfall and flow during examples of each of a type A, C and D event. In the event during April and May 1977 (type A) over 200 mm of rain fell in the Nyambene Hills. The rainfall on the foothills and downstream of Grand Falls was only 12% and 19% of this total respectively. During the type C event shown in November 1977 rainfall on the Nyambene Hills was over 300 mm. The proportion of this rainfall falling elsewhere in the catchment was 15% on the foothills, 28% downstream of Grand Falls and 10% at Garissa. Rainfall in these areas relative to that on the Hills was even higher during the event of November 1984 (type D). During this event 350 mm of rainfall fell on the Nyambene Hills with 15% of this total falling on the foothills, 40% downstream of Grand Falls and at 26% Garissa.

Figure 16-13 Ranges of (A) total rainfall and (B) mean daily rainfall during common flood events.

A:



B:

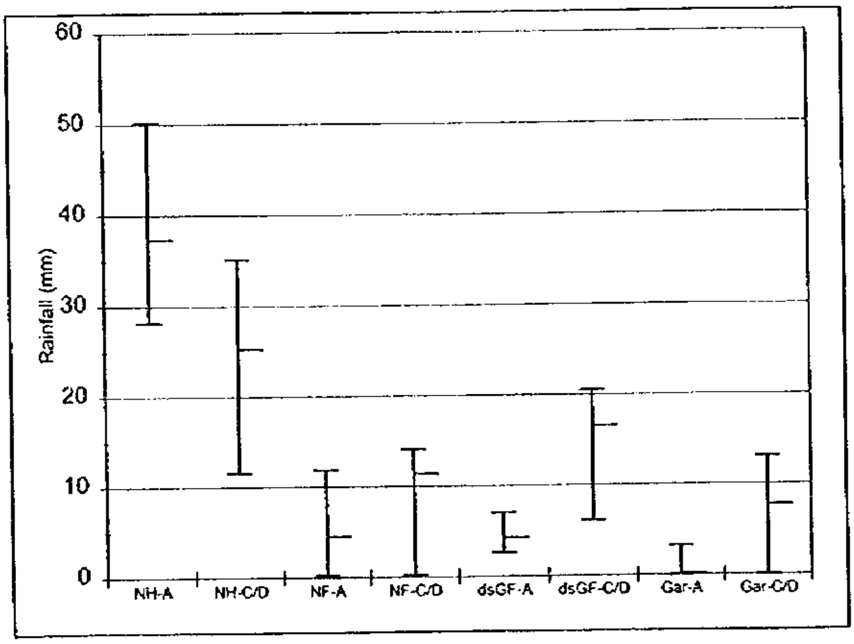
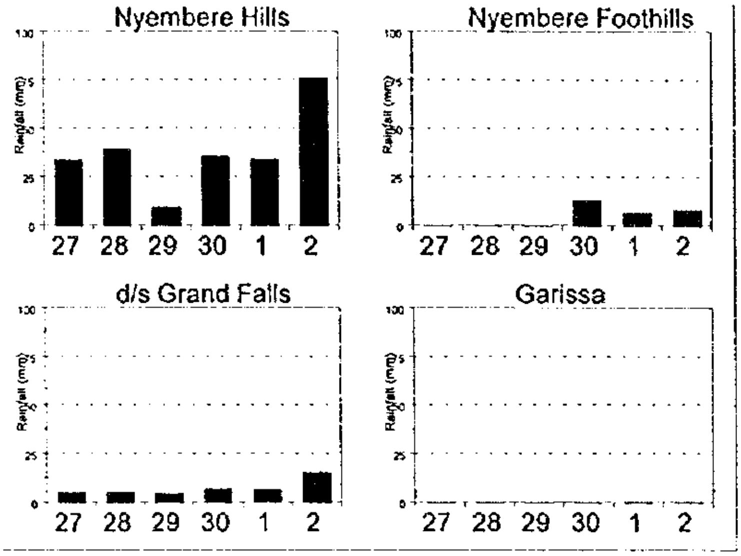


Figure 16-14 Plots of Rainfall and Flow During Type A, C & D Flood Events:

Typical Rainfall Pattern for Event Type A: (27/04/77 -- 09/05/77)



Resulting Flows at Grand Falls and Garissa:

Flow (cumecs)

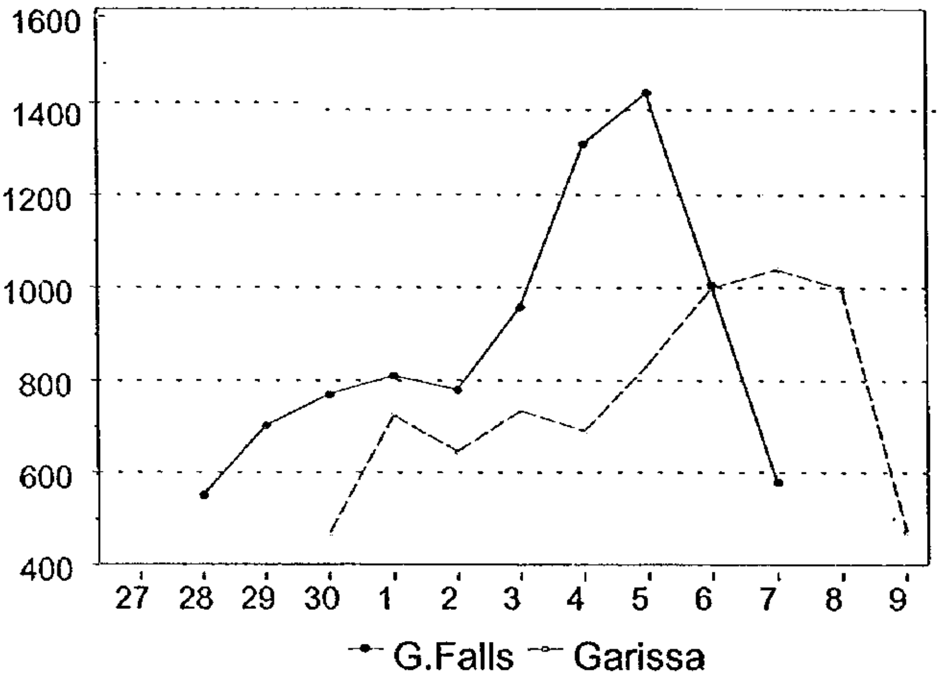
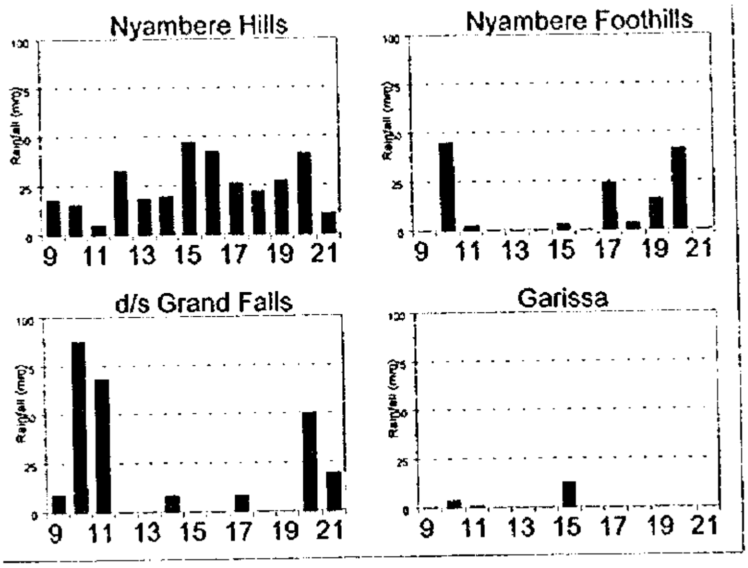


Figure 16-14 (Continued)

Typical Rainfall Pattern for Event Type C: (09/11/77 – 28/11/77)



Resulting Flows at Grand Falls and Garissa:

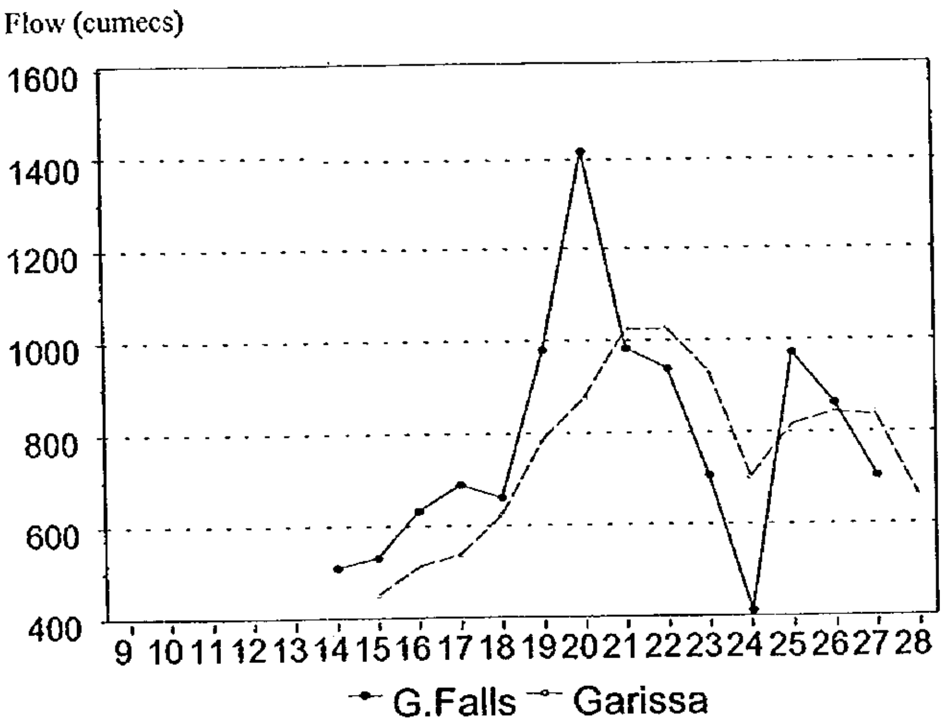
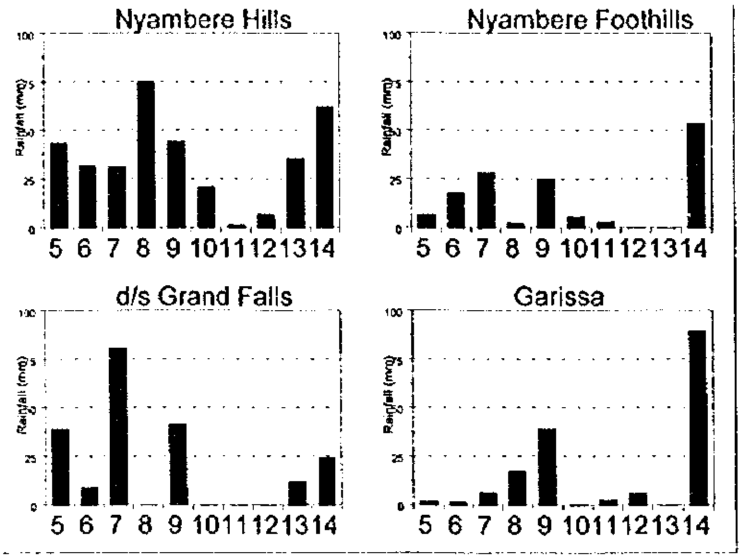
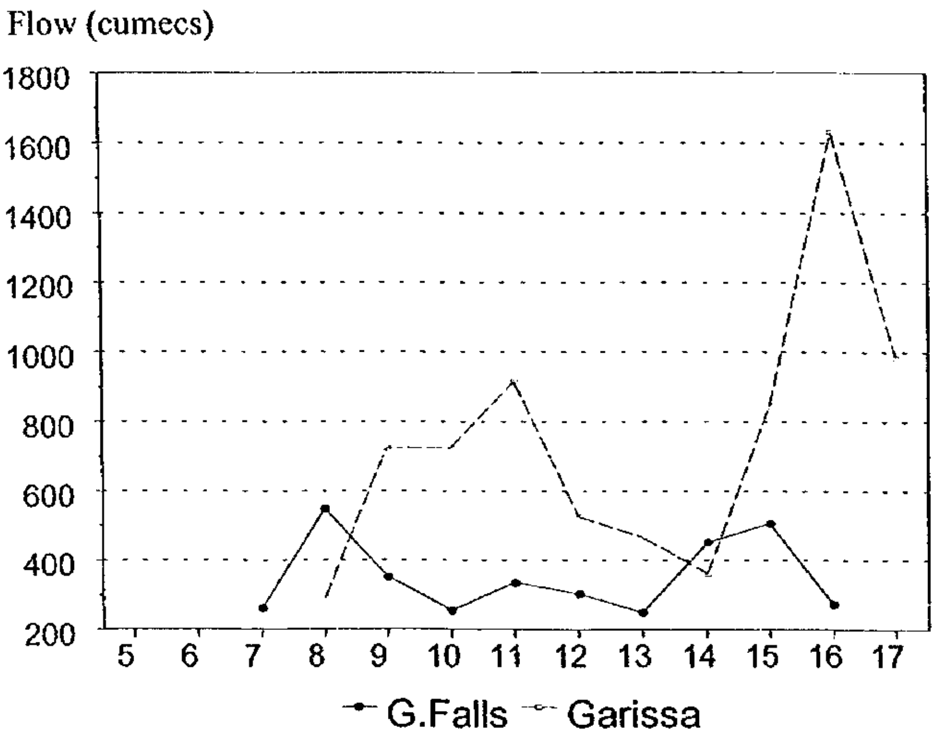


Figure 16-14 (Continued)

Typical Rainfall Pattern for Event Type D: (05/11/84 – 17/11/84)



Resulting Flows at Grand Falls and Garissa:



16.6 EXPLANATION OF FLOOD TYPES

The analysis of flood events described in above showed that the relationship between floods at Grand Falls and those at Garissa is not constant but varies in one of four ways. During type A events the flood attenuates as it moves downstream having a lower peak and total volume at Garissa than at Grand Falls. These floods might be thought of as "classical" events. In contrast, the flood hydrograph appears to undergo little attenuation as it moves downstream during type C floods. The pattern of flooding during type D events is the reverse of that during type A events with higher flood peaks and volumes at Garissa than at Grand Falls. Type B events, during which massive attenuation occurs between Grand Falls and Garissa, were excluded from detailed analysis as they do not appear to be a current feature of the flood regime of the river. The validity of these type B events is also somewhat uncertain.

The rainfall analysis described in 16.5 identified variations in the pattern of rainfall corresponding with each of event types A, C and D. These differences in rainfall are important in determining the additional runoff to the Tana between Grand Falls and Garissa and so directly influence not only the change in the characteristics of a flood as it moves downstream between the two sites, but also in consequence the volume of flood release which would be required from Grand Falls dam. Figure 16-15 illustrates these differences.

During a type A event heavy rainfall falls on the Nyambene Hills, the highest land in the Tana catchment downstream of Grand Falls. Rainfall on the lower slopes of these Hills and in the Tana valley downstream of Grand Falls is relatively insignificant. Runoff from the Nyambene Hills is carried to the Tana via several tributaries, most of which appear to be ephemeral laghas, such as the Ura and the Rojewero. As flow down the tributaries is not supported by further rainfall at lower elevations transmission losses are relatively large and the inflow to the Tana is greatly diminished. With relatively low inflow from its tributaries the flood flow in the Tana attenuates as it travels downstream to Garissa.

The pattern of rainfall during a type C or D event differs from that during a type A event. Rainfall is distributed over a wider area of the catchment with significant amounts falling on the foothills of the Nyambene Hills and in the Tana valley. The wider distribution of rainfall means that, although still heaviest on the Nyambene Hills themselves, rainfall intensities here are lower than during the more concentrated type A rainfall. With a greater area of the catchment contributing runoff losses from tributary inflows are proportionately less than in type A events (as mean travel time from the runoff source to inflow into the main river is reduced). The runoff from these areas of the catchment therefore represents an important component of total flow in the Tana and offsets the transmission losses and evapotranspiration occurring between Grand Falls and Garissa. The difference between type C and D events appears to be one of scale. During type C events losses from the Tana are balanced by tributary inflows whilst during type D events the inflows are significantly greater than the losses. During some type D flood events it is also likely that local heavy rainfall at Garissa and in the river stretch upstream can further supplement flow in the Tana with the result that fairly minor events at Grand Falls become much more significant at Garissa.

According to this explanation the critical factor influencing the characteristics of flooding on the lower Tana is the pattern of rainfall in the top end of the catchment downstream of Grand Falls. Inflow from laghas further downstream towards Garissa is assumed to play a less significant role. This assertion is supported by two pieces of evidence. The first is the map of mean annual rainfall in the catchment (see Figure 16-16). This clearly shows the Nyambene Hills and the surrounding areas to be the most important areas of rainfall, and hence runoff generation, in the lower Tana catchment. Mean annual rainfall is at a maximum of over 2,400 mm on the Nyambene Hills and decreases through a steep rainfall gradient to around 600 mm on the lower foothills and in the Tana valley downstream of Grand Falls. Mean annual rainfall further downstream towards Garissa falls below 300 mm.

The second piece of evidence relates to the pattern of flooding downstream of Garissa. The analysis of flooding at Nanigi and Garsen, described in above, found a consistent attenuation of floods in the lower reaches of the Tana. This pattern of attenuation occurs irrespective of whether the relationship between flooding at Grand Falls and Garissa is of type A, C or D. In general it appears that inflow from laghas in these reaches of the river is not significant in relation to variations in runoff generation in the top end of the lower Tana catchment.

Figure 16-15 Effects of variation in rainfall distribution on patterns of flooding

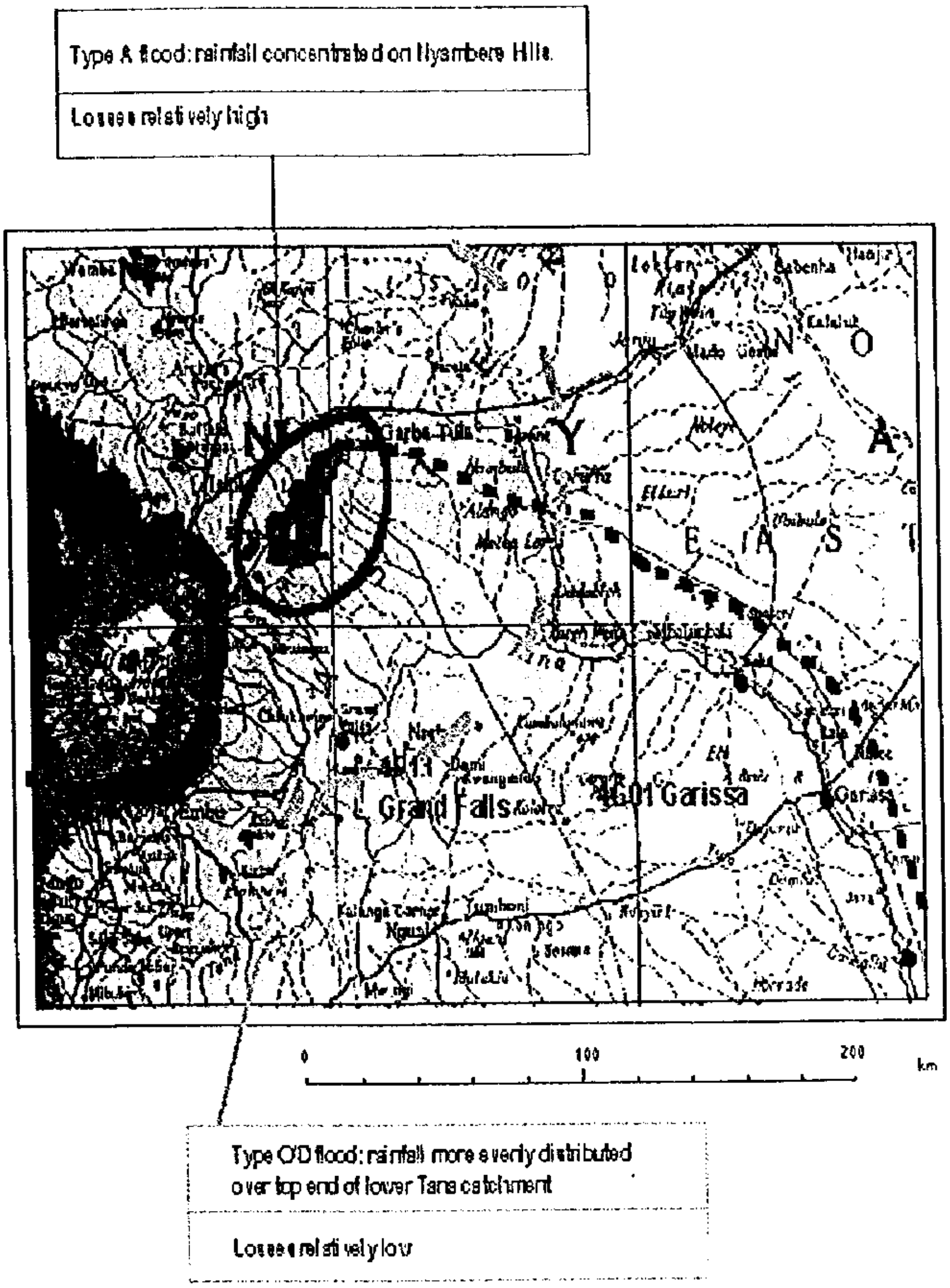
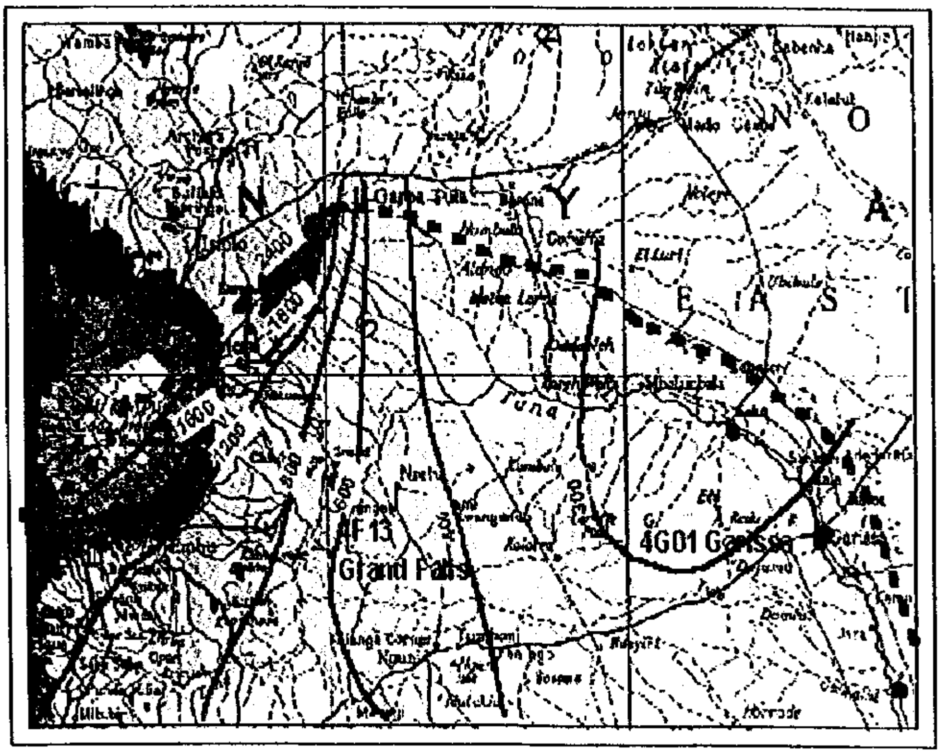


Figure 16-16 Mean Annual Rainfall in the Tana Catchment between the Nyambene Hills and Garissa.



Source: Nippon Koei (1995a)

0 100 200 km

16.7 DOWNSTREAM RIVER MORPHOLOGY

16.7.1 Description of Numerical Model

The numerical model used in this study was Flumorph. This is a computational model developed by HR which will predict the long-term bed level changes in rivers as the result of engineering works.

16.7.2 Hydraulic Equations Used In The Model

The model is based on the St Venant flow equations together with sediment transport equations to determine the quantity of sediment in motion and a sediment continuity equation to determine the changes in bed level. The differential equations are solved in the numerical model using finite-difference approximations to the differential equations. The model is a time-stepping one, that is, on the basis of knowing the bed levels in the river at one time the model calculates the new bed level after a short time interval or timestep. By repeating this process it is possible to predict bed levels up to any time in the future.

16.7.3 Boundary Conditions Applied In The Model

In the model, the topography of the river is described by a number of cross-sections. The discharges in the river are described as boundary conditions. The discharge in the river is specified together with any tributary flows and also flow losses through evaporation or seepage. The sediment on the bed of the river is characterised by its size and specific gravity. At the downstream end of the model a flow boundary condition is applied. For this study as the effect of the reservoir was not expected to propagate as far as the Indian Ocean the model was truncated some 135 km from the sea. The downstream flow boundary condition that was applied was normal flow.

16.7.4 Time-Stepping Procedure

At each time-step the model calculates the velocity, depth and water surface slope at each cross-section. From this information and data on the sediment properties, the model calculates the quantity of sediment passing each cross-section during the timestep. By using a sediment continuity equation applied to adjacent cross-sections the change in bed level at each cross-section during the timestep is determined. The process is then repeated for the next timestep.

16.7.5 Sediment Transport Calculations

To calculate the sediment transport the Ackers and White sediment transport relations were used (Ackers and White 1973). In extensive tests on a wide range of data these equations have been shown to provide satisfactory predictions of sediment transport rates (White, Milli and Crabbe 1973). They are applicable to the size of sediment found in the Tana River and are appropriate for the present study as they include a threshold of motion criterion in which for sufficiently low flows no sediment motion is assumed. Ackers and White recommend that to represent the size of the sediment the D35 sediment size is used, that is, the size which is exceeded 35% of the time. This is the size that was used in the numerical model.

16.8 MORPHOLOGICAL MODEL STUDIES: DATA

16.8.1 General Data Sources

To carry out this study data were collected from a number of sources. Delft Hydraulics carried out an extensive study of the morphology of the Tana River in the period from 1983 to 1986. This provided background information on the sediment processes in the Tana River. As part of the present studies Nippon Koei and the Institute of Hydrology, UK, studied different aspects of the hydrology of the catchment. Also as part of the present study, sediment measurements were obtained from the river in both dry and the wet seasons. These data have been reviewed as part of the present work and used in the study of the morphology as appropriate.

16.8.2 Hydrology

The hydrological data used consisted of a time series discharge data for 35 years at the dam site for three conditions:

a) existing conditions

b) conditions with the proposed reservoirs

c) conditions with the proposed reservoirs and with artificial flood releases downstream.

As part of their studies in 1983 to 1986, Delft Hydraulics (DH) investigated the variation of discharge along the river. By studying the stage records at Grand Falls, Saka, Garissa, Nanigi, Hola, Garsen and Ngao, and converting them into discharges using rating curves, DH were able to study the change in discharge along the Tana River. It was concluded that no significant change in discharge took place between Saka and Garissa. Downstream of Garissa, their study showed that the discharge in the river reduced significantly as one progressed down the river. This was attributed to seepage and evaporation losses. On the basis of their studies they proposed an equation to describe the spatial variation of discharge along the river. In the absence of any further data, this equation was used by the present study.

16.8.3 Topography

In the numerical model the topography of the river is described using cross-sections. DH, as part of their data collection exercise, measured cross-sections of the river approximately every 5 km. In the absence of any further topographic data these were used to describe the shape of the river. In all 95 cross-sections were used in the model.

16.8.4 Sediment data

In the numerical model the properties of the sediment in the river are described by the sediment size and specific gravity. During their data collection work, DH took and analysed sediment data from along the river. This showed variation from section to section but there was an overall trend for the sediment size to reduce in the downstream direction. To carry out the sediment transport calculations in the numerical model the Ackers and White sediment transport relationship was used. This is based on the sediment D35 size. On the basis of the DH data a D35 sediment size of 0.3 mm was selected to represent the sediment in the reach of the river immediately downstream of the proposed Lower Grand Falls dam.

16.8.5 Sediment Yield

To determine the morphology of the river it is important to specify the sediment that is entering the reach under consideration from the upstream end. The quantity of sediment entering the reach was estimated by,

a) on the basis of previous HR experience, assessing the sediment yield from the catchment upstream ,

b) carrying out sediment transport calculations using flow characteristics from the upstream sections.

On the basis of this an upstream incoming sediment load of 2.5 million tonnes of sediment per year was assumed. This is comparable with sediment yields determined from the sediment information that was derived from the data for Garissa gauging station. These data showed annual sediment yields which varied significantly from year to year within the range 0.2 to 36 million tonnes. This latter data included wash load whereas the figure used as input to the numerical model excluded wash load, being limited to bed material load.

To investigate that impact of diverting sediment from the Kathita catchment around the reservoir to the river downstream, it was necessary to estimate the amount of sediment coming from the catchment of the Kathita. It was assumed that the sediment yield of the Kathita was similar to that of the rest of the catchment. If this option is to be pursued then it is recommended that further work is carried out to confirm this assumption.

16.8.6 Numerical Model Calibration

The numerical model was run to simulate existing conditions. The assumption was that under existing conditions there is little or no morphological change. The model was run with the existing river bed levels as initial conditions. The flow sequence used was derived from the flow records for the last 34 years. The incoming sediment load corresponded to that from the present upstream catchment. During the calibration process the incoming sediment load was adjusted.

Figure 16-17 shows a longitudinal bed profile of the initial conditions and the predicted bed level after 34 years. Comparison of the two profiles indicates that the model predicts little or no bed level change during this period. This is consistent with our knowledge of the present situation.

16.9 MORPHOLOGICAL MODEL PREDICTIONS

16.9.1 Lower Grand Falls and Mutonga Dam

The impact of Low Grand Falls Dam on the river downstream is twofold. The presence of the storage modifies the flows in the river downstream, while the reservoir also traps a significant proportion of the sediment load and so modifies the quantity of sediment that is passed downstream. These effects are represented in the model by modifying the two boundary conditions describing the flow and the incoming sediment load.

A simulation exercise was carried out of flows with the presence of the reservoir (see Main Report, Volume 1) This estimates a 34 year sequence of daily flows with the assumption of the reservoir in place. A new flow exceedance curve was derived from these daily flows. From the parameters of the proposed reservoir an overall trapping efficiency of the reservoir was estimated. This indicated that the reservoir would trap approximately 94% of the incoming sediment load. To simulate the impact of the reservoir on sediment input to the reach, therefore, the incoming sediment load was reduced by 94%. The model was then used to simulate the morphological development of the river for 34 years after the dam is constructed.

The impact of the reservoir is to reduce bed levels in the river downstream. This reduction would normally start at the dam itself and progress downstream. Immediately downstream of the dam the river is constrained by the local geology and therefore degradation will not take place in this location. Downstream of Kora Rapids, however, the river enters the alluvium and it will then have the potential to degrade the river bed.

Figure 16-18 compares the initial bed levels with those predicted after 34 years with the dam in place. The chainage shown in the figure is restricted to the upper part of the river as no significant change has taken place further downstream. Figure 16-19 shows the change in bed level over the 34 year period as a function of chainage. The figure shows that the largest amount of degradation will occur immediately downstream of Kora Rapids and then will reduce in the downstream direction. After 34 years the reduction in bed levels immediately downstream of the Rapids will be approximately 11m. For locations further downstream there will be a delay in the onset of degradation but then the bed will begin to degrade. As one progresses downstream the delay in the onset of degradation will increase and the absolute magnitude of the degradation after 34 years will reduce.

The reduction in bed levels will also influence water levels. Figures 16-20 and 16-21 show longitudinal profiles of water levels for discharges of 750 and 90 cumecs, respectively, while Figure 16-22 shows the change in water level as a result of the reservoir as a function of chainage. The results show that after 34 years there will be a reduction in water levels immediately downstream of Kora Rapids of approximately 11m. This will reduce as one progresses downstream. After 34 years the impact on water levels extends approximately 40 km downstream from the Rapids.

The material removed from the area downstream of Kora Rapids will in the short term be deposited further downstream. These materials will gradually move downstream until a new equilibrium is established. Within the time span analysed by the numerical model, 34 years, deposition of sediment removed from the area downstream of Kora Rapids will initially be deposited further downstream in the lower Tana, resulting in probable increases in bed levels. This is indicated by Figures 16-18 and 16-19.

16.9.2 Impact of Artificial Flood Releases

This feasibility study includes a proposal to use artificial flood releases from the reservoir to mitigate some of the environmental impacts resulting from the reservoir and thereby to help maintain the flood plain environment. This would involve a different pattern of discharges released from the dam. The morphological impact of this different pattern of reservoir releases was also investigated with the numerical model. A 34 years simulated time series of releases from the reservoir was used (see Main Report, Volume 1). These data were analysed to provide corresponding flow exceedance data which was then used in the numerical model to make predictions.

Figure 16-23 shows a longitudinal profile of initial bed levels and predicted bed levels after 34 years. It can be seen that the impact of the flood releases does not have a major effect on the pattern of morphological change. The amount and extent of degradation is very similar to that shown in Figure 16-18. Figure 16-24 shows the change in bed level against chainage. The pattern is similar to that in Figure 16-19. Approximately 11m of degradation occurs immediately downstream of Kora Rapids and the degradation extends for approximately 40 km downstream. Figures 16-25 and 16-26 show the water levels corresponding to discharges of 750 and 90 cumecs respectively. The change in water levels as a result of the reservoir are shown in Figure 16-27.

16.9.3 Diversion of Sediment Load from Kathita Catchment

It has been proposed that to reduce the morphological impact of the proposed the reservoir, sediment from the Kathita catchment that might otherwise enter the reservoir could potentially be diverted around the reservoir to enter the river downstream. The morphological impact of this option was investigated using the numerical model. To represent the diversion of the sediment from the Kathita catchment an estimate was made of the sediment load presently coming from the catchment. This sediment load was added to that estimated to be discharged from the dam following its construction. The model was then re-run with this modified sediment load.

Figure 16-28 shows a longitudinal profile showing the initial bed levels and the bed levels after 34 years, while Figure 16-29 shows the change in bed level as a function of chainage. It can be seen that the impact of diverting the sediment from the Kathita is to reduce the amount of degradation from approximately 11m to approximately 9m during this period. There is a corresponding impact on water levels which is shown in Figures 16-30, 16-31 and 16-32.

It should be noted that the feasibility of and engineering works required to divert the sediment load were not considered. If it is considered worth pursuing this option further then these aspects would have to be considered in some detail. This would require detailed information on channel size, bed levels and sediment sizes in the lower part of the Kathita and the topographic relationship of the Kathita to the reservoir and the river downstream.

16.10 DOWNSTREAM RIVER BED DEGRADATION

The Tana river in the reach downstream of the proposed reservoir presently carries a significant sediment load. The impact of the dam will be to significantly reduce the sediment input to the river immediately downstream of the reservoir. In many situations the sediment in rivers contains a wide range of sediment sizes and it is then described as graded. In such situations the presence of a large range of sediment sizes acts to inhibit degradation. The finer sediment is preferentially removed and the bed of the river is covered with the larger sizes of sediment. As these are more difficult to move than the finer sediment, the degradation is reduced.

The Tana situation is different. The sediment in the Tana River is relatively uniform and so there is no similar mechanism to inhibit degradation. The result of the large reduction in sediment load and the uniformity of the sediment is that a large amount of degradation will take place. This will take place over a long time period and will eventually affect a significant length of the river downstream of Kora Rapids.

The large predicted reduction in bed level downstream of Kora Rapids will have an effect on water levels, as demonstrated in Figures 16-22 and 16-27. It will also affect the conveyance of the channel and hence bankfull flows. It is expected that as the bed level reduces, the discharge required to give bankfull flow will increase. This will also affect the frequency and severity of overbank flooding. It is expected that flooding onto the floodplain will occur less frequently and that, when it does occur, the depth of flooding will also be less. This will have a significant impact on those aspects of the environment that rely on flooding on the floodplain. It is also expected that as the water levels in the channel reduce, the surrounding groundwater levels will reduce. This will also have an impact on those aspects of the environment that rely on groundwater.

The numerical model predictions are based on the assumption that the overall shape of the channel cross-sections remains approximately constant. In the reach immediately downstream of Kora Rapids, however, the numerical model predicts reductions in bed level up to 11m. It is unlikely that the present river banks will be able to withstand such a large reduction in bed level. The reduced bed level will therefore have a number of effects. It will tend to de-stabilise the banks of the river. This will lead to changes in the shape of the channel cross-sections. It will also lead to the injection of sediment into the river from the banks. This effect is not represented in the numerical model and will tend to slow the actual morphological change in comparison with the rate of change predicted in the model. It will not affect, however, the final equilibrium that will be achieved, only the time taken to achieve it.

The plan form of a river depends upon the balance between the equilibrium slope of the river, as determined by the flow and sediment characteristics, and the valley slope, as determined by the topography of the land (Bettess & White 1983). The impact of the dam will be to alter the sediment load in the river. This will affect the equilibrium slope of the river, hence resulting in the reduction in bed levels discussed above. A further impact of this change in the equilibrium conditions will be on the plan form of the river. The reduction in equilibrium slope will reduce the discrepancy between the equilibrium slope and the valley slope. The impact will be that in those reaches were the river presently has a braided character, the degree of braiding will reduce and the river may become meandering in character. In those reaches were the river is already meandering, the sinuosity of the river will reduce. This change in plan form could have a significant impact on any infrastructure associated with the river or river banks.

Figure 16-17 Longitudinal Profile, Existing Conditions: Calibration.
(Tana River without dam, 34 years)

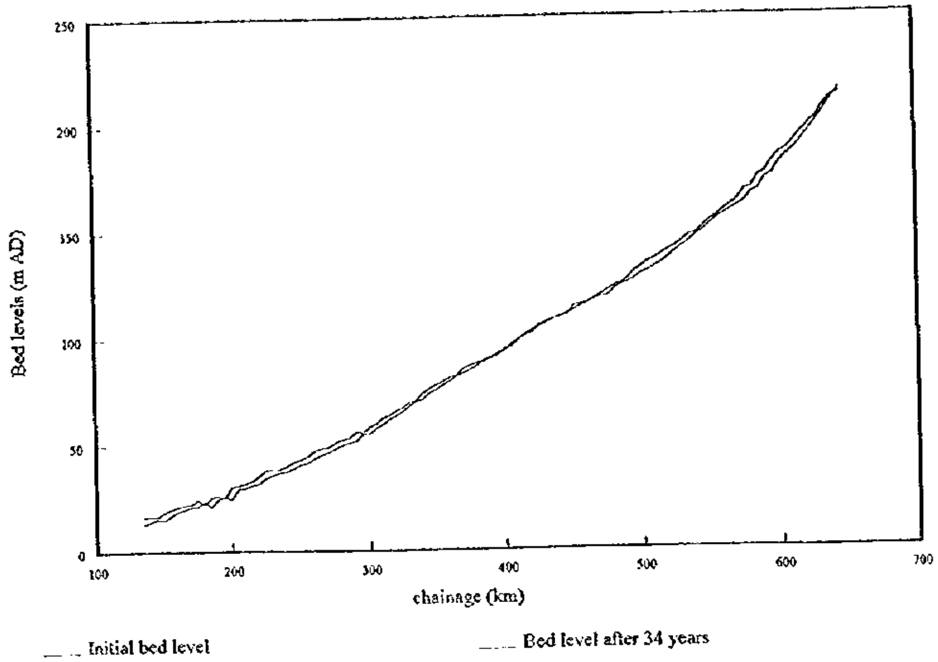


Figure 16-18 Longitudinal Profile of Bed Levels with Dam
(Tana River, Low Grand Falls dam, Normal Flow, 34 years)

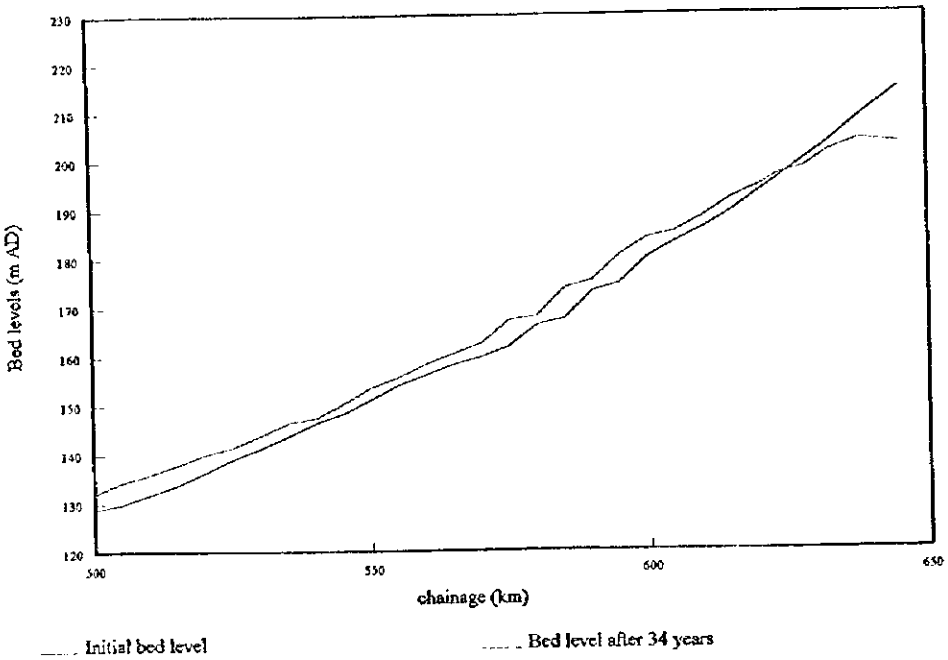


Figure 16-19 delta z against chainage with dam
(Tana River, Low Grand Falls dam, Normal Flow, 34 years)

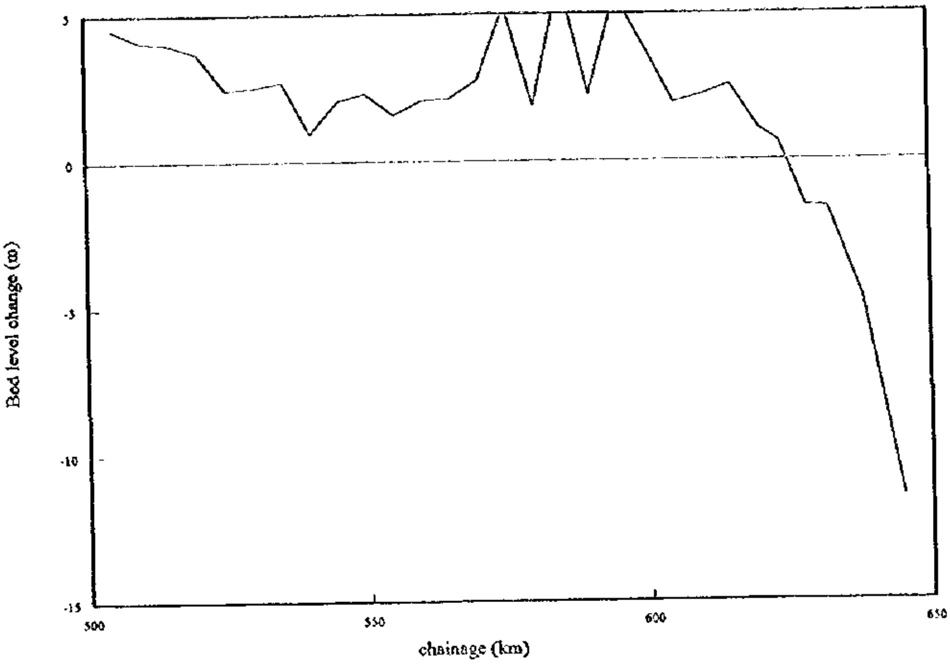


Figure 16-20 Water level against chainage Q=750 cumecs
(Tana River, Low Grand Falls dam, Normal Flow, 34 years)

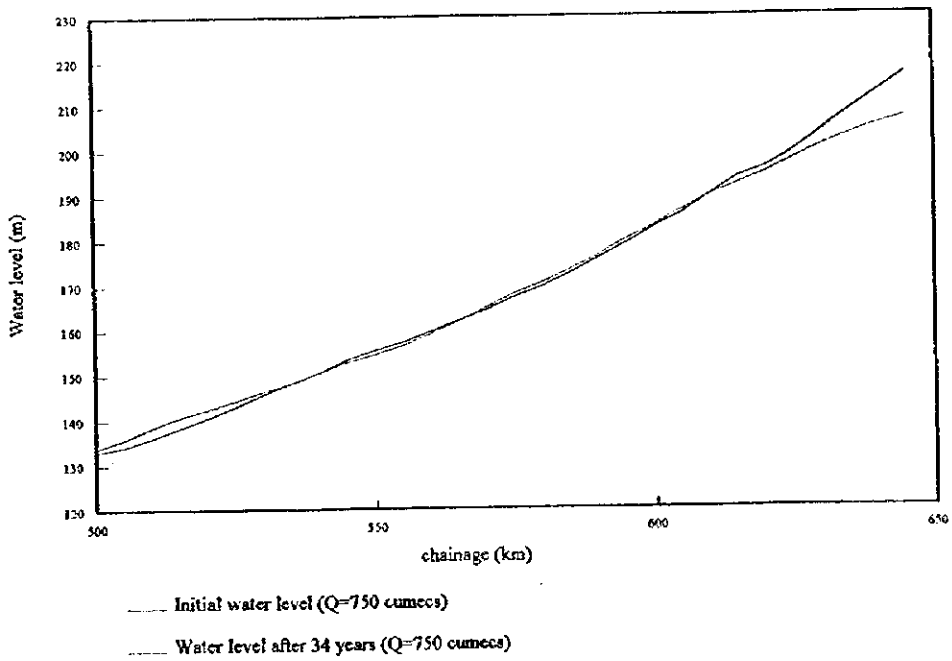


Figure 16-21 Water level against chainage Q= 90 cumecs
(Tana River, Low Grand Falls dam, Normal Flow, 34 years)

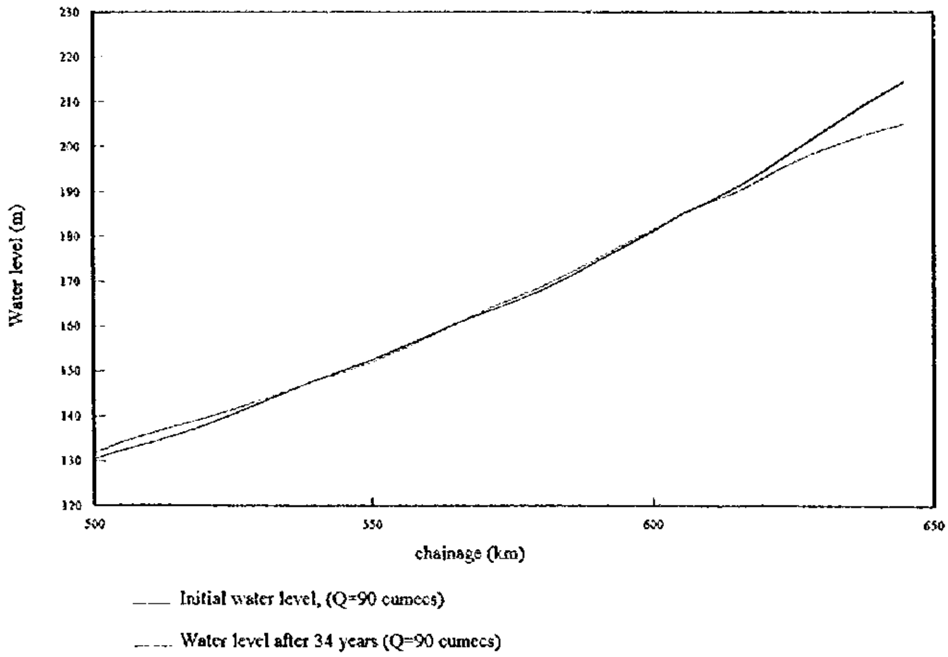


Figure 16-22 Change in water level as a function of chainage
(Tana River, Low Grand Falls dam, Normal Flow, 34 years)

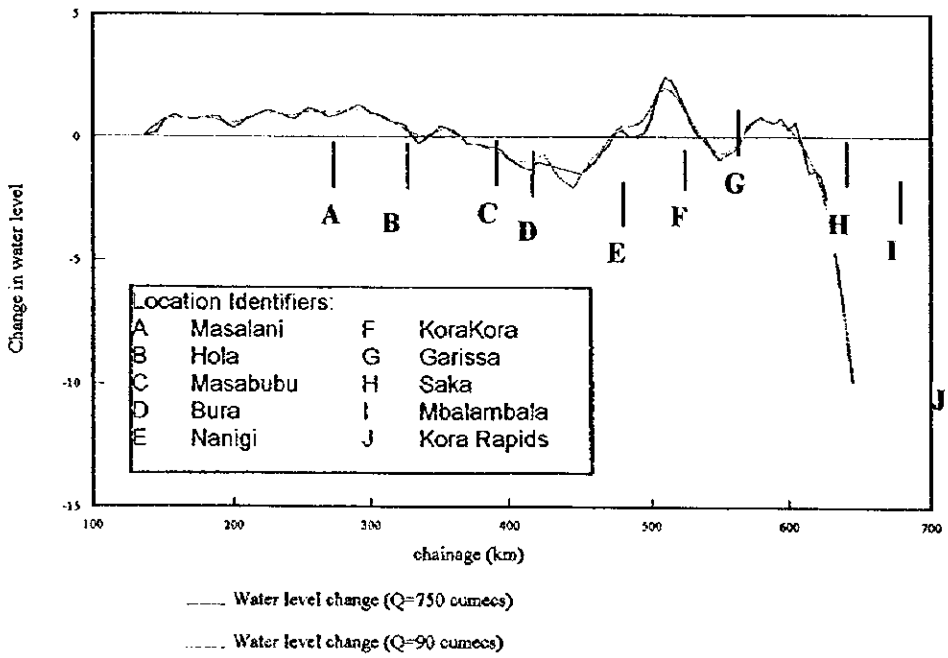


Figure 16-23 Longitudinal profile of bed levels , flood flows
(Tana River, Low Grand Falls dam, "Flood" Flow, 34 years)

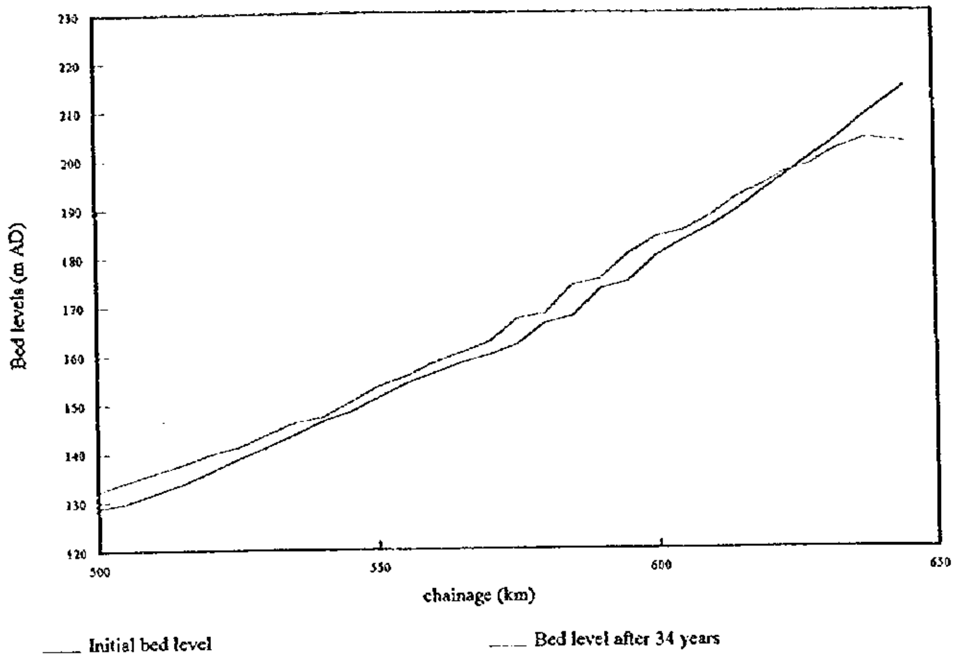


Figure 16-24 Bed level change, flood flows
(Tana River, Low Grand Falls dam, "Flood" Flow, 34 years)

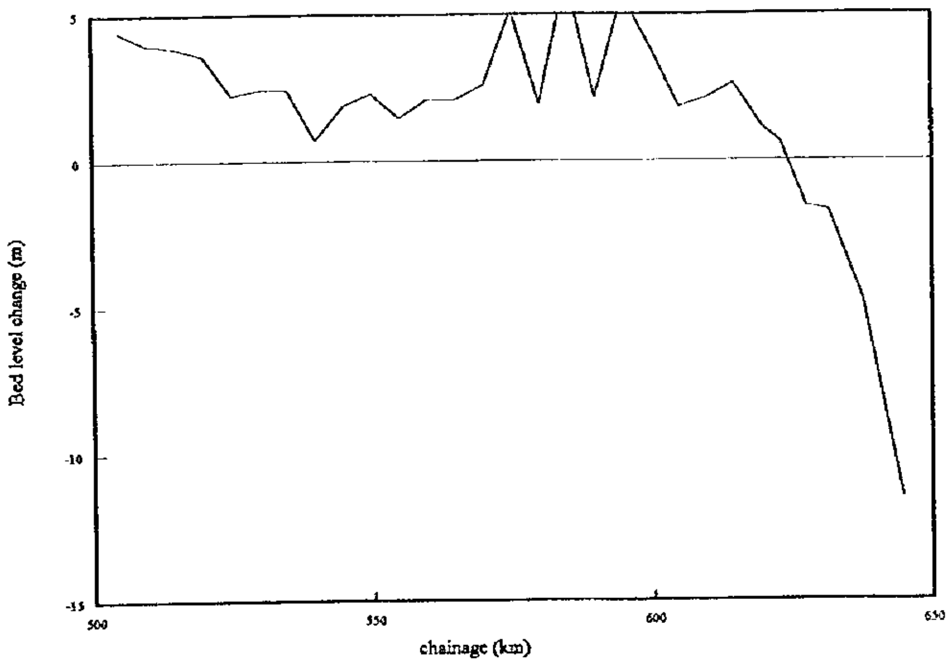


Figure 16-25 Water levels Q=750, flood flows
(Tana River, Low Grand Falls dam, "Flood" Flow, 34 years)

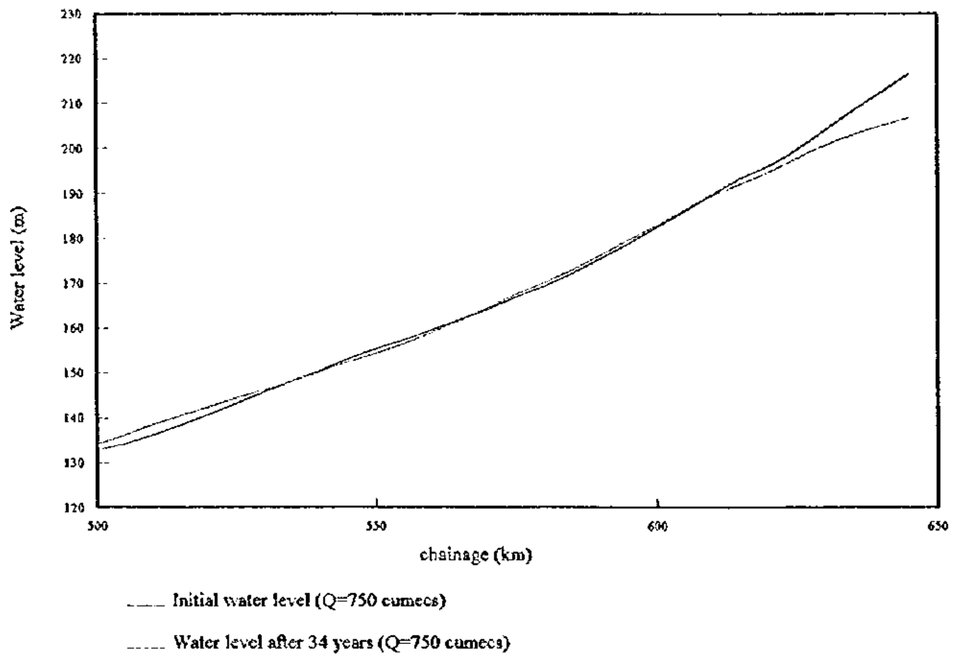


Figure 16-26 Water levels Q=90, flood flows
(Tana River, Low Grand Falls dam, "Flood" Flow, 34 years)

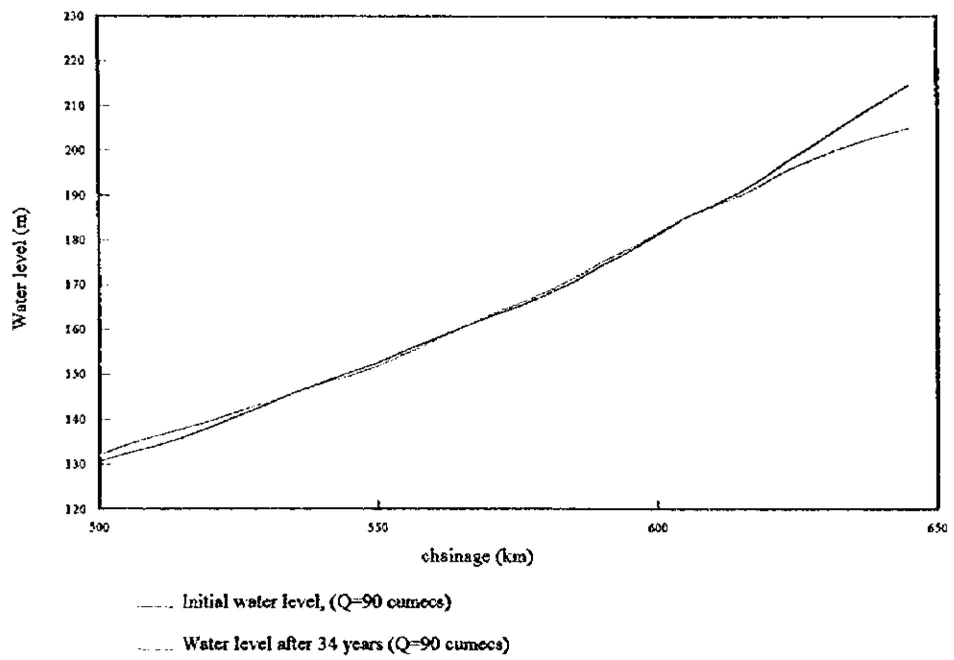


Figure 16-27 Change in water levels as a function of chainage, flood flows (Tana River, Low Grand Falls dam, "Flood" Flow, 34 years)

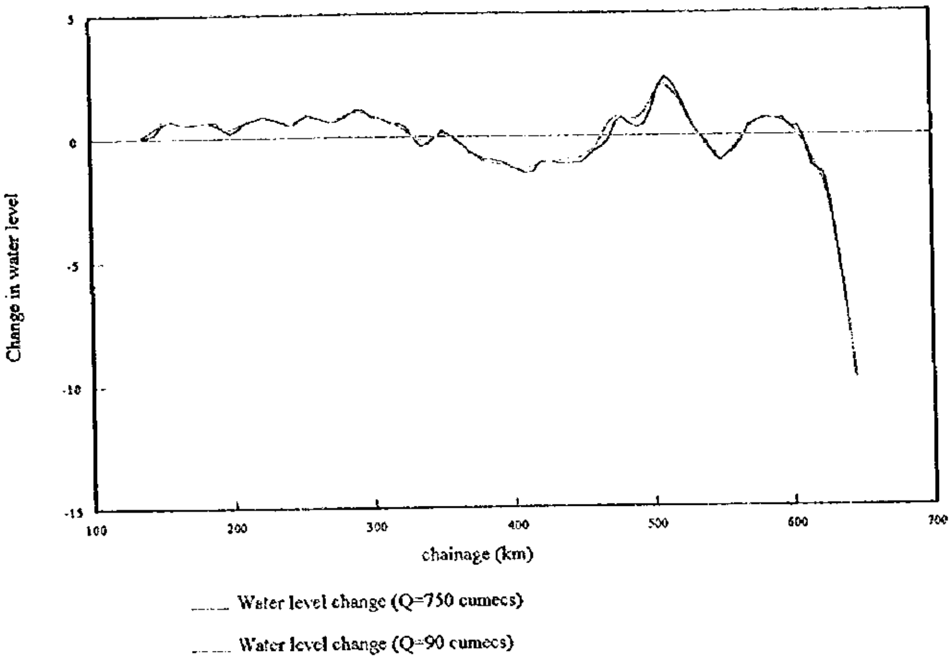


Figure 16-28 Longitudinal profile of bed levels, Kathita sediment (Tana River, Low Grand Falls dam, 34 years)

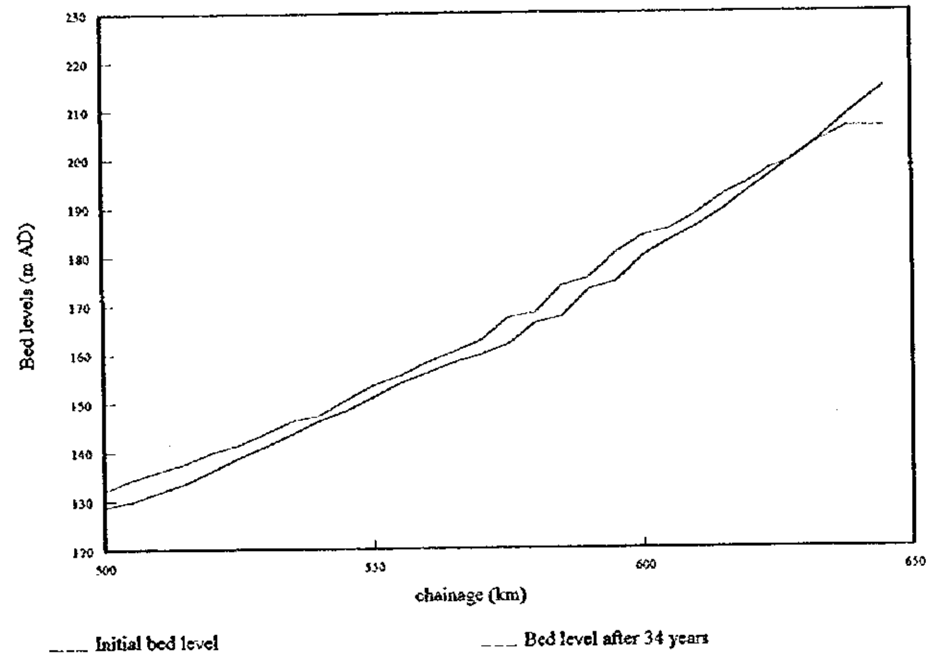


Figure 16-29 Bed level change, Kathita sediment
(Tana River, Low Grand Falls dam, 34 years)

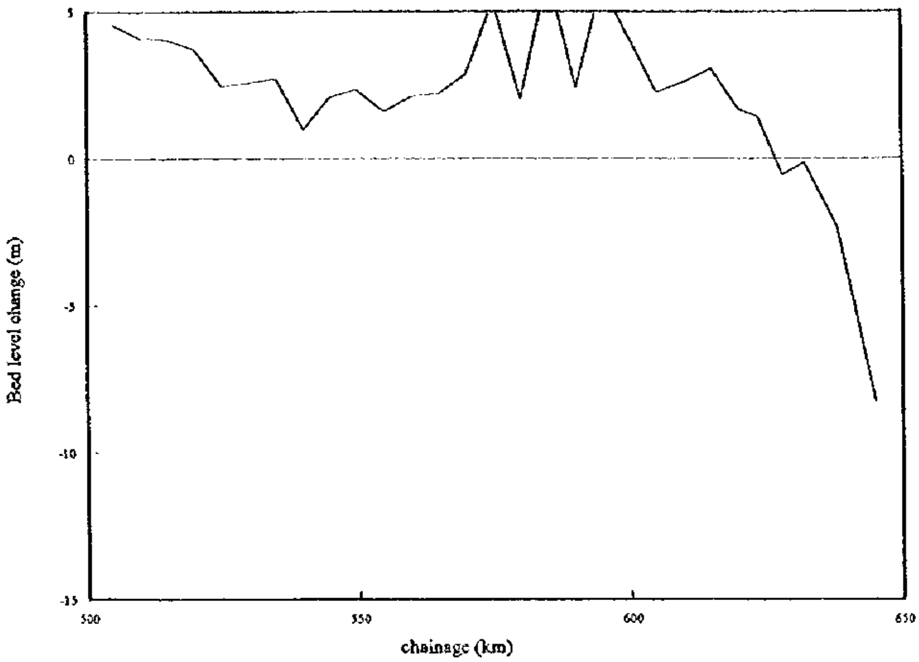


Figure 16-30 Water level against chainage, Q=750 cumecs, Kathita sediment
(Tana River, Low Grand Falls dam, Normal Flow, 34 years)

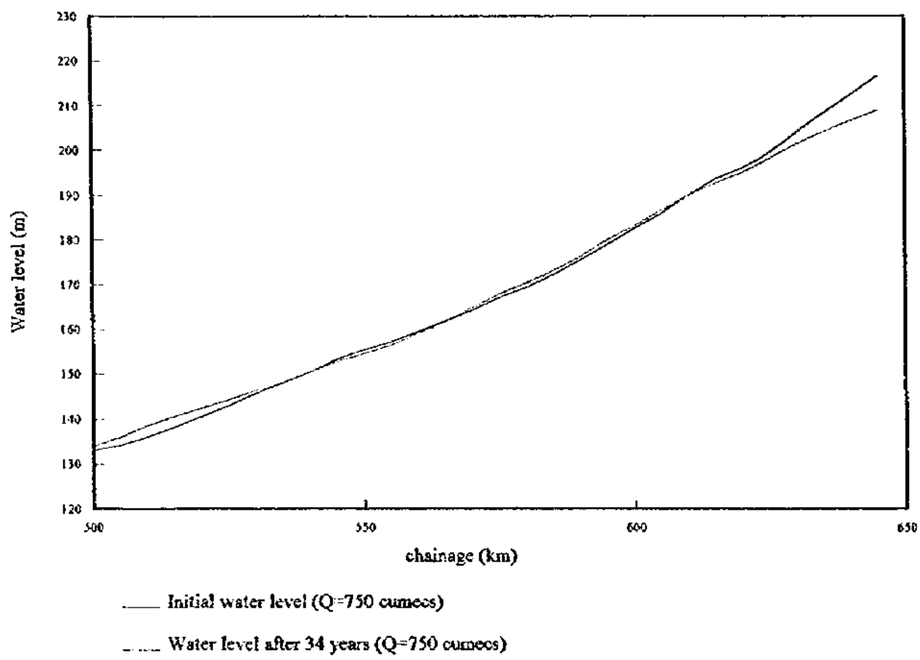


Figure 16-31 Water level against chainage, Q=90 cumecs, Kathita sediment (Tana River, Low Grand Falls dam, Normal Flow, 34 years)

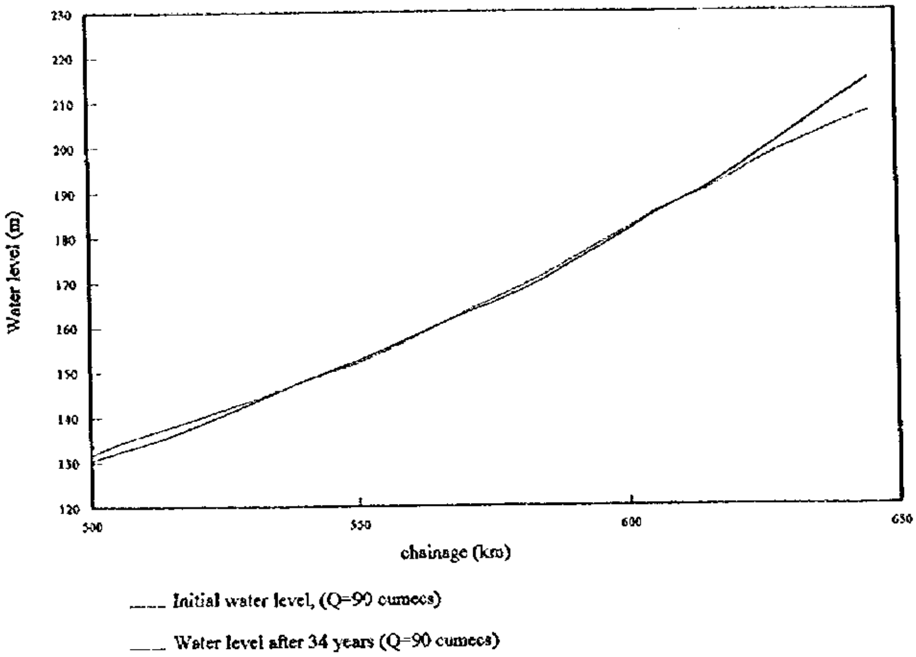
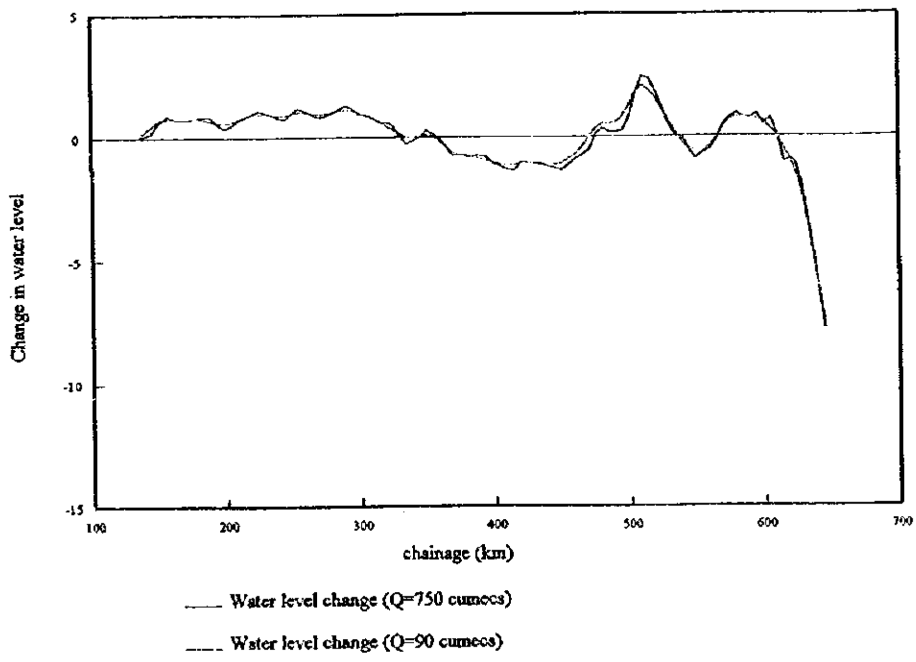


Figure 16-32 Change in water level against chainage, Kathita sediment (Tana River, Low Grand Falls dam, Normal Flow, 34 years)

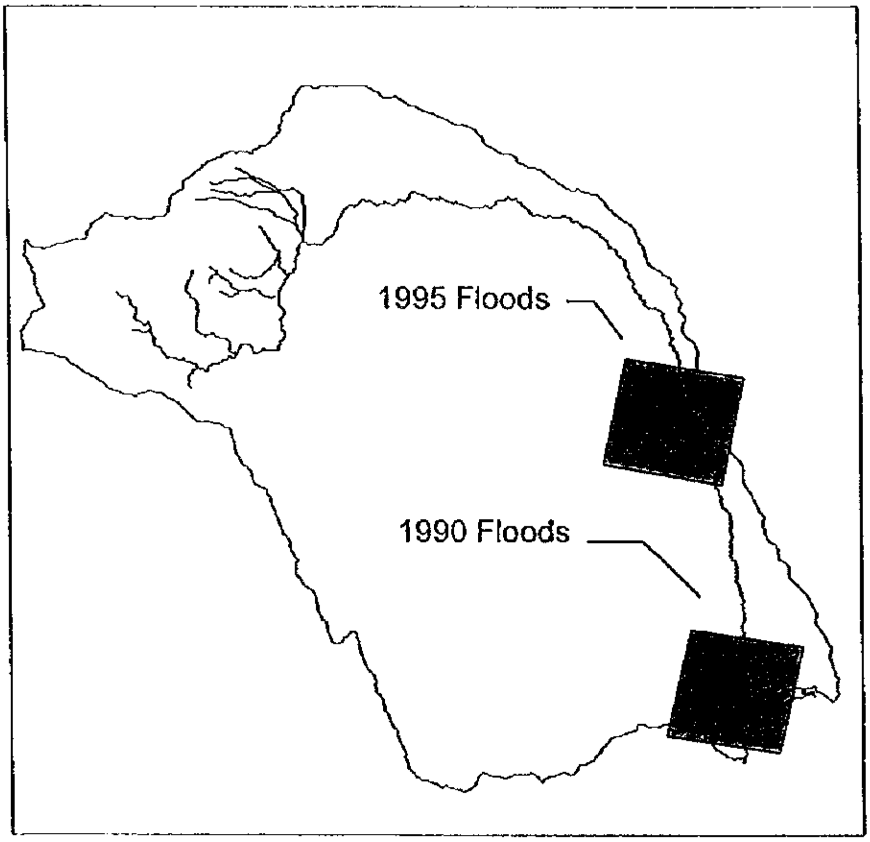


16.11 FLOOD MAPPING FROM REMOTELY SENSED IMAGERY

16.11.1 Data Sources and Methodology

The objective of this task was to contribute to the assessment of "normal" flooding conditions, and to improve understanding of the relationship between flow rates during flood events and the consequent spatial extent of flooding. An extensive search was made for suitable high resolution satellite imagery from available archives that covered sections of the Tana River floodplain during potential flood events. Due to the relatively poor temporal coverage of much of Kenya by the two high resolution satellites, Landsat TM and SPOT, only a small number of possible images were identified. Two SPOT images were selected which either coincided with or showed the aftermath of flood events: one covering the delta region and dating from 9 May 1990, the other covering the mid-floodplain and acquired on 6 May 1995 (see Figure 16-33). No suitable Landsat imagery was identified during a search through the available image archives (i.e. the available Landsat imagery did not coincide with flooding periods).

Figure 16-33 Map of the Tana Basin showing the locations and extent of the available high resolution satellite image data (SPOT) analysed for flooding.

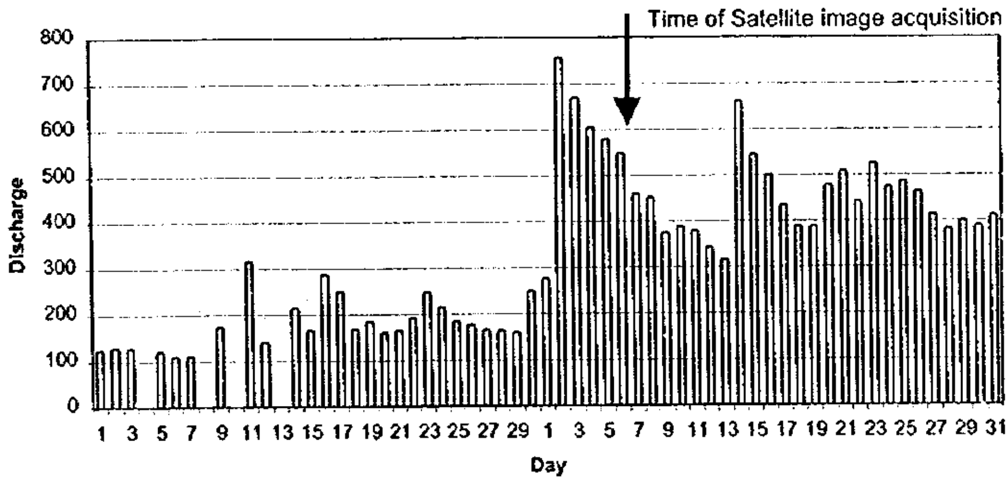


The images were geometrically corrected to the Universal Transverse Mercator projection using topographic maps at a scale of 1:50 000. Initial visual inspection of the images revealed that both were affected by cloud and cloud-shadow. It was decided not to apply an algorithm to automatically detect these areas, since the spectral signature of shadow is, under some circumstances, easily confused with that of open water. Therefore, areas of cloud and cloud-shadow contamination were eliminated manually. Both images had approximately 27% cloud cover within those parts of the images analysed.

Both images required the flood-inundated areas to be identified together with a surface cover of vegetation and bare soil / wet mud. The mid-infrared bands of the Landsat TM sensor are particularly useful for this purpose but, as mentioned above, no suitable Landsat imagery was available. Therefore, the near-infrared Band 3 of the SPOT sensor was used. Wet soils and water-stressed vegetation showed reduced infrared reflectance which was evident through visual inspection of the digital imagery (through on-screen visual inspection of enhanced imagery). In the delta scene in particular (1990 image), some uncertainty was caused by tall vegetation which perhaps obscured flooded ground, but decreased infrared reflectance made the flooded area distinct in clear areas and in areas of lower vegetation.

In the mid-floodplain (1995 image), interpretation concentrated on the narrow floodplain areas adjacent to the river and areas of the hinterland that were also affected by water, while a major portion of the 1990 delta scene was interpreted (i.e. that portion covering the delta). Visual interpretation (including detailed on-screen digitising) was carried out using band 3, with additional confirmation using bands 1 and 2. The resulting products were maps of flood-affected areas in vector format. The map of the delta contained three categories to indicate that areas were classified as flood-affected with varying levels of confidence.

Figure 16-34 Average Daily Discharge: 4G1, Garissa - April-May 1995



Due to the relatively long time interval between successive orbital passes of the SPOT satellite, there is a chance of obtaining images during flood periods but less chance that these images will coincide with the peak of individual floods. In practice, both images were acquired reasonably close to optimum times, following the peaks of the respective flood events.

Discharge data for Garissa (4G01) were obtained from MOWD for the periods covered by the two flood images. These data are shown by Figures 16-34 and 16-37. Discharge data from floodplain stations other than Garissa were unavailable over the periods coinciding with the two satellite images.

16.11.2 Flooding on the Tana River Floodplain: May 1995 satellite image

This image, from the Bura area (see Figure 16-36), is particularly important since the Garissa discharge is similar to that which might be expected from a controlled artificial flood release. Floods at Bura may comprise main Tana River discharges, discharges from intervening laghas, and overland flow. The flood affecting this image covered a large part of the Tana River floodplain (86%, see Table 16-7) adjacent to the main river channel.

Whilst no discharge data were available from the Bura area, average travel times for floods to travel from Garissa to Bura are in the region of one to three days. A small flood such as this one is likely to have a relatively fast travel time and accordingly, a travel time of one to 1.5 days was assumed. This results in three days of Garissa flooding[1] before the satellite acquisition. Discharge data are given in Table A16-8 in the Annex to Chapter 16, and using recorded AM and PM discharges the flooding identified on the satellite image represents a Garissa flood volume of between 175 and 200 million cubic metres.

Lagha flows also contribute to the flooding observed on the satellite image at 6 May 1995, although there was no means of estimating volume and thus the importance of this contribution. Lagha flow can be seen on Figure 16-36 by the obvious flooding of the two large laghas entering the main Tana River channel at Bura (Hirmani & Walesa Tokochla laghas). The two laghas immediately to the north of these show no evidence of flooding. Between Garissa and Bura there are three further laghas, two of which are small and one relatively large (see Figure 16-35). Of these, only the larger lagha was considered as a possible candidate for contributing additional flood volume. However, in the absence of rainfall data from this catchment or, alternatively, detailed discharge measurements from stations between Garissa to Bura (inclusive), there was no means of confirming whether or not the flood observed at Bura included flows from this lagha or not.

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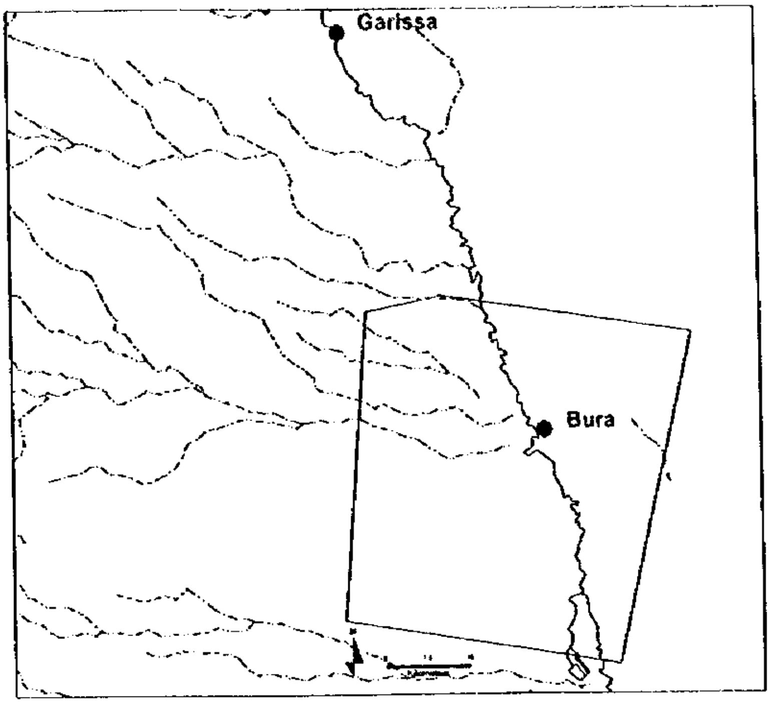
[1] Discharge at Garissa (4G01) greater than 500 m^3/sec.

Figure 16-35 Main Tana River channel and laghas between Garissa and Bura, with outline of the area covered by the satellite image, 6 May 1995.



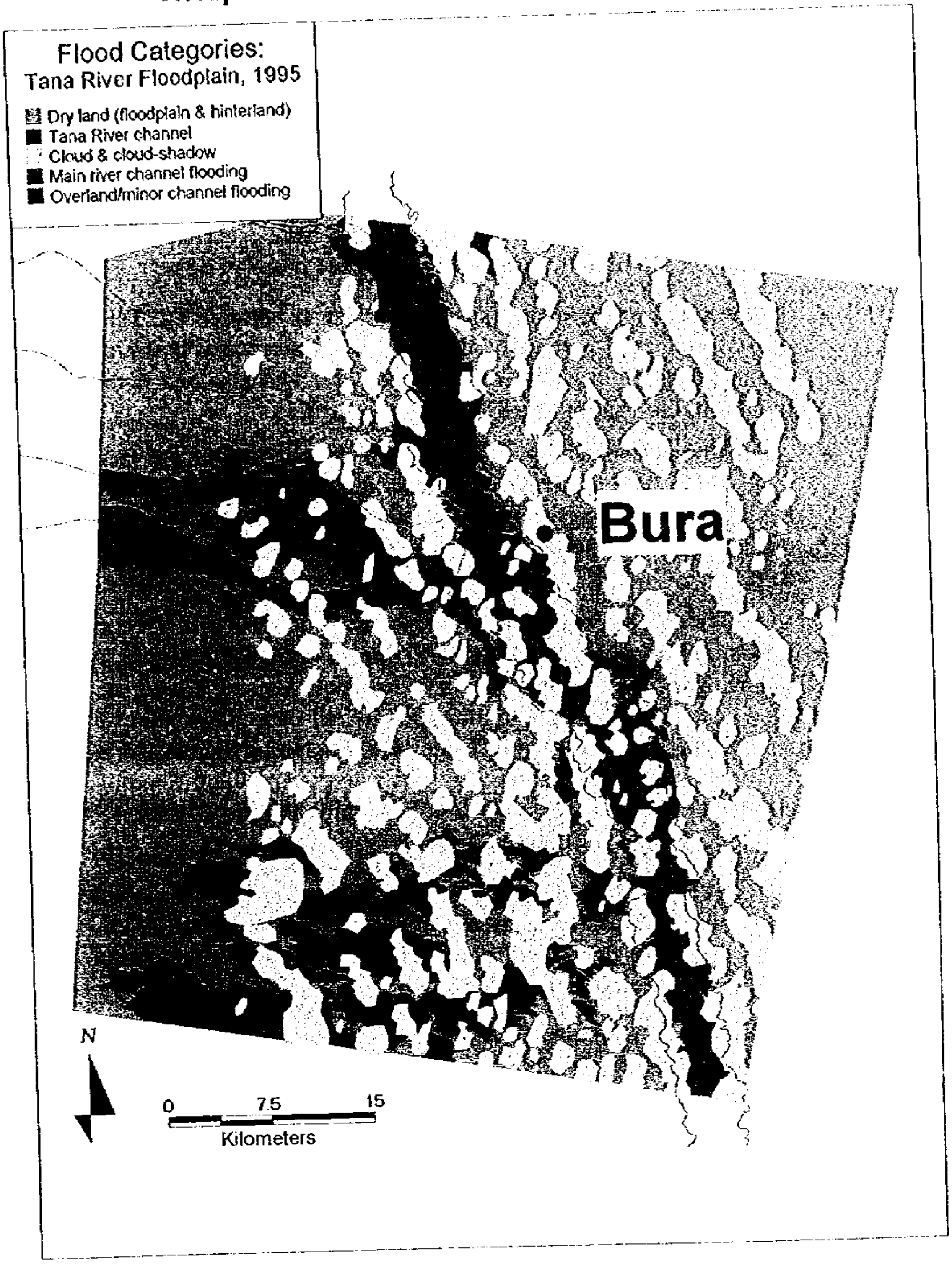
Overland flow, resulting from more localised rainfall, is also a feature observed on the May 1995 image. This can be seen in the south-western part of the image (Figure 16-36) and was identified as relatively shallow flooding (also including wet ground) that was not associated with any main drainage channel. It also appears from this image that, at the time of the satellite overpass, this flow had not joined with the main Tana River channel, although this may have occurred after the satellite overpass.

Areas of flooding are indicated by Table 16-7 which lists the land cover of each of the flood categories identified for the full scene, as shown by Figure 16-36. The main river channel, indicated in Figure 16-36 by a line corresponding to the edge of the floodplain (digitised from the 1:50,000 scale maps) is almost completely covered by flood waters, both above and below the junction with the two large laghas.

Table 16-7 Cover Categories of interpreted SPOT satellite image: Floodplain, 6 May 1995 (full scene, including hinterland and lagha flows).

	% cover	hectares	% cover excl. cloud	% cover floodplain only
Dry land	55.1	179,167	75.73	6.08
Tana River	0.428	1,390	0.59	7.46
Main channel or significant flooding	12.3	40,013	16.92	86.46
Flooding: overland flow / minor channels	4.9	15,981	6.76	-
Cloud & cloud-shadow	27.2	88,441	-	-
Total	100	324,992	100	100

Figure 16-36 Cover Categories of interpreted SPOT satellite image: Tana River Floodplain near Hola, 6 May 1995



16.11.3 Flooding on the Tana Delta: 9 May 1990 satellite image

The image covering the Tana Delta was also partly obscured by cloud, but a significant portion of the delta itself was cloud-free. Discharge data from Garissa for April and May 1990 are shown by Figure 16-37. The time of satellite image acquisition occurred after an important flood event lasting for much of April (flows at Garissa greater than 500 m^3/sec). The time taken for floods to pass from Garissa to Garsen ranges from 3 to 9 days, with an average of 4 to 5 days. The image acquired on the 9th May, should therefore show the full effects of the preceding floods, less any slight recession of the initial flood waters that may have occurred. It is of interest that major flooding occurred in two principal areas (see Figure 16-38):

- To the south of the main Tana River channel between the Tana and the coastal dunes. A portion of this flooding will return to the main river channel and exit at Kipini whilst some water will also exit at the two old mouths of the Tana at Mto Tana and Mto Kilifi.
- A broad band stretching from north of Garsen, across the Garsen-Witu road, along the northern and western side of the delta flowing towards Kipini. This flooding is centred round former courses of the Tana River, indicating their importance in controlling and managing floods within the delta.

In addition to standing / open water, three categories of flooded land were identified: (i) deeper floods, (ii) medium floods and (iii) areas with some slight flooding / probable flooding. This last category also included land that may have been flooded but where flood waters were potentially obscured by tall dense vegetation. The areas of these different categories are given in Table 16-8. Excluding clouds and the ocean, 40% of the analysed image was identified as either deep or medium flooding. Within the delta itself, flooding was in excess of 50%. In addition to this, a further 17% of the image was affected by slight flooding.

The event that was responsible for this (see Figure 16-37) can be classified as a medium scale flood, significantly in excess of a controlled artificial flood. Phase 2 studies indicated that these floods will not be significantly altered in volume by the presence of the proposed reservoirs.

In the absence of a more comprehensive series of discharge data from a number of stations on the Tana, it is not feasible to indicate what proportion of this flood was derived from Garissa flows and what proportion from lagha flows. Although the 1995 image suggests that lagha flows may play a role, their importance can not be estimated with currently available flow data.

Figure 16-37 Average Daily Discharge: 4G1, Garissa - April-May 1990

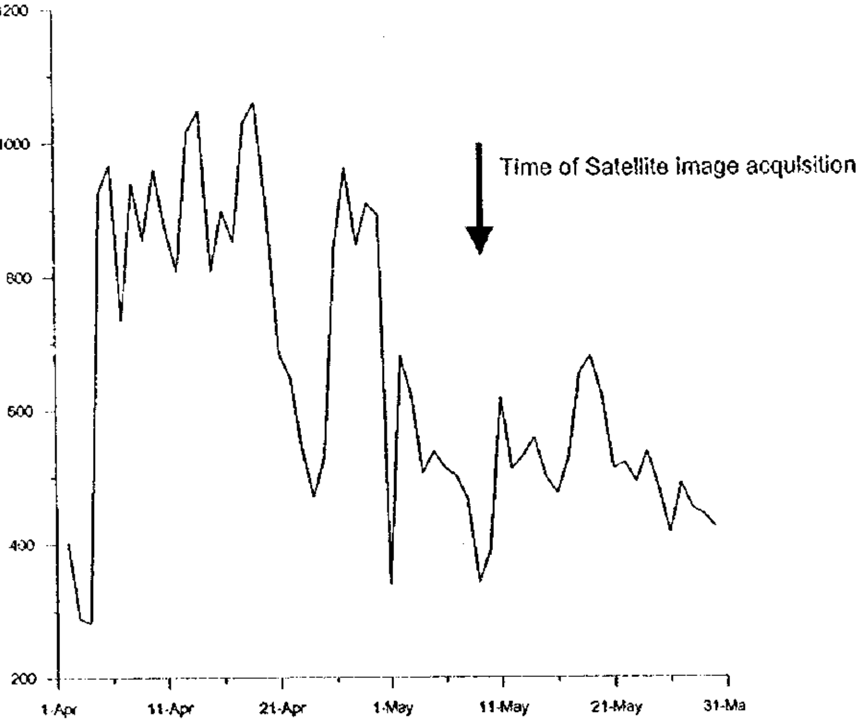
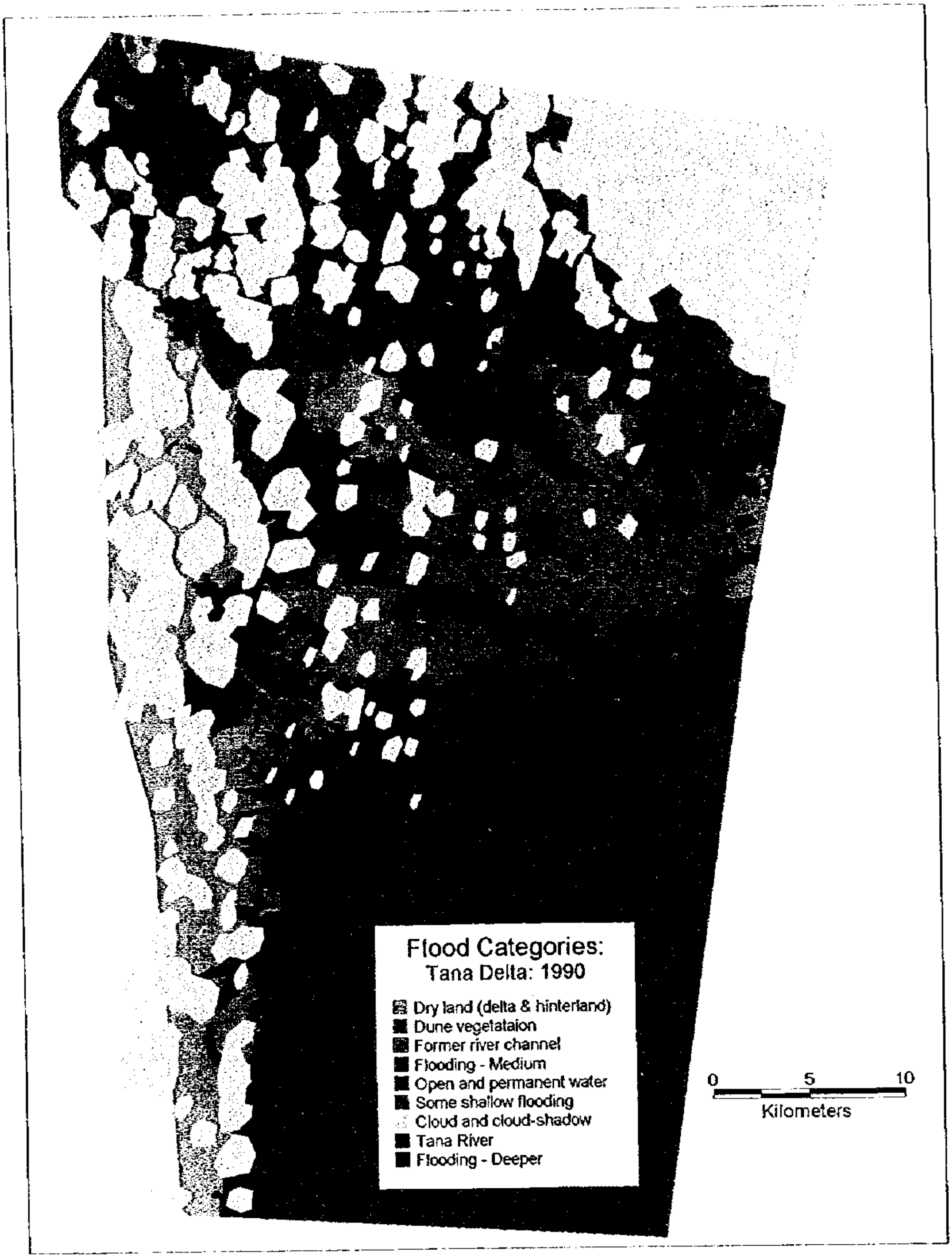


Table 16-8 Cover Categories of interpreted SPOT satellite image: Tana Delta, 9 May 1990

Flood Categories	Hectares	Cover (%)	
		Full Scene	Land cover less cloud & cloud-shadow
Dry land	25,671	13.04	25.07
Dune vegetation	10,445	5.30	10.20
Tana River	889	0.45	0.87
Former river channel	761	0.39	0.74
Some Flooding	17,948	9.11	17.53
Medium Flooding	11,843	6.01	11.56
Deeper Flooding	29,190	14.82	28.50
Open / permanent water	5,663	2.88	5.53
Ocean	40,850	20.74	-
Cloud & cloud-shadow	53,669	27.25	-
Total	196,929	100	100.00

Figure 16-38 Cover Categories of interpreted SPOT satellite image: Tana Delta May 1990



16.12 RESERVOIR IMPOUNDMENT PERIODS

16.12.1 Data Analysis

The time taken to fill the newly created reservoirs will depend on the rainfall at the time. However, it is possible to estimate the probable range of time periods that may be taken to fill the reservoirs given the daily river flow series at Grand Falls and a set of operating rules.

The following rules were used evaluate possibe infilling periods for each of the reservoirs, Mutonga and Grand falls (LGF).

1	Minimum downstream environmental flow Additional flow released downstream Flow used for infilling reservoir (less evaporation)	30 cumecs none 100%
2	Minimum downstream environmental flow Additional flow released downstream Flow used for infilling reservoir (less evaporation)	50 cumecs none 100%
3	Minimum downstream environmental flow Additional flow released downstream Flow used for infilling reservoir (less evaporation)	30 cumecs 25% of inflow 75%
4	Minimum downstream environmental flow Additional flow released downstream Flow used for infilling reservoir (less evaporation)	50 cumecs 25% of inflow 75%

Simulations were carried out using the daily flow series at Grand Falls. Starting at a randomly chosen point the reservoirs were filled, allowing for the above operating rules. Loss through evaporation was accounted for by using average monthly pan evaporation figures for Marimanti Met. Station. Each simulation was run 1000 times and the resulting infilling periods in days are summarised by Figures 16.39 and 16.40 and Table 16-9. Figure 16-41 indicates the probability of infilling for Grand Falls (LGF) reservoir for each operating rule.

Clearly, the infilling times for Mutonga are relatively short with average times taken to fill ranging from 15 to 25 days for the different operating rules used by the simulations.

Impoundment periods for Grand Falls (LGF) are considerably longer with average estimates ranging from 121 days to 191 days. It must be realised however, that these average infilling periods will be exceeded 50% of the time, i.e. there is only a 50% probability of infilling during these periods, or a 50% chance of laking a longer periods to fill the reservoir. A greater certainly can be estimated by assuming higher probability levels. In this study 70% probability levels were assumed and these indicate infilling periods of between 153 days (5.1 months) and 248 days (8.2 months) for the four different operating rules used.

Table 16-9 Summary of results of reservoir infilling simulations

A: Grand Falls (LGF)

Rule	70% probability of infilling	average time	minimum	maximum
1	153 days (5.1 months)	121 days	22 days	300 days
2	205 days (6.8 months)	161 days	31 days	379 days
3	184 days(6.1 months)	143 days	22 days	443 days
4	248 days (8.2 months)	191 days	31 days	577 days

B: Mutonga

Rule	average time	minimum	maximum
1	15 days	1 days	46 days
2	18 days	1 days	97 days
3	20 days	1 days	61 days
4	25 days	2 days	126 days

Table 16-10 Average monthly flow calculated from estimated daily inflow and outflow during infilling: LGF with minimum outflow set at 50 cumecs with additional 25% of inflow above this minimum. (Simulation Results, 1000 runs)

Month	Average Inflow	Average Outflow
1	128.7942	69.6986
2	110.7337	65.1834
3	122.6924	68.1731
4	212.8575	90.7144
5	299.5886	112.3972
6	160.7320	77.6830
7	102.0142	63.0103
8	110.3582	65.0895
9	105.6125	63.9031
10	140.9442	72.7361
11	177.8796	81.9699
12	172.3879	80.5970

The effects of impoundment on downstream flows are considered to be serious from the point of view of all downstream users. The minimum downstream flows released by the simulations (30 and 50 cumecs) are both significantly below the average monthly flows at Grand Falls (Table 16-10). The most conservative operating rule, releasing a minimum of 50 cumecs and releasing 25% of the remaining inflow (retaining 75%), results in a 70% probability of infilling within 8.2 months. The associated average monthly downstream flows released at Grand Falls are given by Table 16-10 and can be compared with the current situation. The resulting downstream flows would be the equivalent of very low dry season flows throughout the year.

By contract, infilling periods for the larger volume of High Grand Falls reservoir were estimated by simulation to be an absolute minimum of 220 days, with 70% probability of infilling estimated at between 632 and 895 days (21 to 32.8 months) and a maximum estimated infilling period of 1,635 days (54 months or 4 and a half years). These estimated infilling periods would **guarantee a prolonged and very serious *de facto* downstream drought** of between 2 and 3 years – whatever the upstream conditions and rainfall elsewhere in the country.

Table 16-11 Summary of results of reservoir infilling simulations for High Grand Falls, for comparison with Low Grand Falls and Mutonga.

Rule	70% probability of infilling	average time	minimum	maximum
1	632 days (21 months)	516 days	221 days	996 days
2	743 days (24.8 months)	615 days	236 days	1,286 days
3	811 days (27 months)	698 days	332 days	1,240 days
4	895 days (32.8 months)	823 days	380 days	1,625 days

16.12.2 Effect on Downstream Users

The effect of the impoundment of Grand Falls (LGF) would therefore be a *de facto* drought situation for all downstream users throughout the infilling period.

16.12.3 Mitigation Measures

No mitigation measures are possible, with the exception of drought relief and food aid programmes. Parts of the downstream area are only now beginning to recover from the effects of previous low-flow periods - caused by a combination of real drought and *de facto* droughts resulting from the impoundment of the other reservoirs in the upper catchment.

This drought period is likely to have its greatest impact on the pastoralist communities since their livestock rely on the flooding of the floodplain for vital dry season grazing resources. In the absence of this grazing, the people and their livestock will be forced to move considerable distances in search of suitable grazing. The traditional refuge in such times is the Tana Delta and this are is therefore likely to bear the greatest impact in terms of icreased grazing pressure and heightened social tensions, in an area where security is already an important issue.

Figure 16-39 Estimates of Time taken to fill Mutonga reservoir: results of 1000 simulations for each of four operational rules.

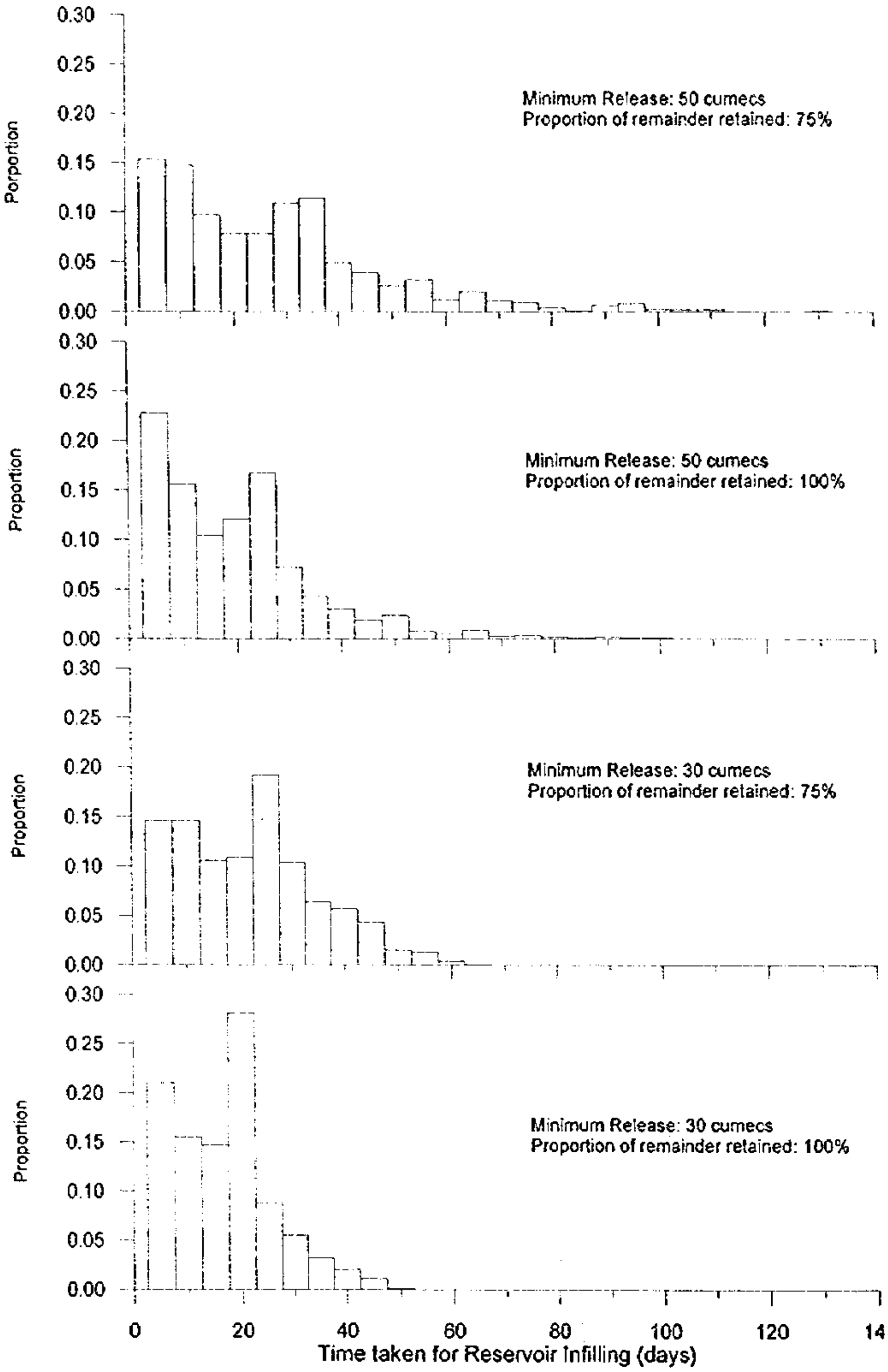


Figure 16-40 Estimates of Time taken to fill Grand Falls (LGF) reservoir: results of 1000 simulations for each of four operational rules.

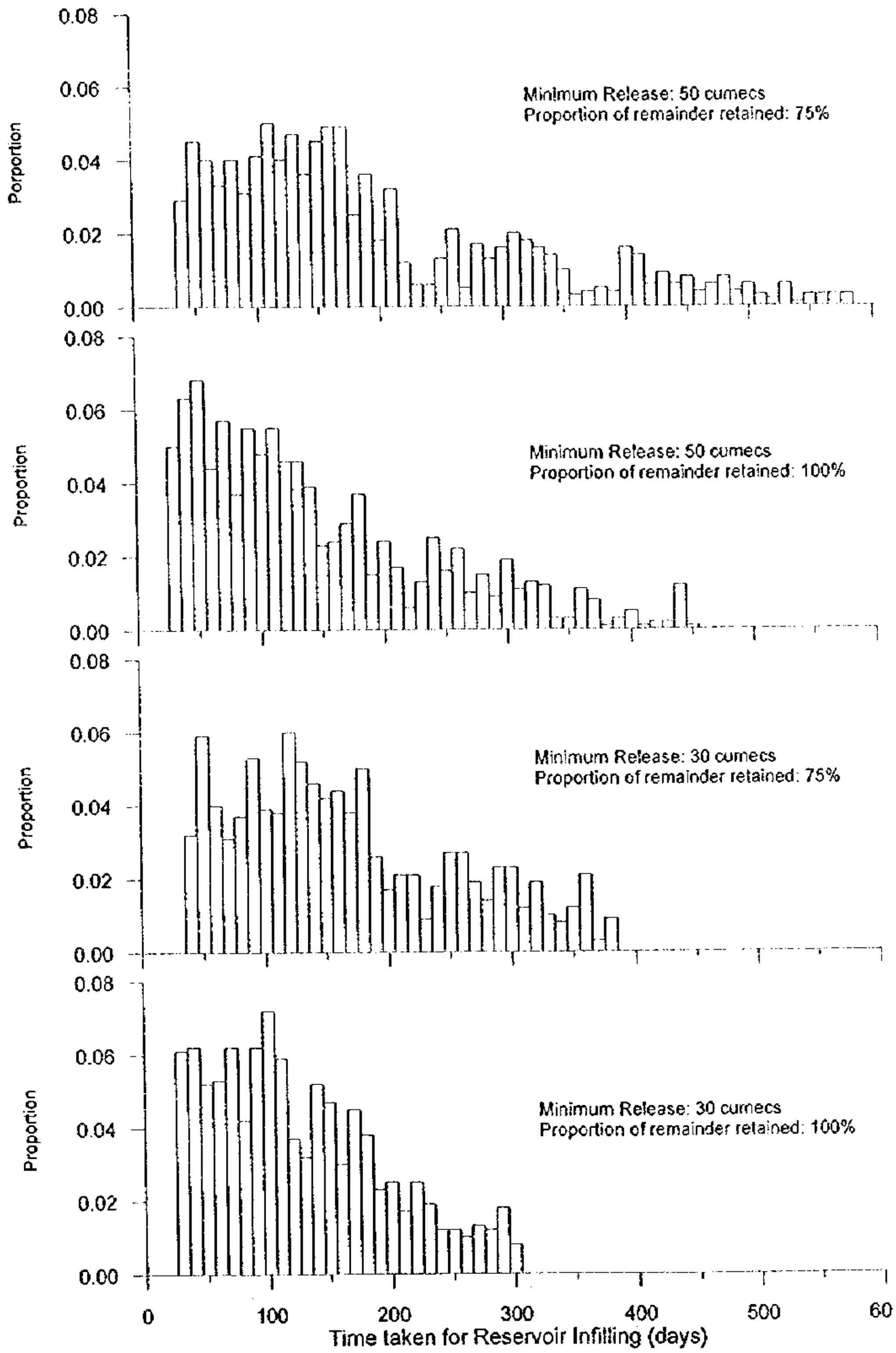


Figure 16-41 Probability of Impoundment Periods for Grand Falls (LGF) with four different operating rules.

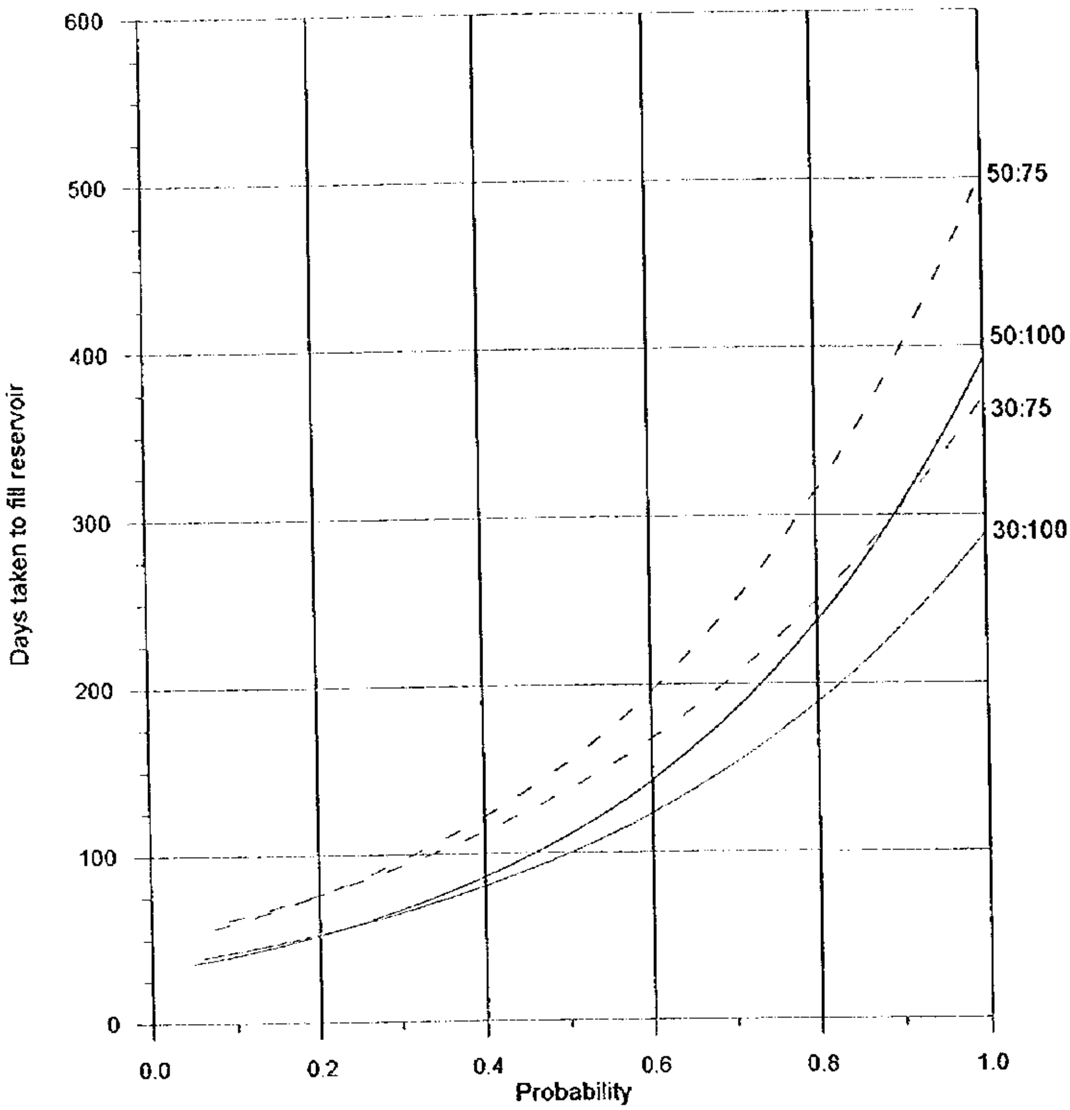


Table 16-12 Estimated Probability of Time (days) taken to fill Grand Falls Reservoir (LGF)

	Operating Rules (minimum outflow: %of remainder released)			
	1	2	3	4
Probability level	30:100	50:100	30:75	50:75
0.10	43	40	63	60
0.20	53	52	76	76
0.30	65	67	93	96
0.40	81	86	113	122
0.50	100	111	138	155
0.60	123	143	168	196
0.65	137	162	185	220
0.70	153	184	205	248
0.75	170	209	226	279
0.80	189	237	249	314
0.85	210	269	275	354
0.90	234	305	304	398
0.95	260	347	335	448
1.00	289	393	370	504

16.13 CONCLUSIONS

16.13.1 Flooding Patterns and the "Normal" Flood

The pattern of flooding on the lower Tana river was examined through an analysis of discharge and rainfall records during flood events. Flood events with at least one day of flow greater than 500 m^3s^{-1} at Garissa were analysed, with this figure taken to be the best estimate above which out of bank flow occurs. The "normal" flood was found to be best represented by the event with median characteristics in terms of its duration, peak flow and total volume. The median flood at Garissa has an estimated duration of 6.5 days, a peak flow of 785 m^3s^{-1} and a total volume of 394 MCM. It is assumed that a flood of this magnitude will inundate the floodplain both upstream and downstream of Garissa for a period sufficient to maintain the environment and level of economic activity currently supported by the current river regime.

Flooding on the lower Tana occurs on a bi-annual basis, usually during April / May and November / December. However, out of bank flooding does not occur in all wet seasons and some years, particularly during the 1970's, have suffered from a lack of such flooding in both seasons. The release of flood discharges to guarantee out of bank flooding at Garissa and the inundation of the floodplain both upstream and downstream would represent a significant improvement on the current situation.

Further flood event analysis revealed that the relationship between floods at Grand Falls and those at Garissa is not constant but varies in one of four ways. During type A events the flood attenuates as it moves downstream with a reduction in both peak flow and total volume. In contrast, the flood hydrograph appears to undergo little attenuation as it moves downstream during type C floods whilst peak flow and total volume increase between Grand Falls and Garissa during a type D event. Type B events, during which massive attenuation occurs between Grand Falls and Garissa, were excluded from detailed analysis as they do not appear to be a current feature of the flood regime of the river and, moreover, there is some doubt as to the validity of these events.

The analysis of rainfall identified variations in the pattern of rainfall corresponding with each of event types A, C and D. These differences in rainfall appear to play an important role in determining the additional runoff to the Tana between Grand Falls and Garissa and hence the relationship between floods at the two sites. Rainfall during a type A event is concentrated on the Nyambene Hills and results in relatively large losses as runoff is carried to the main river via various tributaries. The impact of these tributary inflows on the flood flows of the Tana are relatively insignificant and the flood attenuates as it travels downstream. During type C and D events rainfall is more widespread over the top end of the lower Tana catchment. The mean travel time of runoff between source areas and the main river is less than during a type A event with a consequent reduction in losses. Inflows from tributaries between Grand Falls and Garissa during these events can help to sustain a flood or even boost it to as it moves downstream. As floods move downstream beyond Garissa they appear to attenuate in a consistent fashion with flood peaks and total volumes falling significantly as they reach first Nanigi and then Garsen. There appears to be no real difference in flood behaviour downstream of Garissa resulting from floods of type A, C or D. This confirms that runoff generation at the top end of the lower Tana catchment is the critical influence on the characteristics of floods as they move downstream.

The estimated release, and hence the reservoir storage, required at Grand Falls to support the normal flood at Garissa varies according to the different types of flood. In the case of a type A flood, with relatively low tributary inflow, the estimated release required from Grand Falls is 490 MCM, 16% greater than that estimated in previous studies. A release of this size should be able to guarantee normal flooding at Garissa regardless of inflows below Grand Falls, although there would be a risk of generating large downstream floods in certain circumstances with this type of release pattern. With relatively more runoff from the tributaries of the lower Tana (type C and D floods), the release from Grand Falls could be reduced by 17-26% depending on the extent and intensity of rainfall.

These findings suggest two alternative strategies for the release of flood flows from Grand Falls.

- The first, and more straightforward, strategy is to release the flood flow which will guarantee the normal flood at Garissa regardless of other inflows (full type A release).
- The alternative strategy is to deliberately release floods flows to coincide with tributary inflows. This strategy would require a smaller release, and hence have less impact upon storage at Grand Falls, but is reliant on an ability to make short-term forecasts of runoff generation from the top end of the lower Tana catchment. Such an approach would require a system of instrumentation to monitor rainfall in the critical areas of the catchment combined with a set of release control rules governing the volume of flows released in relation to threshold rainfall values.

Adoption of this second approach is recommended, since it makes better used of the stored water. Furthermore, adoption of this second approach should prevent excessive downstream flooding which might occur from unexpected heavy rainfall and runoff over the lower catchment coinciding with a flood release.

16.13.2 Downstream River Morphology

A numerical model study was carried out to determine the morphological impact of the proposed Low Grand Falls and Mutonga dams. The study assumed that due to the nature of the river between the proposed dam site and the Kora Rapids no significant morphological change will take place in this reach. The numerical model indicates that downstream of Kora Rapids significant, and potentially serious degradation will occur.

After 34 years the degradation will be of the order of 11 metres immediately downstream of Kora rapids. The degradation will extend approximately 40 km downstream, reducing in magnitude as one progresses downstream. Further degradation will take place after 34 years.

It is currently proposed to release artificial floods from the reservoir. This will not have a significant impact on the morphology in comparison with the normal dam releases.

It has been suggested that the sediment from the Kathita catchment could be diverted around the reservoir to enter the river downstream. The impact of this is to reduce the amount of degradation from approximately 11m to approximately 9m. In this study the feasibility of diverting the sediment was not considered nor the engineering works required to achieve this. If this option were to be pursued then more detailed studies of these aspects would have to be considered.

The reduction in bed levels would tend to destabilise the banks of the river, leading to changes in the shape of the channel cross-section and the injection of sediment into the river. Neither of these effects have been included in the present model. They are likely to slow the actual rate of change in comparison with the model predictions but are unlikely to affect the final equilibrium value.

The reduction in bed levels leads to a corresponding reduction in water levels. This will reduce the frequency of overbank flooding and lead to a reduction in the groundwater levels adjacent to the river. This is likely to have an impact on the local environment.

The change in the equilibrium conditions of the river will also induce plan form changes. Those reaches which are presently braided are likely to become less braided and may change to a meandering plan form. The sinuosity in those reaches that are presently meandering may reduce. This will have an impact on any infrastructure along the banks of the river.

These findings suggest that construction of the proposed dam at Grand Falls will:

- Lead to a degradation of the bed of the Tana River of up to 11 metres in a 40 km reach downstream of Kora Rapids.
- Lead to a corresponding reduction in water levels.
- Lead to a reduction in groundwater levels.
- Result in plan form changes of the river channel itself. This will have an impact on any infrastructure along the banks of the river.

16.14 RECOMMENDATIONS FOR FURTHER WORK

1. More detailed quantification of inflows from tributaries to allow:
   a) **Strategy 1:** Assessment of the range of floods resulting from fixed releases as inflows from tributaries downstream of Grand Falls vary, both during minimum normal flood periods, and during major floods (of say greater than once in 10 or 20 years).
   b) **Strategy 2:** Identification of rainfall thresholds necessary for effective flood release.
2. Investigation into the use of real-time remote sensing for rainfall/runoff forecasting in this area.
3. Design of a suitable network of instrumentation and telemetry to guide effective flood releases, in combination with data from remote sensing.