

Sedimentation in reservoirs – Tana river basin, Kenya

II – Hydrographic surveys of Kindaruma and Kamburu reservoirs in June/July 1981, with an analysis of the siltation rates since impoundment

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Abstract

A research project to develop methods of predicting rates of sediment deposition and distribution in tropical reservoirs is currently being undertaken at Hydraulics Research, Wallingford, using funds made available by the Overseas Development Administration of the British Foreign and Commonwealth Office. The project involves data collection from sites in Kenya, Indonesia and the Philippines.

A collaborative investigation was started in Kenya in 1980 to study the distribution of sediment within two, and more recently three, reservoirs on the Tana River, and to monitor the transport of suspended sediment by rivers feeding these reservoirs. The collaborative organisations — the Tana and Athi Rivers Development Authority, the Ministry of Water Development and the East Africa Power and Lighting Co Ltd — are providing finances and staff to cover the Kenya end of the investigation.

The first stage of the investigation was to produce a set of base data against which all future reservoir surveys will be compared. These data, which were abstracted from an aerial survey flown in 1965, are described in HR report OD 45.

The report covers the second stage in which assessments are made of changes in reservoir volumes, following hydrographic surveys carried out in June/July 1981. The survey data are analysed in two ways in an attempt to estimate both the change in capacity of the reservoirs, and the volume of material eroded from the catchments. The analysis shows that over the period 1968-74, the volume of Kindaruma reservoir decreased at a rate of 8.9% per year. Kamburu reservoir was then impounded and its volume dropped at a rate of 2.2% per year until 1981.

The resulting analysis demonstrates that short-term changes in sediment volume can only be assessed if more information is available on the physical properties of the sediment and the reservoir inflow rates.

1 Introduction

- 1.1 The Tana River is the largest river in Kenya and the country's major surface water resource (Figure 1). The catchment area is 94 700km² — representing about 16% of the land area of Kenya and containing some 20% of the national population. Including the headwaters of the Sagana, the river is 1012 km long and flows from Mount Kenya and the Aberdare Range to the Indian Ocean. The potential for development of the river for hydropower and irrigation is high and several schemes are already in existence (Figure 2) or planned for the near future. However, although attention has been given to the study of siltation in the Tana River, there is still a large amount of work required if a full understanding of erosion, sediment transport and deposition is to be obtained. The Overseas Development Unit (ODU) of Hydraulics Research, Wallingford (HR) has undertaken an investigation in collaboration with the Tana and Athi Rivers Development Authority (TARDA), the Ministry of Water Development (MOWD) and the East Africa Power and Lighting Company Limited (EAP&L) to investigate these phenomena. Proposals for an investigation on the Upper Tana River were submitted following a visit to Kenya by a member of the ODU staff⁽³⁾. A revised summary of the proposals was agreed after a series of meetings on site in July 1980⁽¹¹⁾.
- 1.2 The initial phase of this programme is expected to last three years and is concerned primarily with the establishment of sampling methods, installation of field equipment, desk analysis and reservoir surveys. ODU plan to produce separate reports on each of the individual aspects of the investigation and the first — OD 45 — was published in November 1982⁽¹⁰⁾. It describes the desk study of an aerial survey flown in 1965 by Hunting Surveys Ltd. Base data were extracted for Kindaruma and Kamburu reservoirs as the initial step towards producing estimates of siltation rates. This report, OD 46, covers the second stage in which accurate assessments are made of reservoir volumes following detailed hydrographic surveys which were carried out in June/July 1981. Comparisons are also made between the 1981 data and previously published studies⁽¹⁰⁾.
- 1.3 Although the agreed proposals required the collection of reservoir data from only Kindaruma and Kamburu reservoirs, TARDA asked ODU to advise them on suitable range line locations for Masinga reservoir. In July 1981, ODU used hydrographic techniques to complete a survey of Masinga which had been started prior to reservoir impoundment but had to be abandoned when the water level rose quicker than expected. As the data collection techniques vary little from site to site, all three surveys are covered by this report. However, the data analysis and discussions refer only to Kindaruma and Kamburu reservoirs as originally proposed.
- 1.4 The proposals⁽¹¹⁾ included a list of recommended monitoring sites which would provide valuable data on the suspended sediment being carried into the reservoirs by the major rivers in the system. The three most important sites — 4BC2, 4DD2 and 4CA2 (see Figure 2) — were to be equipped with continuously recording "Partech" turbidity monitors, supplied by ODU on three-years free loan. The installation and operation of the first of these sites — 4BC2 at Sagana (Plate 1) — was started in October 1981 by staff of MOWD with finance made available by TARDA and MOWD. MOWD have continued to monitor the performance of this equipment and at the end of 1982, an intensive study was mounted by the Hydrology Section of MOWD to assess the validity of the data being obtained. The remaining 16

sites were to be monitored using either automatic vacuum-sampling systems (Automatic Liquid Samplers — ALS) or transportable, battery-powered pumps (Plate 2). As a result of the problems which had been encountered with the first Partech installation, none of the remaining two Partech's, or the three ALS's, had been sited. However, pumped samples were obtained on a regular basis from all the sites, including the five power stations where samples were collected by local EAP & L staff. The samples which have been collected are analysed for sediment concentration, using vacuum filtration by the Water Quality and Pollution Control Centre of MOWD (Plate 3). A separate report covering this aspect of the investigation will be published when the analysis has been completed.

2 Site details

Location of range lines

- 2.1 The position and number of range lines for any given reservoir needs to be chosen with considerable care to ensure that subsequent soundings along the lines will give all the data necessary for an accurate assessment of the sediment volume. It is fairly easy to list the points which should be considered when selecting range line locations under ideal conditions. However, it is possible that many items included in the list may have to be modified to suit the particular site, so it is difficult to set down hard-and-fast rules.
- 2.2 In selecting the range lines for this investigation, the following recommendations were complied with whenever possible:-
 - a) the range lines were not more than 1 km apart and preferably about $\frac{1}{2}$ km,
 - b) the range lines were approximately normal (ie at right angles) to the old river channel,
 - c) the divergence between adjacent range lines was not more than about 30° except where major bends in the channel made it impracticable; in this case the divergence went up to 60° and, in exceptional conditions, 90° ,
 - d) range lines were drawn directly across the mouth of any tributaries joining the main river channel,
 - e) the end-of-line markers were sited above the maximum high water level. Where there was an island on the line, care was taken to ensure that it did not obscure either of the markers. If there was any doubt, additional markers were sited on each side of the island,
 - f) the positions of the end-of-line markers were chosen to give the maximum inter-visibility.
- 2.3 With the above points as a guide, maps of the three reservoirs were drawn to show 10 range lines on Kindaruma, 29 on Kamburu and 63 on Masinga reservoirs (Figures 3, 15, 46). Each section was given a unique code by which it was identified on the ground, in field books and throughout the analysis. Care was taken to ensure that the names would still be recognisable even when written hurriedly in a field book on board a moving survey boat. The standard convention was used whereby the ends of the lines were labelled "left" and "right" when looking downstream.

- 2.4 During the period 1975-78, Engineering and Power Development Consultants (EPDC) — EAP&L's consultants for the first four reservoirs — ran a series of annual hydrographic surveys of Kamburu reservoir using a total of eight range lines⁽¹²⁾. This was repeated in 1980 with three additional range lines⁽¹³⁾ and these eleven lines were included as a part of the 1982 HRS survey. Ten of the eleven range lines are identified on Figure 15 — the remaining line (TN1) is not shown because co-ordinate data for the end-of-section markers are not available, as is also the case for TN2.

Reservoir beacons

- 2.5 The positions of the range lines were chosen after a careful study of a series of contour maps produced from an aerial survey flown in February 1965 by Hunting Surveys Ltd. On site, the precise locations of the end-of-section markers were selected to be in front of any major obstructions (such as rocks or large trees) and, where possible, to be away from areas frequently visited by people and animals.
- 2.6 Each marker had to be a permanent structure which would be relatively easy to locate after two or three years. The design and construction of the markers on Kindaruma and Kamburu reservoirs were carried out by EPDC staff with finance made available by EAP&L. They were made from in-situ mass concrete and designed to stand about 4.5ft (1.4m) above ground level and were about 1.5ft (0.5m) square in section (Plates 4 and 5). (The design and installation of markers on Masinga reservoir and the initial survey were all carried out by, or on behalf of, TARDA; they are not covered by this report). A pipe was set into the top of each marker so that a target beacon could be supported about 10ft (3m) above ground level to make the position of the marker more obvious during the surveys.
- 2.7 The human eye can resolve a minimum of one second of arc (1/3600 degree) if the target is set against a plain, contrasting background. On Kamburu reservoir, the longest range line was approximately 1700m, which required a minimum target size of 0.49m. In practice, this was doubled to 1m to reduce the risk of losing sight of the beacon when viewing it from a moving boat. The face of the target was also covered with fluorescent pink sheeting to increase the contrast when seen against a background which varied from bright, clear sky to dark, variegated foliage.
- 2.8 After construction, the precise locations of the markers were surveyed for EAP&L by Griffiths Engineering and Hydrographic Surveys of Nairobi, and the co-ordinates and levels were sent to ODU in November 1981. The recorded co-ordinates for the markers are given for each section in Tables 1 and 2. It must be noted that the co-ordinates are related to the Plane Local Engineering (PLE) grids which were used during the periods of dam construction and were specific to each project site (ie the PLE grid at Kindaruma is not directly related to the PLE grid at Kamburu) and EPDC found that it was not possible to tie the PLE grids into the Kenya Survey grid. In order to locate the range lines, each marker position was plotted relative to the PLE grid, and to the same scale as the reservoir drawings. This plot was then superimposed on the reservoir drawings and the position adjusted until all the markers were above the maximum reservoir water level. The Kenya survey grid and the assumed PLE grid are shown on Figures 3 and 15 for Kindaruma and Kamburu reservoirs respectively.
- 2.9 This method of locating the markers, by plotting their relative positions and then adjusting the whole pattern, has been vindicated by comparing the surveyed ground levels with those taken from the contour maps. In most cases, the levels agreed to within the accuracy with which the contours were drawn, that is $\pm \frac{1}{2}$ contour interval (± 5 ft).

- 2.10 The distances between each pair of markers shown in Tables 1 and 2 were calculated using the co-ordinates and checked by measuring the plotted range line length.

3 Hydrographic survey

- 3.1 This section is based on an unpublished report⁽¹⁾ written by the HRS surveyor for this project.
- 3.2 The basic technique which was followed throughout the surveys required a minimum team of four people — 3 men in the boat and one onshore.
- 3.3 The shore man was equipped with a VHF radio and a theodolite which he set up either over or behind a range line marker. The theodolite was aligned to sight the corresponding beacon on the opposite bank — the man was therefore looking along the range line. A small boat fitted with an echo sounder and radio was talked along the line following instructions from the theodolite observer. The position of the boat was fixed as often as possible by observing single, horizontal sextant angles from the boat between the range line and any suitable visible beacon. At the same instant that the position fix was taken, a “fix mark” was made on the echo-sounder trace.
- 3.4 A topographic survey was made at each end of the range line from the top of the end-of-range marker to the water’s edge, so that the marker top became the elevation reference datum for the soundings.
- 3.5 The echo-sounder was calibrated on several occasions during the course of the survey using the conventional bar-check technique. This involved lowering a metal target to known depths below the water surface. The “speed of sound” control was adjusted until the recorded depths corresponded to the actual depths of the target. It was found that very little, if any, adjustment was necessary from one calibration to the next.
- 3.6 Lists of the main items of equipment used during the survey, and the personnel involved are given in Appendix 1 to this report (Plate 6).
- 3.7 The partial survey of Masinga reservoir was started on 11 June 1981 and surveying of all three reservoirs was completed by 10 July 1981. A further week was spent in the site office checking the data before the survey equipment was packed ready for freighting back to HR on 17 July 1981.
- 3.8 The reservoir surveys went smoothly and without any major problems. The use of an inflatable boat for Masinga and Kamburu reservoirs (Plate 7), although not part of the original plan, helped to make more efficient use of the time since it could be transported by road between locations. However, safety of the crew requires that a rigid hull boat (Plate 8) should be used for future surveys if possible; the time saving could be achieved by leaving the boat on site overnight with a watchman rather than returning to camp.

4 Accuracy of field data

- 4.1 Providing the markers were correctly located — and there is no reason to suspect otherwise — and the sextant was in good adjustment, the positional accuracy of fixes across a range line should be better than $\pm 5\text{m}$. However, this figure does depend on two factors:
- i) the distance between markers
 - ii) the contrast between beacons and the background against which they are being viewed.

- 4.2 The choice of echo-sounder and the size of chart enabled depths to be read directly to $\pm 0.1\text{m}$. This resolution does not allow for factors such as:
- i) surface wave action moving the boat
 - ii) changes in the speed of sound through the water due to changing sediment load, water temperature, etc
 - iii) varying reflectivity of the reservoir bed.

Taking these items into account it may reasonably be assumed that the depth information is accurate to $\pm 0.15\text{m}$ or better.

- 4.3 A good check on the accuracy of the field data may be obtained from an examination of the Masinga reservoir data. As mentioned in paragraph 1.3, a topographical survey of sediment range lines on Masinga reservoir was started by Geosurvey International Ltd in 1980, but it was interrupted by heavy rains. Because only the areas above water could be surveyed accurately, gaps remained in a number of sections where the land was submerged. During the 1982 survey, a few days were set aside to repeat the incomplete sections and the resulting plots give a direct comparison between a topographic survey and an echo-sounder survey; the locations of the Masinga range lines are shown on Figure 46 and an example section is shown on Figure 47. This section was chosen because it includes all of the main features which are present in most surveys — steep side slopes, an undulating bed and river channels. The comparison is extremely good when considering the limitations given in paragraphs 4.1 and 4.2 above — it must also be remembered that the area was flooded in the period between the two surveys and so some changes to the land form may have occurred.

5 Sediment distribution

- 5.1 Cross-sections plotted from data obtained during the 1981 hydrographic surveys are shown as discontinuous lines on Figures 4 to 13 for Kindaruma reservoir, and Figures 16 to 44 for Kamburu reservoir. The solid line in each case is a section taken from contour maps produced by Hunting Surveys Ltd following an aerial survey flown in February 1965⁽¹⁰⁾. These data were not available for sections TN1 and TN2 on the Tana arm of Kamburu reservoir because, at the time of writing this report, the co-ordinates of the range line markers were not known. The data which were used to plot all the 1981 sections are given in Tables 1 and 2.
- 5.2 The red lines shown on eleven of the Kamburu sections are levels recorded by EPDC during the period 1975-80^(12,13) (see paragraph 2.4).
- 5.3 An inspection of the Kindaruma reservoir cross-sections shows that the sediment deposits are, for the most part, evenly distributed across each section — a distribution that is thought to be fairly typical for a reservoir which is maintained at, or near, its maximum water level for long periods. This may not have been the case during the first six years after the construction of Kindaruma dam, when significant fluctuations in water level may have resulted from the normal operating programme. However, following the impoundment of Kamburu reservoir in 1974, it is reasonable to assume that the fluctuations in water level were considerably reduced. An increase in the water depth reduces the influence of bed shape on the velocity distribution and results in a general decrease in stream velocity over the whole section. This, in turn, is responsible for a reasonably even settlement of sediment which was previously held in suspension.

- 5.4 The effect of wider ranging water levels can be seen in an inspection of the cross-sections obtained from Kamburu reservoir. Here, the low-water channels are still clearly defined in all the Tana river sections (Figures 28 to 44), and in all but the first two sections on the Thiba river (Figures 18 to 27). Cross-section data collected by EPDC show that the low-water channel has moved across some sections — eg section TN6 on the Tana river (Figure 31) — but in most cases, the higher stream velocities occasioned by reduced water levels have served to maintain the existing low-water channel.
- 5.5 The EPDC data have proved to be most valuable in defining the rates of accretion throughout the first five years of operation of Kamburu reservoir (Figure 48). They show for the most part, a reasonably steady rate of accretion from one year to the next, except for the period from mid-1977 to mid-1978 when there appears to have been a significant increase in the volume of deposited sediment. This, however, is explained by EPDC in their report⁽¹³⁾ where they say that the high sedimentation rate “is probably due to the general heavy rainstorms which occurred over the catchment area in April 1977”.
- 5.6 The loss of cross-sectional area due to sediment accretion has been plotted against distance from the dam face for both reservoirs on Figures 49 and 50. For each site, the correlation between sediment deposit and distance is shown to be a smooth curvi-linear relationship ranging from about 80% loss of cross-sectional area at the upstream end of the reservoir, down to between 10% and 20% loss at the dam. On the assumption that for any given section the mean bed level is directly proportional to the cross-sectional area, it is possible to use the same data points to sketch a curve which exhibits a very strong resemblance to the classical shape of the bed-level versus centre-line distance curve; this is shown on Figures 49 and 50 as the discontinuous line. While being recognised as a somewhat arbitrary, qualitative rather than quantitative description, it serves to disprove the often quoted assumption that all the initial sediment deposition in a reservoir takes place in the deepest area (usually called the “dead” storage since it is below the design level of any dam outlets). What is assumed to have happened is that a fast flowing river, carrying a relatively high sediment load, has entered the reservoir and an increase in the cross-sectional area of the flow has resulted in a commensurate reduction in velocity. The water is no longer capable of carrying much of the sediment which is subsequently dropped out of suspension to form a delta of low-density deposits, the surface of which may remain as a mixture of silt and water, known as “fluid mud”; these delta area deposits may be called the “top set” beds. The situation described above occurs during periods of high rainfall when catchment erosion is at a maximum and the reservoir is at, or near, its top water level. As the impounded water is released, either for hydroelectric power generation or for irrigation, the reservoir level drops and the “fluid mud” is gradually moved further down the reservoir towards the dam. The movement of this material, which is often referred to as “reworking” of the sediment, is initially dependent on the range of water levels and it is usual for a considerable volume of sediment to build up at the low-water line — the plateau which is formed between the upper and lower water levels is known as the “fore-set” beds. Material deposited at the face of this plateau will maintain a continual slow migration under gravity down the reservoir bed until it finally comes to rest in the deepest area which is typically just by the dam; it is then known as the “bottom-set” beds.
- 5.7 When making a direct comparison between Figures 49 and 50 it must be noted that the horizontal axis scales of the two figures are not the same.

6 Survey data analysis

- 6.1 The method of analysis chosen for this study uses a contour slicing technique to obtain the volume of each segment of the reservoir contained between adjacent range lines. The method is described in detail in reference 10, but in order to make this report self-contained, an extract from reference 10 is included herein as Appendix 2. In essence, the reservoir volume contained between two range lines and two adjacent contour planes — the sub-segment volume — is divided by the sum of the sub-segment end areas to produce a constant factor for that sub-segment. (This value remains constant throughout the life of the reservoir because it is obtained from the pre-impoundment survey against which all subsequent surveys are compared). The constant factors which have been obtained from the 1965 base data survey are included in Tables 3 and 4.
- 6.2 The sediment volume contained within any given sub-segment is calculated as the product of the constant factor for that sub-segment and the sum of the corresponding sediment end areas obtained from a range-line survey; the sub-segment, segment and total sediment volumes for 1981 are also shown in Tables 3 and 4 for Kindaruma and Kamburu reservoirs respectively. Using this method, the survey results may be summarised as follows:

	Kindaruma	Kamburu
	(m³ x 10⁶)	(m³ x 10⁶)
1965 survey volume	18.33	146.00
1981 survey volume	11.59	127.46
Sediment volume	6.75	18.55

Stage/capacity curves obtained for the same data, are shown in Figures 14 and 45. It must be noted that since the publication of report OD 46⁽¹⁰⁾, more information has become available on the precise location of the Kamburu Dam. This has enabled some additional data to be abstracted from the 1965 survey which has, in turn, resulted in a more accurate value for the pre-impoundment capacity of Kamburu reservoir.

- 6.3 The four Tana river dams have been constructed over a period of 13 years and their impoundment dates (in topographical order going downstream) are:

Masinga	1981
Kamburu	1974
Gitaru	1978
Kindaruma	1968

If, as a first approximation, it is assumed that suspended sediment only enters a reservoir when there is no other dam upstream of it, then the mean annual loss of volume of Kindaruma reservoir during the period 1968-74 is:

$$\frac{6.75 \times 10^6 \text{ m}^3}{6 \text{ years}} = 1.13 \times 10^6 \text{ m}^3 \text{ per year}$$

The equivalent figure for Kamburu reservoir (1974-81) is:

$$\frac{18.55 \times 10^6 \text{ m}^3}{7 \text{ years}} = 2.65 \times 10^6 \text{ m}^3 \text{ per year}$$

(for comparison, EPDC⁽¹³⁾ estimated the annual change in volume of Kamburu reservoir during the period 1975-80 to be $2.34 \times 10^6 \text{ m}^3$ per year).

- 6.4 Taking the accretion rate for Kindaruma reservoir and assuming a catchment area of some 10 000km², the sediment yield is calculated to be 113m³/km²/year which converts to an annual soil loss of 0.11mm averaged over the whole catchment. Kamburu reservoir has a catchment area of 9520km² which means a sediment yield of 278m³/km²/year or 0.28mm.
- 6.5 These crude, first approximations to catchment sediment yields are successively refined by the procedures outlined in Sections 7 to 10 following. The necessary assumptions are presented and the use of data from the literature is described where information is not presently available from the sites.

7 Reservoir trap efficiency

- 7.1 It is implicit in the assumption made in paragraph 6.3 above that all the sediment entering a reservoir is retained within that reservoir, in which case the reservoir is said to have a "trap efficiency" of 100%.
- 7.2 The trap efficiency of a reservoir depends on a number of inter-related factors such as reservoir shape, size and operating procedure, sediment size, temperature gradient and velocity of the impounded water, catchment area, and river inflow. An attempt to define the trap efficiency in relation to the capacity/watershed ratio was published by Brown in 1943⁽⁴⁾ but this was very limited in its application because the actual reservoir inflow will vary considerably, depending on wheather it is sited in a humid or arid region, even though the capacity/watershed ratio remains unchanged.
- 7.3 In 1953 Brune published a paper⁽⁵⁾ in which he demonstrated that the capacity/inflow ratio offered a much closer correlation trap efficiency than the capacity/watershed ratio. While this is seen to be more reasonable in concept, considerable care must be taken in its application because the work is based on a study of 44 reservoirs in the United States of America and is not necessarily pertinent to the tropical situation. However, in the absence of any other relationships more applicable to tropical conditions, Brune's curve (Figure 51) has been used in this report in an attempt to obtain a better assessment of catchment erosion rates. Long term average river flow data supplied by TARDA for Masinga and Kamburu, converted to catchment run-off values of $0.353 \times 10^6 \text{m}^3/\text{km}^2/\text{year}$ and $0.358 \times 10^6 \text{m}^3/\text{km}^2/\text{year}$. Using a mean figure of $0.356 \times 10^6 \text{m}^3/\text{km}^2/\text{year}$ and applying it to Kindaruma and Gitaru catchments resulted in estimated reservoir inflow rates of $3560 \times 10^6 \text{m}^3/\text{year}$ and $3471 \times 10^6 \text{m}^3/\text{year}$ respectively. On the basis of these inflow data, and using reservoir capacities obtained from the 1965 and 1981 hydrographic surveys, it is possible to calculate theoretical trap efficiencies as shown:

Reservoir	Inflow (m ³ x10 ⁶ /yr)	Design		1981		Mean	
		Capacity (m ³ x 10 ⁶)	Trap efficiency	Capacity (m ³ x 10 ⁶)	Trap efficiency	Capacity (m ³ x 10 ⁶)	Trap efficiency
Kindaruma	3560 (E)	18	26%	12	14%	15	22%
Gitaru	3471 (E)	12	14%	—	—	—	—
Kamburu	3406	150	75%	127	73%	139	74%
Masinga	2586	1560	96%	—	—	—	—

- 7.4 Applying these mean trap efficiencies to the annual reservoir accretion rates given in paragraph 6.3 results in catchment sediment yields of $514\text{m}^3/\text{km}^2$ and $381\text{m}^3/\text{km}^2$ for Kindaruma (1968-74) and Kamburu (1974-81) reservoirs respectively. These values are still based on the assumption that sediment is only available when there is no reservoir upstream of the dam being examined. If an allowance is made for the material trapped by Kindaruma during the period 1974-81 when first Kamburu and later Gitaru reservoirs were brought into operation, then the catchment sediment yield for 1968-74 is reduced to $437\text{m}^3/\text{km}^2$. (The calculations whereby this figure is achieved, are given in Appendix 3). These results, with their implication that the catchment sediment yields are decreasing with time, clearly demonstrate the need for a more detailed analysis of the available data.

8 Initial analysis of sediment input

- 8.1 The first parameter to be examined was variability of the river flow rates and its effect on catchment yield. The yields given in paragraph 7.4 above are based on long term average river flow data quoted by TARDA in a technical leaflet about Masinga Dam. However, monthly discharge data collected by MOWD (Figure 52) show that there was a significant increase in the Tana River average discharge during the period 1977-79 and that prior to that, the discharge was approximately half the long term average used before. On the basis of all the data currently available, it was possible to deduce period average river flows at the dam site as follows:

Period	Kindaruma ($\text{m}^3 \times 10^6/\text{year}$)	Gitaru ($\text{m}^3 \times 10^6/\text{year}$)	Kamburu ($\text{m}^3 \times 10^6/\text{year}$)
1968-74	2238		
1974-78	3915		3758 (3608)
1978-81	3550	3479	3408

Using period average flows of $2238 \times 10^6\text{m}^3$ for Kindaruma and $3608 \times 10^6\text{m}^3$ for Kamburu (1974-81), the catchment sediment yield of $518\text{m}^3/\text{km}^2$ for Kindaruma is reduced to $326\text{m}^3/\text{km}^2$; the value for Kamburu remains unchanged because the relatively small change in river flow does not significantly alter the trap efficiency of 73%. The use of a more accurate river inflow rate has therefore reduced the calculated 1968-74 catchment erosion rate of 37% and it now shows a slight increase from 1968-74 to 1974-81. All of these rates are plotted on Figure 54 and listed in Table 7. If allowance is made for material trapped first in Kindaruma, and later in Gitaru reservoirs, then this rising trend becomes more pronounced with calculated catchment erosion rates of $274\text{m}^3/\text{km}^2$ and $381\text{m}^3/\text{km}^2$ for 1968-74 and 1974-81 respectively. The calculations so far confirm the normally accepted trend of increasing catchment erosion rates. However, they are based on relatively long time periods with the concomitantly wide margins for error. The data collected by EPDC^(12,13) were examined to see if they could be used to obtain a more detailed analysis.

- 8.2 As discussed in paragraph 5.5, the hydrographic data collected by EPDC from Kamburu reservoir have given a useful guide to the pattern of accretion during the period 1974-80. For many reasons, the data which they were able to collect were fairly sparse with only eight sections being used for surveys in 1978-81⁽¹²⁾ and eleven sections in 1980⁽¹³⁾. EPDC recognised that these limited data needed modifying

in order to estimate the total sediment deposition and so they added on an incremental value of $\frac{1}{3}$ to the surveyed total. The un-modified EPDC curve is plotted on Figure 48. The s-shaped curve indicates that there was an increasing rate of accretion within the reservoir up to a maximum in late 1977, after which the rate decreased. This was discussed by EPDC in their report⁽¹³⁾ and they concluded that increased rainfall was the cause. This presumption is backed up by river discharge data obtained from station 4DE2 which was operational until mid-1980 when it was drowned by Masinga reservoir. It will be seen from Figure 43 that even with the incremental allowance of $\frac{1}{3}$ rd used by EPDC, their method seems to have significantly underestimated the total volume of sediment contained within the reservoir. Assuming that the EPDC data gives an accurate indication of the annual variation in sediment accretion rates, their calculated volumes have been increased by the ratio of HR to EPDC final volumes to produce the “extrapolated EPDC” data. The shape of the lines was computed by using an HR cubic splines curve fitting routine.

- 8.3 It is then possible to examine sediment input rates to Kamburu using shorter time periods. The basis by which the data had been obtained made it unreasonable to consider annual increments, but a division of Kamburu into two periods — before and after the impoundment of Gitaru reservoir — seemed feasible. With this more detailed approach (and allowing for material trapped in Kindaruma reservoir between 1978 and 1981) there is seen to be a slight increase in the calculated catchment sediment yield during the first six years, which rises by some 88% for the 1974-78 period and then drops to less than half the initial value for the final three years (see Table 7 and Figure 55). This pattern of increasing and then decreasing sediment yield is totally consistent with the changing river discharges given above and is thought to be very close to representing the field situation. However, the overall trend is still seen to be a reduction in catchment sediment yield with time, and so a preliminary examination has been made of the variation in sediment densities and the effects which any changes may have on the calculated yields.

9 Consolidation of sediments

- 9.1 The fundamental requirement of any reservoir survey is that it should produce sufficient data for an accurate assessment to be made of the bed shape, and hence allow the volume of water in the reservoir to be calculated. The comparison of data collected along the same range lines for successive surveys enables the engineer to calculate changes of volume with time. This water volume may then be directly related to reservoir inflow rates, water level and dam discharge because, within reasonable working limits, the physical properties of the water remain unchanged. The physical properties of the settled sediment, however, may change considerably with time and so the variation in volume from one reservoir survey to the next cannot be used to make an accurate assessment of the catchment sediment yield without some additional calculation.
- 9.2 If a known weight of sediment is introduced into a relatively still body of water, the volume occupied by that sediment will gradually reduce with time as the volume of voids between the particles decreases. This is referred to as consolidation of the sediment and the rate at which it occurs depends to a large extent on the composition of the material⁽²⁾.

When a sediment contains a high proportion of sand, the volume of voids between the particles is relatively small and so, even after a long period of time, there is little difference between the initial and final densities. However, if the sediment contains a preponderance of silts and clays — as is assumed to be the case in the Tana river — the initial deposits will be very loosely compacted and the density may change significantly over a period of years.

- 9.3 In their report on the determination of sediment densities, Lane and Koelzer⁽⁷⁾ assumed that the density of a settled sediment increased logarithmically with respect to time such that:

$$W = W_i + K \log_{10} T \quad (1)$$

where

W = unit weight after T years

W_i = initial unit weight

The values of W_i and K depend on the method of operation of the reservoir, the particle size of the sediment and, to a lesser extent, the condition of flocculation of the sediment. Using Lane and Koelzer's method, the mode of operation of the reservoir basin has to be selected from four classes in which:

- a) the sediment is always submerged or nearly submerged,
- b) normally there is moderate reservoir drawdown,
- c) normally there is considerable reservoir drawdown,
- d) the reservoir is normally empty.

In reservoirs of each of the four classes, the settled sediment may consist of up to three grades which Lane and Koelzer defined as:

Type	Size
Clay	< 0.004 mm
Silt	0.004 — 0.064 mm
Sand	> 0.064 mm

- 9.4 Lane and Koelzer studied the data obtained from a large number of reservoirs in the United States of America and they produced a table showing values of W_i and T for the four sets of conditions. The data taken from reference 7 are reproduced in Table 5 after conversion to metric units. When the sediment consists of a mixture of two or more grades of material, the density of each class is combined in proportion to their respective portions of the total sediment. Therefore, if a sediment consists of $Sa\%$ of sand, $Si\%$ of silt and $Cl\%$ of clay, then the density of the composite material would be:

$$W = (Sa\% \times W_{sa}) + (Si\% \times W_{si}) + (Cl\% \times W_{cl}) \quad (2)$$

- 9.5 Lane and Koelzer also quoted a study of initial sediment densities by Trask⁽⁹⁾ who determined densities after a very short settlement period. In a later work, Miller⁽⁸⁾ suggested that the initial densities presented by Trask were more applicable to sediments which contain a high proportion of clay — a condition which is thought to exist in the Tana reservoirs. Miller produced a table based on Trask's data, which are also reproduced in Table 5. Miller commented that the volumes of W_i for clay would have to be determined on the basis of existing site conditions.

- 9.6 The comments in paragraphs 9.2 and 9.5 above, that the Tana river sediments are thought to contain a high proportion of silt and clay, are based on visual inspections of the residue obtained during the sediment concentration analysis which is referred to in paragraph 1.4. Very seldom was a significant quantity of sand retained on the filter paper and, on many occasions, the filtrate showed signs of colouration which indicated an extremely fine suspension. It therefore seems reasonable to assume that the sediments tend towards the clay end of the particle size range and it follows that the values proposed by Trask in Table 5 should be used in preference to those suggested by Lane and Koelzer. The change of sediment density with time, for a range of composite materials and using Trask's initial data, is given in Figure 53.
- 9.7 This figure clearly demonstrates how critical is the choice of sediment composition; a change from 30% silt and 60% clay to 60% silt and 30% clay results in an increase in the initial density of 47%, although for a given pattern of reservoir operation, the changes of density with time follow similar trends.
- 9.8 The consolidation of deposited sediments is not only dependent on time, there is also a mechanical effect due to the increasing depth of deposition. In their work, Lane and Koelzer⁽⁷⁾ also quote a table which shows the variation of density with depth within a Marl sediment in Lake Niedersoutholfen in Bavaria. The metric version of these data are reproduced as Figure 54. It will be seen that the initial density at this site is given to be 346kg/m³ which is considerably lower than the initial density for silt given by Trask. However, using the same initial densities as for Figure 53, it is possible to plot lines following the same trend as the Lake Niedersoutholfen data and converging at 1490kg/m³ which is the density of deposited sand as given by Lane and Koelzer. The original data and the assumed curves are plotted on Figure 54.

10 Calculation of sediment yield

- 10.1 Having produced data on the consolidation of settled sediments with time, and their compaction with respect to depth, it is now possible to determine a more valid estimate of the catchment sediment yield for Kamburu reservoir.
- 10.2 The ratio of the actual sediment volume (V_{act}) to the initial volume (V_o) of the sediment at the unconsolidated density (ρ_o) is calculated as follows. Consider a column of unit area of material varying in density from ρ_o at the surface to ρ_D at depth D, and if density at depth d is ρ_d

Mass of element of thickness δ_d is $\delta_m = \rho_d \times \delta_d \times 1 \times 1$

hence:

$$\text{total mass } M = \int_0^D \rho_d \cdot dd$$

and:

$$\text{Actual volume } V_{act} = D \times 1 \times 1$$

If this mass had all been deposited at density ρ_o (surface, unconsolidated density), then the initial volume V_o would be given by:

$$V_o = \frac{M}{\rho_o} = \frac{\int_0^D \rho_d \cdot dd}{\rho_o}$$

and hence:

$$\frac{V_o}{V_{act}} = \frac{\int_0^D \rho_d \cdot dd}{\rho_o \times D} \quad (3)$$

By idealising the shape of the curve given in Figure 54, equation (3) may be reduced to:

$$\frac{V_o}{V_{act}} = 0.5 + \frac{\rho_D}{2 \cdot \rho_o} \quad (4)$$

10.3 To obtain a value of ρ_D from Figure 54, it is necessary to calculate a mean depth of sediment deposited in the reservoir. This has been tried in three ways:

- a) mean depth over the whole reservoir,
- b) mean depth in the Tana River reach, Thiba River reach and Dam reach,
- c) mean depth in each segment.

An examination of the results produced by the three methods showed that method c) seemed to give the most realistic depths when studied in conjunction with the Kamburu reservoir cross-sections shown in Figures 16 to 44.

10.4 The method employed was to examine each segment in turn. The calculated sediment volume (Table 4) for any given segment was divided by the mean of the range of "upper contour" areas in that segment (Table 4, report OD 45⁽¹⁰⁾).

10.5 The factor used to determine the change in sediment density with time was set at 1.15. This was the factor taken from Figure 53 for the change in density of a 10/30/60 sediment after seven years — the period being considered for Kamburu reservoir (1974-81).

10.6 The unconsolidated sediment volume was then calculated using equation (4) above with the "age factor" included such that:

$$\frac{V_o}{V_{act}} = 0.5 + \frac{\rho_d (\text{age factor})}{2 \times \rho_o}$$

Throughout the whole of Kamburu reservoir this ratio ranged from 1.1 to 1.6. Having applied the above method to each segment of Kamburu reservoir and then combined them into the two major divisions of the reservoir, the calculated unconsolidated sediment volumes were:

Tana River	25.33 x 10 ⁶ m ³
Thiba River	1.23 x 10 ⁶ m ³
Total	26.56 x 10 ⁶ m ³

A similar calculation for Kindaruma reservoir produced an unconsolidated volume of 9.31 x 10⁶m³.

10.7 The value of 26.56 x 10⁶m³ was plotted on Figure 48 and a third curve showing the variation of unconsolidated sediment volume versus time was produced, again using the cubic splines computer routine and based on the previously produced extrapolated EPDC data (see Paragraph 8.2). Using this curve, it was then possible to re-work the catchment yields given in paragraph 8.3. The results are shown in Table 7 and Figure 55 as catchment sediment yields in m³/km²/year.

11 Discussion of results

- 11.1 As explained in paragraph 9.1, data obtained from a reservoir survey may be required to answer either, or both, of two basic equations:
- by how much has (or will) the useful capacity of a reservoir change during a given time period?
 - how much sediment has been eroded from the catchment and deposited in the reservoir?
- 11.2 The first question is relatively straightforward to answer, and is discussed in paragraph 6.3. A comparison of the base data — that is, topographical data recorded in 1965 before impoundment — and the 1981 survey data shows that during the period 1968 to 1974, Kindaruma reservoir volume decreased at a rate of $1.13 \times 10^6 \text{ m}^3$ per year. Kamburu reservoir volume decreased by $2.65 \times 10^6 \text{ m}^3$ per year during the first seven years of its life. This value compares very favourably with the change in volume of Kamburu reservoir calculated by EPDC of $2.34 \times 10^6 \text{ m}^3/\text{year}$. Their calculations were based on a series of annual surveys of eight and, in 1980, eleven range lines which are shown on the relevant Kamburu cross-sections. In some cases the shape of the EPDC section looks similar to that recorded in 1981 but with a slight distortion. This is thought to be the result of taking slightly different range line locations for the two surveys.
- 11.3 In their paper, Dunne and Ongweny⁽⁶⁾ suggest that a sedimentation rate of between 2 and 3 million tonnes per year seemed probable for Kamburu reservoir. Converting this mass into a volume gives rise to some problems but if, for the sake of continuity, it is assumed that the density is in the range 680 to 1250 kg/m³ (the range of values used in paragraphs 10.5 and 10.6), their volume change covers a range of 1.6 to $4.4 \times 10^6 \text{ m}^3/\text{year}$.
- 11.4 The mean value is higher than that measured by HR for Kamburu reservoir ($2.60 \times 10^6 \text{ m}^3/\text{year}$) but the result is highly dependent on the value of sediment density chosen for the calculation. However, the results are seen to be in the same order and only a slight increase in density is required to make them match.
- 11.5 The second question raised in paragraph 10.1 required an understanding of the basic mechanics which are involved when sediment is deposited in a reservoir. These are described in Section 9 when the concepts of consolidation with depth and time are introduced. Table 7 presents values of catchment sediment yield calculated from the reservoir survey data by eight methods which successively aim to improve the estimates; the final approach makes allowance for changes in density of the deposited sediments with both time and depth of deposits. Figure 55 shows a plot of four of the analytical methods summarised in Table 7.
- 11.6 It is apparent that analytical methods 7 and 8 show the most realistic patterns of sediment yield in view of the variability of the river discharge data presented in Fig 52. The main difference between the methods is the magnitude of the calculated yield for the period 1978-81 which is much lower when the effects of consolidation are not allowed for.
- 11.7 At this stage the catchment sediment yields calculated by method 8 represent our best estimates of the average values over the periods 1968-74, 1974-78 and 1978-81. Table 7 and Fig 55 show these values to be 416, 715 and 330 m³/km/year respectively, that is approximately 0.4, 0.7 and 0.3mm/year.

- 11.8 Sections 6-9 of the report explain in detail the assumptions that have been necessary in undertaking the calculations of catchment sediment yields. The values quoted in paragraph 11.7 and Table 7 should be viewed at present with these assumptions in mind. Further work is planned to refine the estimates when more data are available. In particular the reservoir surveys planned for mid-1982 are to be extended to obtain data on the densities of sediment deposits (paragraph 12.1) which should provide a more accurate basis on which to compute the effects of consolidation.

12 Possible future work

- 12.1 The next reservoir survey in this series is planned to take place in June/July 1983 and it is hoped to include in-situ bed density measurements using a gamma probe, and the collection of sediment samples for grain size analysis. A detailed study of these data, together with the rainfall and inflow data collected by the Hydrology section of MOWD should enable the catchment sediment yield estimates to be refined.
- 12.2 An idealised numerical model has been constructed at HR which determines what proportion of the incoming sediment is trapped in a reservoir, and how it is distributed. Using the data which will be available from Kamburu, it is hoped that the mathematical model may be expanded to cover the more complicated bifurcated shape of Kamburu and to compare its results with the EPDC and HRS surveys. When completed, the model will be used to calculate more accurate trap efficiencies and catchment yields, and to predict the reservoir's useful life.

13 Acknowledgements

- 13.1 The reservoir surveys and data analysis described in this report form part of an investigation by the Overseas Development Unit (ODU) of Hydraulics Research (HR) in collaboration with the Tana and Athi Rivers Development Authority (TARDA), the Ministry of Water Development (MOWD), and the East Africa Power and Lighting Co Ltd (EAPL).
- 13.2 TARDA provided all installation expenses for the river monitoring study and supplied road transport, boats and accommodation throughout the survey and for all the ODU site visits. Their input was originally headed by Mr J D Hamilton and was latterly under the control of Mr M M Gateri.
- 13.3 MOWD were responsible for the design of river monitor housing, and supervision of the manufacture and installation. Staff from the Reservoir Sedimentation Investigation Unit, under the Chief Hydrologist, Mr S H Charania, have carried out the fluvial data collection and instrument maintenance. MOWD staff also took part in the reservoir surveys.
- 13.4 EAPL arranged for, and financed, the design and construction of Kindaruma and Kamburu end-of-section markers, and made power station staff available to assist with the hydrographic surveys. They also supplied historical data relating to the reservoir sites, together with

current data on water usage. The EAPL interest was formerly controlled by Mr R I Trelease whose place has recently been taken by Mr N K Gichuki.

- 13.5 All of the collaborative organisations have supplied valuable advice and assistance throughout this investigation which would not be possible without their full co-operation.
- 13.6 The author acknowledges the value of discussions held with Engineering and Power Development Consultants Ltd, and with Hunting Surveys Ltd.
- 13.7 The author also acknowledges with gratitude the help and advice given to this project by Mr D W Holmes.
- 13.8 The hydrographic survey in 1981 was carried out under the supervision of an HR surveyor, Mr J C M Binks. Much of the data analysis was completed at HR by Mr C R Talbot.
- 13.9 This work was carried out in Mr D W Holmes' section of the Overseas Development Unit at Hydraulics Research Ltd, Wallingford. The Unit is headed by Dr K Sanmuganathan and its input to this investigation is funded by the Overseas Development Administration of the Foreign and Commonwealth Office.

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Appendices

Appendix 1

Equipment and personnel involved in the 1981 reservoir surveys

Equipment The main items of equipment necessary to carry out the hydrographic survey were shipped out to Kenya in advance and included:

- (i) *Portable echo-sounder*
Raytheon Fathometer DE-719 B
- (ii) *Theodolite*
Zeiss Theo 080 A
- (iii) *VHF radios*
Nolton Sabre fixed to frequency of 87.225 MHz
- (iv) *Surveying sextant*
Kelvin Hughes
- (v) *1m square flourescent boards*
Scotchcal mounted on hardboard.

In addition to the above, the following items were supplied by the collaborative organisations:-

- (i) *3m inflatable boat*
Zodiac
- (ii) *10HP outboard motor*
Chrysler
- (iii) *4.3m fibreglass boat*
Dory
- (iv) *12v car batteries*

Personnel Although the personnel and number available varied during the course of the survey, the main staff were:-

Mr J C M Binks — HR surveyor and officer-in-charge

Mr E M Chege — Hydrologist, MOWD, Nairobi

Mr P Oloo — Hydrologist, MOWD, Embu

Mr Kilan — locally employed coxwain

Mr Mathui — Driver, TARDA, Nairobi

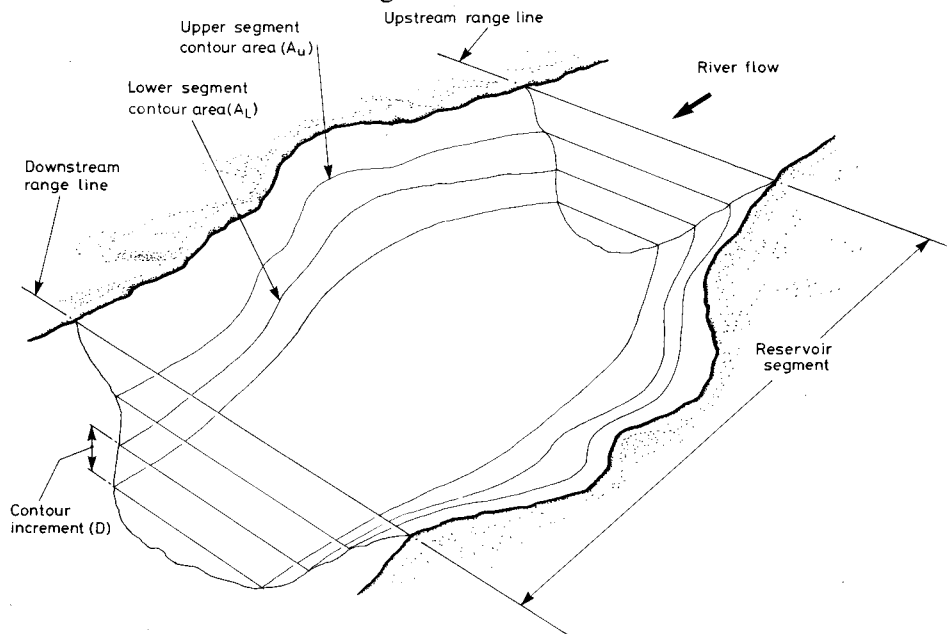
In addition to those people named above, two technicians were provided by EAP&L to assist with the survey work.

Appendix 2

Contour slicing technique

A2.1 The terms used in this Appendix are defined as follows:-

Range line	the line across which reservoir bed levels are measured.
Cross-section area	the area of a vertical plane below a range line, bounded by a defined top contour and the reservoir bed.
Segment volume	the volume of part of a reservoir contained between two given cross-sections and below a defined contour.
Sub-segment volume	the segment volume contained between two defined contours (contour slice).
Sub-segment end area	the cross-section area bounded between two defined contours.
Contour area	the area of a plane surface contained within a defined contour.
Segment contour area	contour area contained within two given range lines.



Contour slicing technique — definition sketch

A2.2 The initial storage volume of the reservoir is calculated using data taken from contour maps. Considering a segment of a reservoir:

Let:

A_U = upper segment contour area

A_L = lower segment contour area

D = vertical increment between contours

V'_{os} = initial sub-segment volume.

Then:

$$V'_{os} = (A_U + A_L) \times \frac{1}{2} D$$

The initial segment volume (V_{os}) is then the summation of all the sub-segment volumes bounded by the defined range lines:

$$V_{os} = \Sigma V'_{os}$$

and similarly, the total initial reservoir volume (V_o) is the summation of all the segment volumes.

$$V_o = \Sigma V_{os}$$

- A2.3 If, for each sub-segment, the volume (V'_{os}) is divided by the sum of the upstream and downstream sub-segment end areas (a'_u and a'_d) then the resulting ratio (C) is known as the Constant Factor for the given sub-segment and remains unchanged throughout the life of the reservoir

$$C = \frac{V'_{os}}{(a'_u + a'_d)}$$

Once this factor is determined for each sub-segment, it is only necessary to multiply it by the sum of the corresponding sediment end areas — obtained from subsequent reservoir surveys using the same range lines — to determine the change in volume of the sub-segment.

Appendix 3

Calculation of catchment sediment yields using Brune's curves

A3.1 This calculation is based on three periods of time:-

- i) 1968-74 — Kindaruma reservoir only
- ii) 1974-78 — Kindaruma and Kamburu reservoirs
- iii) 1978-81 — Kindaruma, Kamburu and Gitaru reservoirs

The site data used in this Appendix were taken from TARDA publicity. Where data were not available to the author at the time of writing this report, assumptions were made and these are defined at the beginning of the section in which they are first used.

A3.2 First period — 1968-74

Kindaruma reservoir study

a) The catchment area of Kindaruma reservoir is assumed to be 10 000km² by inspection of available charts.

b) The annual river flow is assumed to be 3560 x 10⁶ m³/year on the basis that the long term average river flows for Masinga and Kamburu convert to 0.353 x 10⁶ m³/km²/year and 0.358 x 10⁶ m³/km²/year respectively.

Catchment area (estimated)	A	= 10 000km ²
Annual river flow (estimated)	I	= 3560 x 10 ⁶ m ³ /year
Reservoir volume (mean)	C	= 14.91 x 10 ⁶ m ³
Capacity/inflow ratio	C/I	= 0.004
Brune's trap efficiency		= 22%
Total sediment volume retained		= 6.84 x 10 ⁶ m ³
Annual accretion rate		= 1.13 x 10 ⁶ m ³
Therefore:		
Sediment input rate		= $\frac{1.13 \times 10^6}{0.22}$ m ³ /year
		= 5.14 x 10 ⁶ m ³ /year

hence:

Sediment output rate	= (5.14 - 1.13) x 10 ⁶ m ³ /yr
	= 4.01 x 10 ⁶ m ³ /year

it therefore follows that:

Catchment sediment yield	= 514 m ³ /km ² /year
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A3.3 Second period — 1974-78

Kamburu reservoir

a) The “mean” and “total” reservoir volumes are based on the 1981 survey values as given in paragraph 6.2. All the volumes are therefore based on a seven year period in order to obtain annual rates.

Catchment area	A	= 9520 km ²
Annual river flow	I	= 3406 x 10 ⁶ m ³ /year
Reservoir volume (mean)	C	= 136.74 x 10 ⁶ m ³
Capacity/inflow ratio	C/I	= 0.040
Brune's trap efficiency		= 73%
Total sediment volume retained		= 18.55 x 10 ⁶ m ³
Annual accretion rate		= 2.65 x 10 ⁶ m ³ /year

therefore:

$$\begin{aligned}\text{Sediment input rate} &= \frac{2.65 \times 10^6}{0.73} \text{ m}^3/\text{year} \\ &= 3.63 \times 10^6 \text{ m}^3/\text{year}\end{aligned}$$

hence:

$$\begin{aligned}\text{Sediment output rate} &= (3.63 - 2.65) \times 10^6 \text{ m}^3/\text{yr} \\ &= 0.98 \times 10^6 \text{ m}^3/\text{year}\end{aligned}$$

it therefore follows that:

$$\text{Catchment sediment yield} = 381 \text{ m}^3/\text{km}^2/\text{year}$$

Kindaruma reservoir

a) Following the assumption that all the sediment was trapped during the first six-year period, Kindaruma is now considered to be at its 1981 volume.

$$\begin{aligned}\text{Catchment area} \quad A &= 10\,000 \text{ km}^2 \\ \text{Annual river flow} \quad I &= 3560 \times 10^6 \text{ m}^3/\text{year} \\ \text{Reservoir volume} \quad C &= 11.59 \times 10^6 \text{ m}^3 \\ \text{Capacity/inflow ratio} \quad C/I &= 0.003 \\ \text{Brune's trap efficiency} &= 14\% \\ \text{Sediment inflow from Kamburu} &= 0.98 \times 10^6 \text{ m}^3/\text{year} \\ \text{Sediment inflow from catchment} &= 480 \text{ km}^2 \times 381 \text{ m}^3/\text{km}^2/\text{year} \\ &= 0.18 \times 10^6 \text{ m}^3/\text{year}\end{aligned}$$

therefore:

$$\text{Sediment input rate} = 1.16 \times 10^6 \text{ m}^3/\text{year}$$

hence:

$$\begin{aligned}\text{Volume of sediment trapped} &= (1.16 \times 10^6) \times 0.14 \\ &= 0.16 \times 10^6 \text{ m}^3/\text{year}\end{aligned}$$

from which:

$$\begin{aligned}\text{Volume of sediment trapped during the four year period} &= 0.64 \times 10^6 \text{ m}^3\end{aligned}$$

A3.4 Third period 1978-81

Kamburu reservoir

The data produced in paragraph A3.3 was taken to be the mean values throughout the total period 1974-81 for Kamburu reservoir. The calculated sediment rates were:

$$\begin{aligned}\text{Sediment input rate} &= 3.63 \times 10^6 \text{ m}^3/\text{year} \\ \text{Sediment output rate} &= 0.98 \times 10^6 \text{ m}^3/\text{year} \\ \text{Catchment sediment yield} &= 381 \text{ m}^3/\text{km}^2/\text{year}\end{aligned}$$

Gitaru reservoir

a) Gitaru reservoir catchment area is based on a visual examination of the available charts.

b) The river flow is based on the long-term average runoff of $0.356 \times 10^6 \text{ m}^3/\text{km}^2/\text{year}$.

$$\begin{aligned}\text{Catchment area} \quad A &= 9750 \text{ km}^2 \\ \text{Annual river flow} \quad I &= 3471 \text{ m}^3/\text{year} \\ \text{Reservoir volume} \quad C &= 12 \times 10^6 \text{ m}^3/\text{year} \\ \text{Capacity/inflow ratio} \quad C/I &= 0.003\end{aligned}$$

Brune's trap efficiency	= 14%
Sediment inflow from Kamburu	= $0.98 \times 10^6 \text{m}^3/\text{year}$
Sediment inflow from catchment	= $230 \text{km}^2 \times 381 \text{m}^3/\text{km}^2$ = $0.088 \times 10^6 \text{m}^3/\text{year}$

Therefore:

Sediment input rate	= $1.07 \times 10^6 \text{m}^3/\text{year}$
hence:	
Volume of sediment trapped	= $(1.07 \times 10^6) \times 0.14$ = $0.15 \times 10^6 \text{m}^3/\text{year}$

and:

Sediment output rate	= $0.92 \times 10^6 \text{m}^3/\text{year}$
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<i>Kindaruma reservoir</i>	Catchment area	A	= $10\,000 \text{km}^2$
	Annual river flow	I	= $3560 \times 10^6 \text{m}^3/\text{year}$
	Reservoir volume	C	= $11.59 \times 10^6 \text{m}^3$
	Capacity/inflow ratio	C/I	= 0.003
	Brune's trap efficiency		= 14%
	Sediment inflow from Gitaru		= $0.92 \times 10^6 \text{m}^3/\text{year}$
	Sediment inflow from catchment		= $250 \text{km}^2 \times 381 \text{m}^3/\text{km}^2/\text{year}$ = $0.095 \times 10^6 \text{m}^3/\text{year}$

therefore:

Sediment input rate	= $1.02 \times 10^6 \text{m}^3/\text{year}$
hence:	
Volume of sediment trapped	= $(1.02 \times 10^6) \times 0.14$ = $0.14 \times 10^6 \text{m}^3/\text{year}$

from which:

Volume of sediment trapped during the three year period	= $0.43 \times 10^6 \text{m}^3$
---	---------------------------------

A3.5 1968-74

It is now possible to return to the first period to review the figures for Kindaruma reservoir.

<i>Kindaruma reservoir</i>	Using data from paragraphs A3.3 and A3.4 above, it is seen that $0.64 \times 10^6 \text{m}^3 + 0.43 \times 10^6 \text{m}^3 = 1.07 \times 10^6 \text{m}^3$ of sediment were trapped during the period 1974-81.
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It is therefore possible to re-work the analysis for the period 1968-74 — period i), paragraph A3.2 — with a more accurate estimate of the sediment trapped during this period.

Catchment area	A	= $10\,000 \text{km}^2$
Annual river flow	I	= $3560 \times 10^6 \text{m}^3/\text{year}$
Reservoir volume (mean)	C	= $15.45 \times 10^6 \text{m}^3$
Capacity/inflow ratio	C/I	= 0.004
Brune's trap efficiency		= 22%

Total sediment volume
retained

$$= 5.72 \times 10^6 \text{m}^3$$

Annual accretion rate

$$= 0.96 \times 10^6 \text{m}^3/\text{year}$$

therefore:

Sediment input rate

$$= \frac{0.96 \times 10^6}{0.22} \text{m}^3/\text{year}$$

$$= 4.37 \times 10^6 \text{m}^3/\text{year}$$

hence:

Sediment output rate

$$= (4.37 - 0.96) \times 10^6 \text{m}^3/\text{yr}$$

$$= 3.41 \times 10^6 \text{m}^3/\text{year}$$

It therefore follows that:

Catchment sediment yield

$$= 437 \text{m}^3/\text{km}^2/\text{year}$$

Tables

TABLE 1 - Kindaruma reservoir survey data – June/July 1981

Notes:

- 1. Distances and levels taken from HRS survey 1981.
- 2. RB = Right Bank, LB = Left Bank.
- 3. Distance (metres) measured from left hand beacon looking downstream.
- 4. Levels (metres) relative to Kenya Datum.
- 5. Co-ordinates apply to a Plane Local Engineering Grid.
- 6. * = top of survey beacon, † = bottom of survey beacon.

Section K1

Length of section = 230.768 m

RB beacon co-ordinates = 4394.041, 5059.330

LB beacon co-ordinates = 4288.175, 5261.382

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*783.97	67	781.0	148	779.7
0	†782.67	72	779.7	158	779.7
7	781.87	104	779.9	163	779.6
13	781.42	111	780.1	166	779.3
29	781.00	113	779.9	169	779.4
31	780.10	116	779.5	182	779.4
41	779.4	121	779.9	190	779.4
45	779.5	127	780.0	194	778.2
48	779.3	130	779.8	210	777.8
51	779.7	134	779.9	217	777.6
55	779.2	137	779.7	226	781.4
62	780.1	140	779.9	228	782.9
64	780.0	145	780.0	231	†782.08
				231	*783.38

Section K2

Length of section = 301.422m

RB beacon co-ordinates = 4658.181, 5258.709

LB beacon co-ordinates = 4781.678, 5533.670

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*783.23	101	774.8	210	777.4
0	†781.93	109	775.1	215	777.4
2	781.27	115	775.4	219	777.2
4	780.42	122	775.6	224	777.4
20	778.5	129	775.7	225	777.2
23	778.4	136	775.8	230	777.4
27	778.6	142	775.9	235	777.7
39	779.2	150	775.9	241	778.4
49	779.1	158	776.0	250	778.6
53	779.1	164	776.2	254	778.5
57	778.1	171	776.2	260	778.8

TABLE 1 - Section K2 (Cont'd)

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
62	777.3	179	776.4	265	779.1
68	776.6	186	776.4	275	779.7
75	775.4	190	776.2	280	780.1
81	774.7	194	776.4	287	780.42
84	774.4	197	776.5	293	780.77
87	774.5	200	776.4	301	†781.09
93	774.6	206	776.9	301	*782.39

Section K3

Length of section = 386.870m

RB beacon co-ordinates = 5372.964, 5394.913

LB beacon co-ordinates = 5047.159, 5603.526

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*783.15	137	775.9	306	775.9
0	†781.85	145	775.9	313	776.4
2	781.52	157	776.0	327	777.7
3	781.10	168	776.3	331	778.4
9	780.28	180	776.3	337	778.7
14	779.3	186	776.7	342	779.3
29	778.7	190	776.5	359	779.5
34	778.2	201	777.0	367	779.9
42	778.3	211	777.1	376	780.28
54	778.3	219	776.7	383	781.20
69	778.4	230	776.5	384	781.68
83	778.4	240	776.3	387	†781.59
99	778.2	250	776.2	387	*782.89
114	777.8	261	776.1		
120	777.6	272	776.0		
129	776.9	283	776.0		
131	776	294	775.9		

Section K4

Length of section = 539.830m

RB beacon co-ordinates = 5574.572, 5606.418

LB beacon co-ordinates = 5540.887, 6145.196

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*782.77	214	778.8	417	773.9
0	†781.47	224	778.9	420	773.8
5	781.07	235	779.9	422	773.6
11	780.30	247	779.0	423	773.8
21	778.9	261	778.9	434	773.8
57	777.9	268	778.9	440	773.8
59	777.6	273	778.7	444	774.1
62	777.7	285	777.6	446	775.1
92	777.1	295	777.3	452	775.9
94	776.9	307	777.0	455	776.2
103	777.1	319	776.0	456	776.6

TABLE 1 - Section K4 (Cont'd)

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
111	777.1	328	775.2	474	777.2
124	777.5	338	774.7	485	777.9
145	777.7	349	774.4	502	778.4
153	777.8	360	774.1	517	778.7
155	778.0	374	773.9	523	779.7
160	777.9	385	773.8	526	780.3
168	778.7	399	773.8	533	781.17
181	778.7	408	773.8	540	†781.3
204	778.8	413	773.6	540	*782.6

Section K5

Length of section = 551.360m

RB beacon co-ordinates = 6131.429, 5825.573

LB beacon co-ordinates = 5672.262, 6130.800

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*782.76	200	776.3	389	775.9
0	†781.46	216	775.5	401	775.8
5	780.96	229	775.5	410	776.1
11	780.26	240	774.8	414	776.5
23	779.5	255	773.6	422	776.6
36	779.3	258	773.5	429	777.2
44	779.1	262	773.8	449	777.4
57	778.4	269	773.8	460	777.3
70	778.1	285	774.0	475	776.3
82	777.6	297	774.2	489	776.5
97	777.0	315	774.2	501	776.7
112	776.6	331	774.3	510	777.1
127	776.5	343	774.3	516	777.8
140	776.4	351	774.9	522	778.8
158	776.6	355	775.3	541	780.26
174	777.0	360	775.5	551	†781.47
188	777.5	373	775.6	551	*782.77

Section K6

Length of section = 425.894m

RB beacon co-ordinates = 6481.521, 6426.064

LB beacon co-ordinates = 6154.345, 6698.721

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*782.8	127	774.4	287	772.3
0	†781.5	130	774.2	297	772.3
6	781.07	139	774.0	306	772.4
12	780.23	145	773.2	320	772.7
15	779.6	149	773.3	328	774.0
37	778.6	164	773.8	341	775.0
47	777.7	172	773.9	355	775.5
59	777.1	191	773.8	374	776.1
70	776.6	203	773.6	383	777.1
79	776.1	206	772.8	389	777.7

TABLE 1 - Section K6 (Cont'd)

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
90	776.0	212	772.5	394	779.0
103	776.1	237	772.2	419	780.23
113	776.3	245	772.1	422	780.81
119	776.0	255	772.1	426	†781.1
123	775.4	269	772.2	426	*782.4

Section K7

Length of section = 458.249m

RB beacon co-ordinates = 7000.000, 7000.000

LB beacon co-ordinates = 6725.594, 7367.006

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*782.64	148	771.5	289	773.6
0	†781.34	156	771.5	298	774.0
2	781.17	165	771.5	310	774.4
4	780.71	174	771.4	316	774.8
9	780.23	184	770.9	323	775.2
19	779.0	194	770.7	332	775.5
35	778.6	203	770.5	338	775.9
49	777.9	205	770.8	351	776.2
57	777.0	209	770.4	361	776.5
65	776.4	214	770.4	365	776.9
73	775.9	225	770.2	372	777.3
80	775.5	233	770.2	381	777.6
87	775.2	241	770.2	386	778.2
98	774.9	250	771.5	397	778.5
103	774.8	253	771.8	406	778.8
111	774.5	258	771.4	411	779.1
119	774.4	266	772.1	415	779.7
126	773.8	272	772.3	432	780.23
131	773.0	274	771.8	445	781.01
133	773.0	278	771.6	458	†781.32
141	771.8	281	773.2	458	*782.62

Section K8

Length of section = 997.522

RB beacon co-ordinates = 7000.000, 7000.000

LB beacon co-ordinates = 7341.173, 7937.364

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*782.78	322	768.5	679	773.4
0	†781.48	323	769.4	686	773.6
24	780.16	328	768.9	699	773.9
45	779.3	337	769.7	713	774.4
56	778.5	347	770.0	724	774.7
69	777.9	356	770.3	737	775.2
79	777.5	366	770.4	749	775.4
89	777.0	378	770.7	757	775.4
97	776.7	387	770.8	766	775.3

TABLE 1 - Section 8 (Cont'd)

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
105	776.2	397	770.9	775	775.4
114	775.9	406	771.2	783	775.7
128	775.5	414	771.4	790	776.0
139	775.2	427	771.6	799	776.1
152	774.4	435	771.7	803	776.3
165	774.2	447	771.7	814	776.3
171	774.3	457	771.8	825	776.2
177	774.0	466	771.9	831	776.0
202	773.7	487	772.1	855	775.7
213	773.5	496	772.2	862	775.4
223	773.4	505	772.2	870	775.0
233	773.3	514	772.2	876	774.9
241	773.3	525	772.1	885	775.0
249	773.2	534	771.9	894	775.2
259	773.1	547	771.7	895	775.4
270	773.0	558	771.6	909	775.9
271	772.9	569	771.5	920	776.5
272	773.0	578	771.3	928	777.0
280	772.8	589	771.2	936	777.4
283	773.1	599	771.2	942	777.9
289	773.0	609	771.2	950	778.2
297	771.8	620	771.2	964	778.5
298	772.0	632	771.2	969	779.1
302	772.3	639	771.2	971	779.7
306	771.1	642	770.8	983	780.16
308	770.5	645	770.9	990	780.63
311	770.5	658	771.2	998	†781.32
315	769.2	669	771.7	998	*782.62
318	768.5	676	773.2		

Section K9

Length of section = 593.284m

RB beacon co-ordinates = 7000.000, 7000.000

LB beacon co-ordinates = 7593.186, 7010.760

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*783.28	190	769.8	439	770.1
0	†781.98	206	770.1	445	769.9
2	781.30	213	770.2	450	769.2
9	780.76	219	770.2	461	769.1
16	780.7	228	770.0	472	769.3
35	779.3	245	769.7	480	770.4
46	778.1	257	769.6	486	770.5
57	777.2	269	769.8	489	770.8
71	776.3	280	770.2	492	774.1
81	775.5	293	770.1	494	774.6
96	774.8	304	770.3	510	775.9
106	774.0	316	770.6	520	776.5
113	773.4	331	770.6	525	777.2
127	772.9	341	770.6	539	777.9
138	772.5	353	770.5	552	778.5
143	771.0	375	770.6	559	779.2
152	770.4	387	770.6	574	779.6
159	769.8	401	770.3	-	780.07
168	769.6	417	770.3	585	780.45
176	769.6	429	770.3	593	†781.32
				593	*782.62

TABLE 1 (Cont'd)

Section K10

Length of section = 525.051m

RB beacon co-ordinates = 5372.964, 5394.913

LB beacon co-ordinates = 4952.171, 5080.888

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*782.47	114	780.10	300	779.96
0	†781.17	126	780.10	326	779.96
4	780.93	139	780.03	344	780.01
8	780.46	151	780.10	375	779.49
19	780.11	162	780.02	396	779.24
32	780.14	178	780.33	410	779.34
43	780.13	193	780.19	430	779.94
53	780.14	199	780.16	453	779.89
65	780.12	216	780.14	475	779.94
77	780.09	230	780.13	510	779.94
89	780.08	250	780.09	518	780.84
102	780.10	277	780.06	525	†781.59
				525	*782.89

TABLE 2 - Kamburu reservoir survey data — June/July 1981

Notes:

- 1. Distances and levels taken from HRS survey 1981.
- 2. RB = Right Bank, LB = Left Bank.
- 3. Distance (metres) measured from left-hand beacon looking downstream.
- 4. Levels (metres) relative to Kenya Datum.
- 5. Co-ordinates apply to a Plane Local Engineering Grid.
- 6. * = top of survey beacon, † = bottom of survey beacon.

Section TN1

Length of section = 115.281m

No co-ordinates available

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	† LB				
0	* LB				
3	1007.83	43	1004.80	83	1004.80
6	1006.80	47	1004.50	88	1005.00
17	1006.20	52	1004.40	93	1005.10
21	1005.90	57	1004.40	97	1005.30
21	1005.60	62	1004.40	103	1005.40
24	1005.50	67	1004.50	107	1005.70
34	1005.20	72	1004.40	113	1006.80
39	1004.90	78	1004.80	115	† RB
				115	*1008.70?

(No levels available for beacon tops)

Section TN2

Length of section = 145.135

No co-ordinates available

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	Beacon	55	1004.2	98	1004.3
10	1005.2	61	1004.2	105	1004.8
15	1004.9	66	1004.3	107	1006.8
23	1004.7	72	1004.4	112	1007.9
28	1004.3	79	1004.3	118	1007.2
32	1004.4	85	1004.0	126	1007.4
38	1004.2	88	1003.6	139	1008.1
43	1004.0	91	1003.8	142	1010.3
49	1004.0	96	1004.3	145	Beacon

(No levels available for beacon tops)

Section TN3

Length of section = 430-130m

TABLE 2 - Section TN3 (Cont'd)

RB beacon co-ordinates = 46066.858, 55813.814

LB beacon co-ordinates = 46434.584, 56036.950

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0 LB	*1008.54	25	1002.6	44	1003.6
0	†1007.24	26	1002.8	46	1004.0
3	1006.76	27	1002.9	49	1004.0
10	1005.8	28	1003.0	54	1004.1
12	1004.7	30	1003.0	60	1004.1
13	1004.1	32	1003.3	66	1004.4
15	1003.8	36	1003.3	71	1004.8
18	1003.7	38	1003.3	72	1006.6
21	1003.3	39	1003.5	76	1006.6
23	1002.8	41	1003.6		

Section TN4

Length of section = 415.162m

RB beacon co-ordinates = 46131.990, 55580.348

LB beacon co-ordinates = 46546.838, 55596.497

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.42	90	1002.6	229	1006.74
0	†1007.12	97	1002.7	273	1006.74
6	1006.90	101	1002.9	321	1006.16
27	1006.11	106	1003.0	328	1005.94
38	1005.3	112	1002.6	336	1006.27
52	1004.5	117	1002.8	346	1005.76
61	1004.3	121	1003.0	356	1006.11
68	1003.9	125	1004.6	388	1007.68
76	1003.3	131	1006.11	415	†1009.05
81	1002.9	175	1006.48	415	*1010.35
86	1002.7	199	1007.84		

Section TN5

Length of section = 190.151m

RB beacon co-ordinates = 45898.043, 55100.831

LB beacon co-ordinates = 46005.212, 54943.757

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.66	47	1003.5	114	1003.4
0	†1007.36	49	1003.1	114	1003.9
3	1006.92	55	1003.0	119	1004.7
8	1006.61	62	1002.6	125	1005.4
10	1005.97	71	1002.2	133	1005.5
19	1005.40	79	1002.5	142	1005.4
24	1004.4	86	1002.6	151	1005.4
35	1004.0	94	1002.7	158	1005.3
37	1003.7	97	1002.8	165	1005.5
40	1004.0	105	1002.6	173	1005.4
41	1004.0	113	1002.9	179	1005.6

TABLE 2 - Section TN5 (Cont'd)

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
				181	1005.9
				187	1006.72
				189	1007.6
				190	†1008.11
				190	*1009.41

Section TN6

Length of section = 229.016m

RB beacon co-ordinates = 45792.910, 54408.552

LB beacon co-ordinates = 45984.136, 54534.572

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.34	146	1002.9	194	1002.5
0	†1007.04	150	1002.1	201	1003.0
6	1006.8	160	1002.0	208	1003.5
18	1006.5	170	1001.9	214	1004.5
33	1006.5	174	1001.8	215	1005.75
58	1006.4	178	1001.9	217	1006.45
135	1003.4	182	1001.8	223	1006.70
144	1003.0	186	1001.9	229	†1007.04
				229	*1008.34

Section TN7

Length of section = 320.058m

RB beacon co-ordinates = 45733.272, 53914.675

LB beacon co-ordinates = 46048.696, 53860.411

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.40	81	1002.8	158	1003.5
0	†1007.10	84	1002.7	164	1005.4
4	1006.6	96	1002.3	181	1006.28
13	1005.8	105	1002.2	202	1006.34
19	1005.3	114	1002.0	220	1006.32
27	1004.7	123	1002.3	243	1005.86
40	1003.7	132	1002.1	303	1005.79
45	1003.1	140	1002.0	315	1006.87
57	1003.4	147	1001.6	318	1007.95
67	1002.8	154	1001.2	320	†1008.28
71	1002.8	157	1001.8	320	*1009.58

TABLE 2 - (Cont'd)

Section TN8

Length of section = 387.754

RB beacon co-ordinates = 45619.031, 53173.360

LB beacon co-ordinates = 45992.969, 53070.774

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.39	126	1003.9	299	1001.6
0	†1007.09	134	1004.1	303	1000.4
5	1006.61	147	1004.3	306	999.5
12	1005.93	169	1004.4	313	998.4
16	1005.60	191	1004.3	320	1000.9
36	1004.2	215	1004.0	327	1001.9
43	1003.8	225	1003.4	334	1003.1
56	1002.5	235	1003.4	362	1004.2
63	1002.1	245	1003.0	368	1005.6
79	1003.0	258	1003.3	375	1006.32
99	1003.8	271	1003.2	384	1007.33
109	1003.9	286	1002.9	388	†1007.85
119	1003.9	293	1002.4	388	*1009.15

Section TN9

Length of section = 304.614

RB beacon co-ordinates = 45333.109, 52784.194

LB beacon co-ordinates = 45309.501, 52480.496

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.27	80	1002.1	232	1000.9
0	†1006.97	89	1002.4	245	1001.8
3	1006.92	101	1003.0	249	1002.5
10	1009.91	113	1003.4	255	1002.7
16	1005.40	125	1003.6	261	1003.4
18	1004.8	136	1003.4	279	1003.9
34	1003.4	146	1003.1	285	1005.4
40	1002.7	170	1002.3	291	1006.49
40	1002.4	188	1001.7	297	1006.97
51	1002.2	194	1000.7	305	†1007.9
59	1002.3	198	1000.7	305	*1009.2
72	1002.2	220	1000.6		

TABLE 2 (Cont'd)

Section TN10 (L)

Length of section = 288.883m

RB beacon co-ordinates = 46110.462, 52292.549

LB beacon co-ordinates = 46345.034, 52461.159

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.132	106	991.3	193	995.8
0	†1006.832	112	991.4	204	996.9
7	1005.912	118	991.4	218	998.3
14	1004.932	123	993.3	232	1000.2
39	1003.7	135	994.4	244	1001.2
48	1001.2	145	994.6	259	1002.3
62	999.7	155	994.4	275	1004.9
74	997.4	165	993.8	279	1005.5
88	994.9	174	993.8	283	1006.3
94	993.0	184	994.6	289	†1007.00
101	992.4	189	994.9	289	*1008.30

Section TN10 (R) (*All these levels are suspect due to incorrect W/L being used*)

Length of section = 387.979m

RB beacon co-ordinates = 45656.068, 52365.467

LB beacon co-ordinates = 46043.449, 52343.933

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.94	142	1000.5	255	999.0
0	†1007.64	155	1000.3	272	999.3
27	1003.2	173	1001.1	282	999.5
42	1001.8	186	999.9	292	999.6
56	1000.6	197	999.7	311	999.9
69	999.9	212	999.5	322	1000.1
84	999.6	219	999.5	325	1000.7
99	999.9	226	999.1	334	1001.9
112	1000.2	235	998.9	341	1003.9
128	1000.3	245	998.9	388	†1008.48
				388	*1009.78

Section TN 11

Length of section = 701.106

RB beacon co-ordinates = 46318.403, 51521.417

LB beacon co-ordinates = 46872.444, 51951.055

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.37	264	990.4	547	996.9
0	†1007.07	281	988.9	567	998.6
5	1006.51	289	988.4	585	998.8
16	1005.62	316	988.6	602	1000.5
34	1005.3	344	988.7	612	1001.4
58	1003.2	359	989.0	627	1003.6
80	1001.8	373	991.2	636	1004.7

TABLE 2 - Section TN11 (Cont'd)

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
99	1000.1	378	991.7	646	1004.7
115	998.7	394	991.5	663	1005.62
142	996.6	420	991.3	688	1006.7
172	994.2	446	991.5	696	1007.1
198	992.1	468	991.1	697	1007.4
226	991.1	498	993.6	701	†1007.63
248	990.7	506	994.9	701	*1008.93

Section TN12

Length of section = 645.251m

RB beacon co-ordinates = 46951.680, 51104.348

LB beacon co-ordinates = 47176.811, 51709.042

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.55	200	986.9	440	994.4
0	†1007.25	214	984.7	463	996.1
4	1006.79	230	984.6	490	997.7
11	1005.88	248	984.7	515	990.0
19	1004.89	264	984.8	540	1000.4
23	1003.9	278	985.0	567	1001.5
43	1002.3	285	986.1	582	1002.7
60	1000.8	295	987.7	594	1004.89
77	998.8	306	988.3	613	1004.95
108	995.4	327	989.2	626	1005.84
129	992.9	350	989.8	638	1006.60
151	990.2	366	990.6	645	†1006.89
182	987.9	391	991.7	645	*1008.19
191	987.1	407	992.9		

Section TN13

Length of section = 1006.650m

RB beacon co-ordinates = 47495.262, 50819.044

LB beacon co-ordinates = 47712.954, 51801.874

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.2	377	986.2	763	1001.1
0	†1006.9	393	986.9	783	1000.1
103	1002.6	410	987.5	794	999.5
137	999.8	427	989.1	800	1000.0
161	997.2	465	991.9	802	999.8
185	994.9	486	994.3	830	998.4
215	991.5	548	997.4	848	998.5
241	988.5	555	998.2	869	990.0
274	985.1	571	998.3	882	1000.6
287	983.0	596	999.3	919	1001.7
304	982.9	622	1001.1	950	1002.7
312	983.2	630	1003.2	980	1004.5
339	984.1	681	1004.0	1007	†1007.49
354	983.9	738	1003.3	1007	*1008.79
366	983.9	742	1002.3		

TABLE 2 (Cont'd)

Section TN14

Length of section = 1438.844m

RB beacon co-ordinates = 47495.262, 50819.044

LB beacon co-ordinates = 48922.414, 51002.099

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.36	498	981.1	929	984.6
0	†1007.06	505	981.4	940	985.2
6	1006.51	550	980.3	993	986.2
11	1005.80	598	980.9	1049	985.3
19	1005.08	614	981.6	1057	985.3
64	1003.6	618	983.9	1069	986.8
105	1002.0	637	985.7	1080	987.5
140	999.5	651	986.5	1088	987.2
168	997.1	665	987.6	1140	989.0
211	993.6	682	986.6	1174	991.1
246	990.9	707	984.8	1245	994.0
270	989.7	727	984.3	1273	996.1
292	991.0	747	981.9	1325	998.3
305	991.6	770	981.4	1382	1001.4
338	991.4	776	983.6	1404	1003.7
372	990.6	789	985.6	1413	1005.08
401	988.7	808	985.0	1425	1005.81
437	986.1	840	933.8	1433	1006.59
459	984.8	848	984.0	1435	1007.08
471	984.8	887	984.6	1439	†1007.49
481	985.0	914	985.2	1439	*1008.79

Section TN15 (L)

Length of section = 602.203m

RB beacon co-ordinates = 48440.060, 50641.568

LB beacon co-ordinates = 48922.414, 51002.099

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.36	259	988.8	486	979.9
0	†1007.06	269	988.7	492	980.0
3	1006.23	280	989.4	509	979.2
8	1005.58	294	988.9	516	978.5
16	1004.76	311	989.1	521	979.1
47	1001.6	340	988.4	533	984.5
80	999.0	359	988.4	553	994.7
127	997.7	372	987.9	574	1004.76
138	994.7	400	986.9	587	1005.94
175	992.2	421	985.2	595	1006.69
205	990.5	442	983.9	602	†1007.29
226	989.9	461	980.7	602	*1008.59
239	989.5	480	980.7		

Section TN15 (R)

Length of section = 388.036

TABLE 2 - Section TN15 (R) (Cont'd)

RB beacon co-ordinates = 48133.317, 50301.086

LB beacon co-ordinates = 48376.850, 50603.185

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1011.12	125	986.0	261	995.1
0	†1009.82	135	986.0	284	997.1
16	1002.30	138	986.0	297	998.3
21	1001.4	151	986.6	302	1000.1
33	996.3	170	988.1	310	999.9
54	992.8	191	989.4	333	1002.3
77	990.3	213	991.3	350	1003.6
98	988.0	222	991.6	388	†1007.21
106	986.8	229	991.0	388	*1008.51
120	987.1	236	992.2		

Section TN16

Length of section = 861.743

RB beacon co-ordinates = 49352.499, 50299.133

LB beacon co-ordinates = 49430.834, 51157.308

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.1	293	989.4	587	985.1
0	†1006.8	316	986.3	622	987.4
4	1006.61	334	983.8	647	989.1
8	1005.88	353	980.8	661	991.2
12	1004.55	381	980.5	696	993.4
62	1003.8	395	978.1	740	995.0
78	1002.5	418	978.3	741	996.9
102	1001.6	430	979.1	763	998.3
121	999.8	447	979.1	777	999.9
144	998.7	456	978.2	832	1001.3
155	997.7	468	978.2	842	1004.55
177	996.9	477	976.9	849	1005.37
194	995.5	509	978.2	854	1006.26
219	994.3	524	980.6	855	1006.78
241	991.6	534	980.9	862	†1007.09
265	990.9	563	982.9	862	*1008.39

Section TN17

Length of section = 1035.139m

RB beacon co-ordinates = 50000.000, 50000.000

LB beacon co-ordinates = 50000.000, 51035.139

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.18	492	975.1	760	985.4
0	†1006.88	522	974.6	765	985.2
12	1006.35	551	977.9	777	986.2
26	1005.7	572	978.9	799	988.0
51	1004.64	593	980.2	823	990.0
104	1001.7	605	980.4	851	992.5

TABLE 2 - Section TN17 (Cont'd)

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
144	998.8	618	980.1	875	994.6
171	997.4	632	979.9	890	996.2
214	994.2	641	980.3	912	997.7
237	992.5	643	980.4	926	999.3
265	990.0	663	978.6	962	1001.0
291	987.6	688	976.9	982	1002.0
317	985.0	699	976.9	996	1003.2
337	982.6	711	979.0	1019	1004.65
373	977.6	722	981.0	1025	1005.30
393	977.4	733	981.3	1030	1006.04
414	977.1	739	981.8	1035	†1007.23
454	976.0	756	985.5	1035	*1008.53

Section TB1

Length of section = 288.993m

RB beacon co-ordinates = 50896.304, 56346.697

LB beacon co-ordinates = 50930.219, 56059.701

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.398	97	1003.0	189	1003.4
0	†1007.098	110	1004.1	203	1003.5
5	1006.24	122	1004.4	210	1003.5
13	1006.0	134	1004.6	218	1003.6
17	1005.3	140	1004.6	225	1004.0
22	1004.8	144	1004.1	229	1004.6
36	1003.3	146	1004.2	236	1005.1
42	1004.0	155	1003.8	242	1005.3
52	1003.3	160	1003.6	250	1005.9
60	1003.9	165	1003.7	278	1006.24
73	1004.0	173	1003.7	288	†1006.957
85	1004.0	180	1003.4	288	*1008.257

Section TB2

Length of section = 330.132m

RB beacon co-ordinates = 50262.878, 56190.396

LB beacon co-ordinates = 50349.472, 55871.823

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.45	82	1000.3	187	1001.1
0	†1007.15	85	1000.8	199	1001.1
9	1006.23	94	1000.9	216	1001.0
17	1005.2	102	1001.0	224	1001.2
33	1004.4	113	1001.0	236	1001.4
38	1003.2	125	1001.0	246	1001.7
45	1002.4	135	1001.0	259	1002.2
51	1002.0	145	1001.0	269	1002.9
57	1001.2	157	1001.0	285	1003.9
60	999.9	165	1001.1	298	1005.3
63	999.8	177	1001.1	321	1006.23
				330	†1007.30
					*1008.60

TABLE 2 (Cont'd)

Section TB3

Length of section = 521.106m

RB beacon co-ordinates = 49344.238, 55635.286

LB beacon co-ordinates = 49831.657, 55450.965

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.54	194	998.8	382	997.1
0	†1007.24	205	998.6	391	997.1
14	1006.37	216	998.4	405	997.0
25	1005.8	233	998.5	413	997.1
38	1005.1	242	998.5	419	997.3
55	1004.4	253	998.5	421	997.6
67	1003.9	265	998.5	431	999.4
75	1003.4	274	998.5	443	1000.6
87	1003.0	289	998.5	451	1001.4
98	1002.4	302	998.5	461	1002.1
106	1002.1	310	998.5	471	1002.9
118	1001.5	327	998.5	478	1003.8
128	1001.0	341	998.5	487	1004.6
146	1000.4	349	998.3	495	1005.4
158	1000.0	360	998.1	503	1005.9
172	999.6	366	997.8	510	1006.37
183	999.1	373	997.2	521	†1007.07
				521	*1008.37

Section TB4

Length of section = 377.008m

RB beacon co-ordinates = 49126.349, 55173.032

LB beacon co-ordinates = 49476.381, 55032.986

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.42	169	999.7	283	995.9
0	†1007.12	180	999.1	294	995.8
12	1006.4	192	998.7	307	995.6
42	1005.7	197	998.7	314	995.8
44	1005.1	206	998.5	321	997.3
67	1003.9	210	998.2	326	999.4
72	1003.5	215	998.2	333	1000.6
89	1002.8	226	998.1	341	1002.2
109	1001.5	236	998.0	352	1004.0
125	1001.4	243	998.0	362	1005.1
144	1000.7	245	997.7	369	1006.2
156	1000.2	258	997.1	372	1006.4
		270	996.7	377	†1006.86
		275	996.1	377	*1008.16

TABLE 2 (Cont'd)

Section TB5

Length of section = 472.174m

RB beacon co-ordinates = 48946.234, 54858.508

LB beacon co-ordinates = 49231.345, 54842.131

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.66	140	996.0	305	998.1
0	†1007.36	147	995.0	321	998.9
9	1006.63	154	995.2	334	999.4
15	1006.1	169	995.4	347	999.9
28	1004.8	184	995.4	362	1000.8
39	1003.5	187	995.4	382	1001.8
50	1002.3	190	995.6	396	1002.6
63	1000.9	195	996.4	413	1003.4
76	999.3	209	996.8	429	1004.6
90	998.2	222	996.8	457	1005.9
109	997.5	239	996.8	464	1006.63
123	997.1	252	996.9	472	†1008.11
131	997.1	264	997.1	472	*1009.41
136	997.2	283	997.4		

Section TB6

Length of section = 411.728m

RB beacon co-ordinates = 48597.509, 5455.585

LB beacon co-ordinates = 48843.696, 54229.567

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.35	204	999.6	337	994.0
0	†1007.05	211	996.2	342	994.1
5	1006.79	220	995.8	348	994.8
6	1006.48	229	995.7	357	997.2
87	1005.2	240	995.5	363	998.8
99	1004.7	249	995.5	375	1000.3
107	1004.1	258	995.6	385	1001.1
120	1003.1	268	995.8	390	1002.1
130	1002.3	276	996.0	403	1003.2
137	1001.5	284	996.2	408	1006.48
146	1000.7	286	996.2	410	1006.53
158	999.8	296	995.7	410	1006.87
166	999.1	302	994.2	412	†1007.04
175	998.3	311	994.0	412	*1008.34
184	997.7	319	994.1		
193	997.0	327	994.1		

TABLE 2 (Cont'd)

Section TB7

Length of section 473.715m

RB beacon co-ordinates = 48240.387, 53960.459

LB beacon co-ordinates = 48600.814, 53653.054

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.4	126	995.8	323	996.0
0	†1007.1	138	994.8	333	996.2
7	1006.43	151	994.1	346	996.8
13	1005.99	158	993.5	359	997.4
18	1005.4	166	992.0	374	998.4
23	1004.9	185	990.5	387	999.5
34	1004.0	201	990.0	397	1000.4
42	1003.2	217	990.2	411	1001.4
51	1002.4	233	991.5	425	1002.5
61	1001.6	241	992.7	433	1004.0
69	1000.8	246	993.4	451	1004.8
77	1000.2	260	994.1	474	†1008.28
88	999.5	275	994.4	474	*1009.58
100	998.3	287	994.8		
114	996.8	299	995.2		

Section TB8

Length of section 474.595m

RB beacon co-ordinates = 48011.752, 53322.934

LB beacon co-ordinates = 48472.142, 53207.688

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.39	173	993.4	315	992.8
0	†1007.09	184	993.6	320	993.4
4	1006.43	197	993.7	326	993.6
6	1006.26	209	993.5	336	994.1
26	1004.3	217	993.6	347	995.2
41	1003.2	219	993.8	357	996.1
61	1001.3	230	992.9	376	997.3
68	1000.0	241	992.3	398	999.2
86	998.2	252	991.7	413	1000.2
102	996.9	259	989.8	423	1002.0
114	996.4	266	989.5	431	1003.5
124	996.3	279	988.4	458	1004.3
134	995.5	290	988.0	470	1006.26
145	994.0	297	988.2	472	1006.65
159	993.6	302	989.1	475	†1007.94
				475	*1009.14

TABLE 2 (Cont'd)
Section TB9

Length of section = 1252.901m

RB beacon co-ordinates = 47741.689, 52616.207

LB beacon co-ordinates = 48991.000, 52521.430

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.24	296	988.8	875	1003.1
0	†1006.94	314	990.1	902	1002.5
4	1006.62	341	989.9	923	1001.3
35	1005.9	364	989.6	946	999.6
53	1004.9	394	990.1	969	997.6
70	1004.3	423	991.1	987	995.5
82	1003.7	436	992.0	1007	993.6
90	1002.6	459	992.4	1024	992.1
106	1001.9	474	992.3	1046	990.5
116	1001.5	500	991.4	1052	990.2
132	1000.5	522	990.2	1066	990.8
141	1000.0	545	989.2	1086	992.8
150	998.8	552	988.8	1088	993.5
169	996.7	582	990.0	1095	993.3
185	994.8	602	990.9	1104	993.7
196	993.3	625	992.5	1120	995.2
208	990.7	649	993.8	1134	998.0
216	989.0	681	995.7	1159	1000.6
224	984.9	710	997.1	1190	1000.2
232	983.1	730	998.0	1204	1003.2
243	983.1	753	998.9	1233	1004.4
254	983.5	778	1000.1	1248	1006.62
264	986.1	799	1001.1	1249	1007.17
271	988.6	819	1001.9	1252	†1007.42
288	988.7	847	1002.8	1252	*1008.72

Section TB10

Length of section = 731.872m

RB beacon co-ordinates = 47723.109, 52313.361

LB beacon co-ordinates = 48433.034, 52135.834

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.32	322	987.7	476	987.2
0	†1007.02	337	987.7	484	987.2
6	1006.5	342	987.5	490	988.1
20	1006.2	348	987.0	497	988.6
31	1005.4	354	986.9	507	989.1
43	1004.5	362	987.1	523	990.3
59	1003.5	371	983.5	535	991.3
73	1002.4	377	983.9	546	992.5
92	1001.3	379	984.4	562	993.5
110	999.9	389	983.0	578	994.8
125	998.8	400	983.0	591	995.8

TABLE 2 (Cont'd)

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
139	997.5	409	983.9	610	997.2
160	996.2	410	983.7	621	998.1
178	994.7	415	983.4	632	999.2
196	993.2	422	984.3	646	1000.3
217	991.7	427	986.5	665	1001.7
232	990.1	435	987.6	718	1004.0
250	989.0	437	987.8	726	1006.5
266	987.9	448	987.9	732	†1007.97
279	987.4	455	987.9	732	*1009.27
294	987.0	462	987.7		
307	987.3	470	987.3		

Section TB11

Length of section = 1092.065m

RB beacon co-ordinates = 47712.954, 51801.874

LB beacon co-ordinates = 48796.645, 51666.830

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.37	376	986.3	650	986.7
0	†1007.17	416	986.1	670	986.9
18	1004.2	444	985.2	705	988.2
60	1002.6	462	981.9	747	990.3
94	1000.9	488	981.9	796	991.8
114	998.7	510	981.9	848	993.2
143	995.7	532	982.4	881	994.7
199	992.7	544	982.4	953	996.4
239	991.4	556	985.9	987	998.2
280	989.4	573	986.4	1020	999.9
334	986.7	626	986.8	1092	†1007.63
				1092	*1008.93

Section TB12

Length of section = 1449.952

RB beacon co-ordinates = 47712.954, 51801.874

LB beacon co-ordinates = 48922.414, 51002.099

<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>	<i>Distance</i>	<i>Level</i>
0	*1008.55	622	981.2	1003	987.5
0	†1007.25	630	980.5	1008	987.2
95	1004.0	655	980.5	1018	985.9
119	1003.6	663	981.3	1033	986.1
148	1002.2	667	981.7	1039	986.1
176	999.3	680	985.1	1052	982.8
190	997.3	684	985.0	1065	982.5
198	997.2	689	984.8	1079	981.8
204	997.6	700	986.5	1093	981.8
232	999.8	711	986.2	1100	983.0
279	1002.6	740	988.9	1112	985.8
284	1002.5	756	991.0	1124	986.0
301	1002.4	762	990.8	1150	987.1
327	1002.0	768	990.9	1164	987.5
361	1000.3	806	991.6	1198	987.3
399	997.9	850	991.7	1230	989.1
428	995.5	888	991.5	1268	992.9
462	992.8	914	991.4	1302	996.5
496	989.9	923	992.2	1328	998.6
526	986.9	932	991.5	1354	1002.2
562	985.2	960	989.4	1375	1001.5
580	985.8	977	989.0	1392	1002.6
591	982.2	981	988.6	1411	1003.1
598	982.2	989	987.7	1421	1004.0
610	981.4			1450	†1006.90
				1450	*1008.20

TABLE 3 Kindaruma reservoir — areas and volumes, 1981

Sections	Upper contour (m KD)	Lower contour (m KD)	End areas		Sum of end areas (m ²)	Constant factor	1981 capacity (m ³)	Design capacity (m ³)	Sediment volume (m ³)	% loss of capacity
u/s — K1	781.20	777.24	340	0	340	250	85 000	193 489	108 489	79.85
	777.24	774.19	0	0	0	306	0	139 123	139 123	
	774.19	771.14	0	0	0	246	0	78 341	78 341	
	771.14	(769.62)	0	0	0	140	0	10 800	10 800	
							85 000	421 753	336 753	
K1 — K2	781.20	777.24	924	340	1264	299	377 936	543 878	165 942	64.09
	777.24	774.19	220	0	220	406	89 320	415 433	326 113	
	774.19	771.14	0	0	0	384	0	294 006	294 006	
	771.14	(769.92)	0	0	0	258	0	48 002	48 002	
							467 256	1 301 319	834 063	
K2 — K3	781.20	777.24	1216	924	2140	367	785 380	884 648	99 268	50.58
	777.24	774.19	189	220	409	430	175 870	615 877	440 007	
	774.19	771.14	0	0	0	349	0	376 782	376 782	
	771.14	(769.62)	0	0	0	263	0	67 569	67 569	
							961 250	1 944 876	983 626	
K3 — K4	781.20	777.24	1679	1216	2895	250	723 750	814 616	90 866	52.82
	777.24	774.19	419	189	608	300	182 400	635 628	453 228	
	774.19	771.14	30	0	30	261	7 830	378 882	371 052	
	771.14	(768.10)	0	0	0	153	0	108 078	108 078	
							913 980	1 937 204	1 023 224	
K4 — K5	781.20	777.24	1944	1679	3623	157	547 073	587 292	40 219	47.83
	777.24	774.19	584	419	1003	199	199 597	474 138	274 541	
	774.19	771.14	13	30	43	212	9 116	303 329	294 213	
	771.14	(768.40)	0	0	0	127	0	83 926	83 926	
							755 786	1 448 685	692 899	

TABLE 3 (Cont'd)

Sections	Upper contour (m KD)	Lower contour (m KD)	End areas		Sum of end areas (m ²)	Constant factor	1981 capacity (m ³)	Design capacity (m ³)	Sediment volume (m ³)	% loss of capacity
K5 – K6	781.20	777.24	1501	1944	3445	220	757 900	765 837	7 934	
	777.24	774.19	778	584	1362	288	392 256	576 637	184 381	
	774.19	771.14	248	13	261	303	79 083	375 914	296 831	
	771.14	(769.01)	0	0	0	211	0	94 876	94 876	
							1 229 239	1 813 261	584 022	32.21
K6 – K7	781.20	777.24	1563	1501	3064	342	1 047 888	1 044 842	3 046	
	777.24	774.19	791	778	1569	438	687 222	765 077	77 855	
	774.19	771.14	416	248	664	439	291 496	503 018	211 522	
	771.14	768.10	44	0	44	446	19 624	299 519	279 895	
	768.10	(767.18)	0	0	0	254	0	34 074	34 074	
							2 046 230	2 646 530	600 300	22.68
K7 – K8	781.20	777.24	3708	1563	5271	113	595 623	599 539	3 916	
	777.24	774.19	2168	791	2959	140	414 260	463 675	49 415	
	774.19	771.14	1125	416	1541	159	245 019	322 392	77 373	
	771.14	768.10	98	44	142	163	23 146	242 177	219 031	
	768.10	(766.27)	0	0	0	130	0	65 909	65 909	
							1 278 048	1 693 692	415 644	24.54
K8 – K9	781.20	777.24	2134	3708	5842	171	998 982	1 029 151	30 169	
	777.24	774.19	1330	2168	3498	238	832 524	908 345	75 821	
	774.19	771.14	1090	1125	2215	293	648 995	785 282	136 287	
	771.14	768.10	370	98	468	311	145 548	659 782	514 234	
	768.10	(765.96)	0	0	0	363	0	211 483	211 483	
							2 626 049	3 594 043	967 994	26.93
K9 – Dam	781.20	777.24	2134	2134	4268	103	439 604	469 134	295 30	
	777.24	774.19	1330	1330	2660	142	377 720	390 130	12 410	
	774.19	771.14	1090	1090	2180	141	307 380	328 440	21 060	
	771.14	768.10	370	370	740	136	100 640	262 689	162 049	
	768.10	(765.96)	0	0	0	205	0	80 222	80 222	
							1 225 344	1 530 615	305 271	19.95

TABLE 3 (Cont'd)

Total reservoir capacity = $11.59 \times 10^6 \text{ m}^3$ (base data volume = $18.33 \times 10^6 \text{ m}^3$)

Total volume of sediment = $6.75 \times 10^6 \text{ m}^3$

% loss of capacity = 58.49%

Note: The 1965 water surface area used in calculating constant factors for the upper sub-segment in each segment was taken from the 2560ft KD contour.

TABLE 4 Kamburu reservoir – areas and volumes, 1981

Sections u/s d/s	Upper contour (m KD)	Lower contour (m KD)	End areas		Sum of end areas Ao (m ²)	Constant factor (C)	1981 capacity (m ³)	Design capacity (m ³)	Sediment volume (m ³)	% loss of capacity
TN3-TN4	1005.84	1002.79	200	132	332	262	86 984	419 780	332 796	
	1002.79	999.74	2	0	2	316	632	263 756	263 124	
	999.74	(998.00)	0	0	0	377	0	<u>63 794</u>	<u>63 794</u>	
							87 616	747 330	659 714	88.28
TN4-TN5	1005.84	1002.79	286	200	486	560	272 160	623 410	357 250	
	1002.79	999.74	11	2	13	567	7 371	358 477	351 106	
	999.74	996.70	0	0	0	459	0	136 444	136 444	
	996.70	(995.55)	0	0	0	235	0	<u>8 677</u>	<u>8 677</u>	
							279 531	1 127 008	847 477	75.20
TN5-TN6	1005.84	1002.79	250	286	536	534	286 224	536 386	250 162	
	1002.79	999.74	37	11	48	459	22 032	365 919	343 887	
	999.74	996.70	0	0	0	509	0	238 145	238 145	
	996.70	(995.55)	0	0	0	656	0	<u>36 753</u>	<u>36 753</u>	
							308 256	1 177 203	868 947	73.81
TN6-TN7	1005.84	1002.79	478	250	728	553	402 584	721 167	318 583	
	1002.79	999.74	47	37	84	522	43 848	536 152	492 304	
	999.74	996.70	0	0	0	516	0	368 770	368 770	
	996.70	993.65	0	0	0	674	0	258 656	258 656	
	993.65	(991.70)	0	0	0	483	0	<u>71 974</u>	<u>71 974</u>	
							446 432	1 956 719	1 510 287	77.18
TN7-TN8	1005.84	1002.79	213	478	691	640	442 240	1 151 210	708 970	
	1002.79	999.74	78	47	125	620	77 500	872 991	795 491	
	999.74	996.70	8	0	8	565	4 520	603 057	598 537	
	996.70	993.65	0	0	0	443	0	351 413	351 413	
	993.65	(991.00)	0	0	0	316	0	<u>108 842</u>	<u>108 842</u>	
							524 260	3 087 513	2 563 253	83.02

TABLE 4 (Cont'd)

Sections u/s d/s	Upper contour (m KD)	Lower contour (m KD)	End areas		Sum of end areas Ao (m ²)	Constant factor (C)	1981 capacity (m ³)	Design capacity (m ³)	Sediment volume (m ³)	% loss of capacity
TN8-TN10/10A	1005.84	1002.79	1732	213	1945	495	962 775	1 380 450	417 675	
	1002.79	999.74	1410	78	1488	517	769 296	1 203 387	434 091	
	999.74	996.70	494	8	502	500	251 000	972 154	721 154	
	996.70	993.65	288	0	288	428	123 264	676 027	552 763	
	993.65	990.60	49	0	49	377	18 473	427 749	409 276	
	990.60	(988.80)	0	0	0	361	0	99 568	99 568	
							2 124 808	4 759 335	2 634 527	55.35
u/s - TN9	1005.84	1002.79	733	0	733	591	433 203	460 614	27 411	
	1002.79	999.74	154	0	154	423	65 142	265 321	200 179	
	999.74	996.70	0	0	0	209	0	105 679	105 679	
	996.70	993.65	0	0	0	120	0	34 442	34 442	
	993.65	(992.60)	0	0	0	140	0	2 519	2 519	
							498 345	868 575	370 230	42.62
TN10/10A - TN11	1005.84	1002.79	1873	1732	3605	571	2 058 455	2 011 448	-47 007	
	1002.79	999.74	1590	1410	3000	589	1 767 000	1 756 910	-10 090	
	999.74	996.70	1360	494	1854	573	1 062 342	1 494 227	431 885	
	996.70	993.65	1114	288	1402	529	741 658	1 234 202	492 544	
	993.65	990.60	737	49	786	517	406 362	961 878	555 516	
	990.60	987.55	178	0	178	918	163 404	733 206	569 802	
							0	400 955	400 955	
							0	30 253	30 253	
							6 199 221	8 623 079	2 423 858	28.11
TN11 - TN12	1005.84	1002.79	1829	1873	3702	829	3 068 958	2 936 606	-132 352	
	1002.79	999.74	1516	1590	3106	768	2 385 408	2 317 678	- 67 730	
	999.74	996.70	1287	1360	2647	680	1 799 960	1 800 880	920	
	996.70	993.65	1041	1114	2155	596	1 284 380	1 374 346	89 966	
	993.65	990.60	801	737	1538	543	835 134	986 942	151 808	
	990.60	987.35	492	178	670	540	361 800	633 201	271 401	
							107 415	371 461	264 046	
							0	166 471	166 471	
							0	18 994	18 994	
							9 843 055	10 606 579	763 524	7.20

TABLE 4 (Cont'd)

Sections u/s	d/s	Upper contour (m KD)	Lower contour (m KD)	End areas		Sum of end areas Ao (m ²)	Constant factor (C)	1981 capacity (m ³)	Design capacity (m ³)	Sediment volume (m ³)	% loss of capacity
TN12-TN13		1005.84	1002.79	d/s	u/s						
		1002.79	999.74	(m ²)	(m ²)	4575	391	1 788 825	1 699 175	- 89 650	
		999.74	996.70	1959	1516	3475	395	1 372 625	1 402 269	29 644	
		996.70	993.65	1347	1287	2634	379	998 286	1 138 971	140 685	
		993.65	990.60	1007	1041	2048	401	821 248	914 464	93 216	
		990.60	987.55	774	801	1575	394	620 550	711 489	90 939	
		987.55	984.50	583	492	1075	396	425 700	526 813	101 113	
		984.50	981.46	363	231	594	372	220 968	368 482	147 514	
		981.46	(978.55)	88	0	88	216	19 008	163 784	144 776	
				0	0	0	38	0	15 478	15 448	
								6 267 210	6 940 895	673 685	9.71
TN13 - TN14 TB12		1005.84	1002.79	4200	6979	11179	193	2 157 547	2 043 228	-114 319	
		1002.79	999.74	3926	5478	9404		2 003 052	2 009 628	6 576	
		999.74	996.70	3675	4290	7965	228	1 816 020	1 899 573	83 553	
		996.70	993.65	3224	3735	6959	231	1 607 529	1 660 622	53 093	
		993.65	990.60	2964	3032	5996	219	1 313 124	1 410 598	97 474	
		990.60	987.55	2294	2073	4367	247	1 078 649	1 184 153	105 504	
		987.55	984.50	1568	1072	2640	245	646 800	932 979	286 179	
		984.50	981.46	523	449	972	232	225 504	671 439	445 935	
		981.46	978.41	74	36	110	266	29 260	388 987	359 727	
		978.41	(977.15)	0	0	0	181	0	50 331	50 331	
								10 877 485	12 251 738	1 374 253	11.22
TN14-TN15/15A		1005.84	1002.79	2812	4200	7012	280	1 963 360	1 916 282	- 47 078	
		1002.79	999.74	2518	3926	6444	260	1 675 440	1 647 752	- 27 688	
		999.74	996.70	2223	3675	5898	238	1 403 724	1 408 242	4 518	
		996.70	993.65	1955	3224	5179	220	1 139 380	1 152 961	13 581	
		993.65	990.60	1652	2964	4616	183	844 728	882 957	38 229	
		990.60	987.55	828	2294	3122	184	574 448	664 848	90 400	
		987.55	984.50	388	1568	1956	163	318 828	482 855	164 027	
		984.50	981.46	247	523	770	151	116 270	314 052	197 782	
		981.46	978.41	100	74	174	220	38 280	192 274	153 994	
		978.41	(976.70)	0	0	0	197	0	42 782	42 782	
								8 074 458	8 705 005	630 574	7.24

TABLE 4 (Cont'd)

Sections	Upper contour (m KD)	Lower contour (m KD)	End areas		Sum of end areas Ao (m ²)	Constant factor (C)	1981 capacity (m ³)	Design capacity (m ³)	Sediment volume (m ³)	% loss of capacity
	d/s	u/s	d/s	u/s						
TN15/15A – TN16	1005.84	1002.79	2515	2812	5327	618	3 292 086	3 246 615	– 45 471	
	1002.79	999.74	2136	2518	4654	610	2 838 940	2 916 808	77 868	
	999.74	996.70	1889	2223	4112	614	2 524 768	2 593 854	69 806	
	996.70	993.65	1664	1955	3619	609	2 203 971	2 258 580	54 609	
	993.65	990.60	1265	1652	2917	625	1 823 125	1 914 220	91 095	
	990.60	987.55	1064	828	1892	670	1 267 640	1 549 295	281 655	
	987.55	984.50	868	388	1256	688	864 128	1 176 412	312 284	
	984.50	981.46	679	247	926	731	676 906	842 367	165 461	
	981.46	978.41	411	100	511	748	382 228	585 576	203 348	
	978.41	975.36	50	0	50	686	34 300	385 423	351 123	
	975.36	(973.85)	0	0		739	0	71 658	71 658	
						15 908 092	17 540 808	1 632 716	9.31	
TN16-TN17	1005.84	1002.79	2978	2515	5493	518	2 845 374	2 744 137	–101 237	
	1002.74	999.74	2678	2136	4814	493	2 373 302	2 375 665	2363	
	999.74	996.70	2346	1889	4235	477	2 020 095	2 015 673	– 4422	
	996.70	993.65	2097	1664	3761	447	1 681 167	1 674 277	– 6890	
	993.65	990.60	1873	1265	3138	443	1 390 134	1 367 068	– 23066	
	990.60	987.55	1627	1064	2691	416	1 119 456	1 111 981	– 7475	
	987.55	984.50	1448	868	2316	377	873 132	877 806	4674	
	984.50	981.46	1278	679	1957	343	671 251	665 075	– 6176	
	981.46	978.41	940	411	1351	357	482 307	513 100	– 30793	
	978.41	975.36	386	50	436	332	144 752	397 328	252 576	
	975.36	(968.55)	2	0	2	355	710	373 954	373 244	
						13 601 680	14 116 064	514 384	3.64	

TABLE 4 (Cont'd)

Sections u/s	d/s	Upper contour (m KD)	Lower contour (m KD)	End areas d/s (m ²)	u/s (m ²)	Sum of end areas Ao (m ²)	Constant factor (C)	1981 capacity (m ³)	Design capacity (m ³)	Sediment volume (m ³)	% loss of capacity
TN17-Dam		1005.84	1002.79	2978	2978	5956	397	2 364 532	2 255 672	-108 860	
		1002.79	999.74	2678	2678	5356	394	2 110 264	1 996 897	-113 367	
		999.74	996.70	2346	2346	4692	388	1 820 496	1 758 843	- 61 648	
		996.70	993.65	2097	2097	4194	373	1 564 362	1 530 248	- 34 114	
		993.65	990.60	1873	1873	3746	360	1 348 560	1 307 896	- 40 664	
		990.60	987.55	1627	1627	3254	336	1 093 344	1 096 365	3 021	
		987.55	984.50	1448	1448	2896	301	871 696	894 892	23 196	
		984.50	981.46	1278	1278	2556	274	700 344	699 973	- 371	
		981.46	978.41	940	940	1880	277	520 760	577 093	- 3 667	
		978.41	975.36	386	386	772	247	190 684	357 378	166 694	
		975.36	972.31	2	2	4	251	1 004	240 639	239 635	
		972.31	969.36	0	0	0	160	0	120 853	120 853	
		969.26	(968.60)	0	0	0	311	0	4 356	4 356	
								12 586 046	12 781 110	195 064	1.53

TABLE 4 (Cont'd)

Sections u/s	d/s	Upper contour (m KD)	Lower contour (m KD)	End areas		Sum of end areas Ao (m ²)	Constant factor (C)	1981 capacity (m ³)	Design capacity (m ³)	Sediment volume (m ³)	% loss of capacity
		d/s	u/s								
TB1-TB2	1003-84	802	430	1232	666	820 512	663 868	156 644			
	1002-79	373	0	373	597	222 681	412 071	189 390			
	999-74	0	0	0	391	0	157 134	157 134			
	996-70	0	0	0	72	0	5 936	5 936			
		(995-85)									
TB2-TB3	1002-79	1291	802	2093	638	1 043 193	1 239 009	195 816			15.80
	999-74	998	373	1371	681	1 335 334	840 452	494 882			
	996-70	385	0	385	665	933 651	605 019	328 632			
	(994-20)	0	0	0	554	256 025	357 619	101 594			
						0	91 486	91 486			
TB3-TB4	1005-84	886	1291	2177	467	2 525 010	1 894 576	630 434			(33.28)
	1002-79	633	998	1631	486	1 016 659	797 793	218 866			
	999-74	302	385	687	477	792 666	583 535	209 131			
	996-70	37	0	37	436	327 699	335 920	8 221			
		(991-75)	0	0	439	16 132	146 360	130 228			
TB4-TB6	1005-84	935	886	1821	925	2 153 156	1 895 681	257 475			(13.58)
	1002-79	734	633	1367	833	1 684 425	1 955 418	270 993			
	999-74	557	302	859	796	1 138 711	1 409 735	271 024			
	996-70	230	37	267	596	683 764	894 579	210 815			
		(992-70)	0	0	285	159 132	422 148	263 016			
TB6-TB7	1005-84	1281	935	2216	341	3 666 032	4 714 357	1 048 325			22.24
	1002-79	1067	734	1801	320	755 656	819 653	63 997			
	999-74	807	557	1364	313	576 320	647 154	70 834			
	996-70	516	230	746	272	426 932	477 724	50 792			
		(993-65)	212	212	393	202 912	293 347	90 435			
		0	0	0		83 316	139 749	56 433			

TABLE 4 (Cont'd)

Sections u/s	d/s	Upper contour (m KD)	Lower contour (m KD)	d/s	End areas u/s (m ²)	Sum of end areas Ao (m ²)	Constant factor (C)	1981 capacity (m ³)	Design capacity (m ³)	Sediment volume (m ³)	% loss of capacity
TB7-TB8		990.60	(987-90)	16	0	16	268	4 288	37 240	32 952	
								2 049 424	2 414 867	365 443	15.13
	1005-84	1002-79	1310	1287	2591	380	984 580	981 987	-	2 623	
	1002-79	999-74	1104	1067	2171	356	772 876	790 613	17 737	539	
	999-74	996-70	900	807	1707	359	612 813	613 352		8 126	
	996-70	993-65	670	516	1186	361	428 146	436 272		102 754	
		993-65	990-60	217	212	429	401	172 029	274 783	76 603	
		990-60	987-55	92	16	108	360	38 880	115 483	10 304	
		987-55	(985-35)	0	0	0	145	0			
TB8-TB9								3 009 324	3 222 764	213 440	6.62
	1005-84	1002-79	3683	1310	4993	439	2 191 927	2 181 452	-	10 475	
	1002-79	999-74	2860	1104	3964	493	1 954 252	1 911 162	-	43 090	
	999-74	996-70	2320	900	3220	501	1 613 220	1 612 625	-	595	
	996-70	993-65	1886	670	2556	508	1 298 448	1 291 680	-	6 768	
	993-65	990-60	1352	217	1569	485	760 965	921 723	160 758	222 583	
		990-60	987-55	382	92	474	654	309 996	532 579	1 394	
		987-55	(985-70)	159	0	159	665	105 735	104 341		
TB9-TB10								8 234 543	8 555 562	321 019	3.75
	1005-84	1002-79	2046	3683	5729	224	1 283 296	1 260 624	-	22 672	
	1002-79	999-74	1723	2860	4583	244	1 118 252	1 076 381	-	41 871	
	999-74	996-70	1464	2320	3784	238	900 592	883 982	-	16 610	
	996-70	993-65	1278	1886	3164	225	711 900	696 168	-	15 732	
	993-65	990-60	1011	1352	2363	201	474 963	496 864	21 901	56 300	
		990-60	987-55	787	382	1169	211	246 659	302 959	73 982	
		987-55	984-50	197	159	356	263	93 628	167 610	59 448	
		984-50	981-46	50	0	50	186	9 300	68 478	3 798	
		981-46	(980-25)	0	0	0	65	0			
								4 838 590	4 957 134	118 544	2.39

TABLE 4 (Cont'd)

Sections u/s d/s	Upper contour (m KD)	Lower contour (m KD)	End areas		Sum of end areas Ao (m ²)	Constant factor (C)	1981 capacity (m ³)	Design capacity (m ³)	Sediment volume (m ³)	% loss of capacity
TB10-TB11	1005-84	1002-79	d/s (m ²)	u/s (m ²)	5261	268	1 409 948	1 340 149	- 69 799	
	1002-79	999-74	3215	2046	4621	270	1 247 670	1 181 638	- 66 032	
	999-74	996-70	2898	1723	4096	271	1 110 016	1 016 849	- 93 167	
	996-70	993-65	2632	1464	3725	251	934 975	847 762	- 87 213	
	993-65	990-60	2447	1278	2828	241	681 548	669 886	- 11 662	
	990-60	987-55	1817	1011	2119	208	440 752	496 678	55 926	
	987-55	984-50	1332	787	818	185	151 330	341 506	190 176	
	984-50	981-46	621	197	283	183	51 789	214 140	162 351	
	981-46	978-41	233	50	0	315	0	119 154	119 154	
	978-41	(977-30)	0	0	0	301	0	14 427	14 427	
TB11-TB12	1005-84	1002-79	4233	3215	7448	188	6 028 028	6 242 189	214 161	3.43
	1002-79	999-74	3519	2898	6417	190	1 400 224	1 032 251	-367 973	
	999-74	996-70	2943	2632	5575	199	1 219 230	928 157	-291 073	
	996-70	993-65	2728	2447	5175	190	1 109 425	834 590	-274 835	
	993-65	990-60	2258	1817	4075	184	983 250	738 152	-245 098	
	990-60	987-55	1490	1332	2822	201	749 800	629 790	-120 010	
	987-55	984-50	709	621	1330	214	567 222	576 263	- 50 959	
	984-50	981-46	361	233	594	215	284 620	397 000	112 380	
	981-46	978-41	36	0	36	240	127 710	786 081	158 371	
	978-41	(977-00)	0	0	0	197	8 640	192 309	183 669	
							0	34 223	34 223	
							6 450 121	5 588 816	-861 305	(15.41)

(base data volume 133.23 x 10⁶ m³)

Notes:

- * negative sign indicates an increase in reservoir capacity
- ** values in brackets show percentage by which segment volume has been increased

Table 5 Initial sediment densities according to Lane and Koelzer and Trask

1. Lane and Koelzer

Reservoir operation	Sand		Silt		Clay	
	W_i (kg/m ³)	K	W_i (kg/m ³)	K	W_i (kg/m ³)	K
a) Sediment always submerged or nearly submerged	1490	0	1041	91	481	256
b) Normally a moderate reservoir drawdown	1490	0	1185	43	737	171
c) Normally considerable reservoir drawdown	1490	0	1265	16	961	96
d) Reservoir normally empty	1490	0	1314	0	1249	0

2. Trask

a) Sediment always submerged or nearly submerged	1409	0	1073	91	208	256
b) Normally a moderate reservoir drawdown	1409	0	1217*	43	—	171
c) Normally considerable reservoir drawdown	1409	0	1298*	16	—	96
d) Reservoir normally empty	1409	0	1346*	0	—	0

* estimated values

Table 6 Variation of sediment density with depth in Lake Niedersoutholfen

Sediment depth (m)	Density (kg/m ³)
Upper layer	346.0
1	634.3
2	664.8
3	557.4
4	674.4
5	722.4
6	845.8
7	863.4
8	897.0
9	1179.0
10	1185.4
11	1287.9
12	1364.8
13	1565.0
14	1484.9
15	1345.6
16	1396.8
17	1366.4
18	1486.5
19	1411.2
20	1435.3

Based on Table 5, Reference 10

Table 7 Catchment sediment yields

	1968-74 (m ³ /km ² /year)	1974-78 (m ³ /km ² /year)		1978-81 (m ³ /km ² /year)
<i>Method</i>				
1. First approximation assuming 100% trap efficiencies	114	—	278	—
2. Using calculated trap efficiencies	518	—	381	—
3. Method 2 with allowance for material trapped in Kindaruma between 1974-81	437	—	381	—
4. Method 2 with period-averaged river flows	326	—	381	—
5. Method 3 with period-averaged river flows	274	—	381	—
6. Method 4 with Kamburu sub-divided into two time periods	326	576		132
7. Method 5 with Kamburu sub-divided into two time periods	306	576		132
8. Method 7 with an allowance for changes in density of bed material	416	715		330

Figures

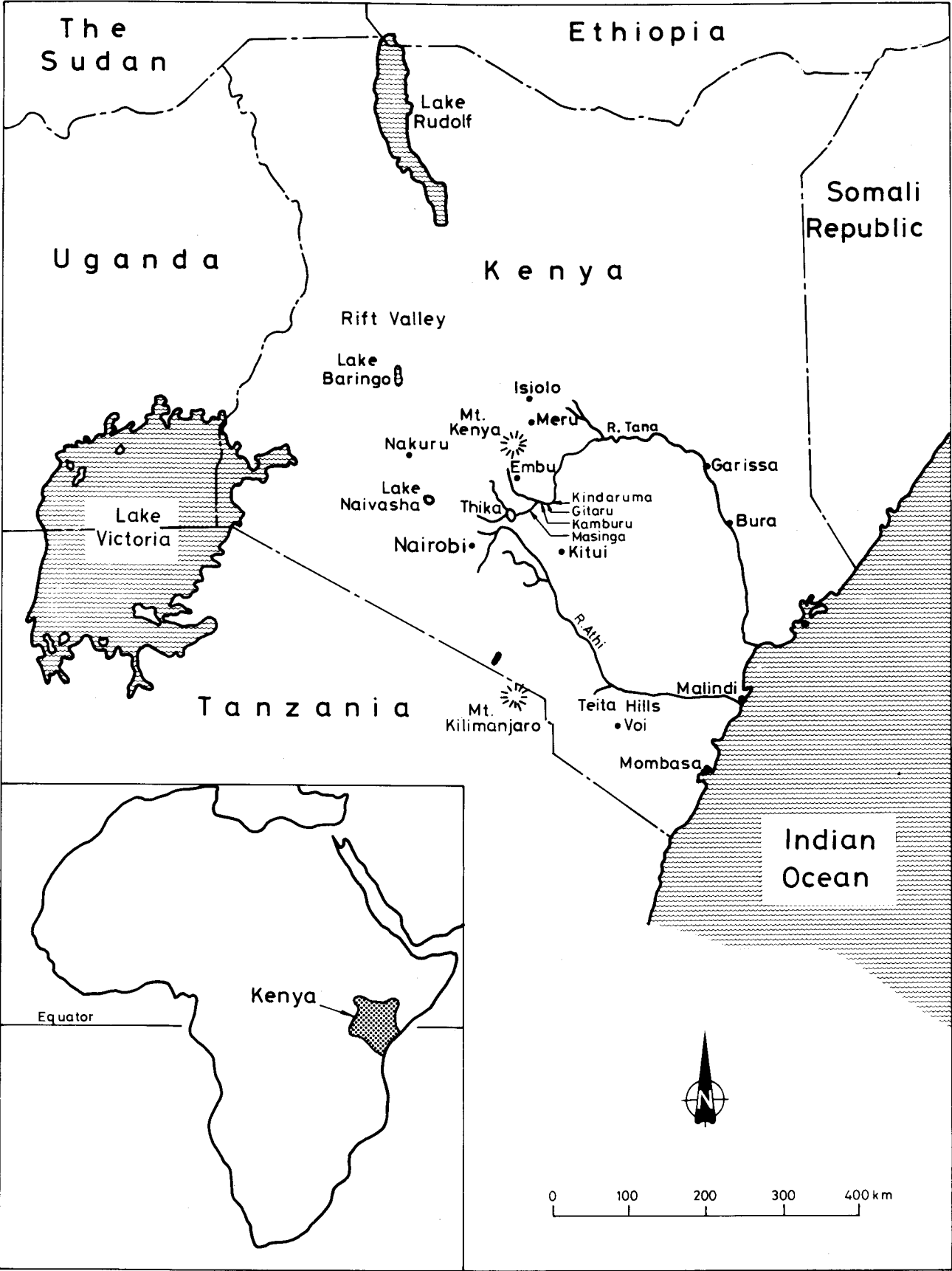


Fig 1 Location map

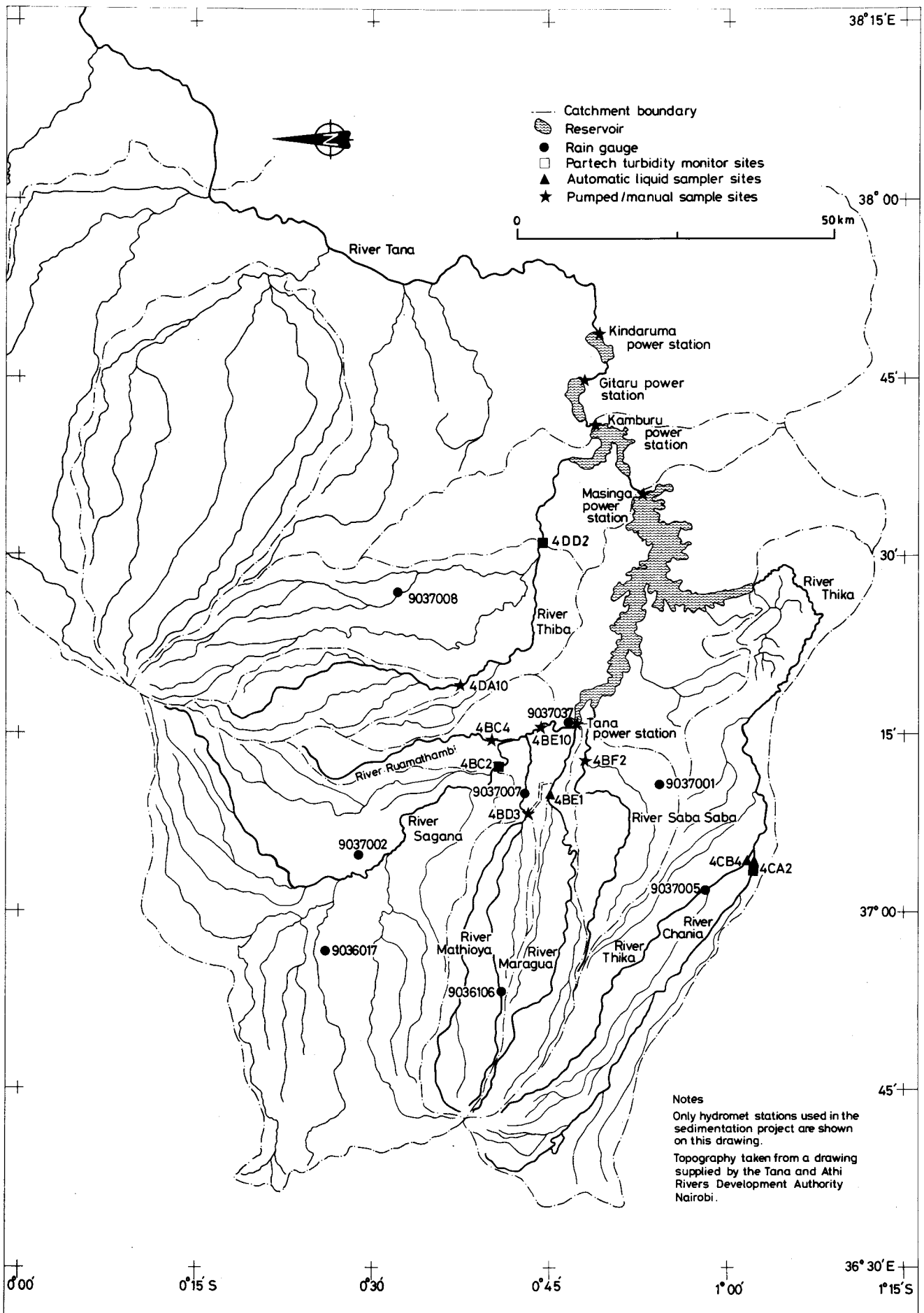


Fig 2 Tana River Basin

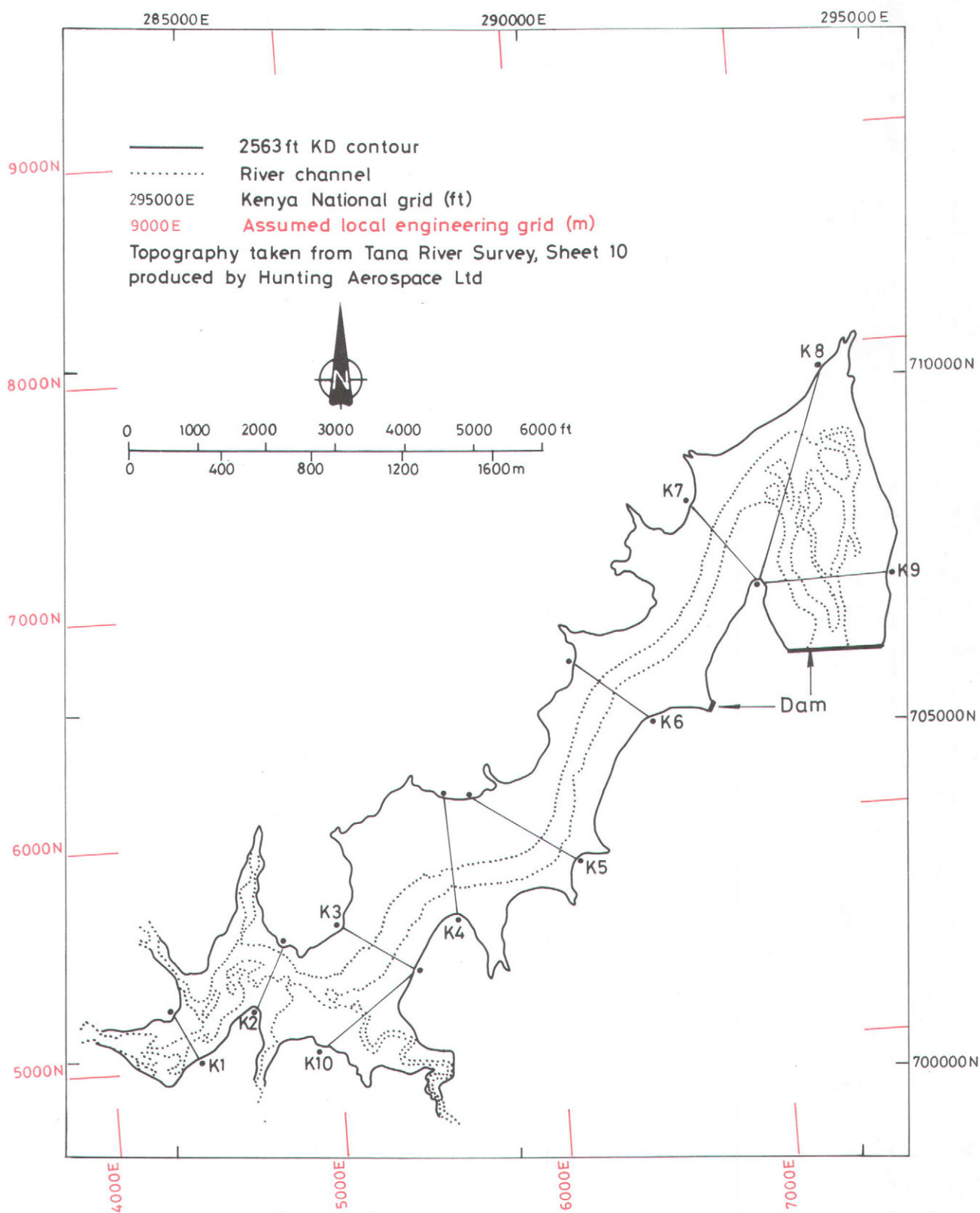


Fig 3 Kindaruma Reservoir

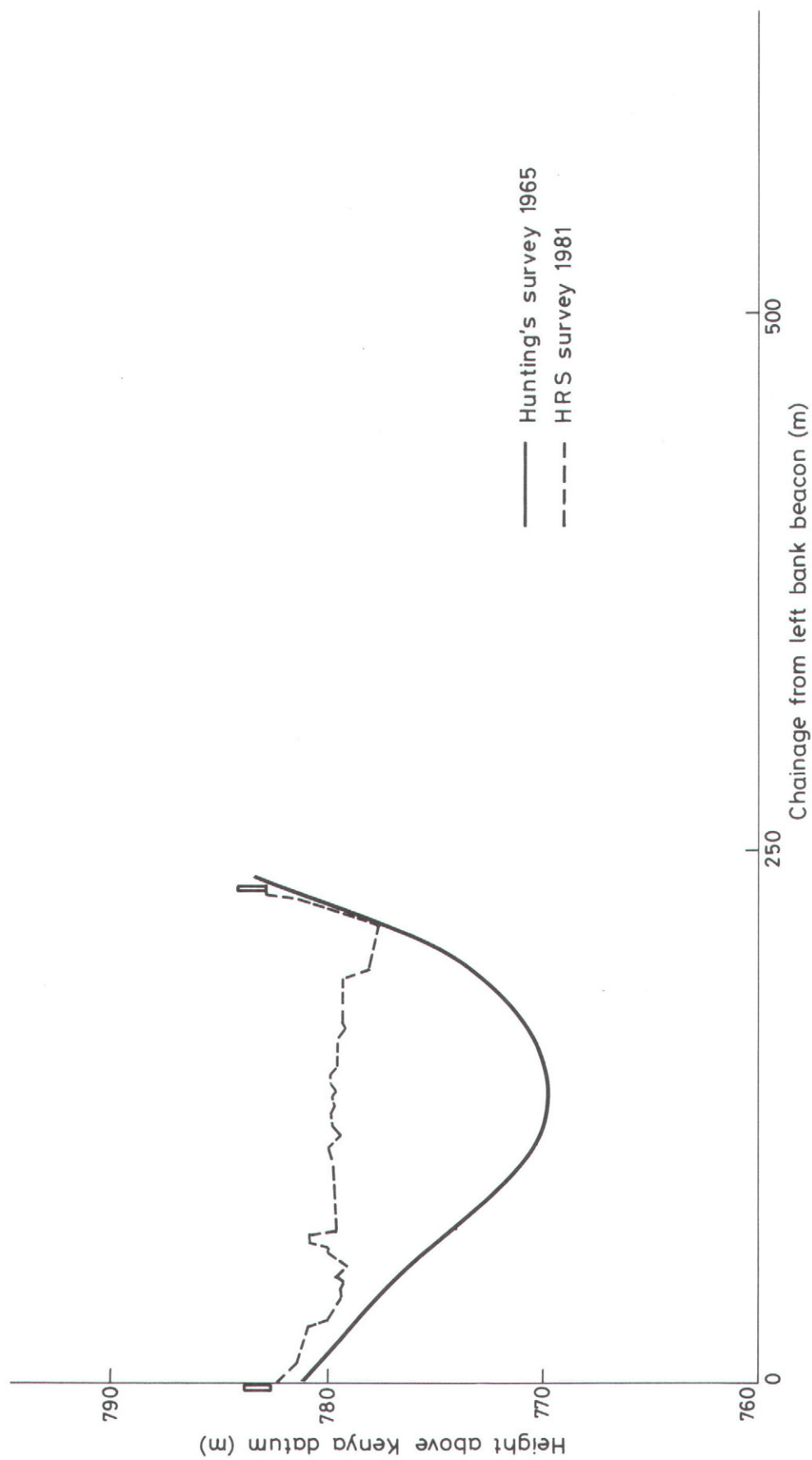


Fig 4 Kindaruma Reservoir section K1

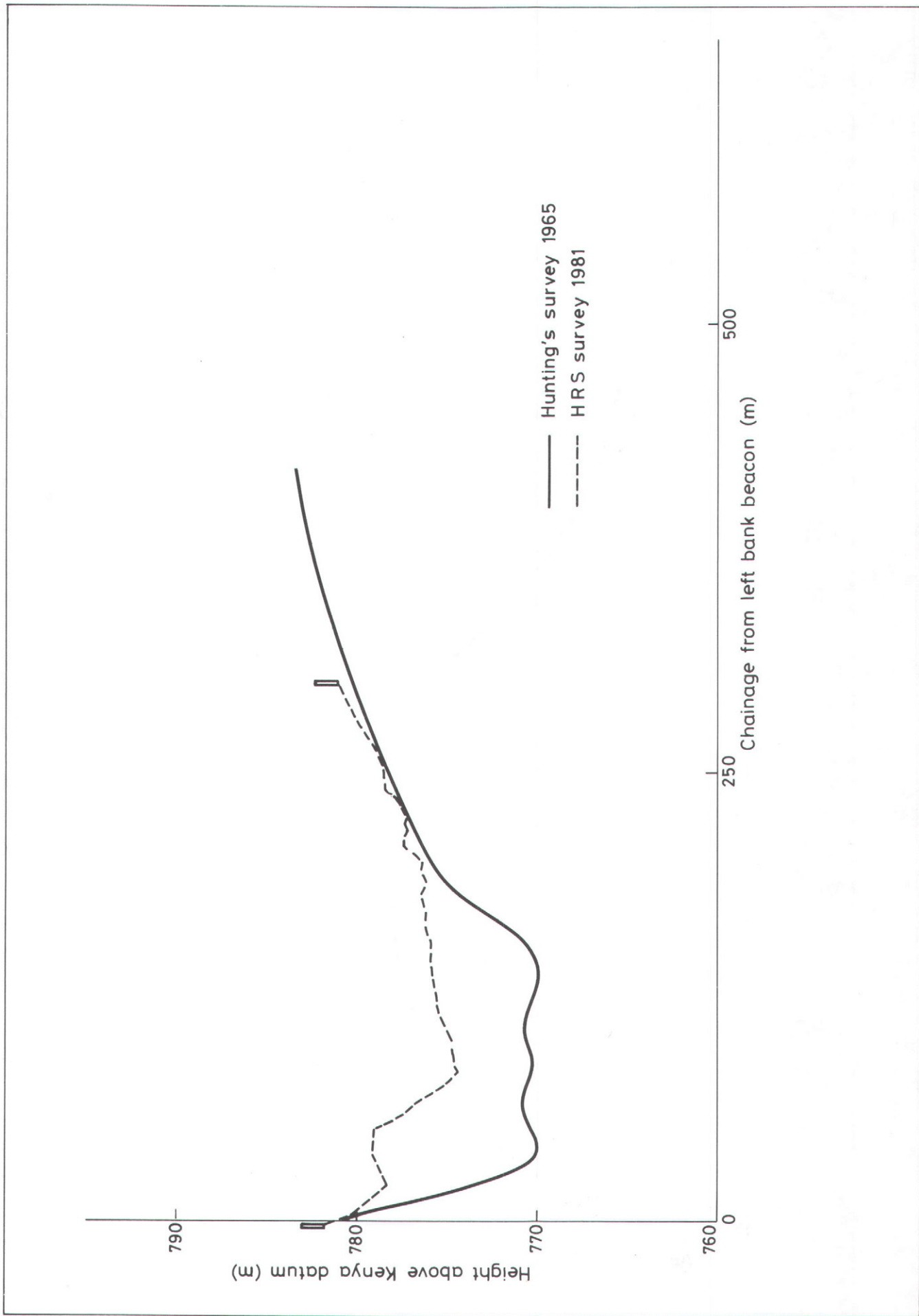


Fig 5 Kindaruma Reservoir section K2

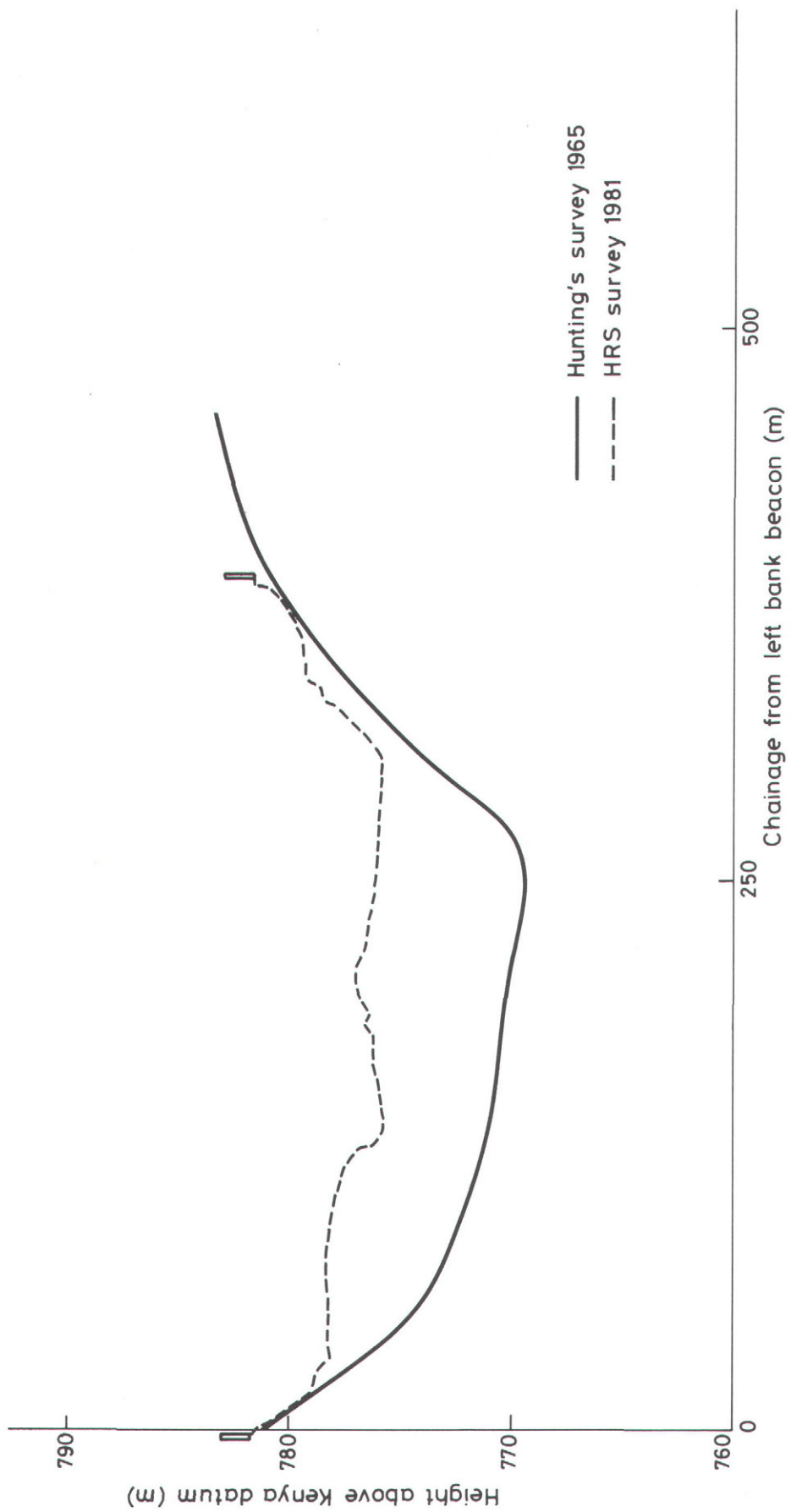


Fig 6 Kindaruma Reservoir section K3

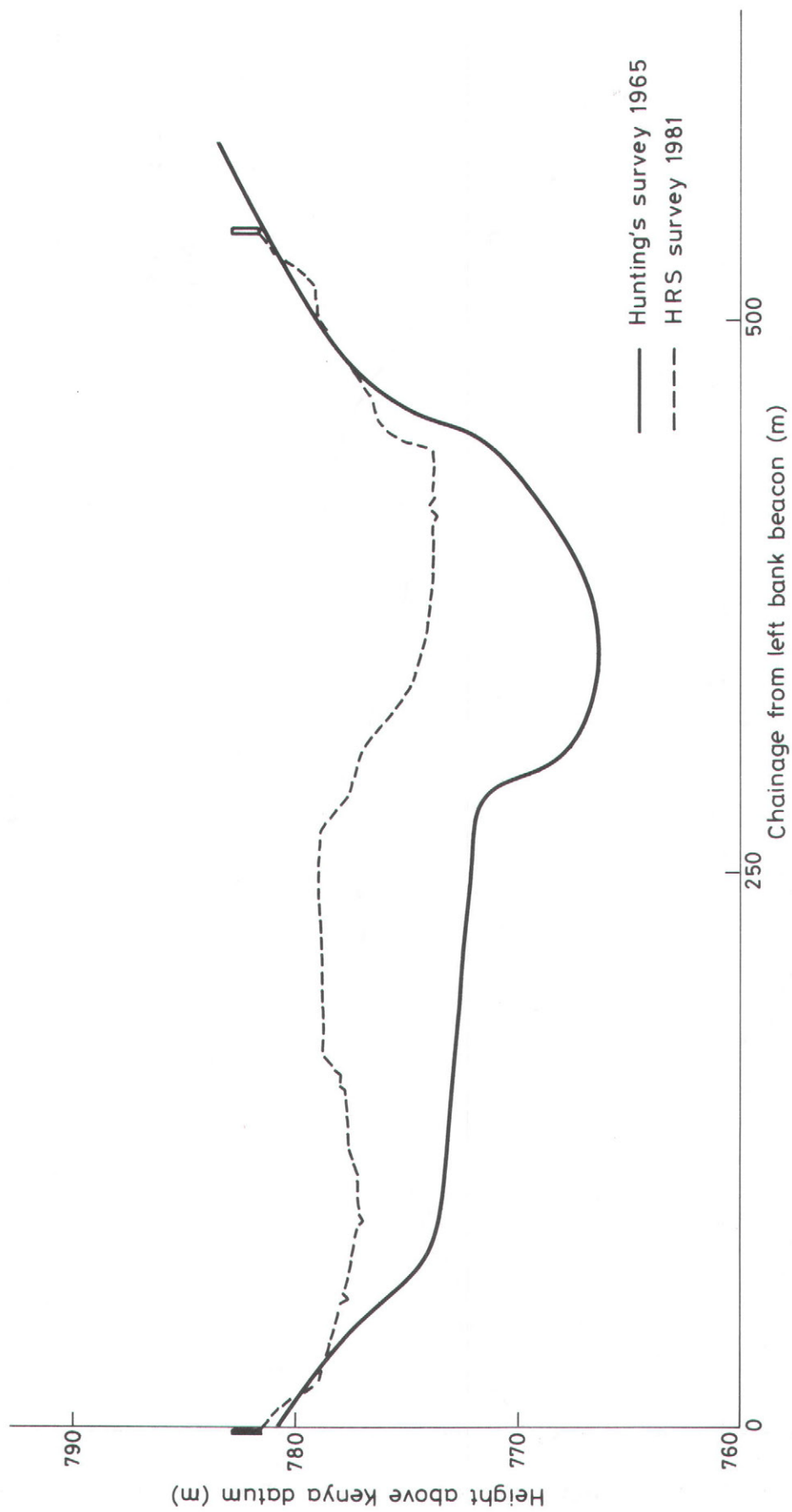


Fig 7 Kindaruma Reservoir section K4

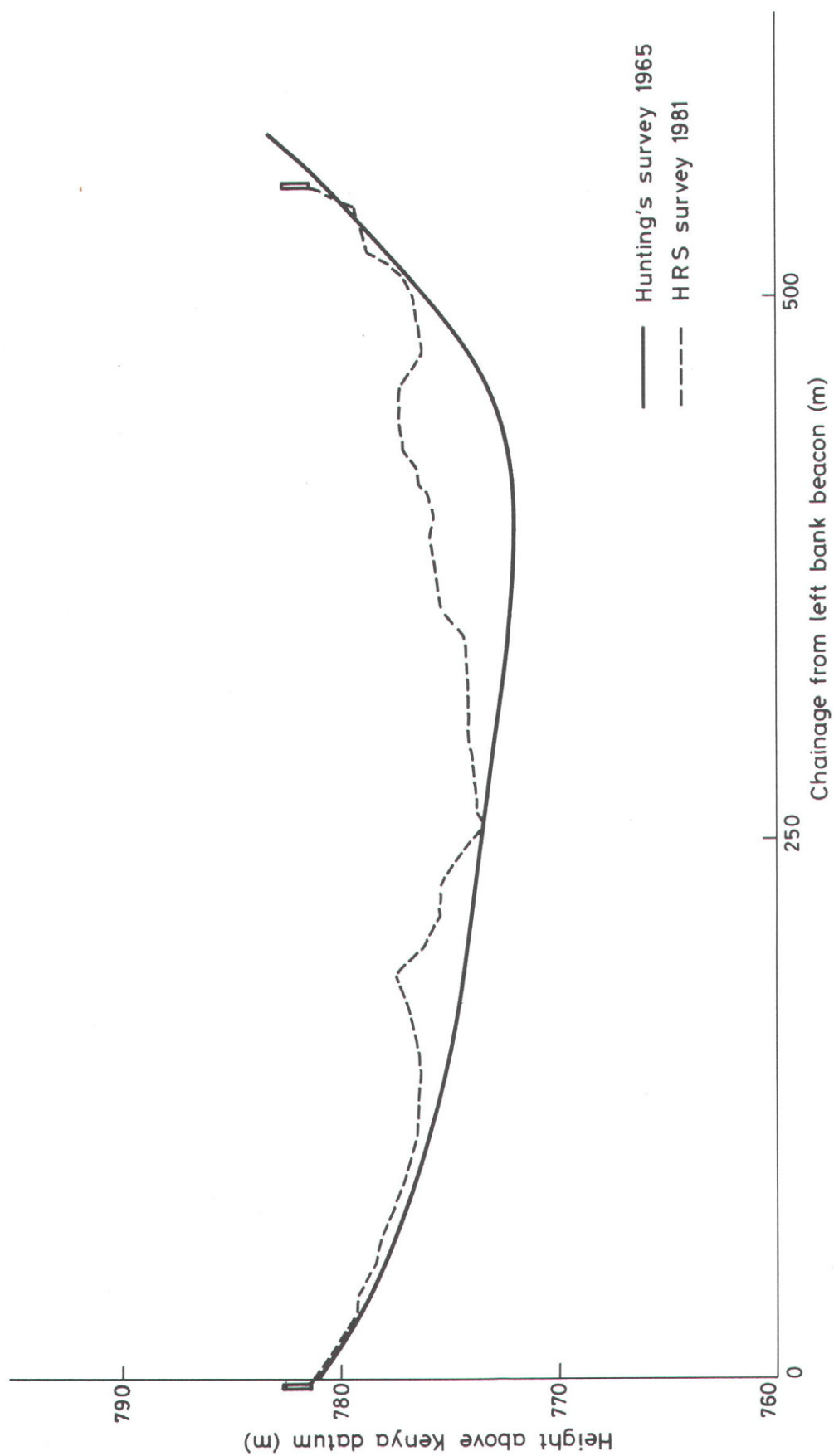


Fig 8 Kindaruma Reservoir section K5

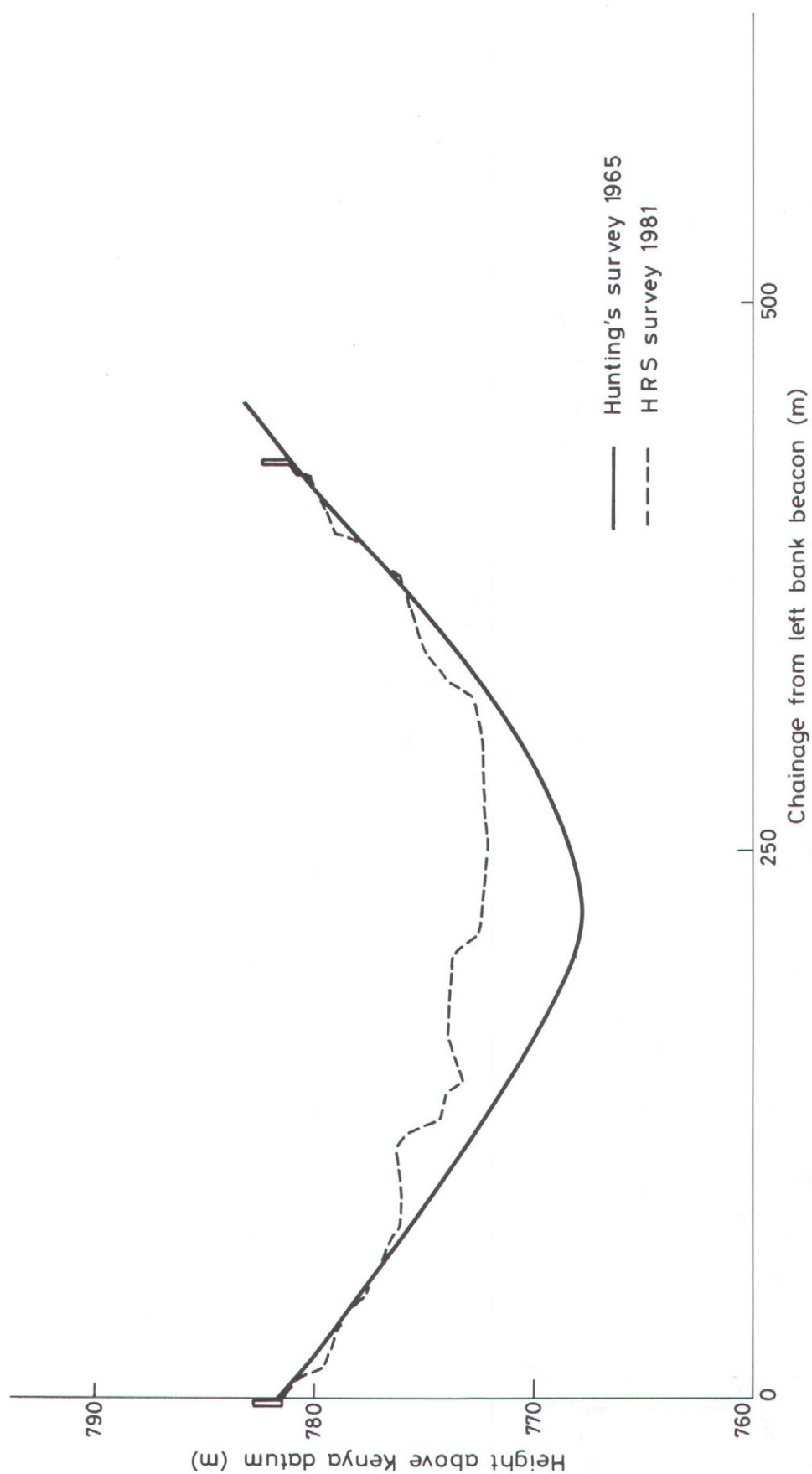


Fig 9 Kindaruma Reservoir section K6

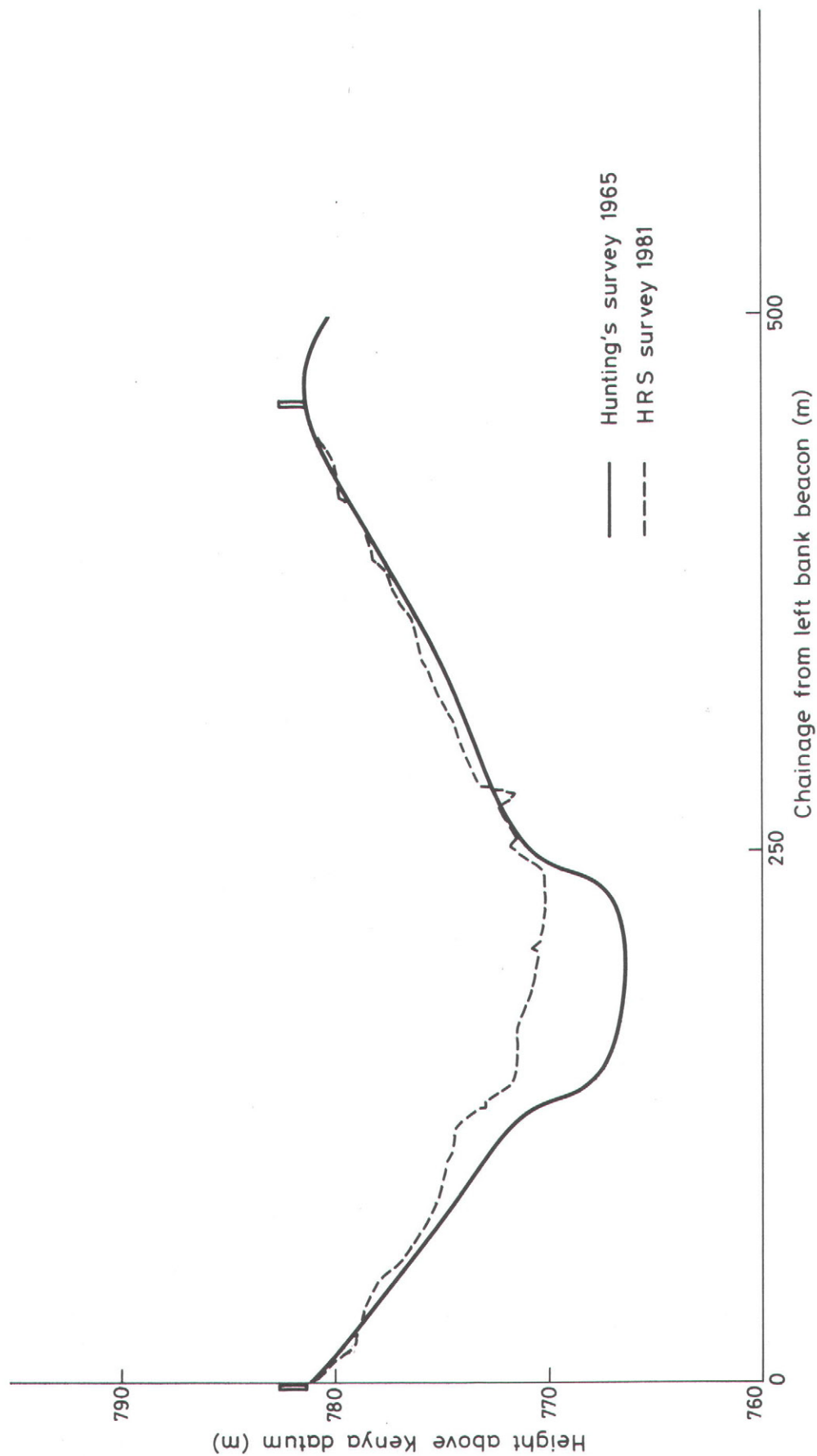


Fig 10 Kindaruma Reservoir section K7

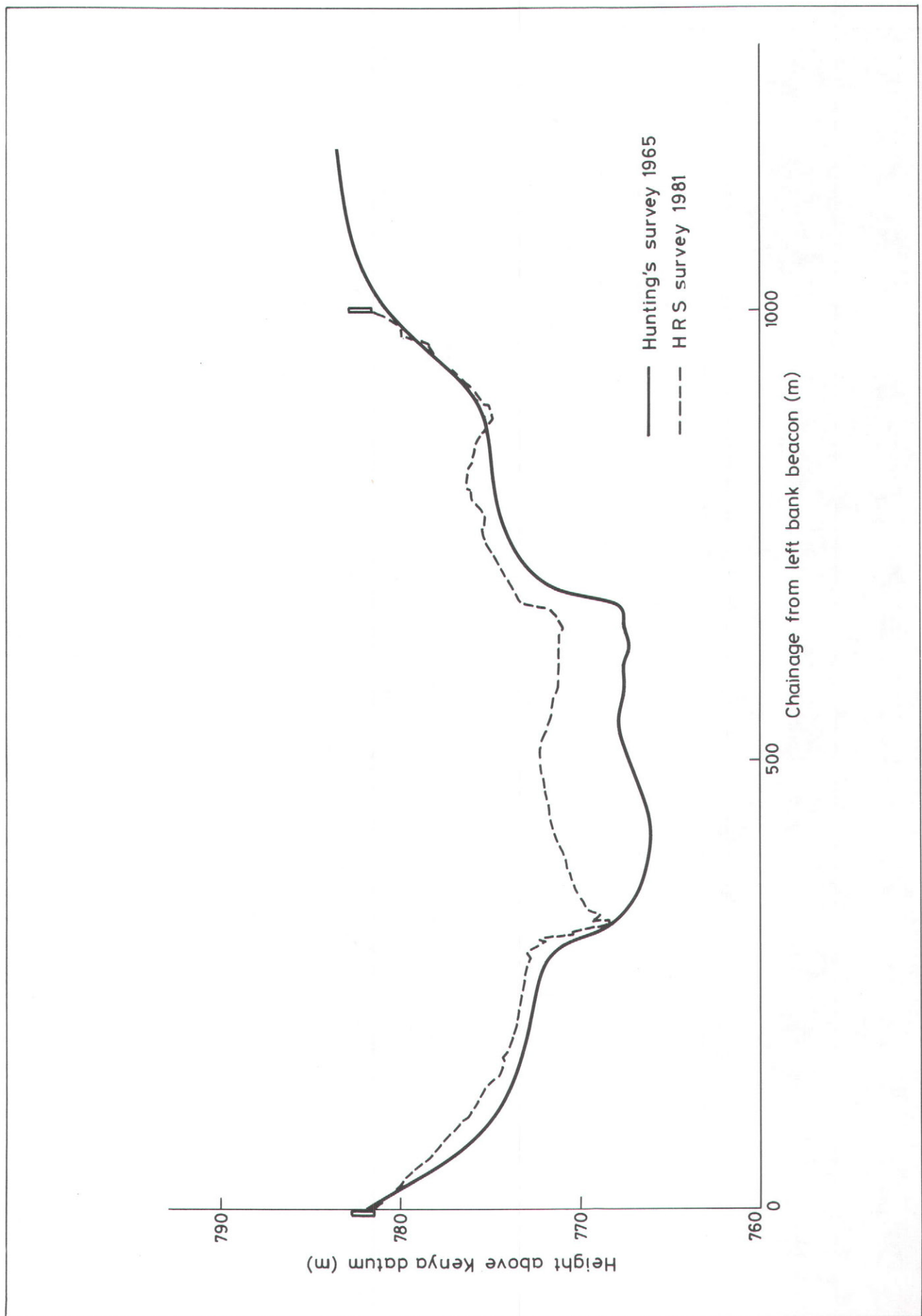


Fig 11 Kindaruma Reservoir section K8

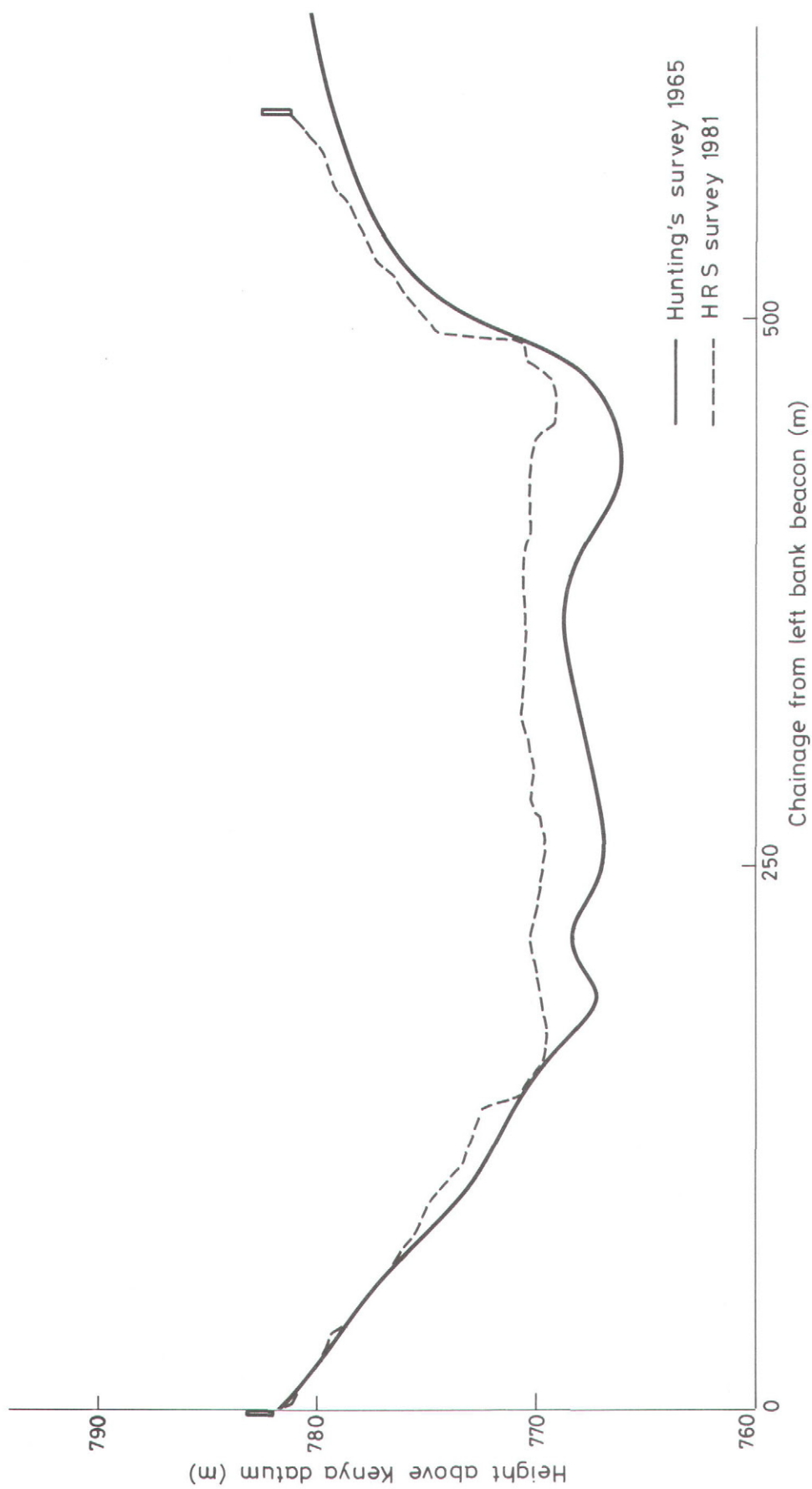


Fig 12 Kindaruma Reservoir section K9

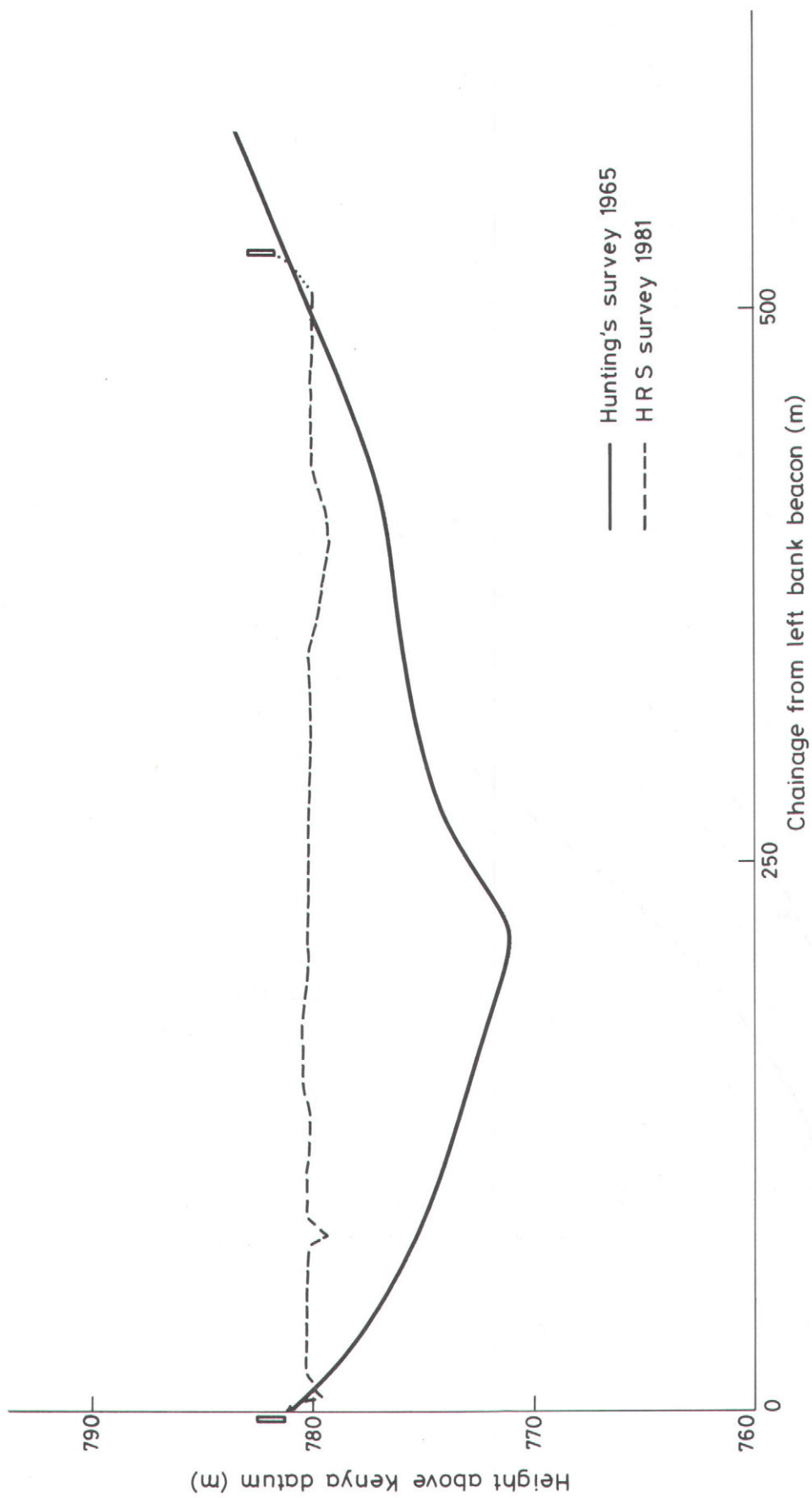


Fig 13 Kindaruma Reservoir section K10

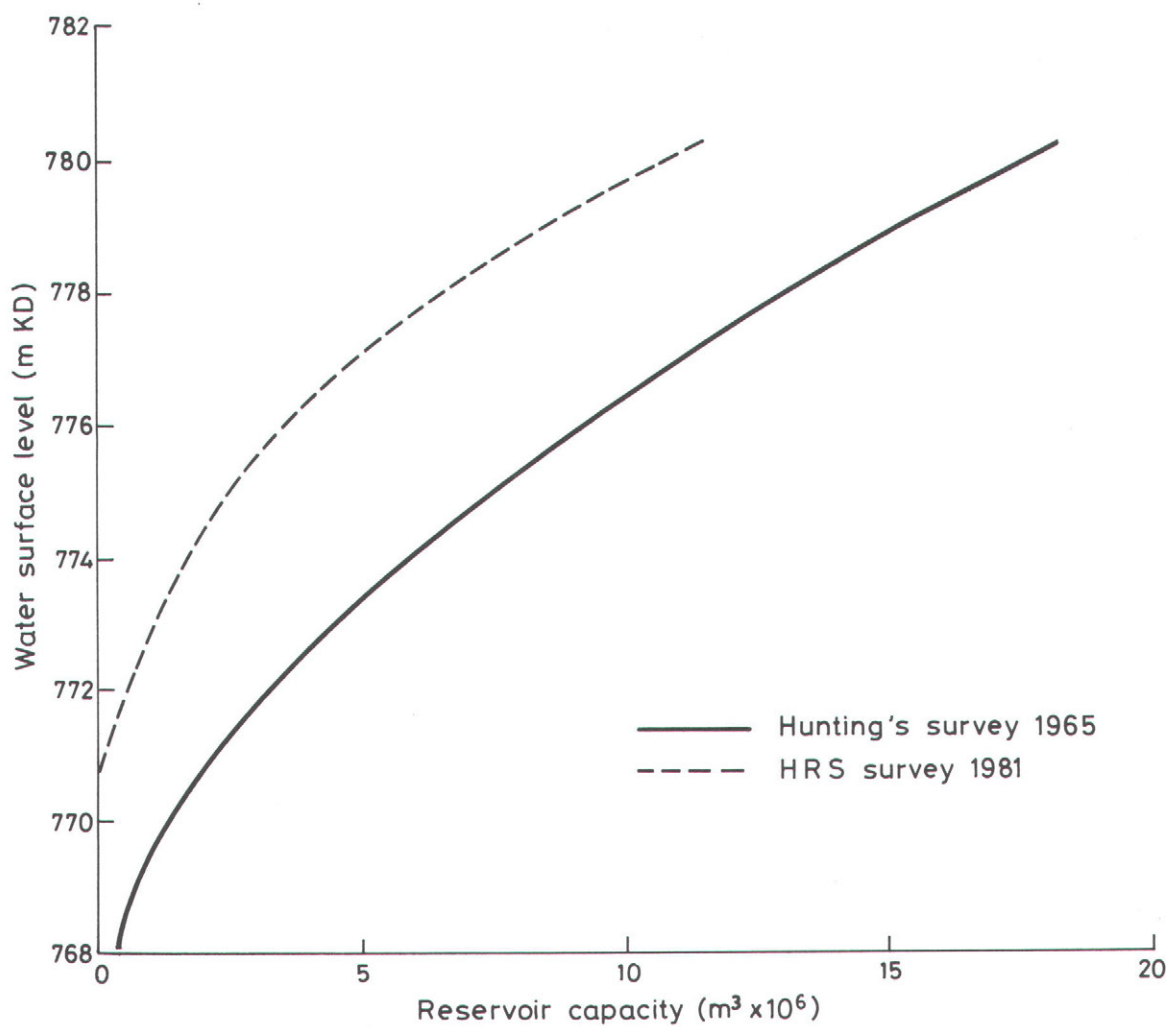


Fig 14 Kindaruma Reservoir stage/capacity curve

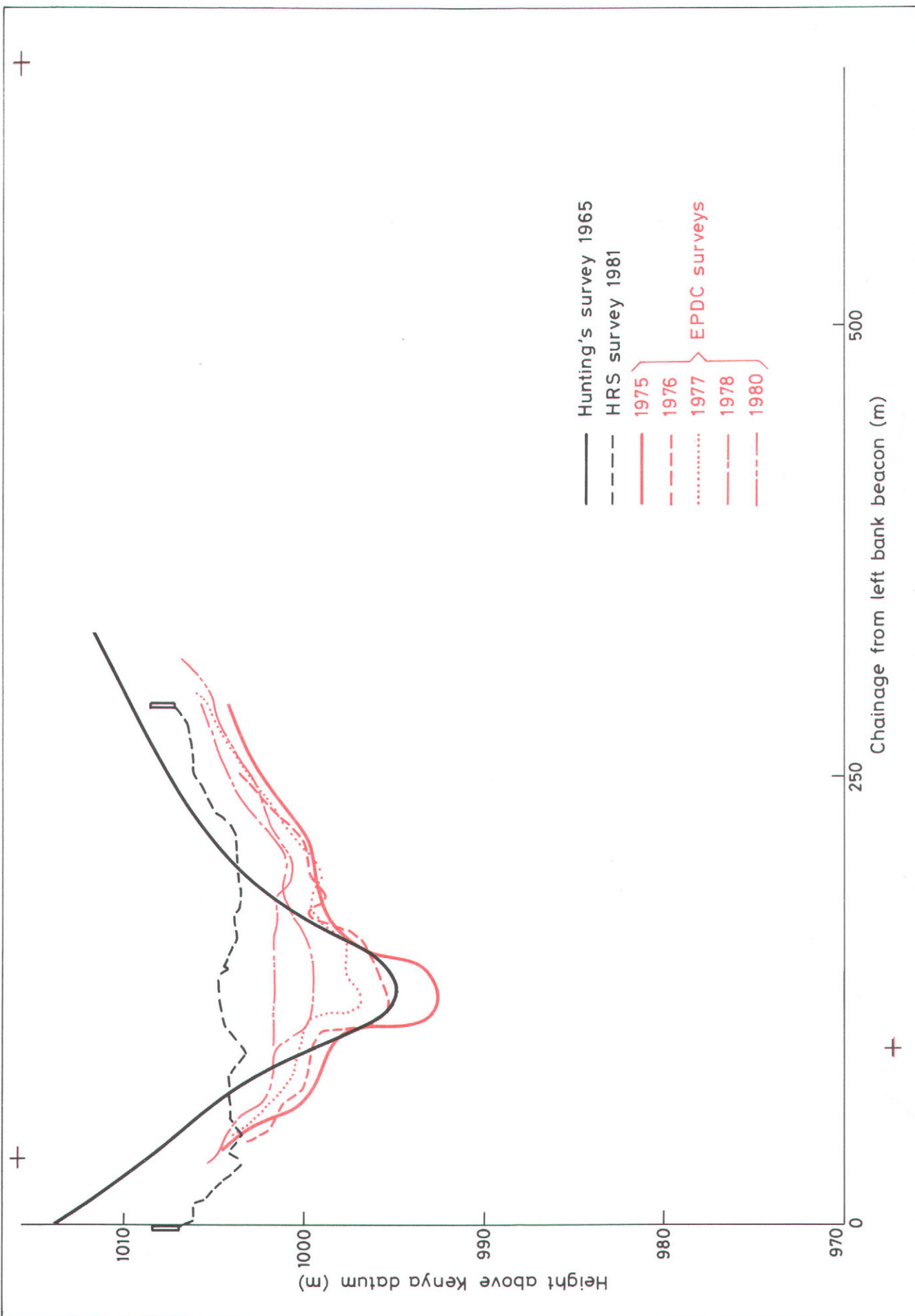


Fig 16 Kamburu Reservoir section TB1

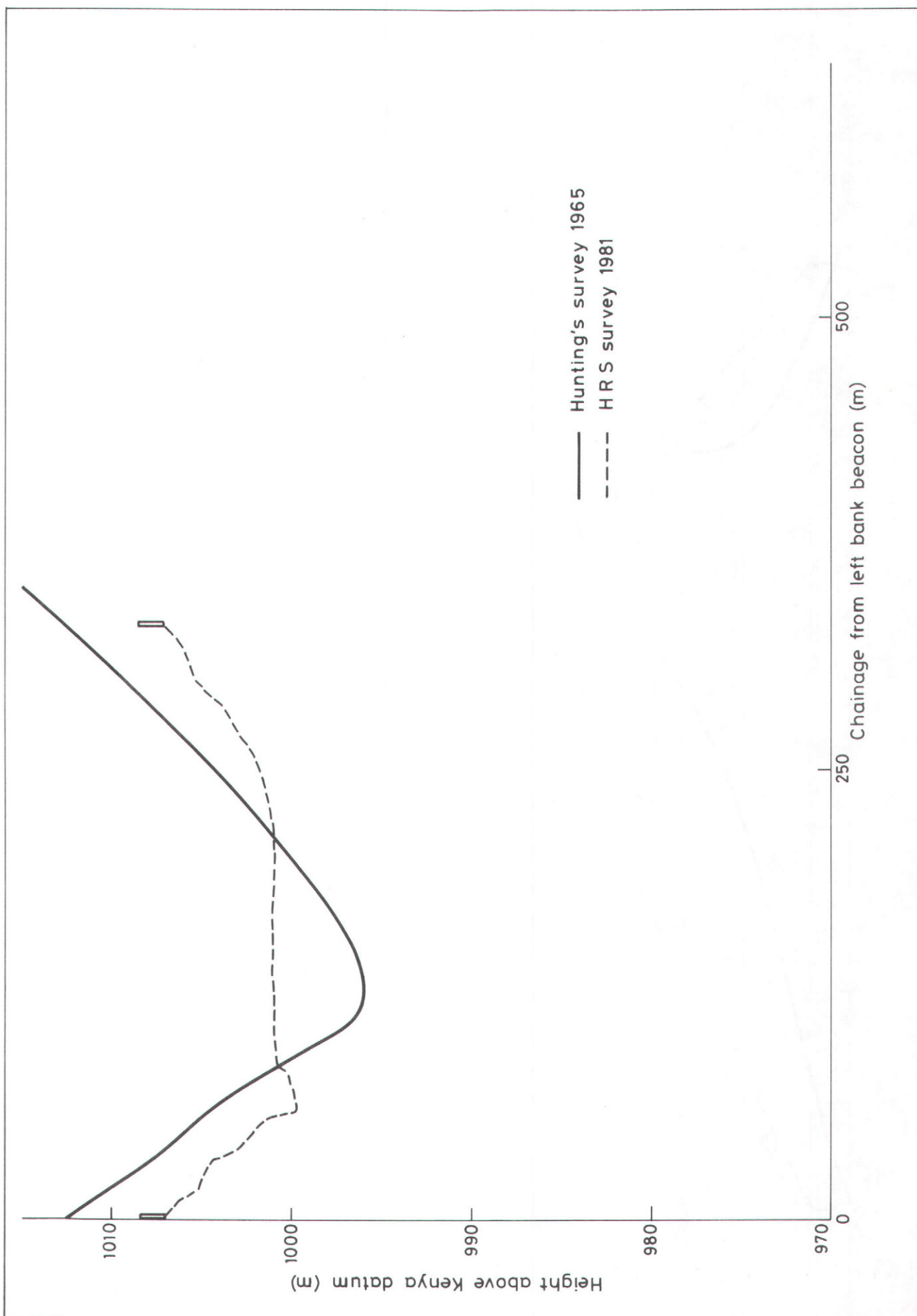


Fig 17 Kamburu Reservoir section TB2

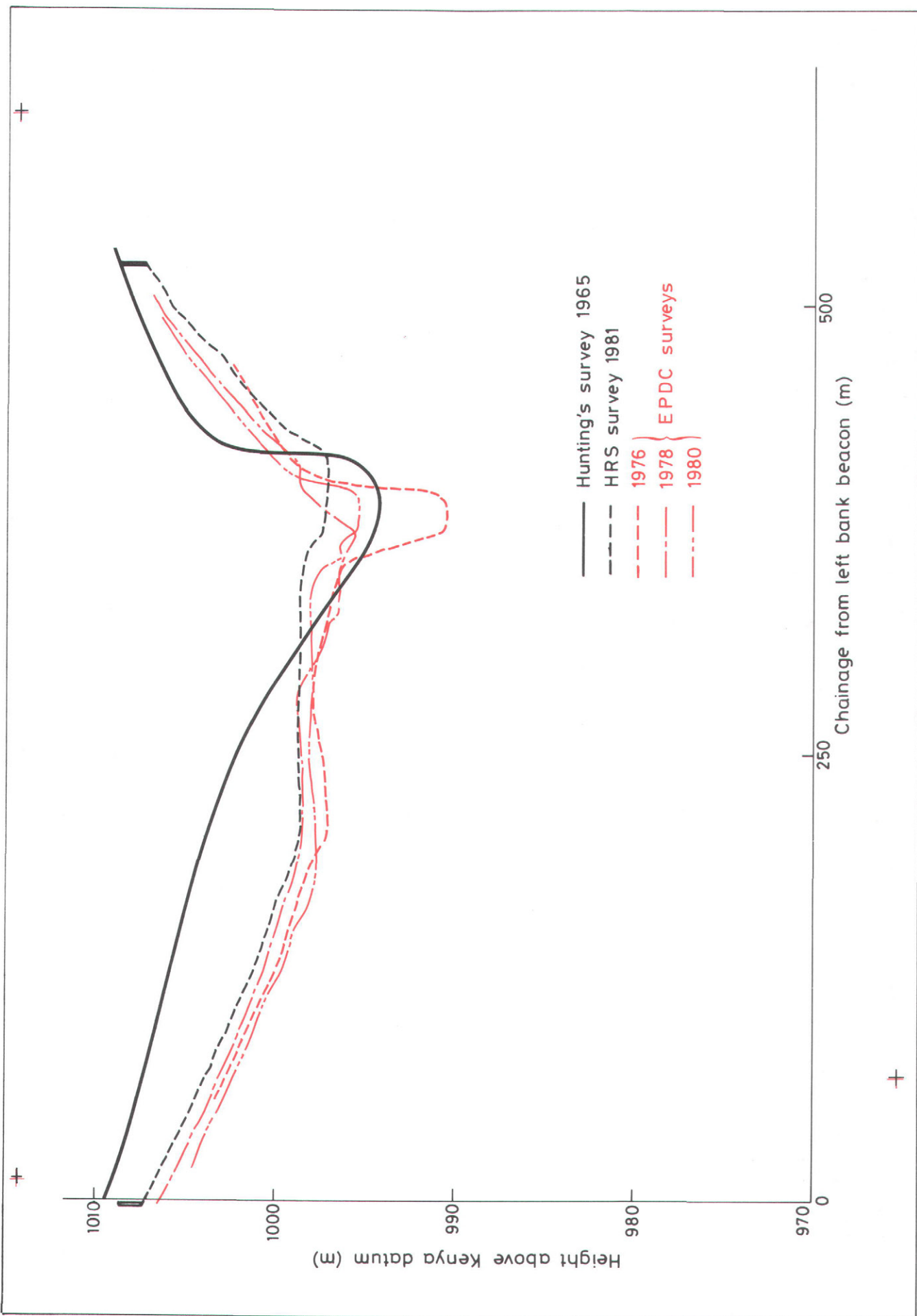


Fig 18 Kamburu Reservoir section TB3

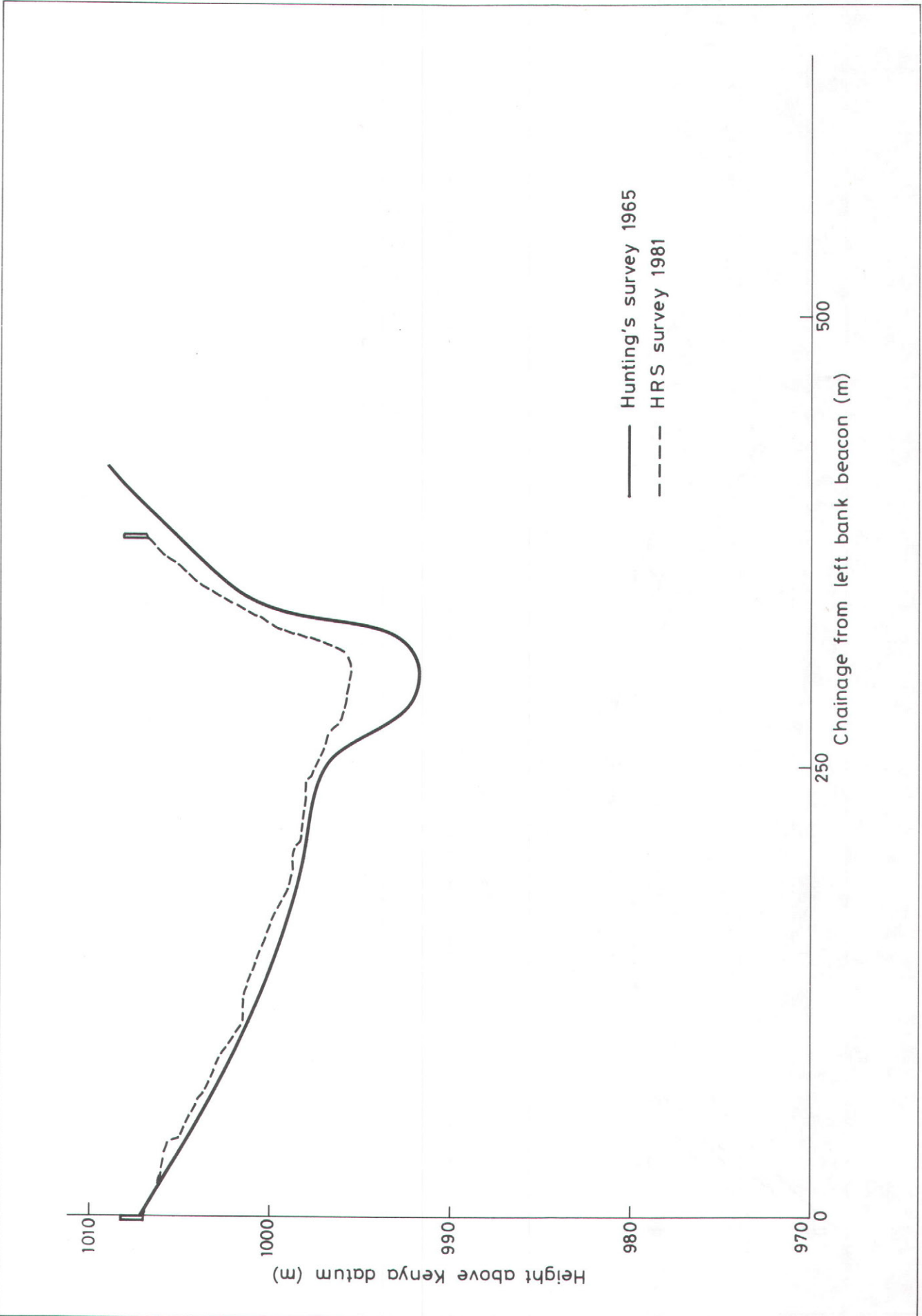


Fig 19 Kamburu Reservoir section TB4

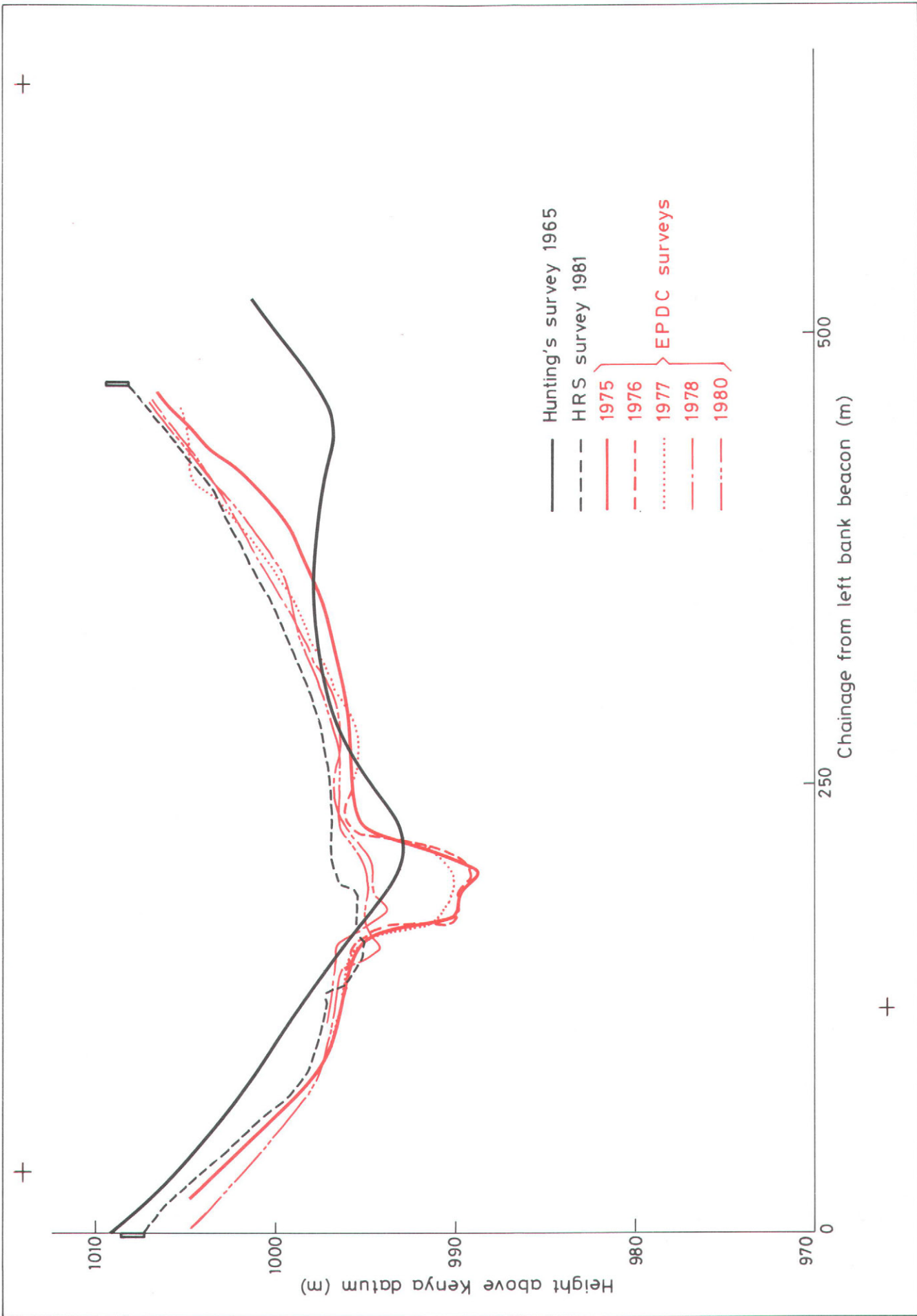


Fig 20 Kamburu Reservoir section TB5

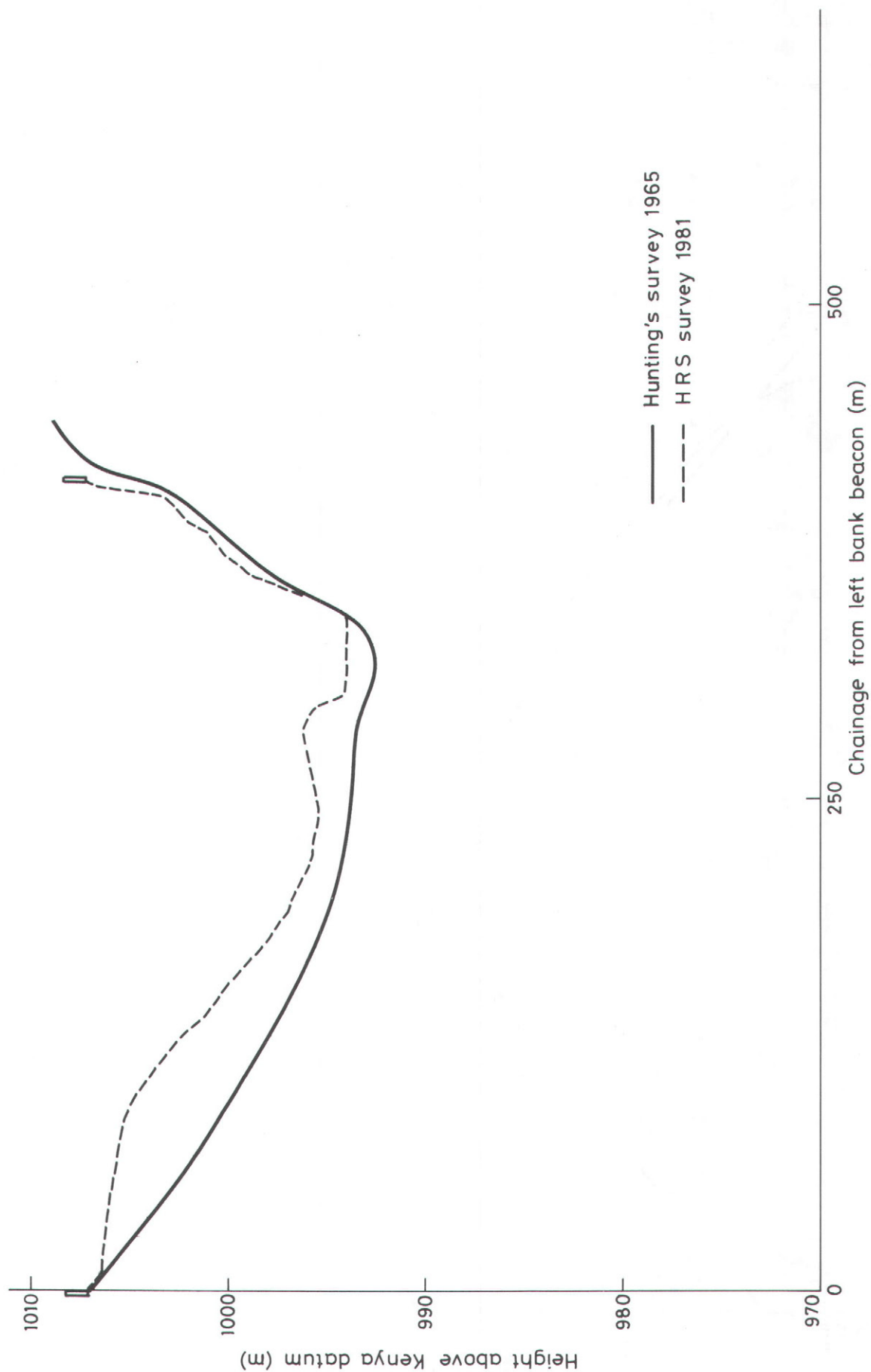


Fig 21 Kamburu Reservoir section TB6

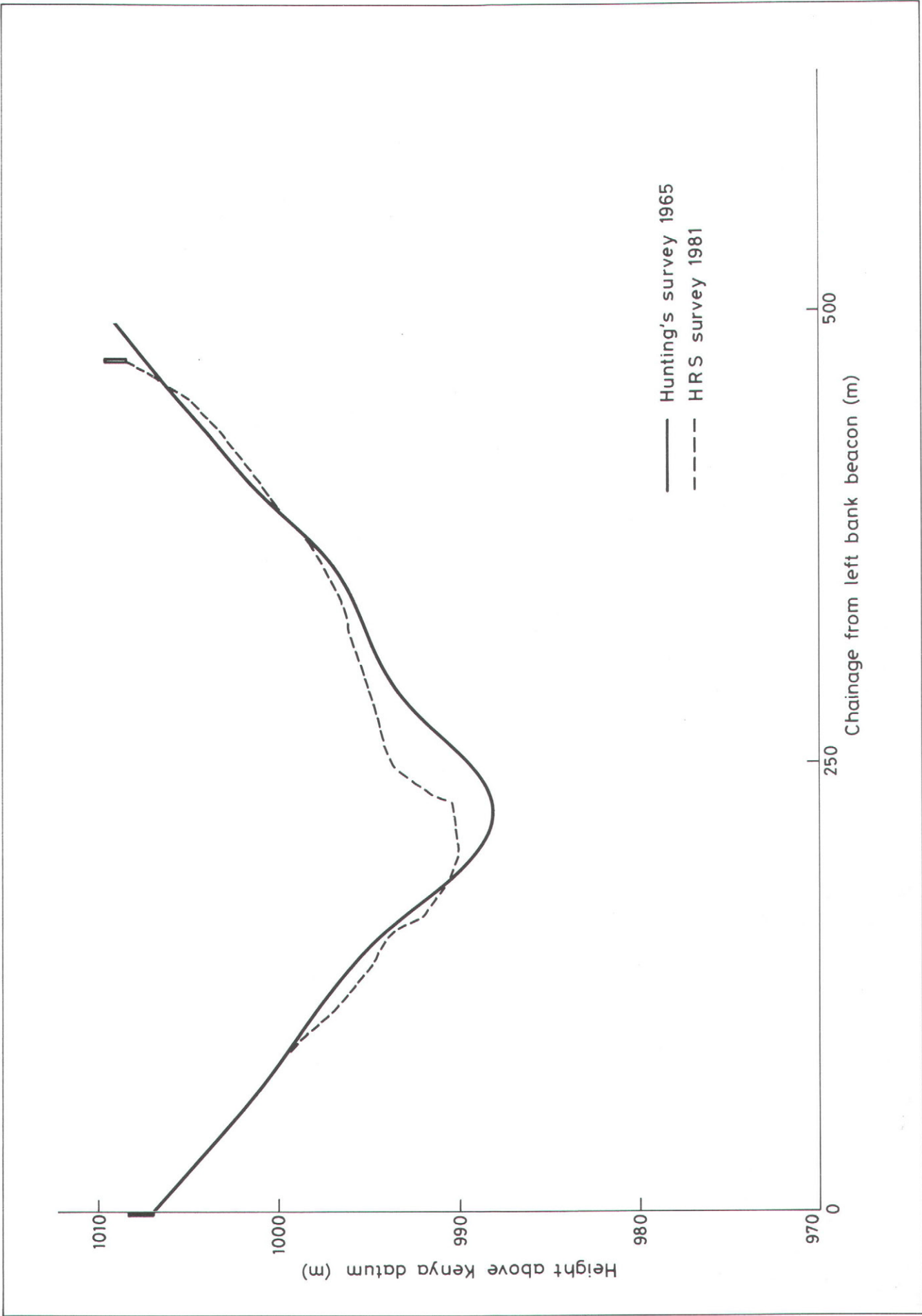


Fig 22 Kamburu Reservoir section TB7

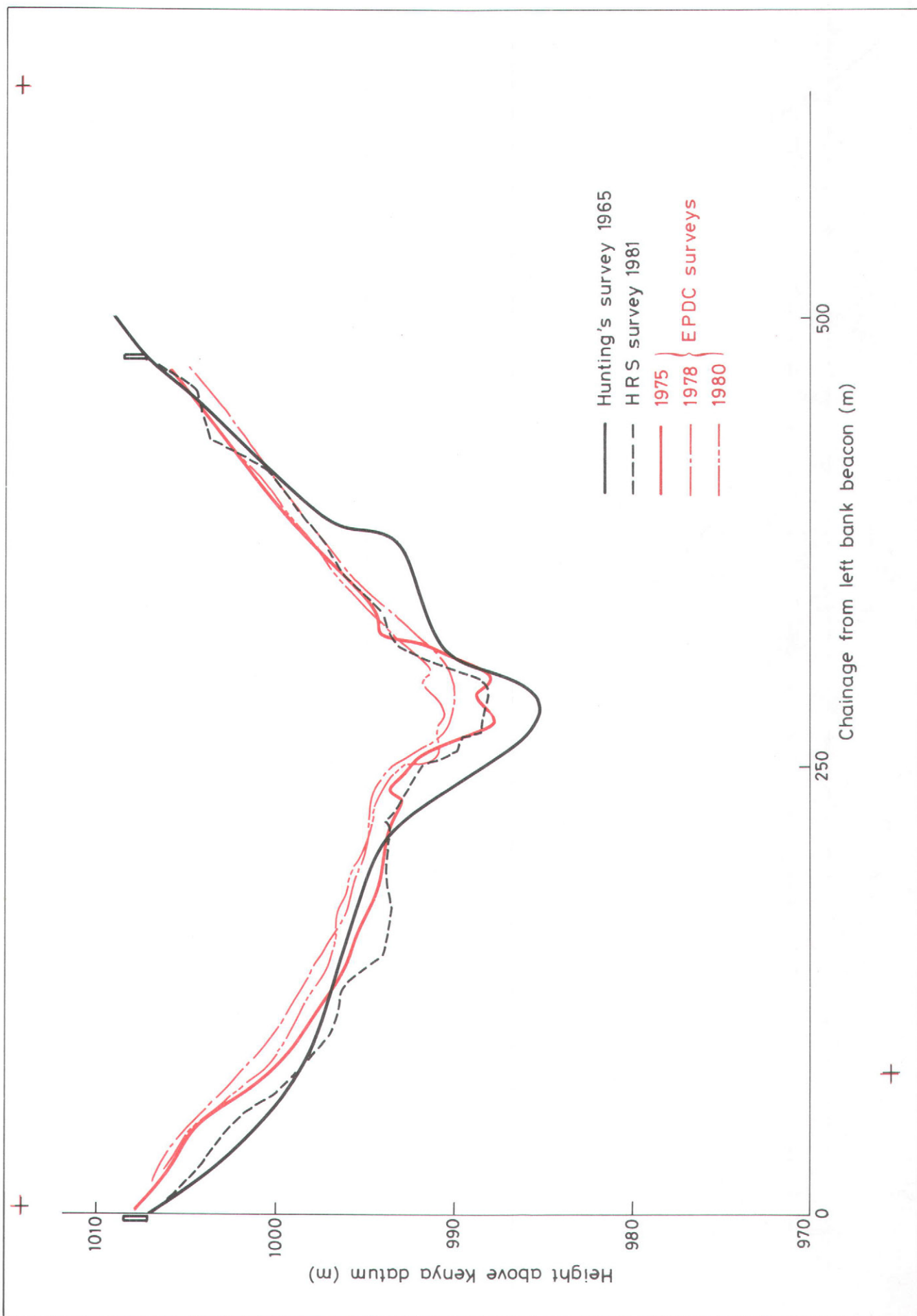


Fig 23 Kamburu Reservoir section TB8

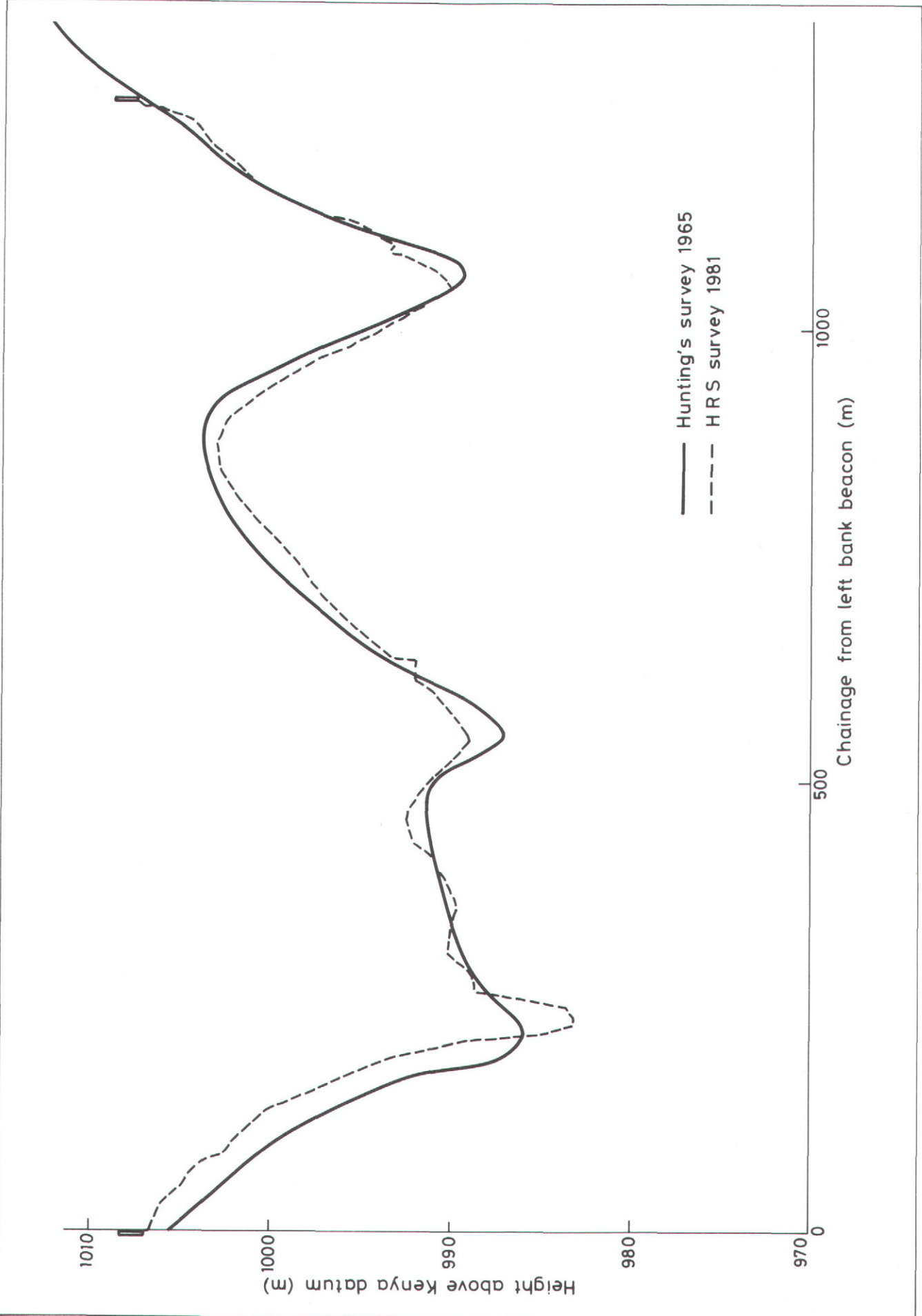


Fig 24 Kamburu Reservoir section TB9

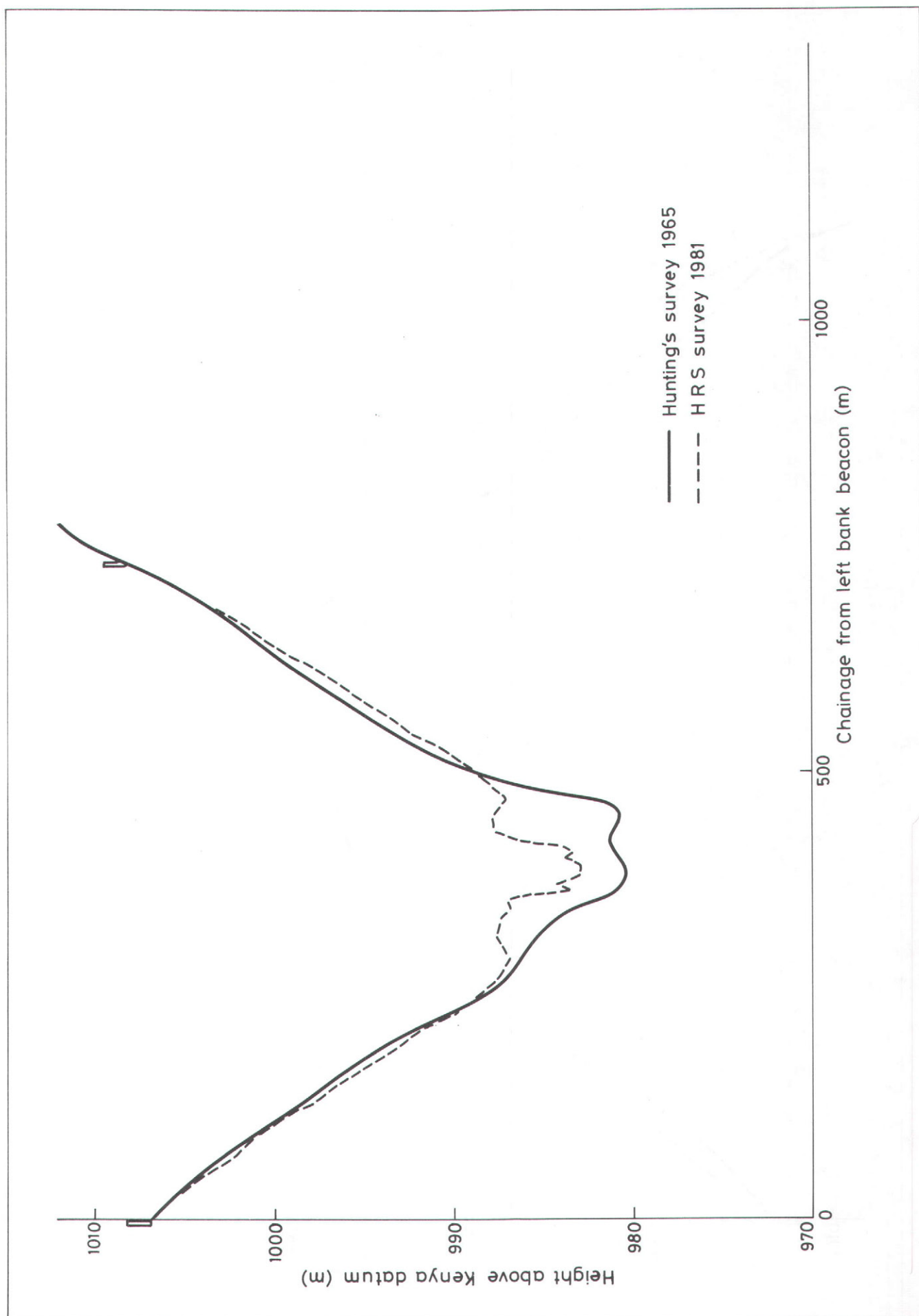


Fig 25 Kamburu Reservoir section TB10

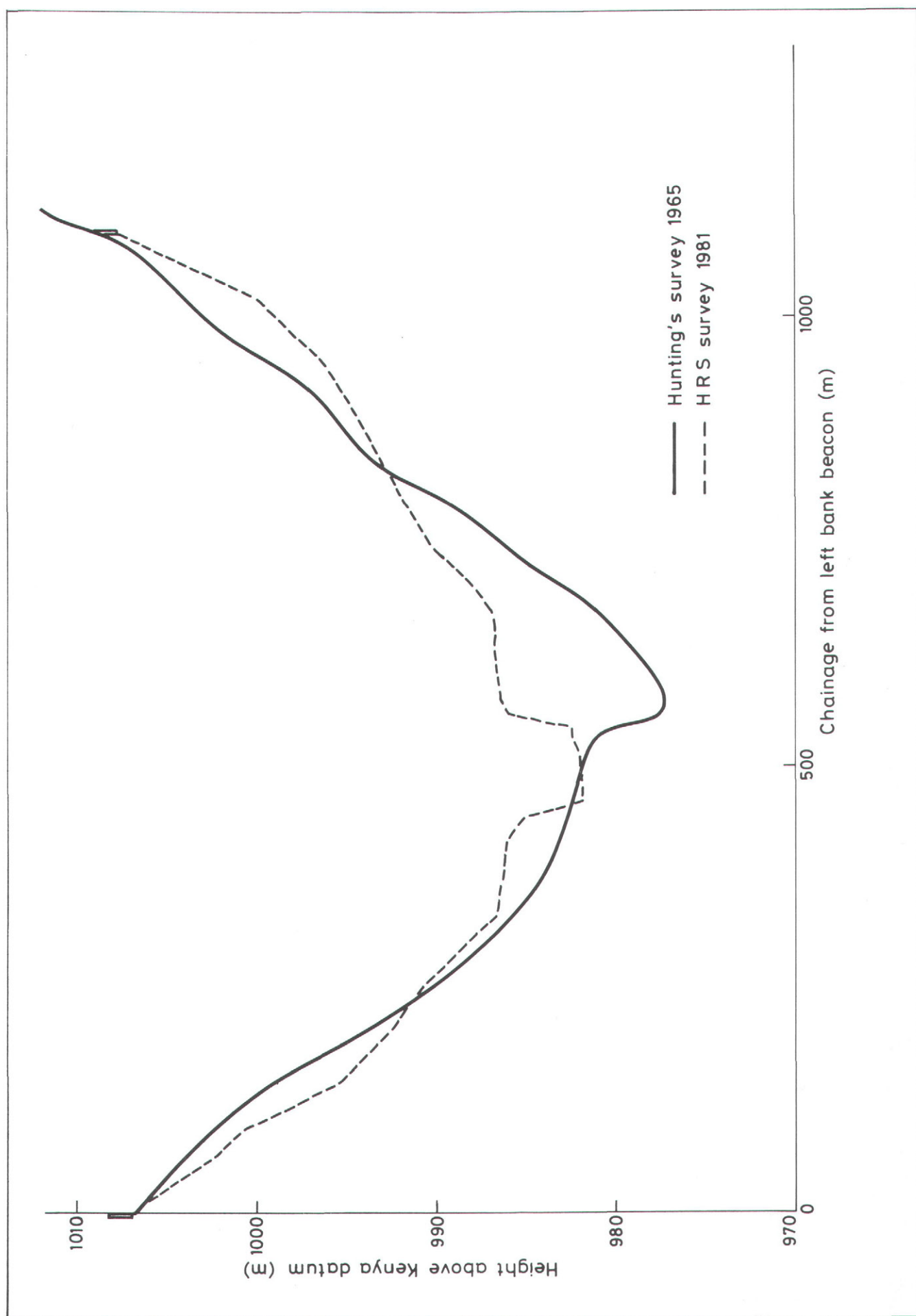


Fig 26 Kamburu Reservoir section TB11

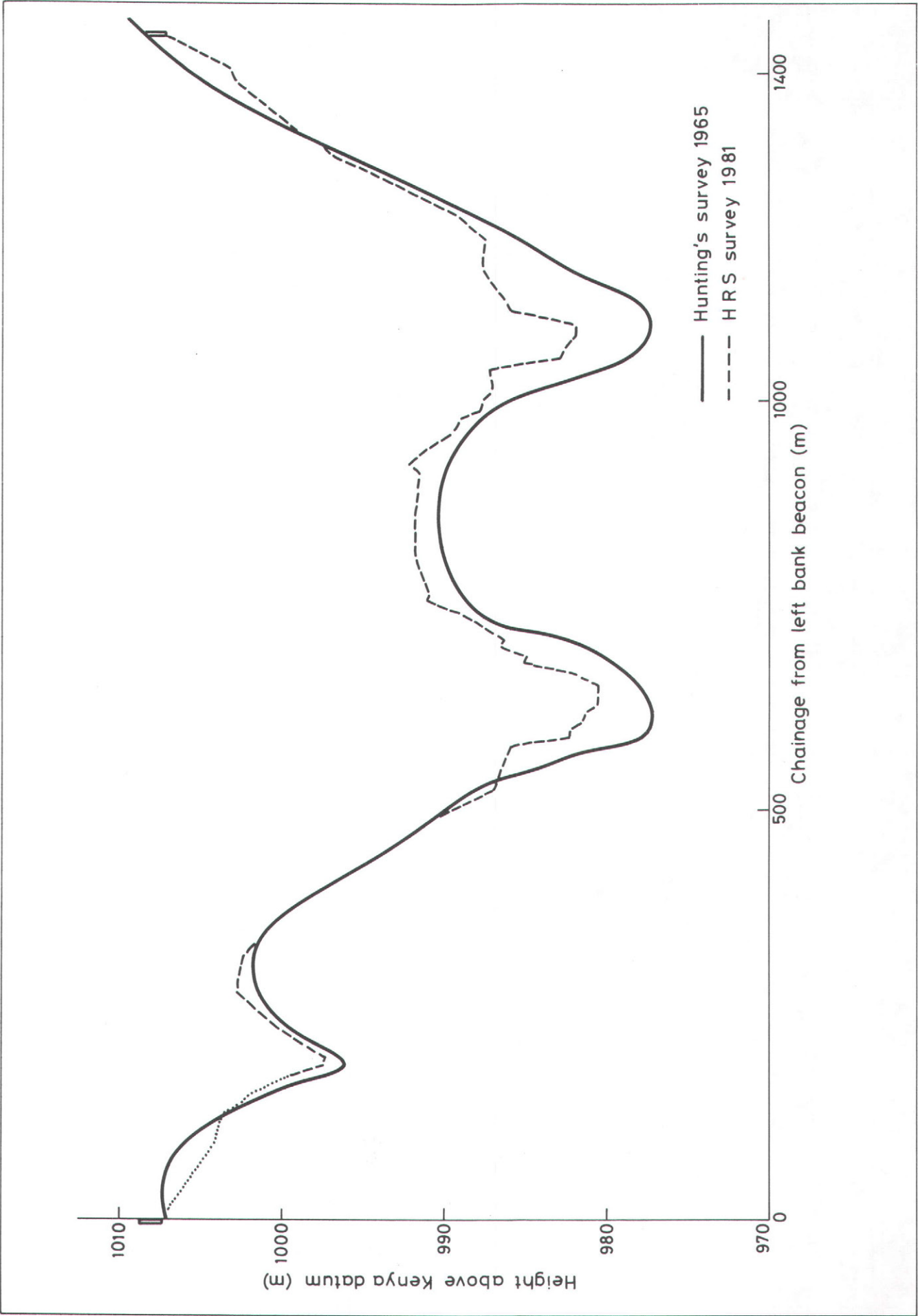


Fig 27 Kamburu Reservoir section TB12

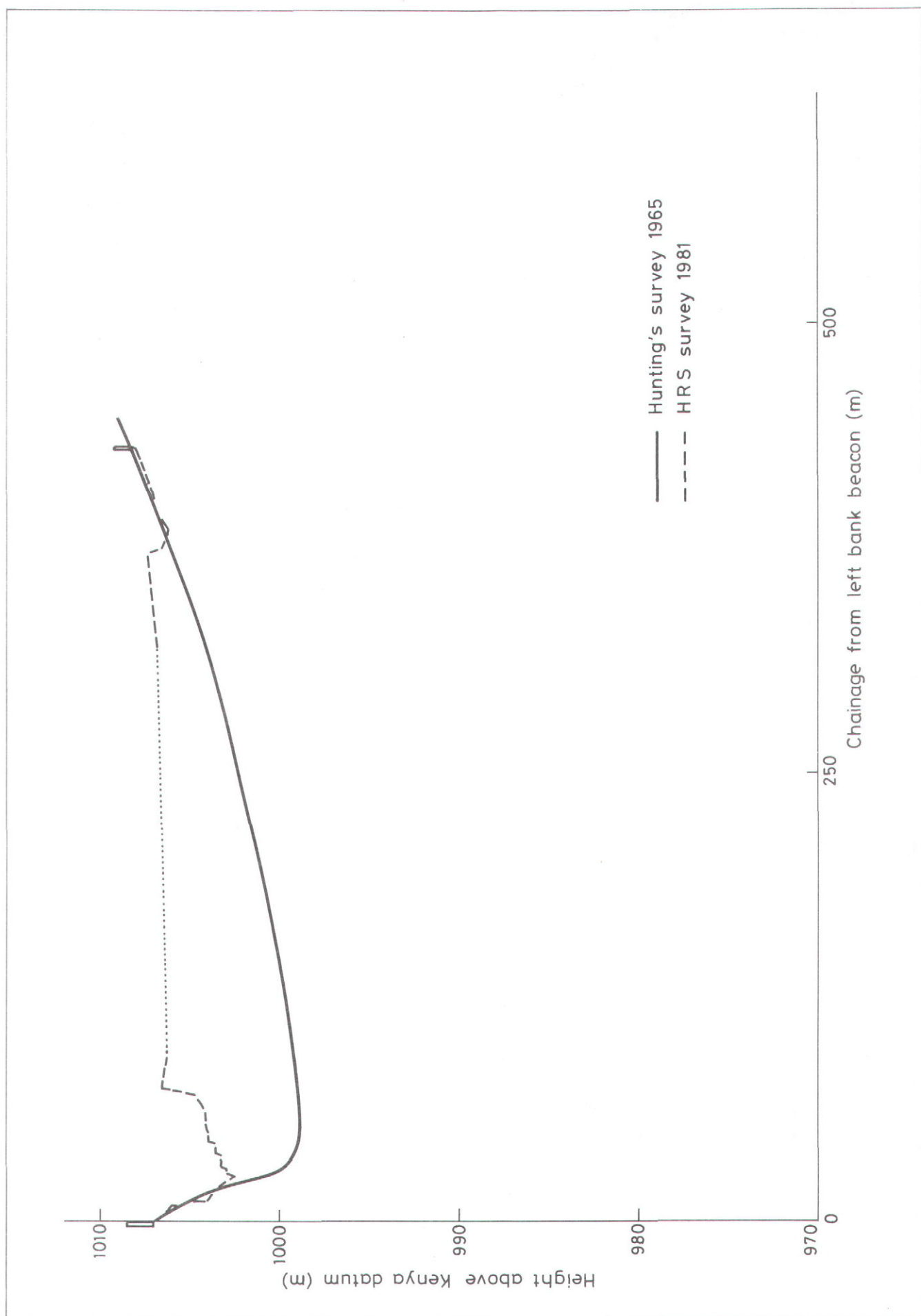


Fig 28 Kamburu Reservoir section TN3

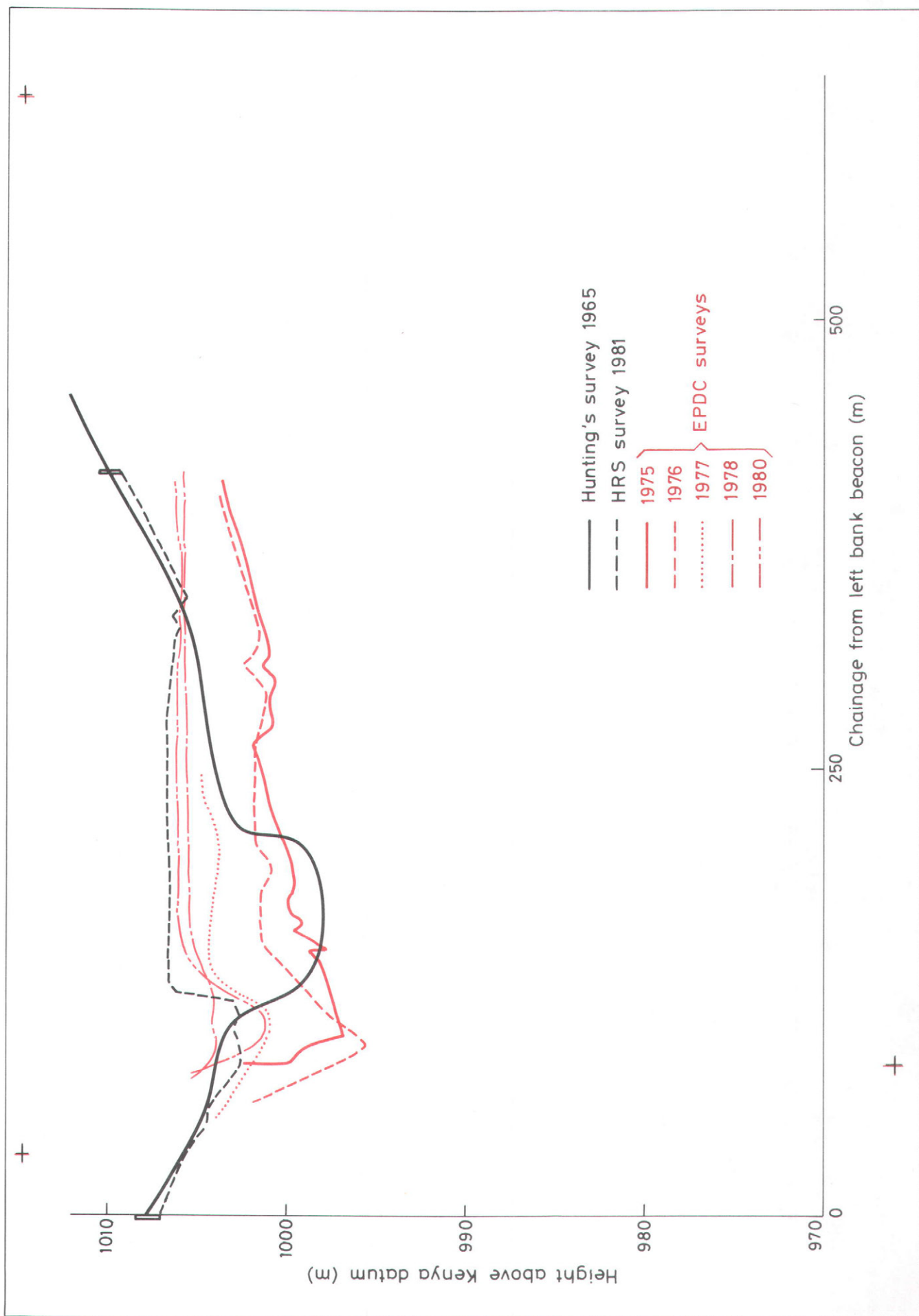


Fig 29 Kamburu Reservoir section TN4

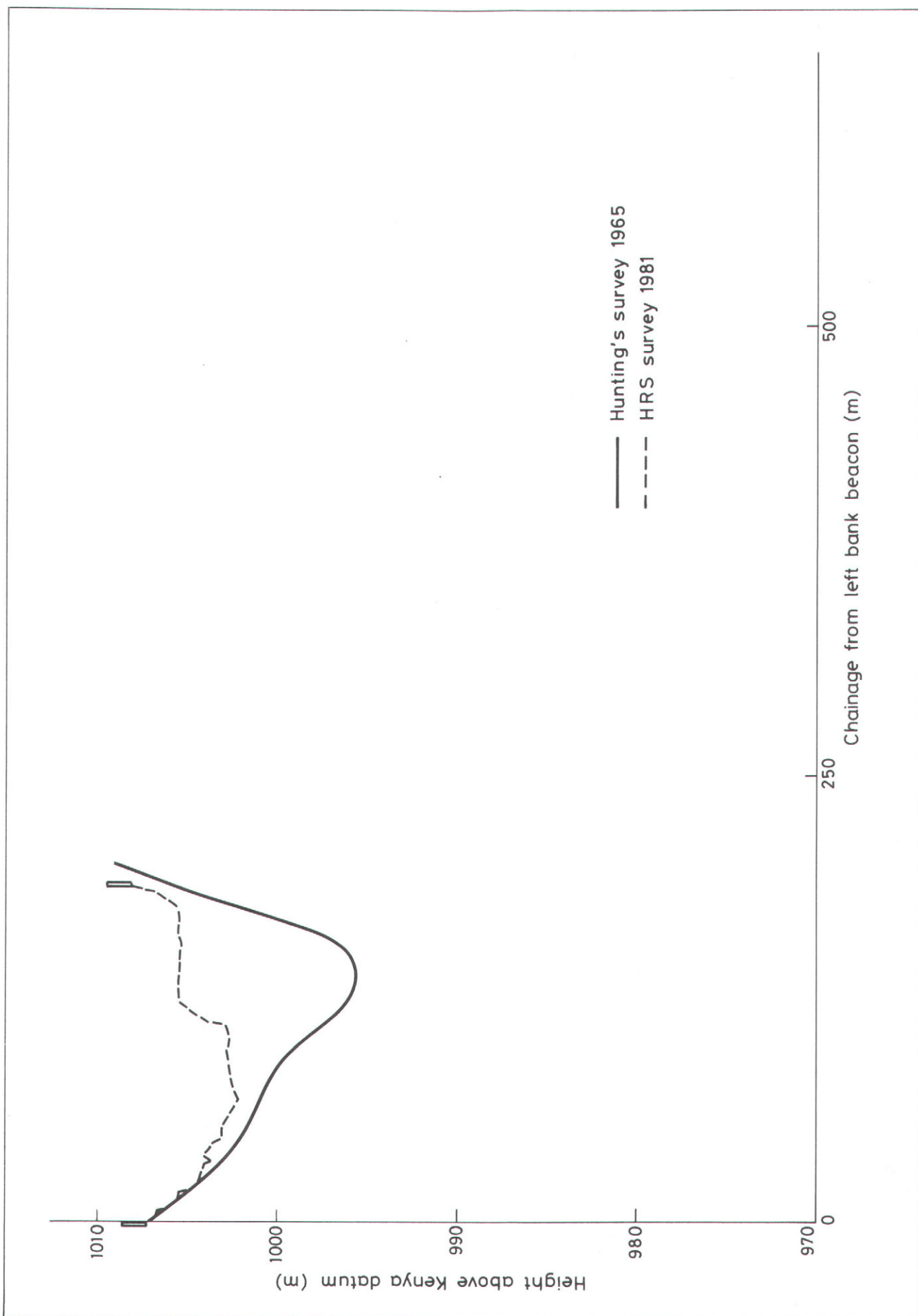


Fig 30 Kamburu Reservoir section TN5

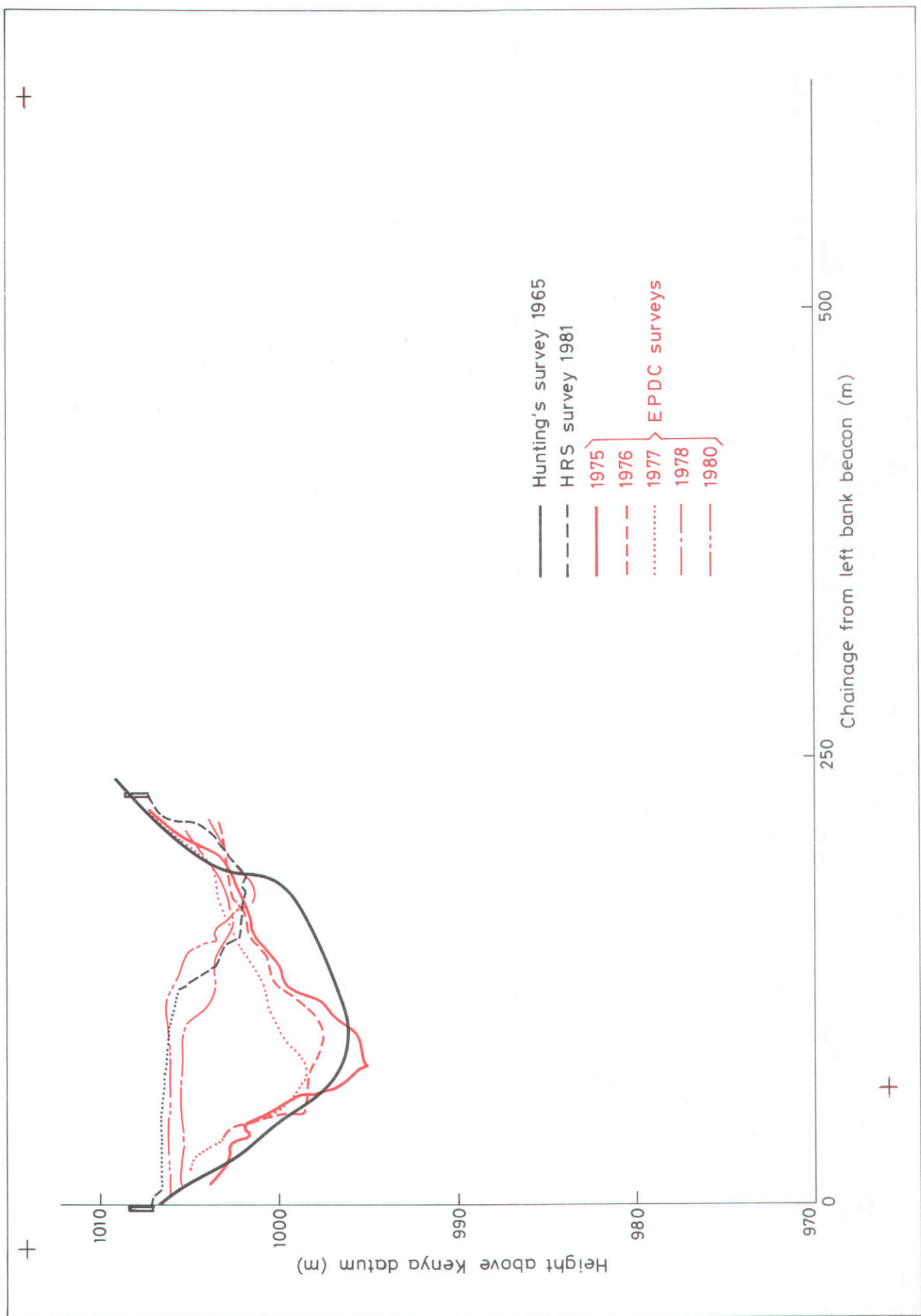


Fig 31 Kamburu Reservoir section TN6

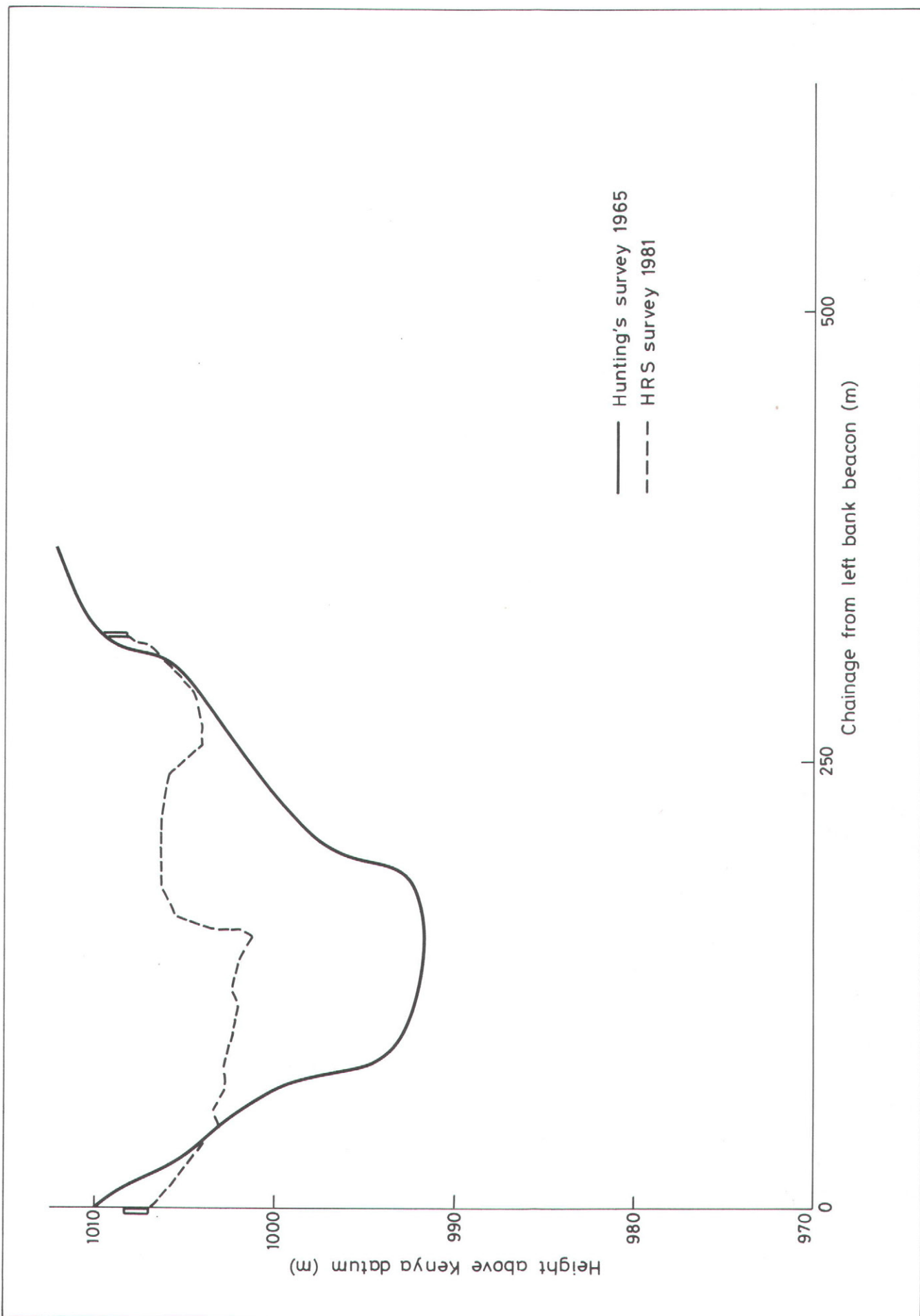


Fig 32 Kamburu Reservoir section TN7

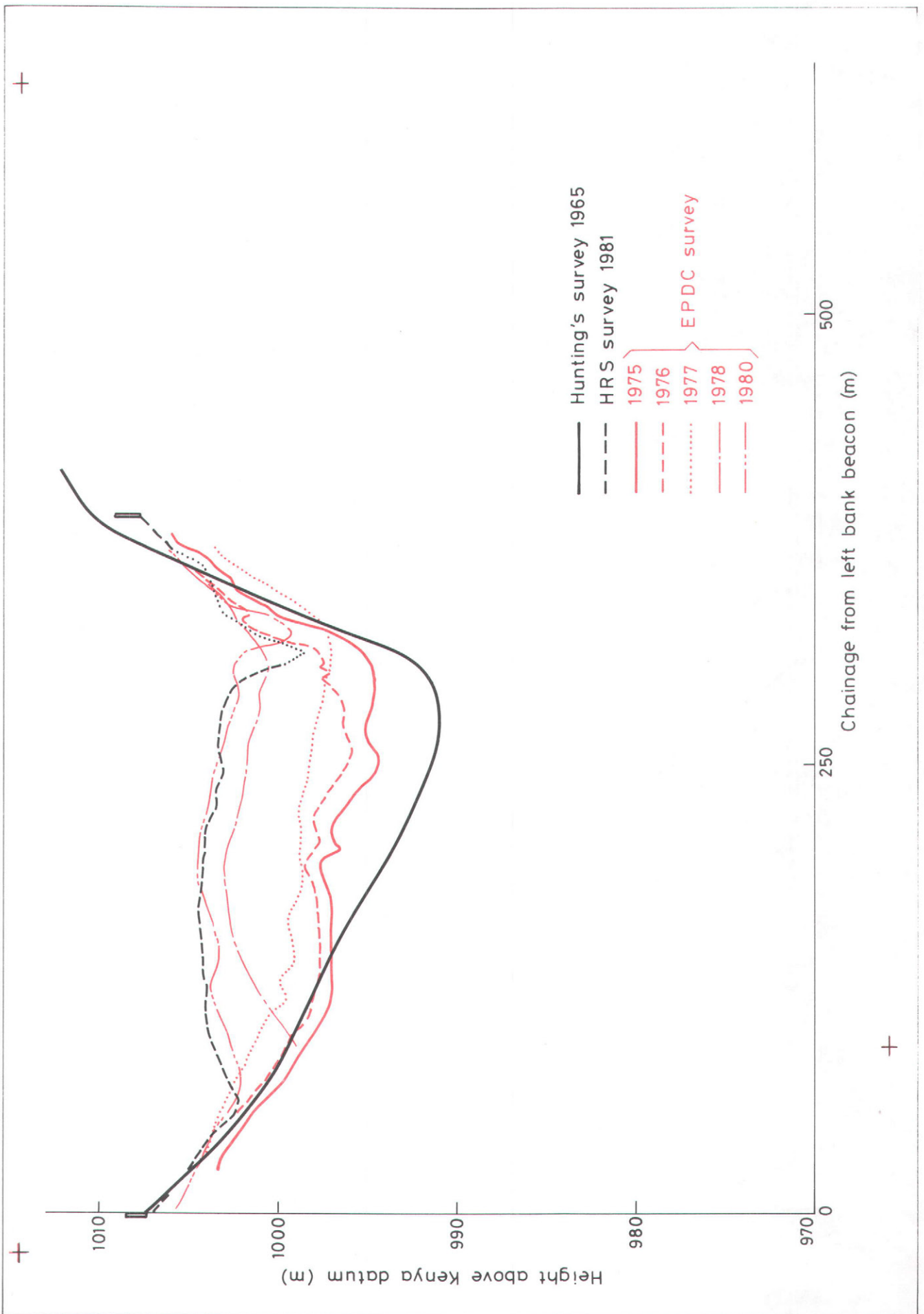


Fig 33 Kamburu Reservoir section TN8

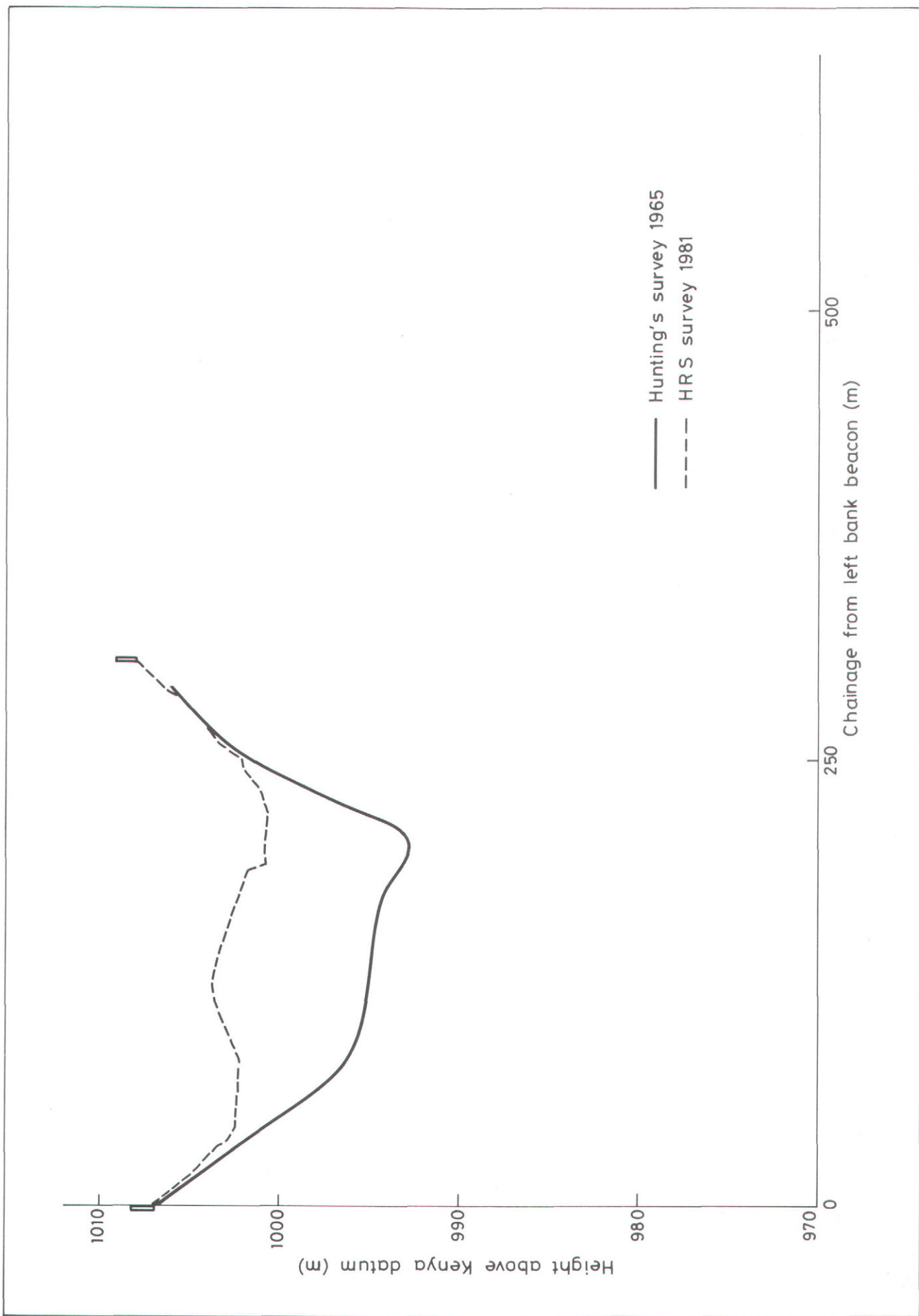


Fig 34 Kamburu Reservoir section TN9

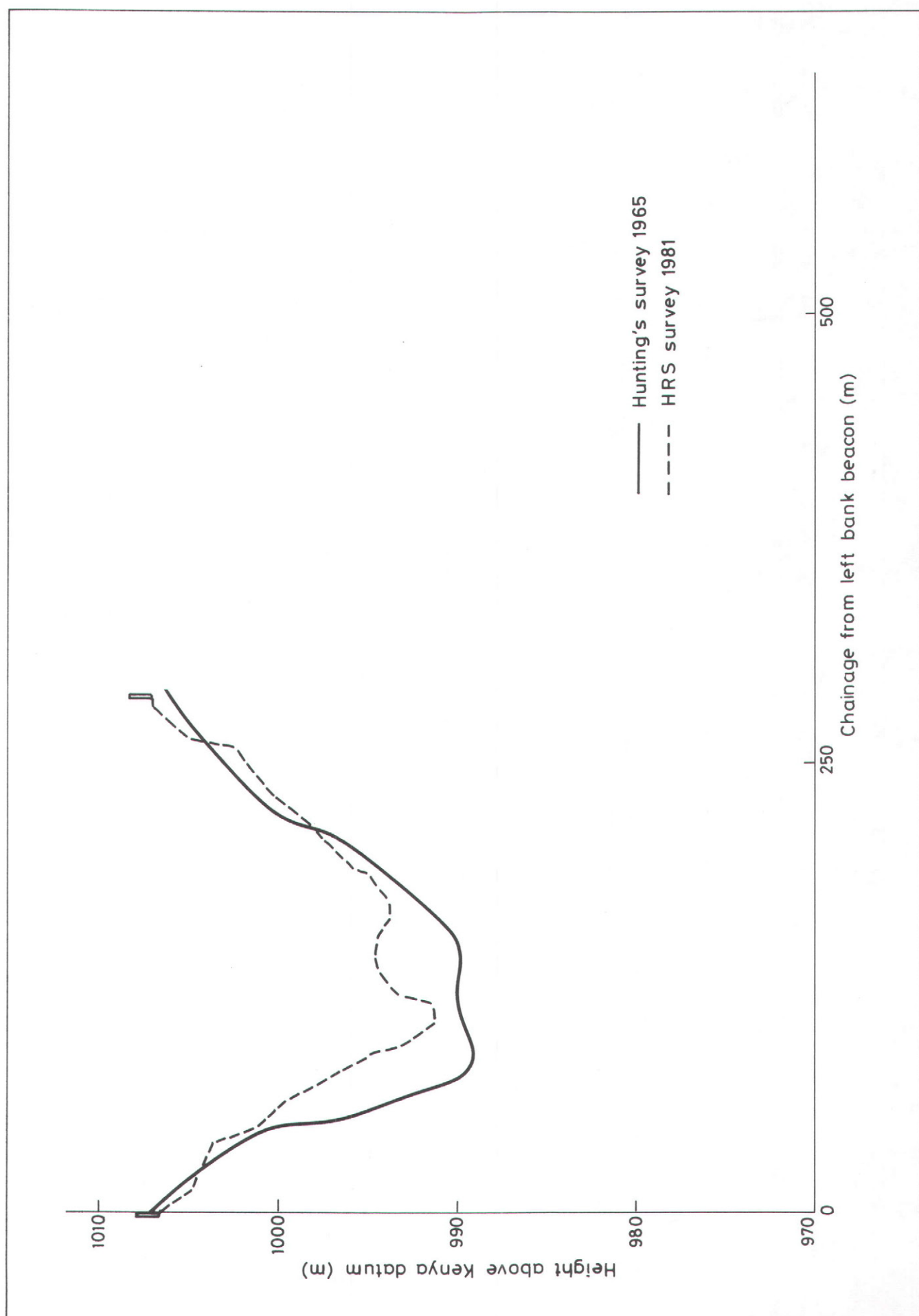


Fig 35 Kamburu Reservoir section TN10 (L)

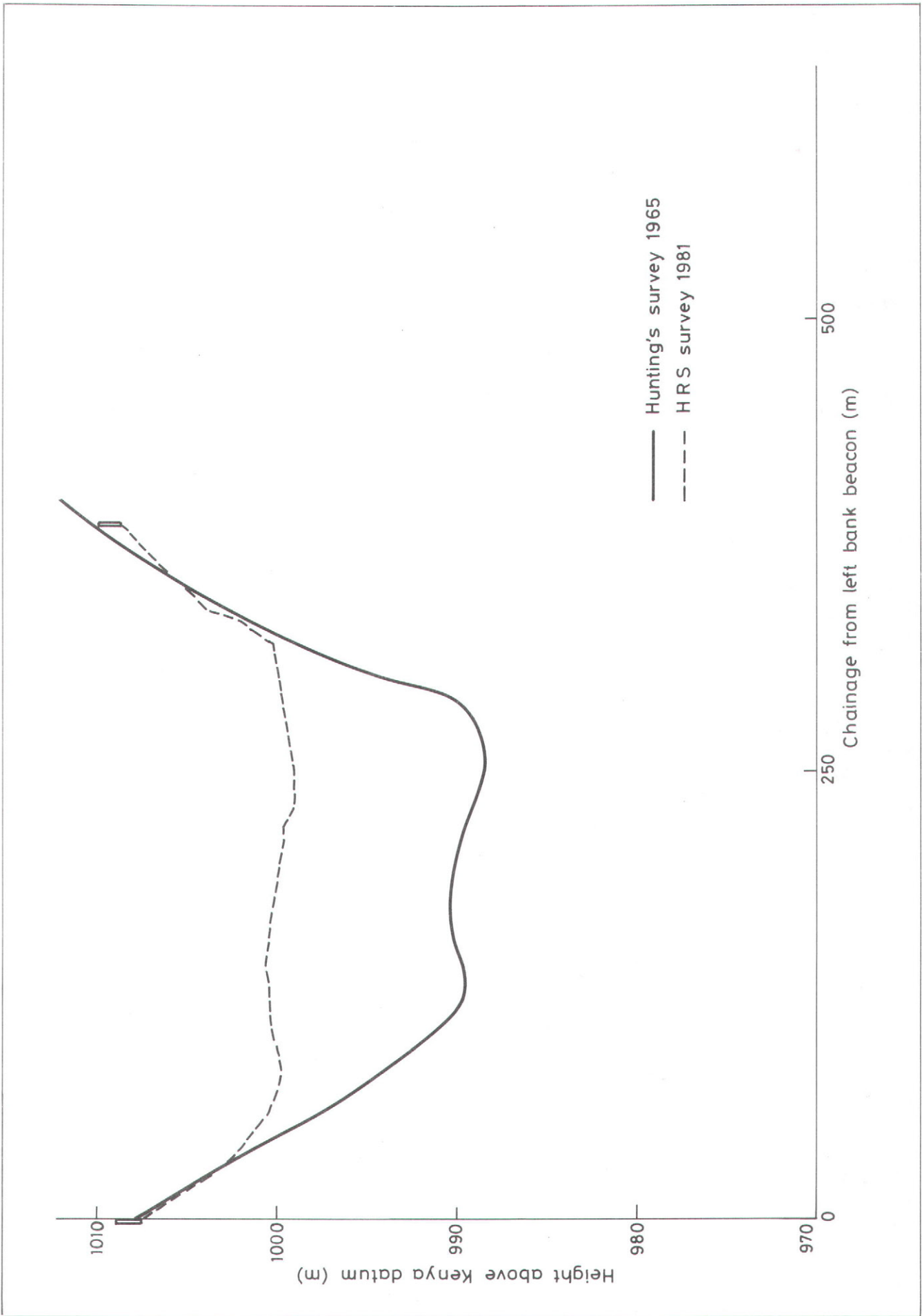


Fig 36 Kamburu Reservoir section TN10(R)

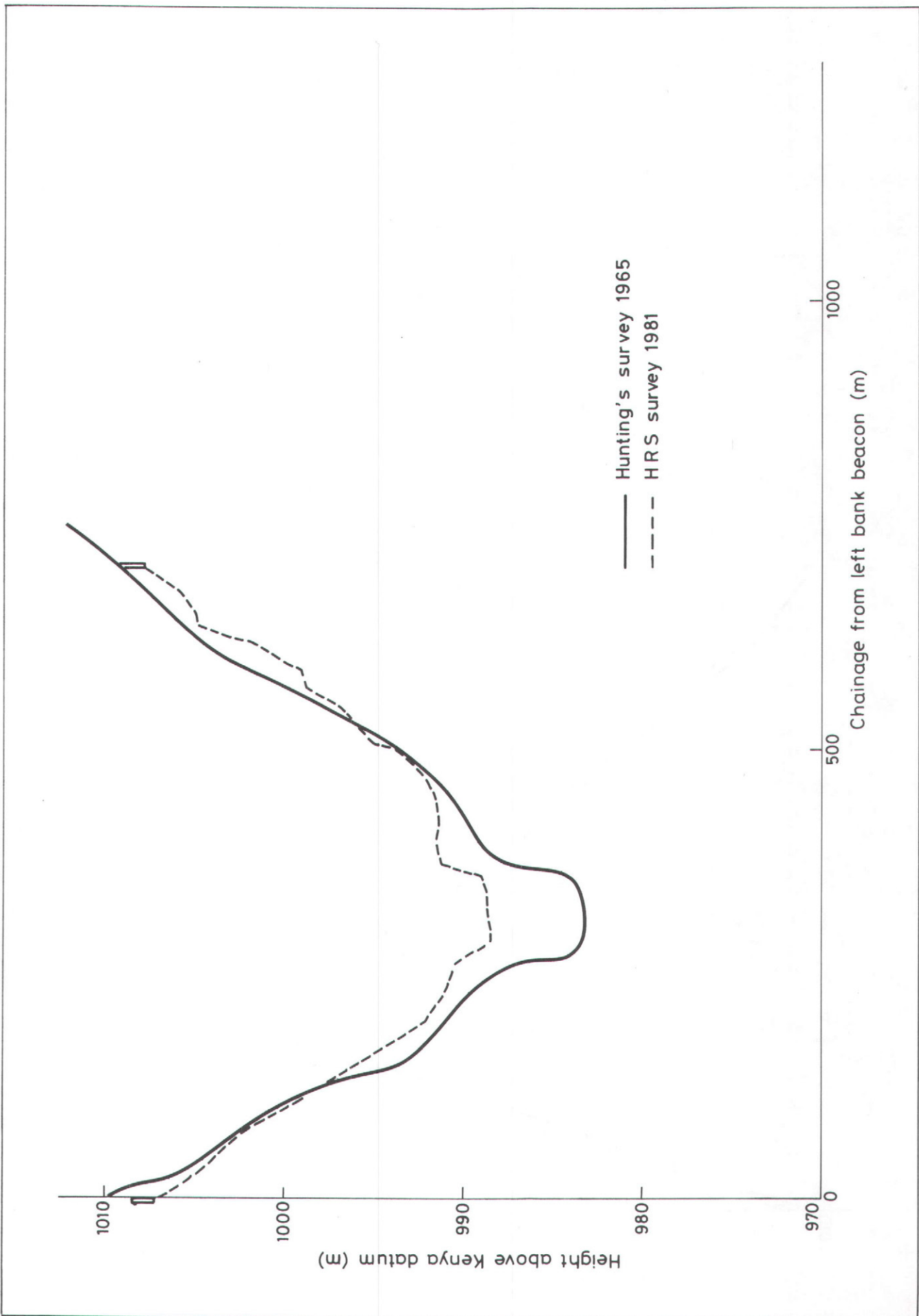


Fig 37 Kamburu Reservoir section TN11

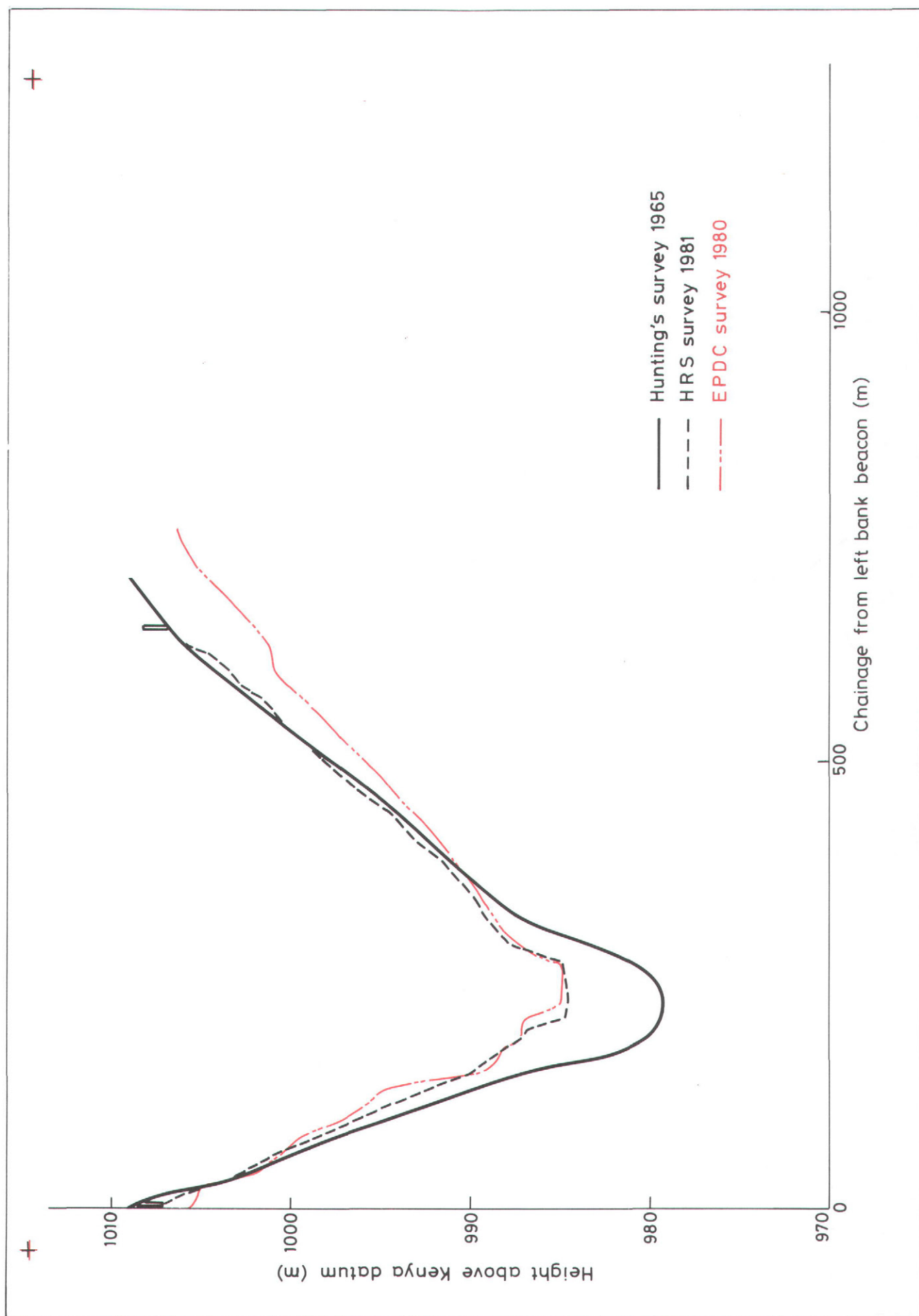


Fig 38 Kamburu Reservoir section TN12

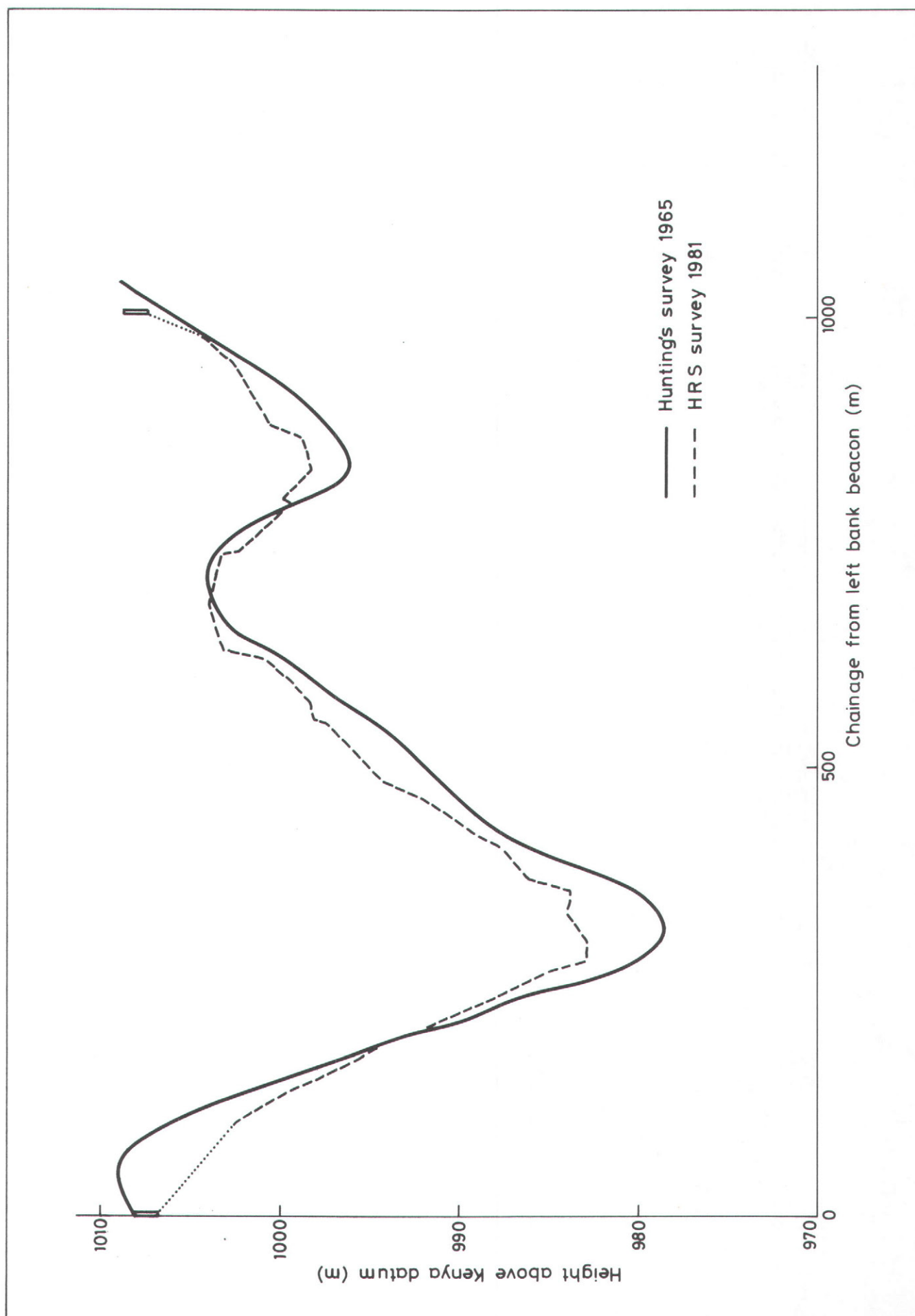


Fig 39 Kamburu Reservoir section TN13

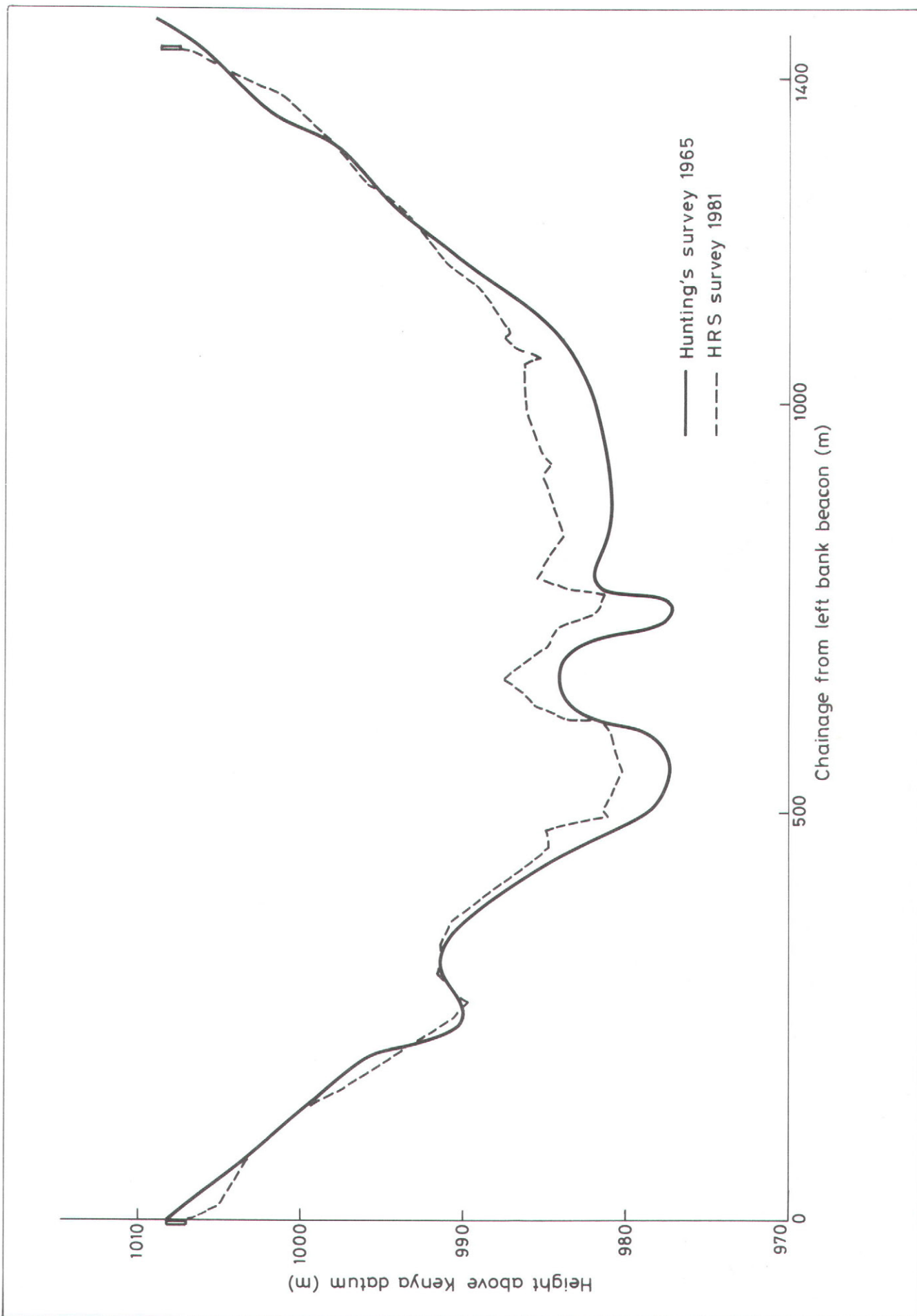


Fig 40 Kamburu Reservoir section TN14

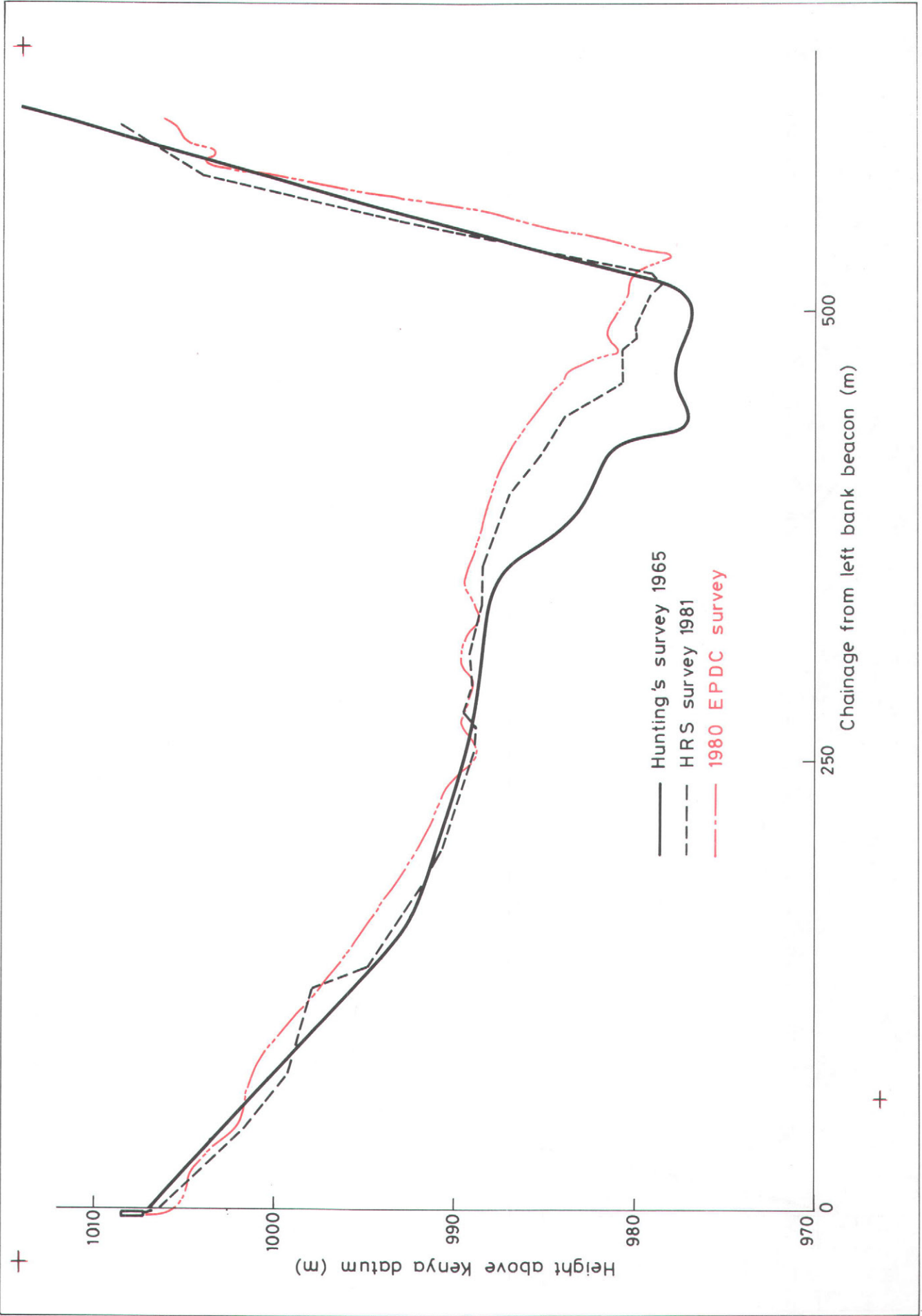


Fig 41 Kamburu Reservoir section TN15(L)

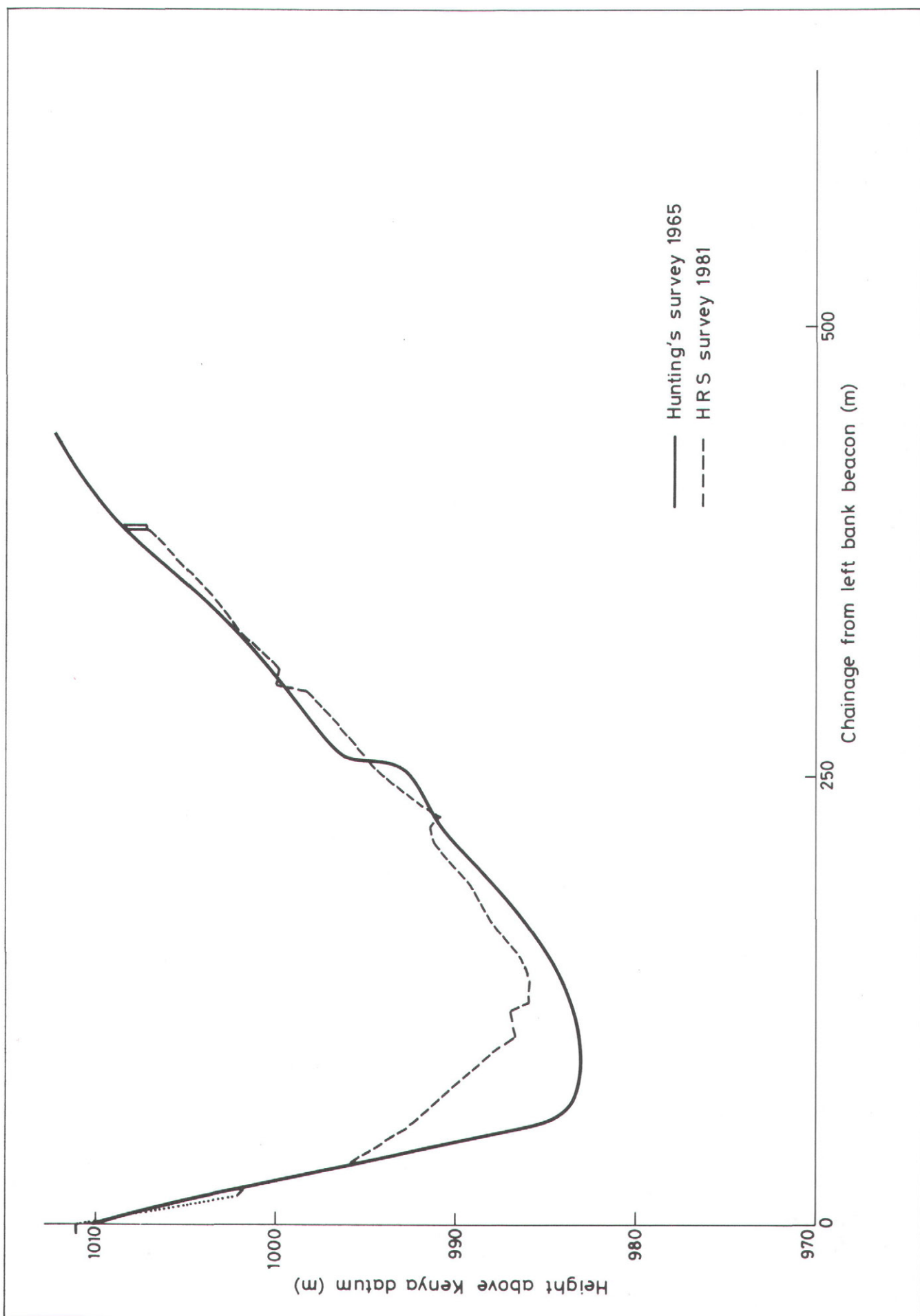


Fig 42 Kamburu Reservoir section TN15 (R)

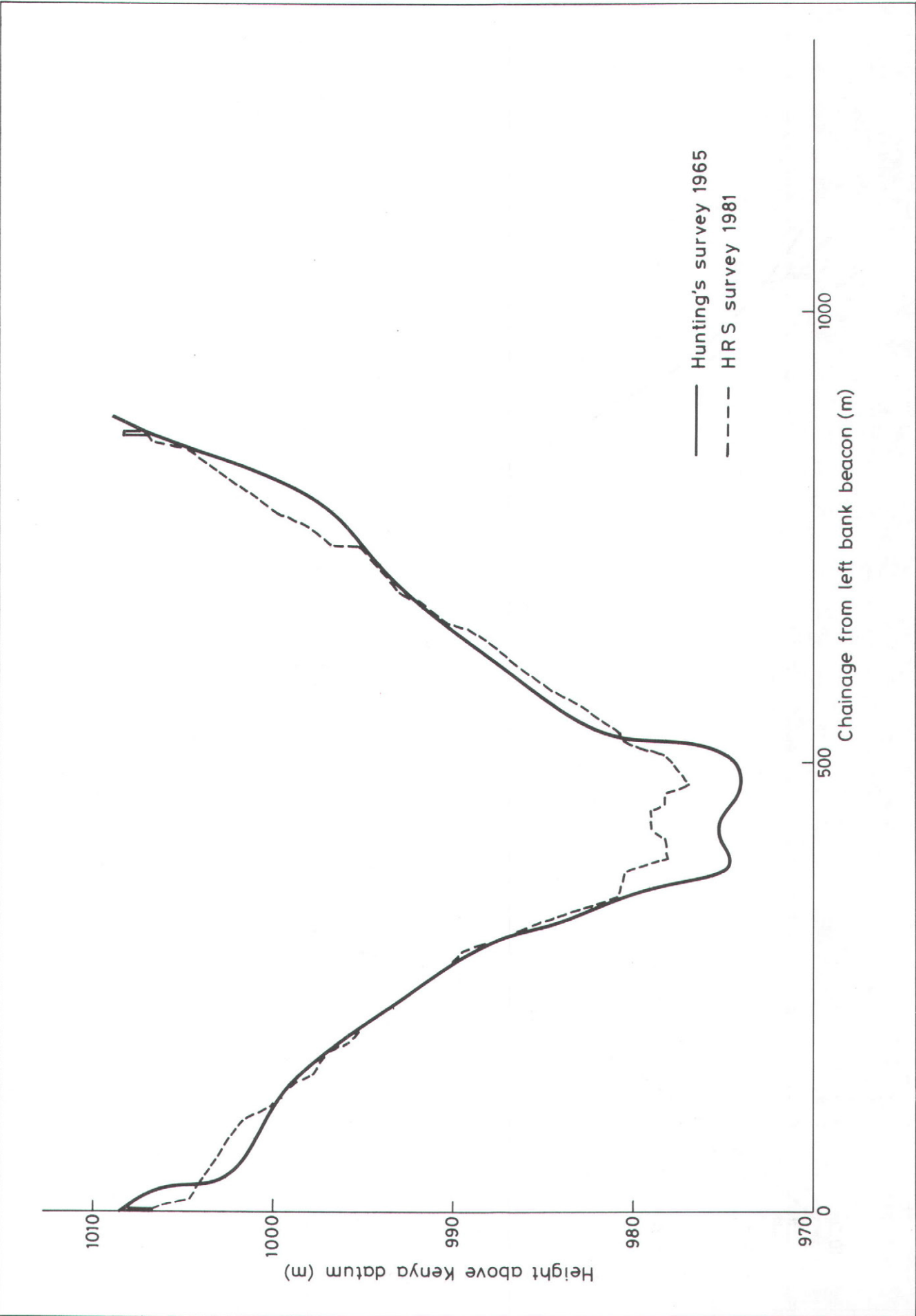


Fig 43 Kamburu Reservoir section TN16

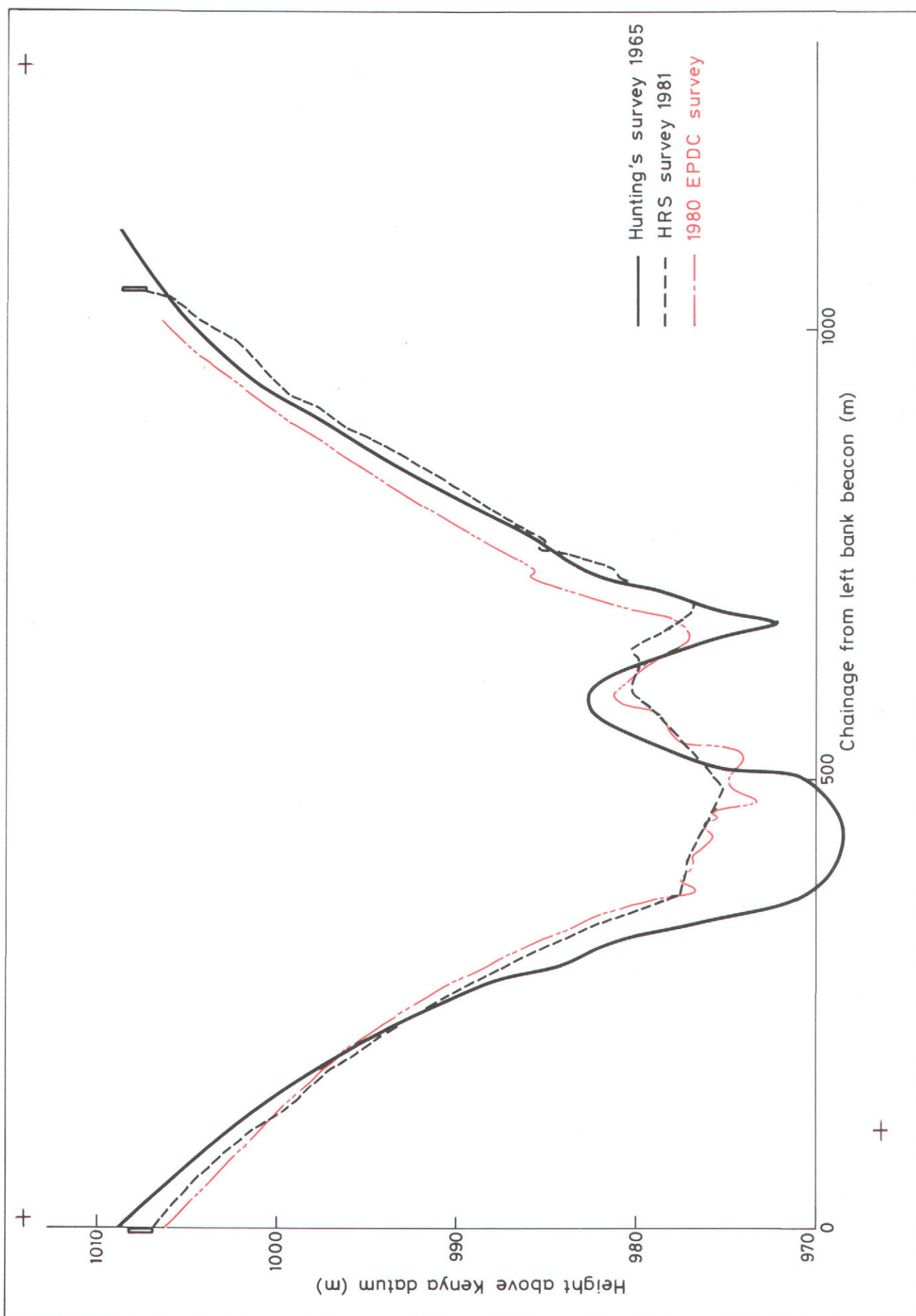


Fig 44 Kamburu Reservoir section TN17

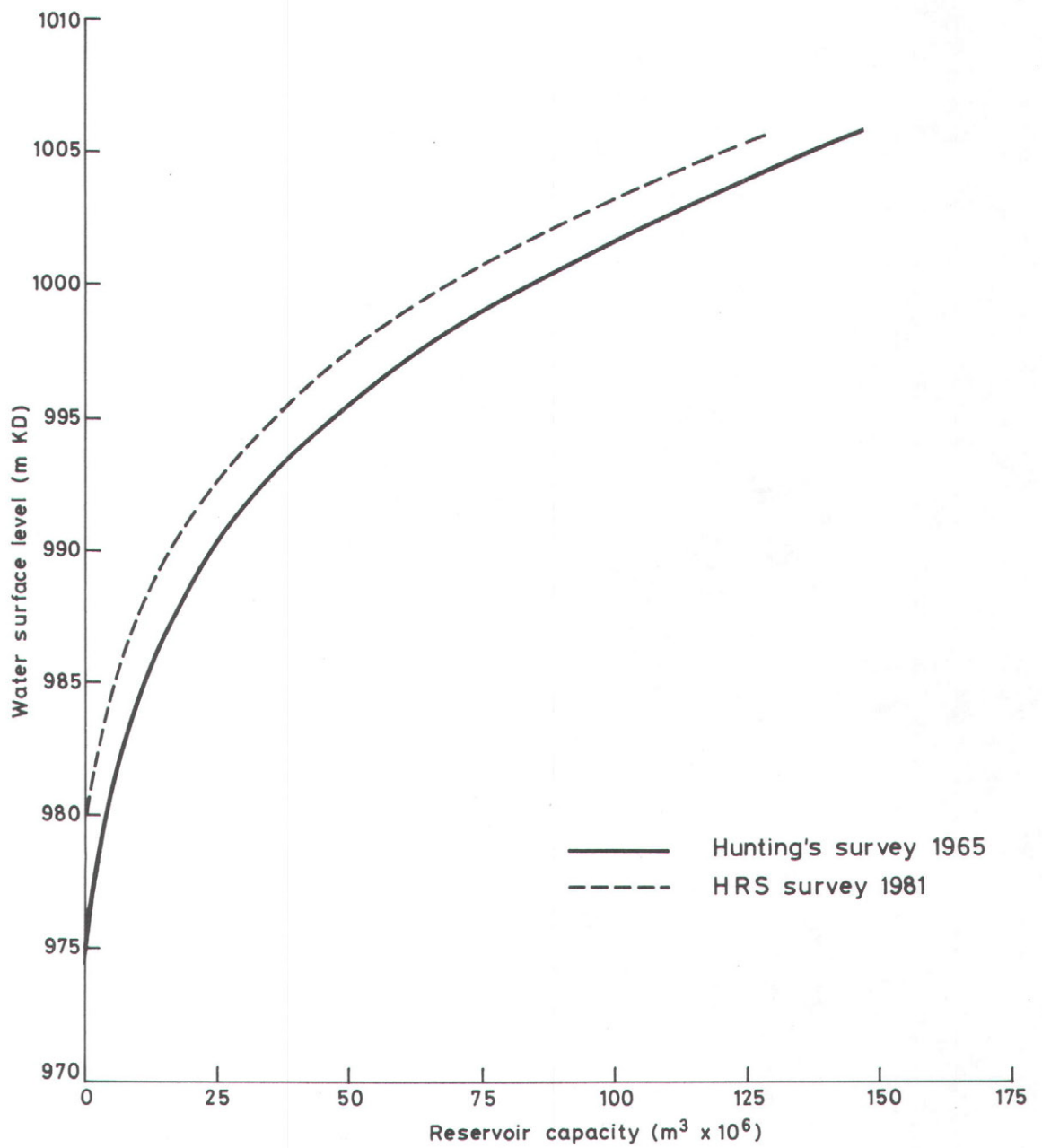


Fig 45 Kamburu reservoir- stage/capacity curve

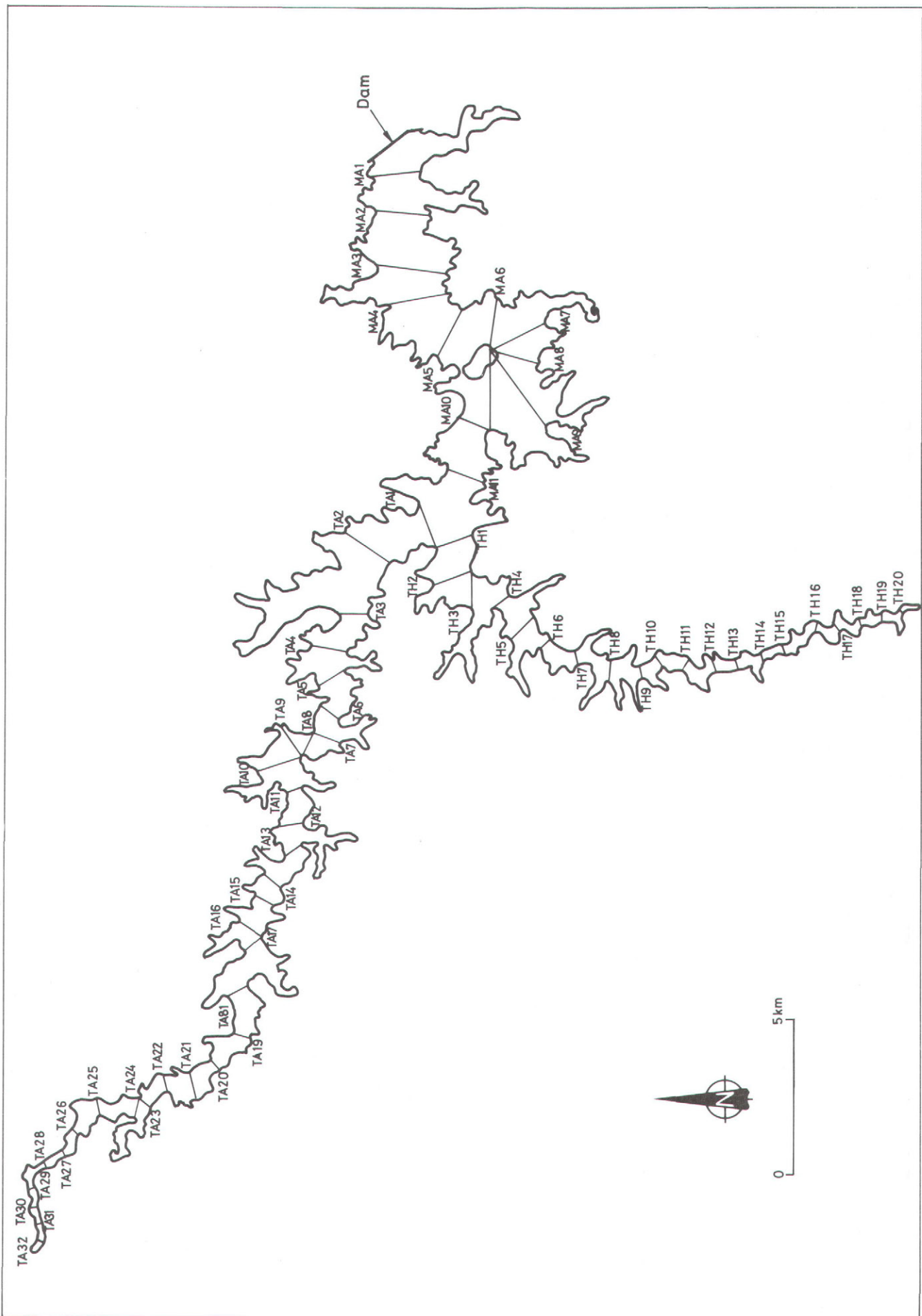


Fig 46 Masinga Reservoir

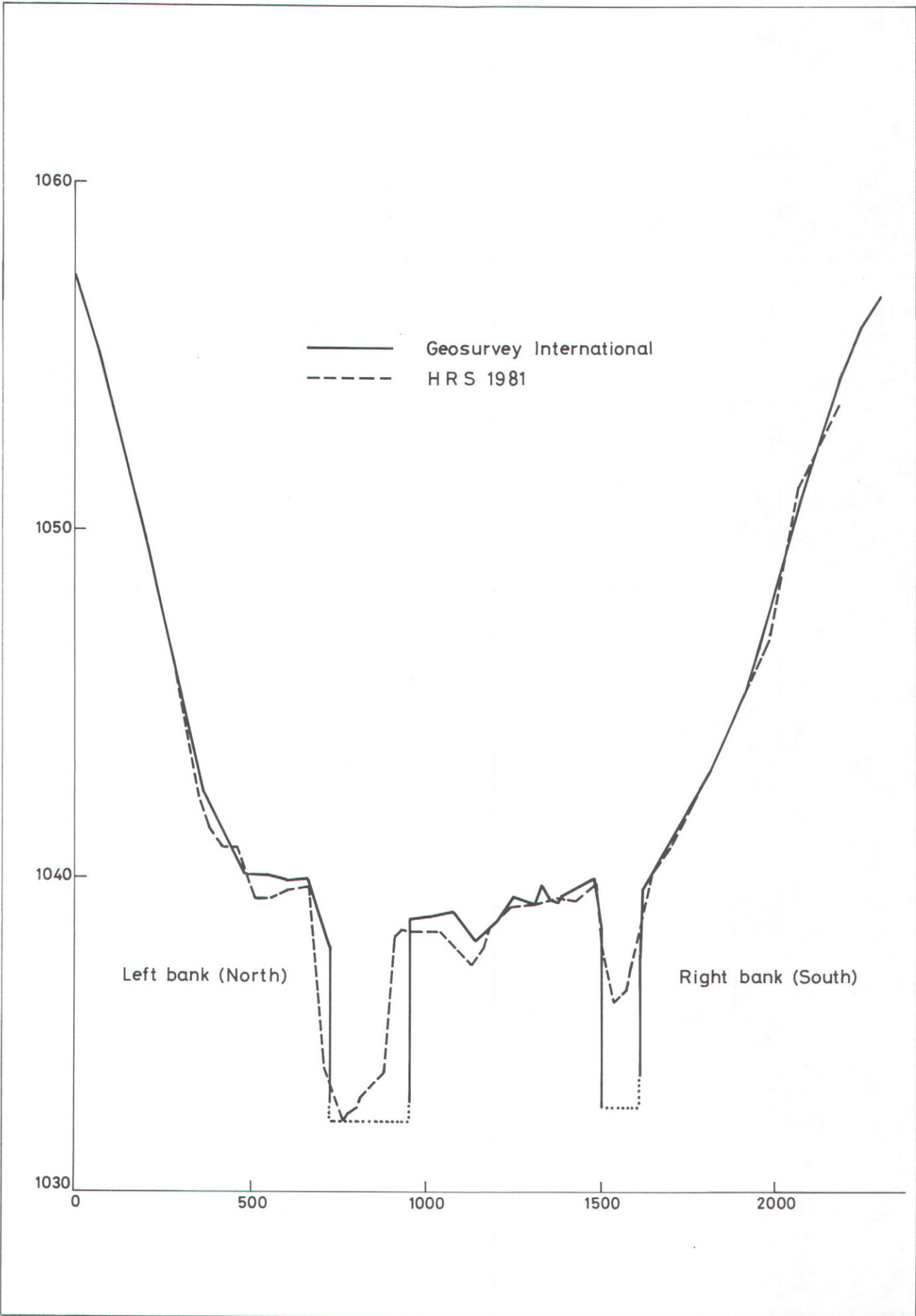


Fig 47 Masinga Reservoir – cross section TA 12

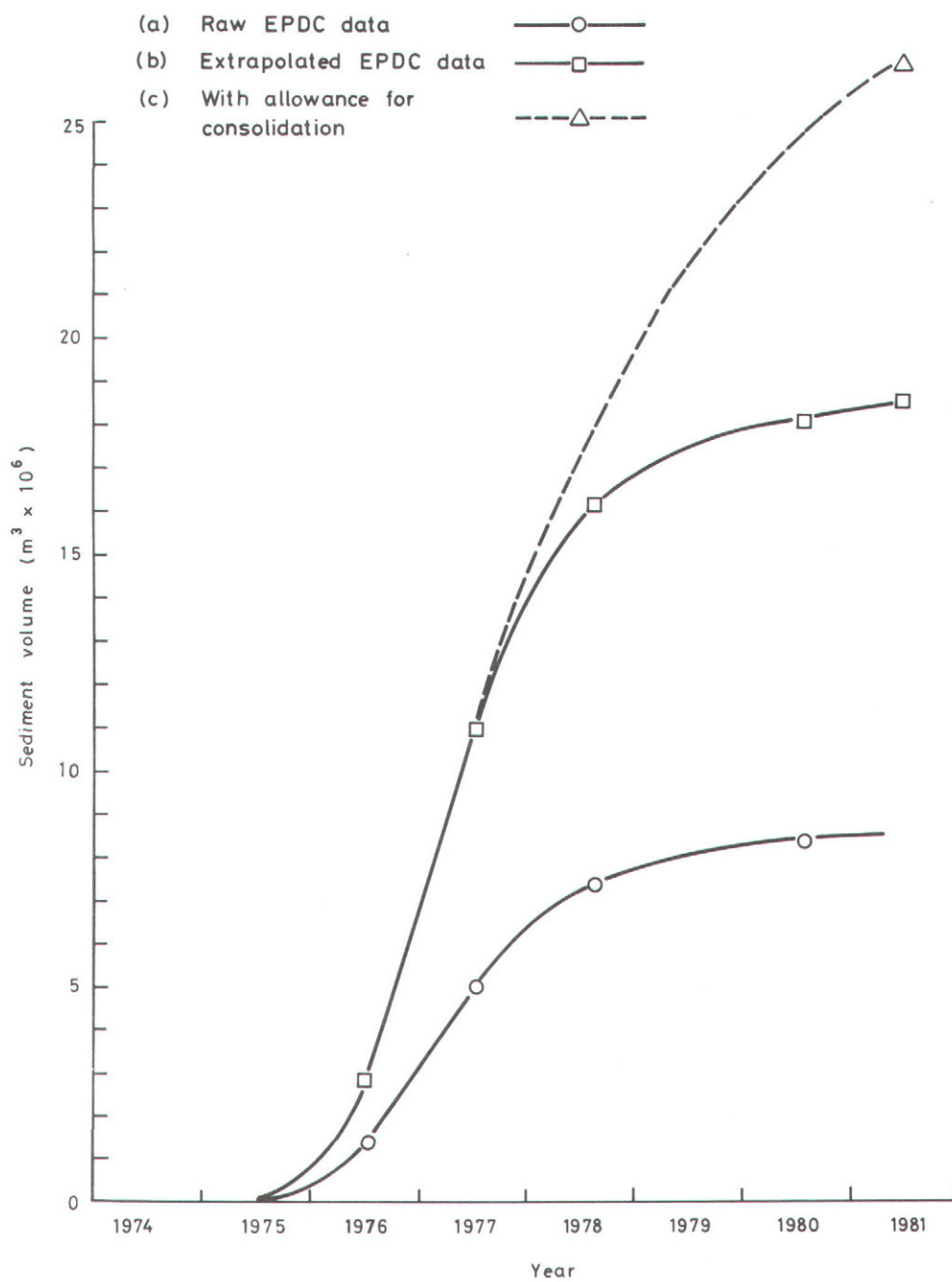


Fig 48 Kamburu Reservoir - Sediment volumes

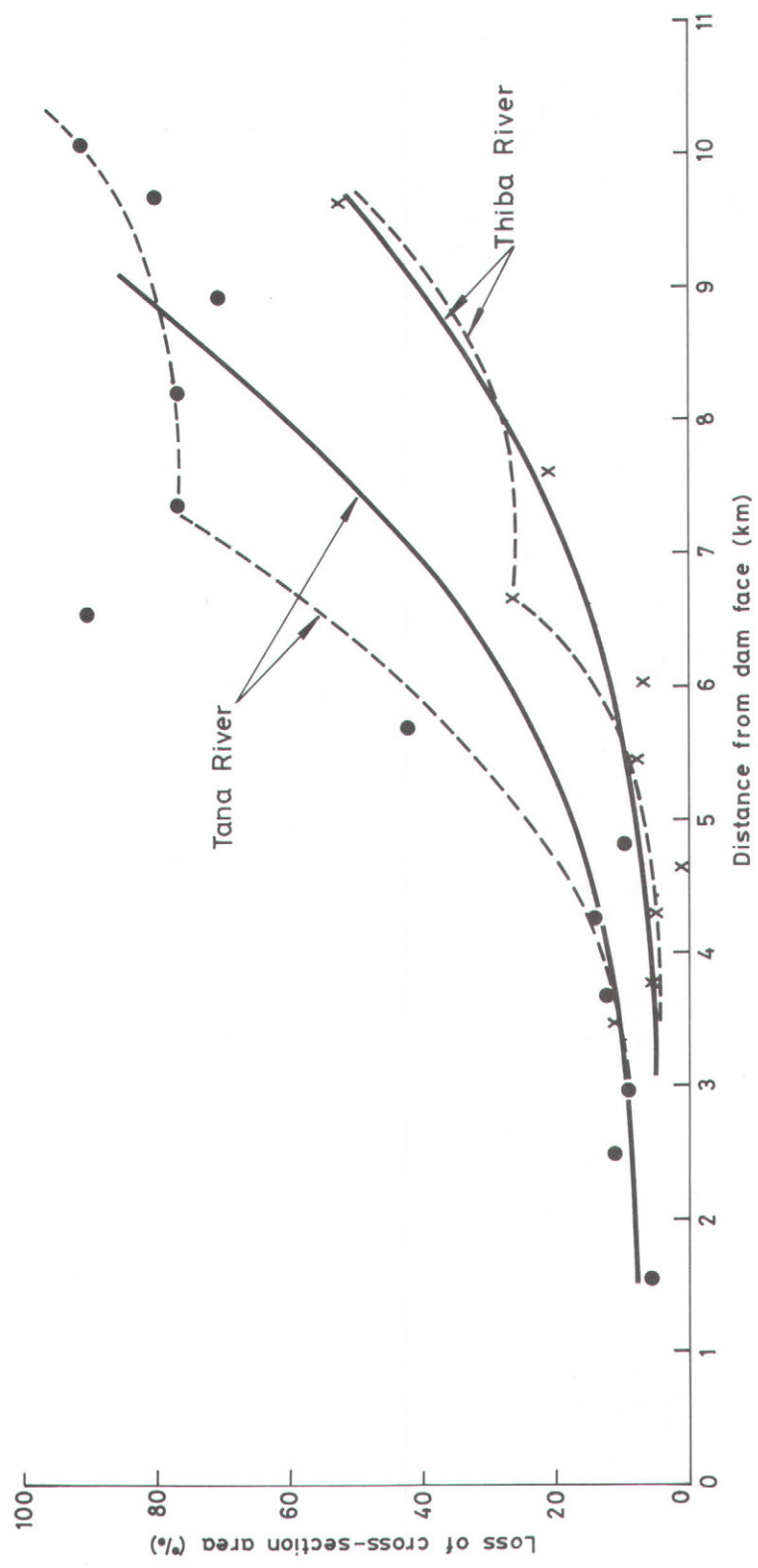


Fig 49 Kamburu Reservoir- loss of cross-section area versus distance from dam face

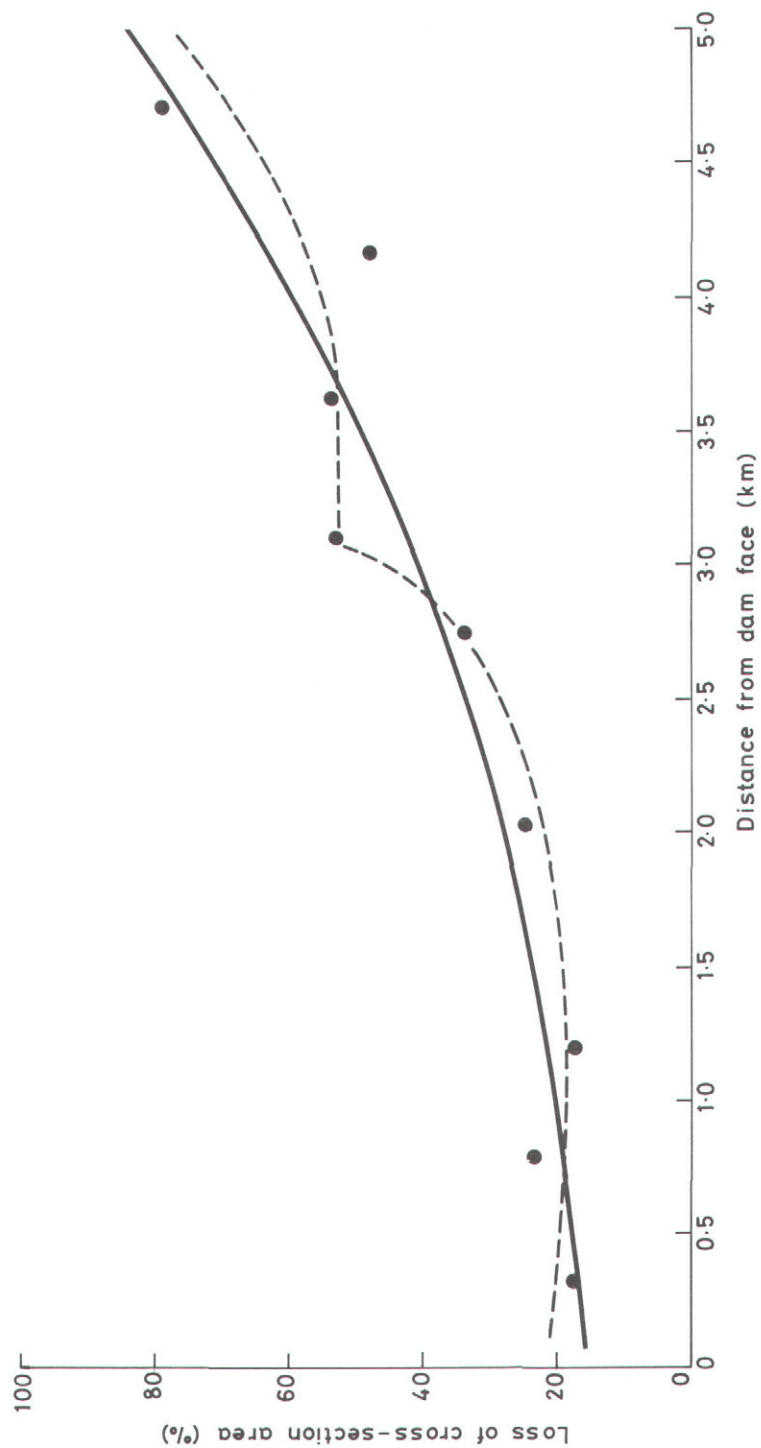
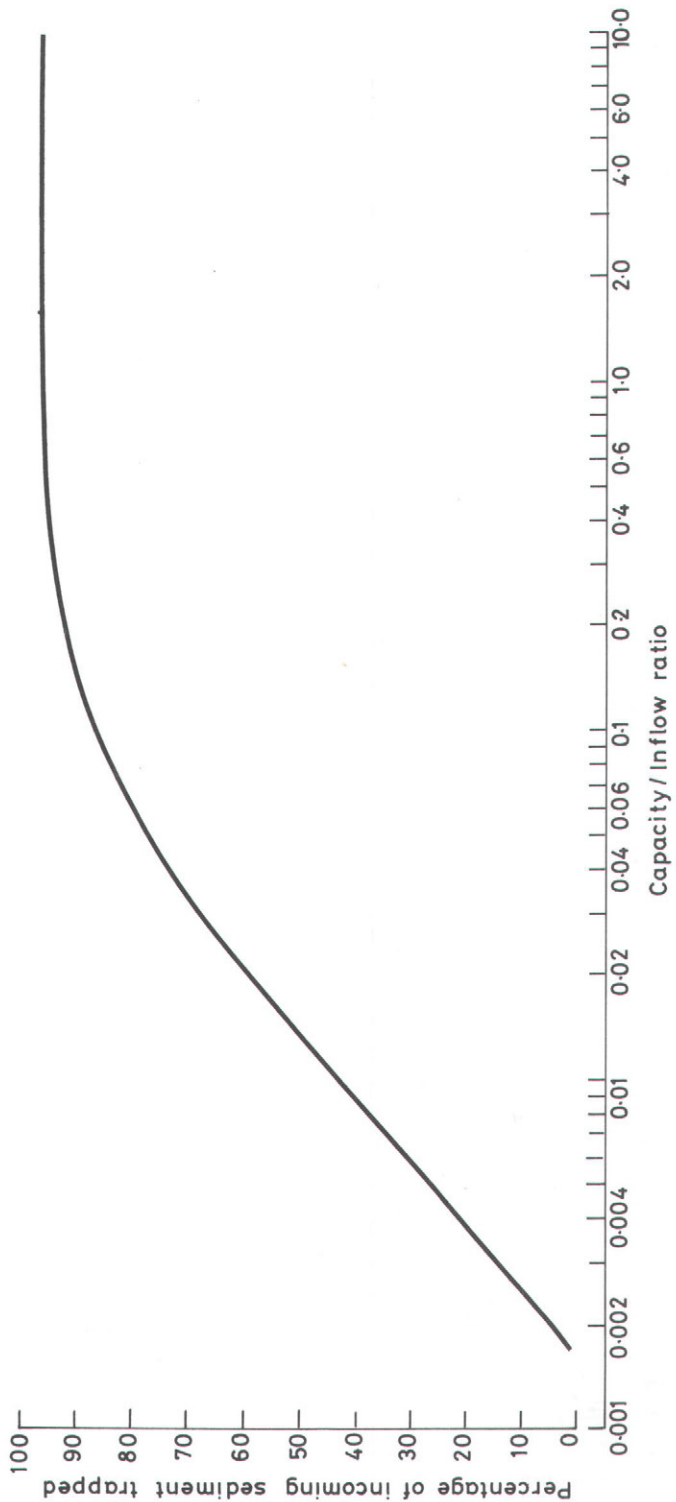


Fig 50 Kindaruma Reservoir—loss of cross-section area versus distance from dam face



Based on data from reference 5

Fig 51 Relationship between capacity/inflow ratio and trap efficiency

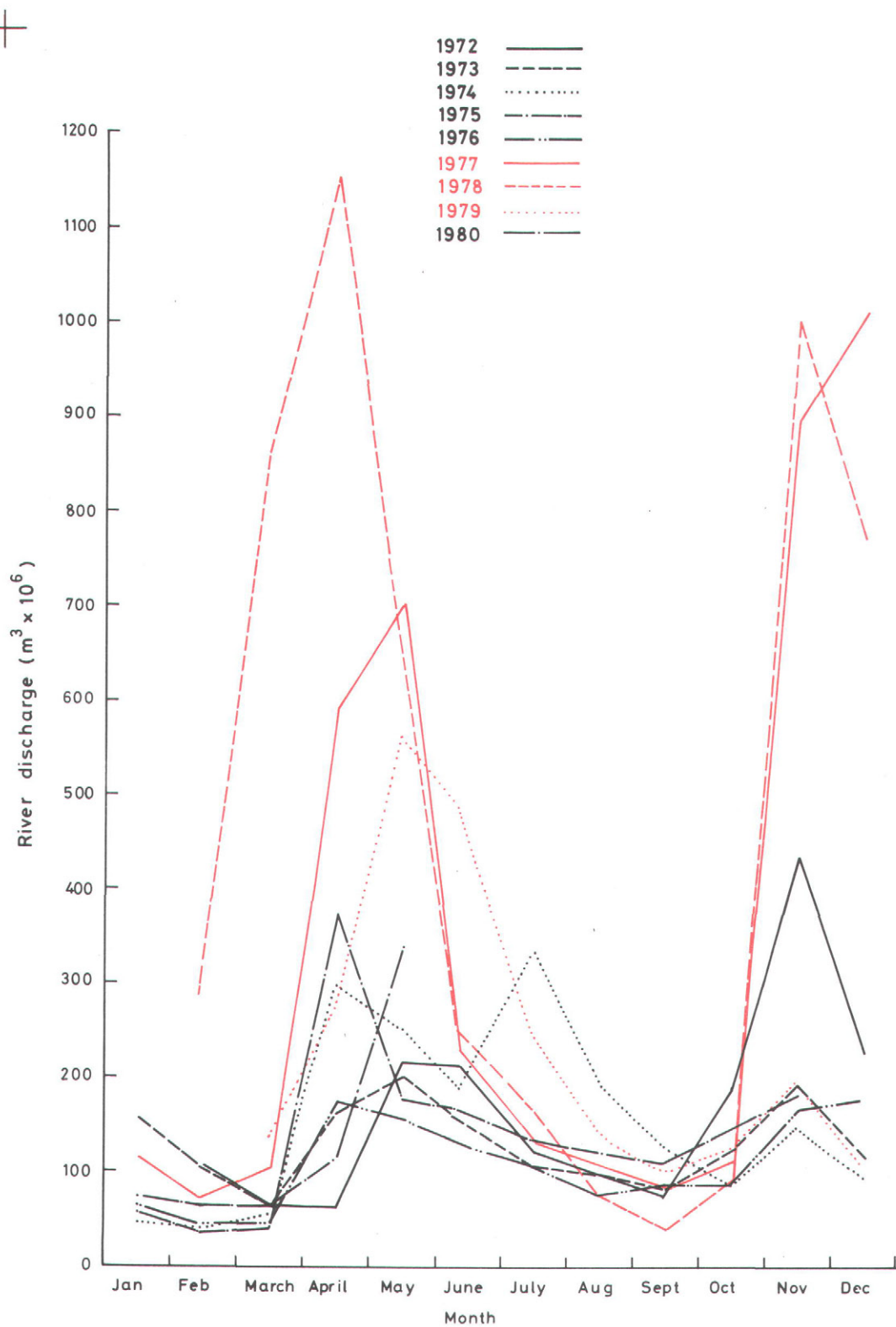


Fig 52 Tana River discharge at station 4DE2

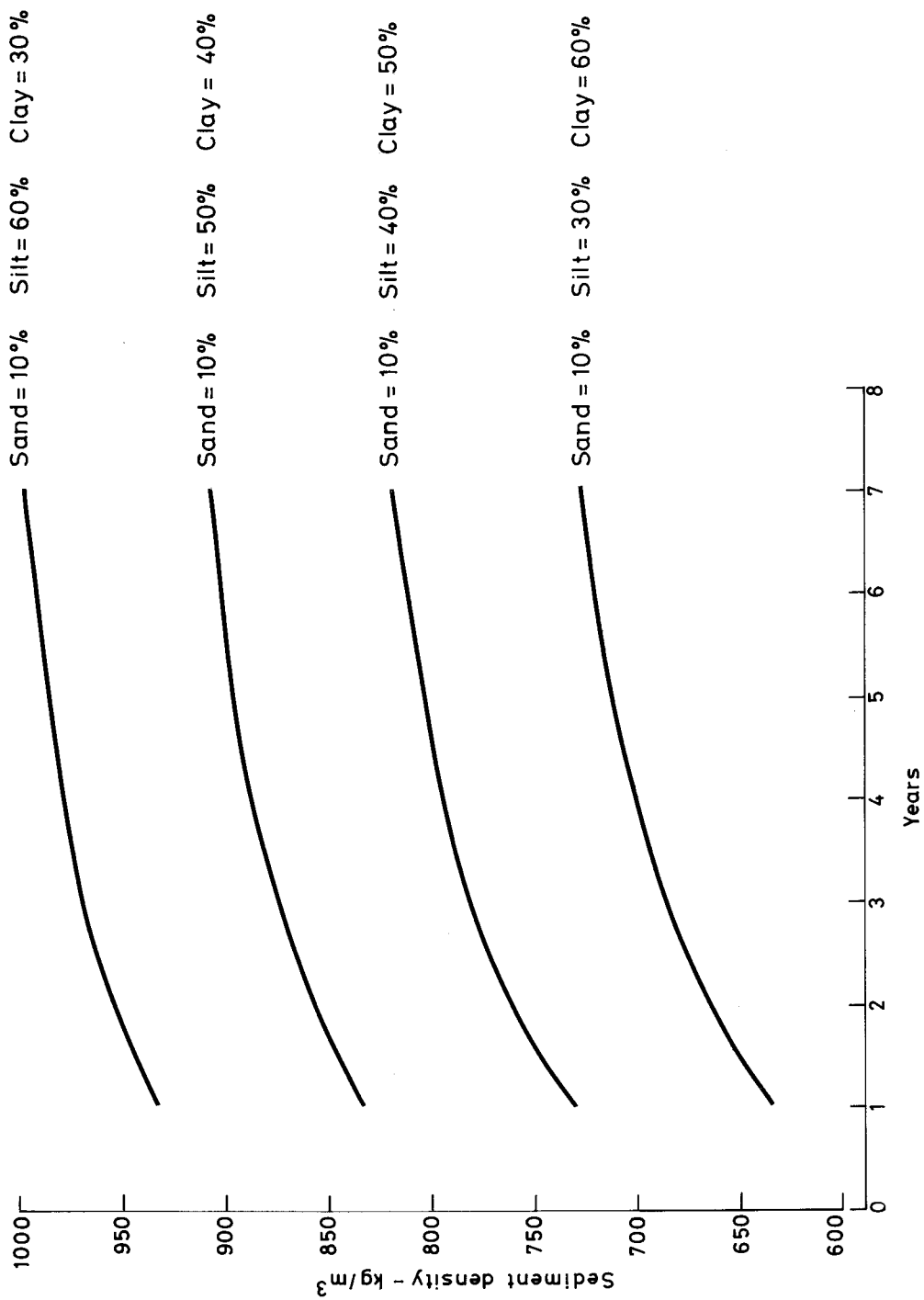


Fig 53 Variation of sediment density with time

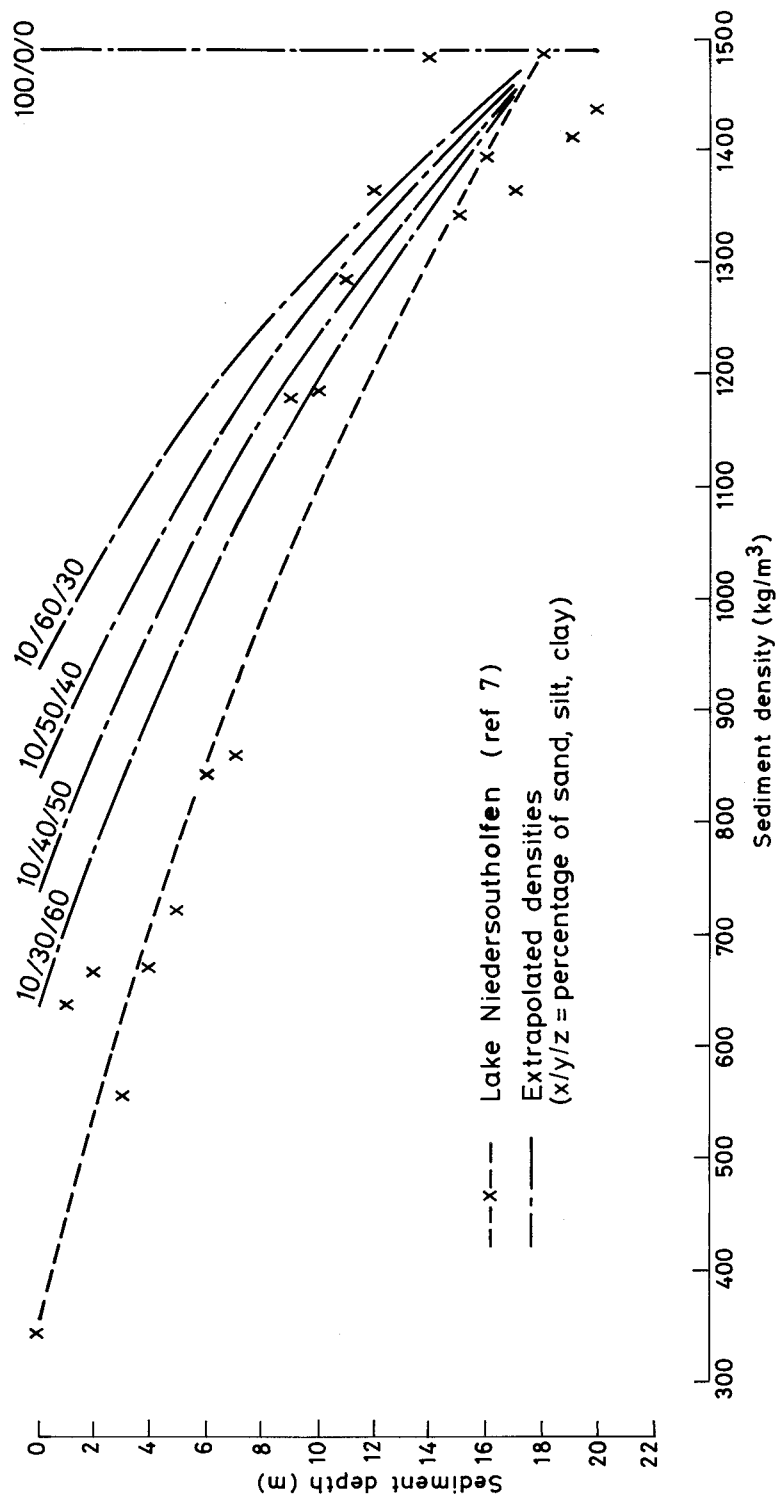


Fig 54 Variation of sediment density with depth

For definition of analytical methods, see Table 7

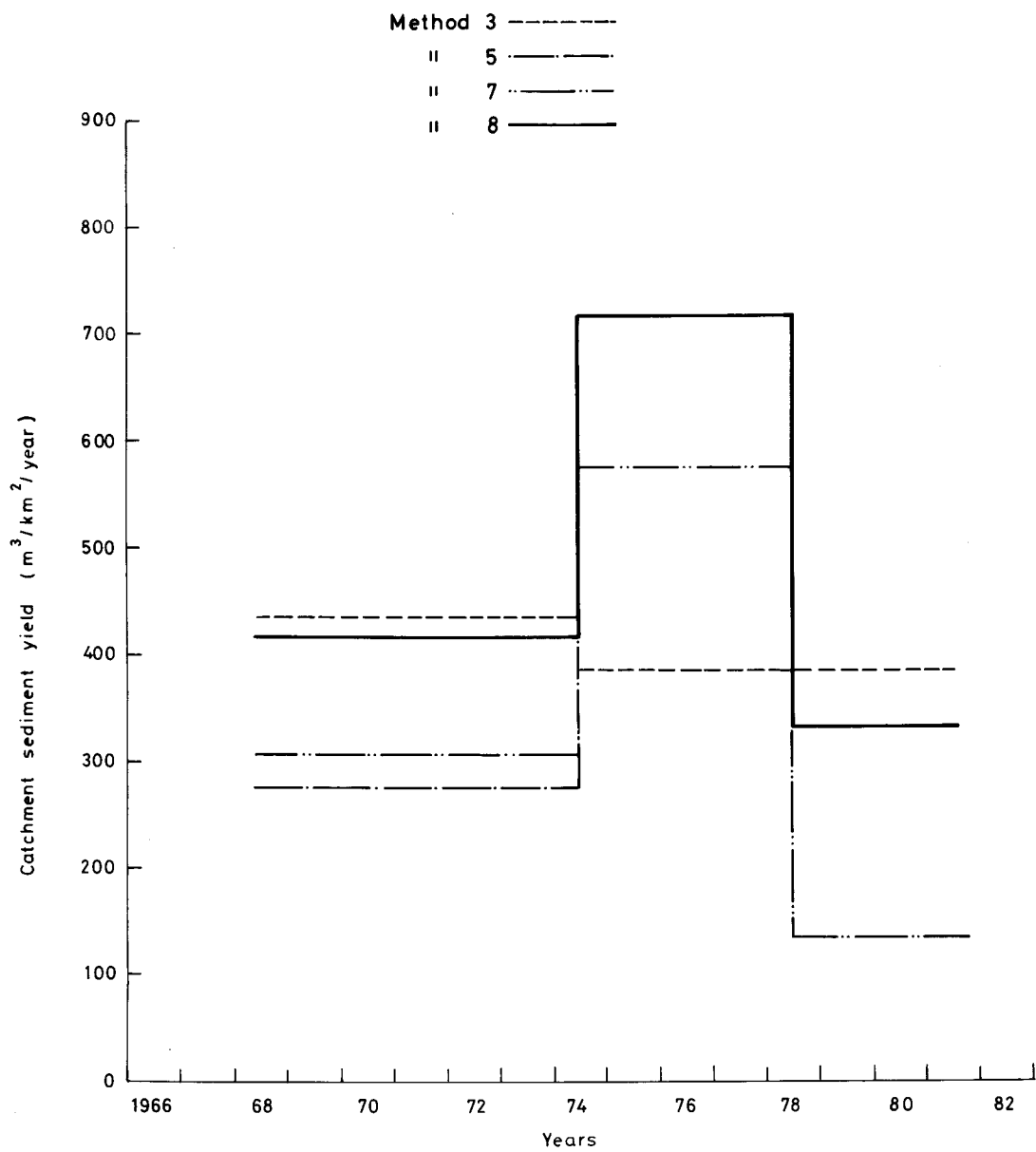


Fig 55 Calculated catchment sediment yield

Plates



Plate 1 Partech meter housing at site 4BC2

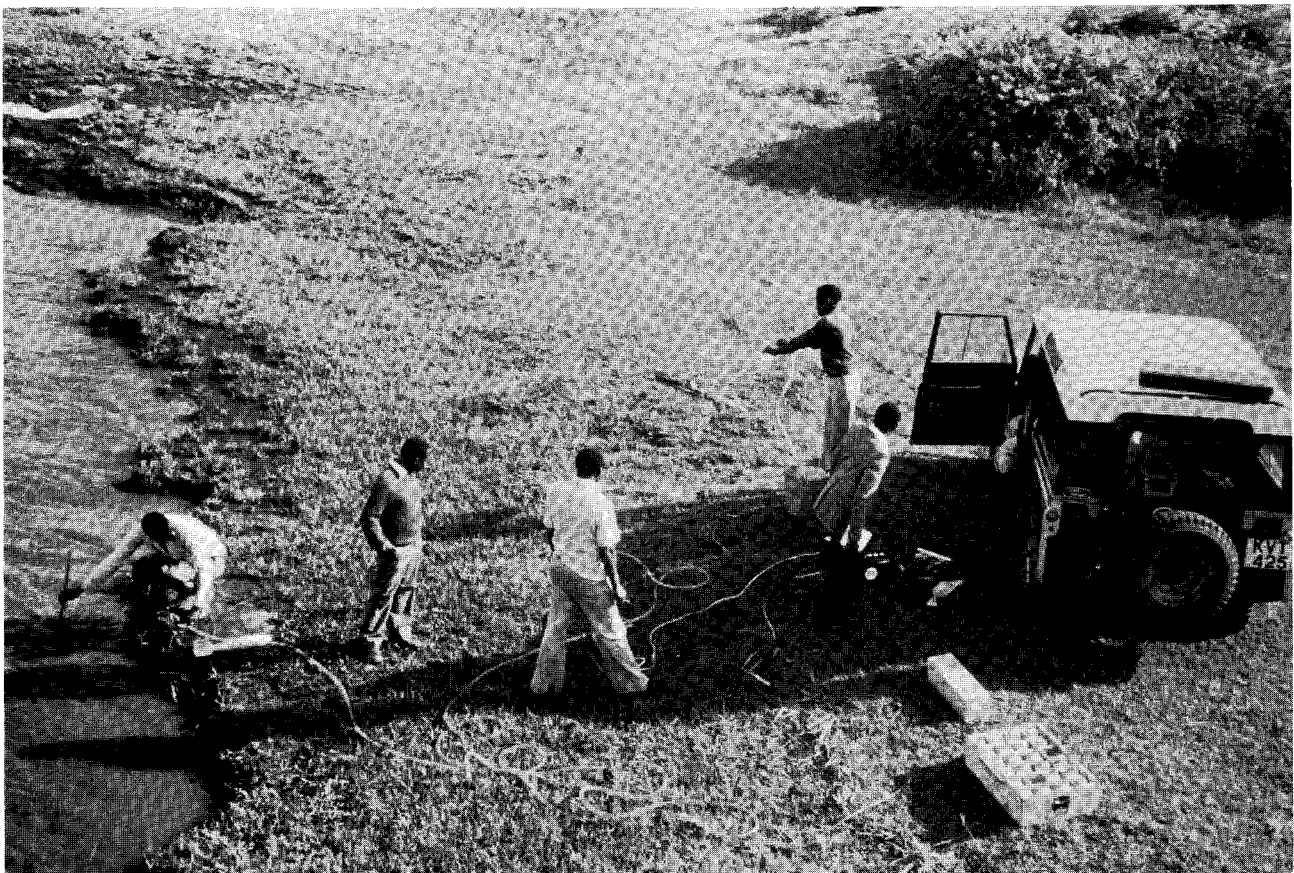


Plate 2 Pump sampling at site 4BC4



Plate 3 Water Quality and Pollution Control Centre vacuum filtration equipment

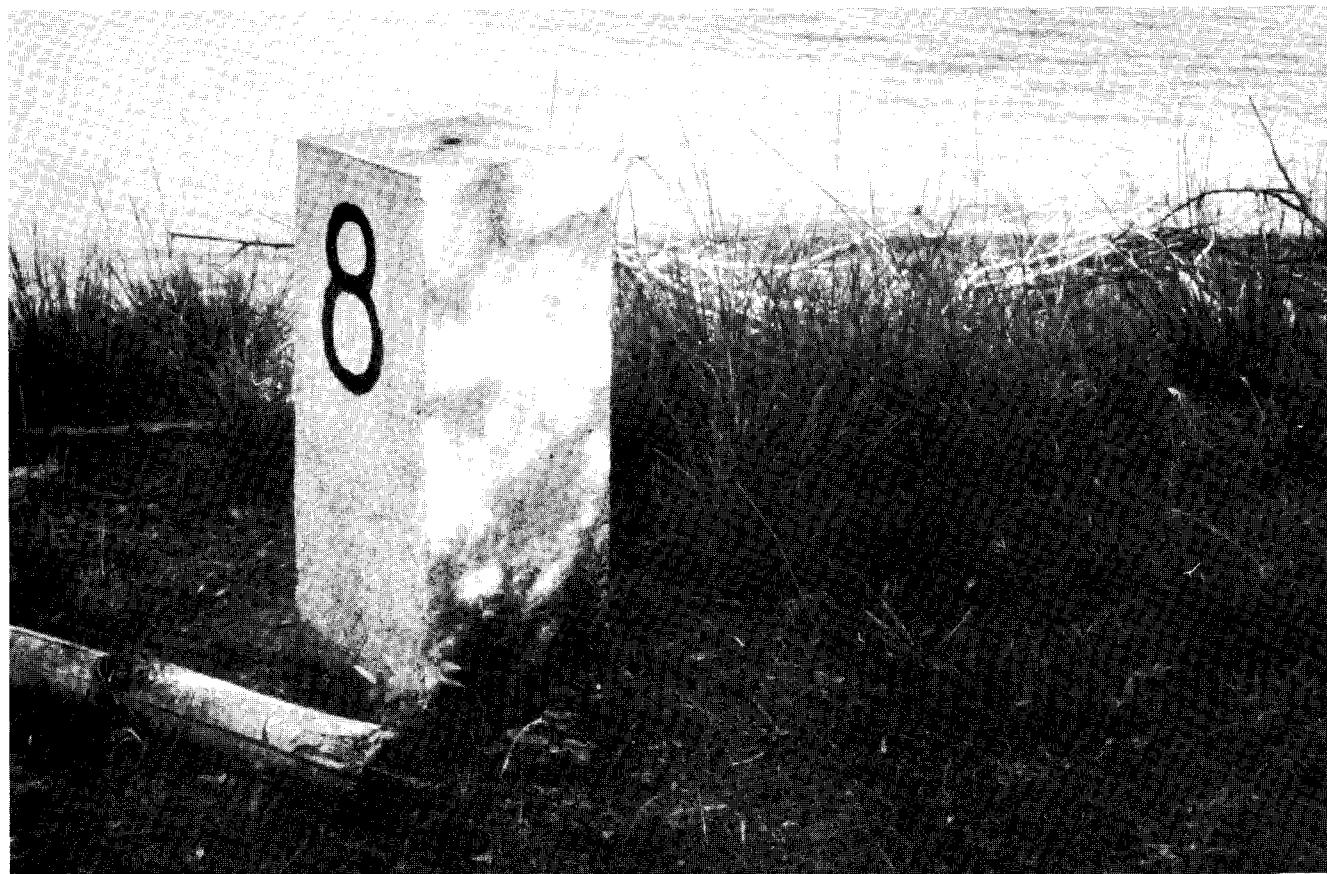


Plate 4 Survey end-of-section marker K8 (left), Kindaruma Reservoir



Plate 5 Survey end-of-section marker K11 (right), Kindaruma Reservoir



Plate 6 Survey equipment at Kamburu Reservoir



Plate 7 TARDA inflatable boat on Kamburu Reservoir



Plate 8 EAP&L glass-fibre boat

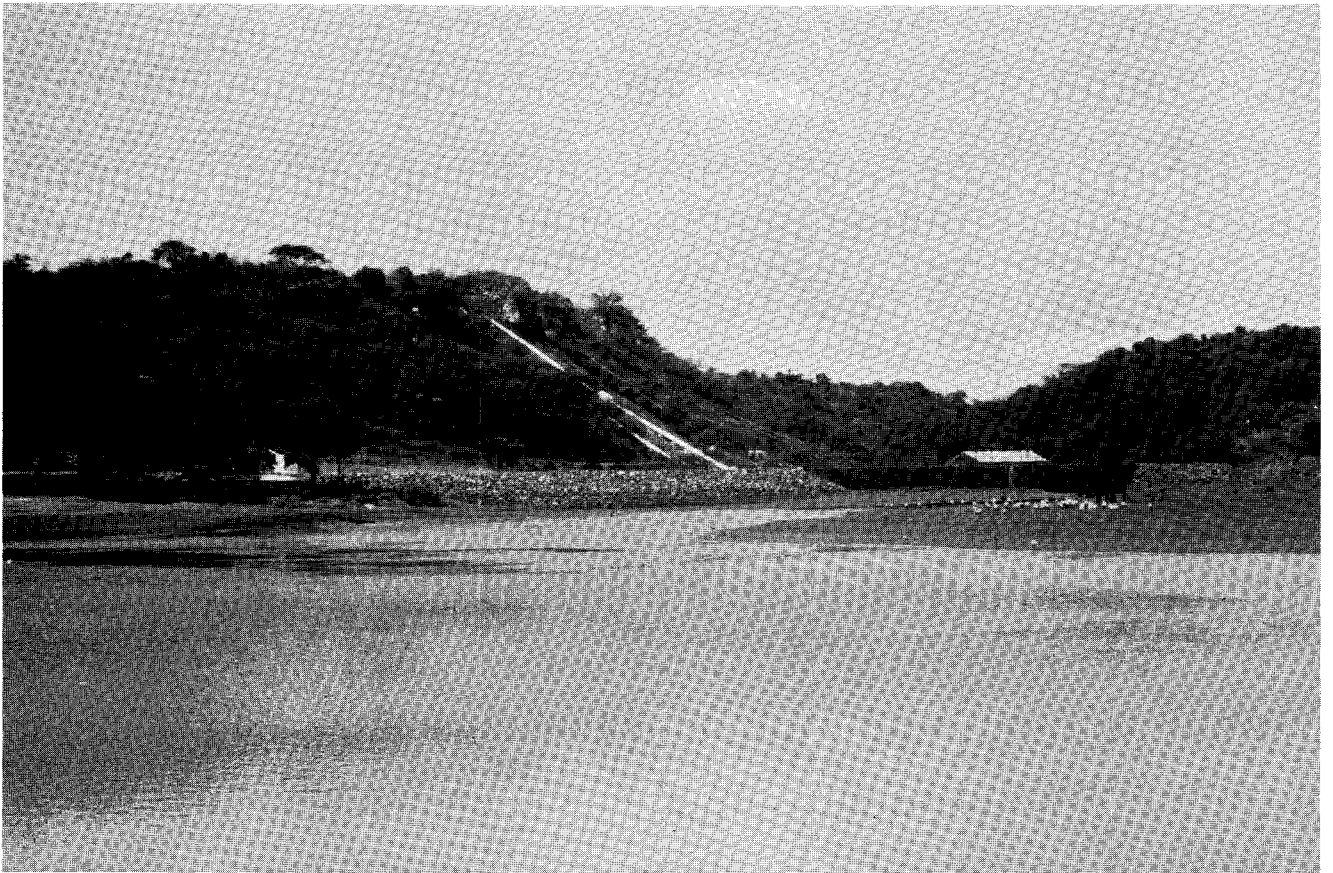


Plate 9 Tana Power Station, Masinga Reservoir



Plate 10 Masinga Dam and power station intake tower



Plate 11 Kindaruma Reservoir

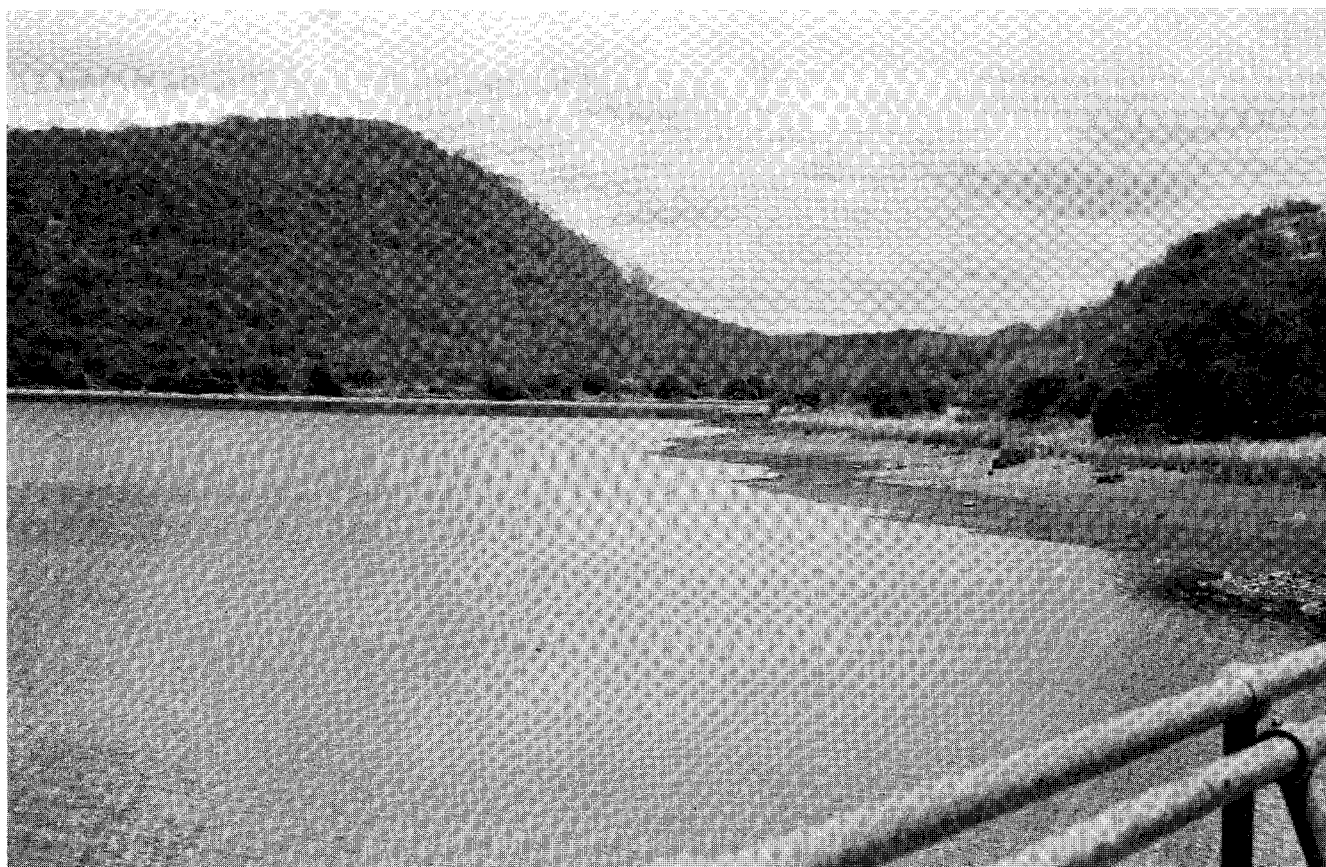


Plate 12 Kindaruma Reservoir



Plate 13 Kamburu Reservoir



Plate 14 Kamburu Reservoir

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