Sedimentation in reservoirs – Tana river basin, Kenya

I – Base data taken from aerial surveys of Kindaruma and Kamburu reservoir sites, 1965

R Wooldridge MIMG TechE TEng (CEI)

In collaboration with:

Tana and Athi Rivers Development Authority, Kenya
Ministry of Water Development, Kenya
East Africa Power and Lighting Co Ltd, Kenya

Report No. OD 45
September 1982

Hydraulics Research Station
Wallingford
Oxon OX10 8BA
Telephone 0491 35381
Telex 848552

Abstract

The Tana River is Kenya's major surface water resource, and siltation of the river has been the subject of a number of studies. However, there is still a large amount of work to be done if the factors influencing erosion, sediment transport and deposition are to be fully understood. One step towards reaching this understanding is achieved by making an analysis of the sediment accretion rates for two of the reservoirs which form part of the Seven Forks Project.

This report presents an analysis of data taken from aerial surveys which were flown in 1965 for the design stages of Kindaruma and Kamburu reservoirs. This data will form the base against which all future reservoir surveys may be compared in order to obtain estimates of accretion rates. Following each hydrographic survey, a report will be published in the OD series giving details of the data collection techniques and reservoir volume analysis.

A list of titles of other reports in the OD series is given at the end of this report.

Contents

Tables and Figures

Contents (Cont'd)

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 94,700 km^2 – 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 Aberdare Ranges to the Indian Ocean. The potential for the 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 an understanding of erosion, sediment transport and deposition is to be obtained. The Overseas Development Unit (ODU) of the Hydraulics Research Station Ltd. is undertaking 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 Co. Ltd. (EAPL) to investigate these phenomena. Proposals for this investigation on the upper Tana River were submitted as the result of a visit to Kenya by a member of the ODU staff. Agreement on the project between ODU and the above Kenyan institutions was reached in July 1980.

1.2 The project may conveniently be split into three distinct, but inter-related parts. Firstly, there is a programme to monitor the sediment load carried by the major rivers in the upper Tana River basin. This involves the establishment of sampling methods, installation and calibration of field equipment (by staff of MOWD using finance made available by TARDA) and data analysis. The second, but equally important part, is a study of accretion (and possibly erosion) rates of Kindaruma and Kamburu reservoirs derived from reservoir surveys carried out by ODU staff with a field team of staff from MOWD, TARDA and EAPL. The project is expected to last three years after which time progress will be reviewed.

1.3 This report deals solely with the first step towards evaluating the changes in reservoir volume — namely, the production of a set of pre-impoundment base data with which all future hydrographic surveys will be compared.

1.4 It is proposed that a separate report will be written to describe the results obtained from each survey. The first of these — OD 46 describing the reservoir surveys carried out in June/July 1981 — is currently in production (Reference 2).

2 Brief history

2.1 This section is based largely on a series of articles in an edition of a Nairobi daily newspaper (Reference 1) published at the time of the official opening of Masinga dam on 21 December 1981, and on leaflets supplied by TARDA.

2.2 The potential for hydro-electric power generation and the regulation of water for irrigation in the Seven Forks area had been realised during the mid-1950's. In 1959 it was recommended that the area should be developed in stages to meet the gradual increase in electrical energy demand. Six years later a decision was taken to implement the first stage of the Kindaruma project (Figure 2) and in the same year, the Tana River Development Company (TRDC) was formed solely to investigate and develop the Seven Forks energy potential.

2.3 Construction of the Kindaruma dam was begun in March 1965 and it was completed during April 1968. Kindaruma dam is 550m long with a maximum height of 25m. It is a standard compacted rockfill structure with an asphaltic concrete face on the upstream (reservoir) side. The impounded lake is about 5 km long and has a total design volume of 16.2 x 10^6 m^3 of which 7.5 x 10^6 m^3 constitute the usable storage. Kindaruma power station houses two hydraulic turbines coupled to generators which produce 22MW each.

2.4 Work on the Kamburu project was started in 1971 and it lasted about four years. The construction of the main dam followed the established design of compacted rockfill with asphaltic concrete on the upstream face. The dam reaches a height of 56m and is 900m long. The total design volume of the reservoir, which is sited at the confluence of the Tana and Thiba rivers (see Figure 2), is 150 x 10^6 m^3 and it is supplied by a catchment area of 9520 km^2. The power station is housed some 54m underground and contains three turbines, each of which drives a 31MW generator.

2.5 The third phase of development was the Gitaru dam and power station which was started in 1974 and finished in 1978. The dam, which is similar in design to the other two sites, has a maximum height of 30m and is 670m long. The power station at Gitaru is located 130m underground and houses two vertical turbines each driving a 72MW generator.

2.6 The most recent project to be completed on the Upper Tana River is the Masinga dam and power house. Work on this, the largest dam and reservoir on the Tana River so far, was started in 1978 and the reservoir was first impounded to its top level in May 1981. The scheme consists of a zoned earthfill dam with a maximum height of 53 m and a total crest length of 2200m. The reservoir, which has a maximum surface area of some 120 km^2 and extends about 45 km upstream of the dam, includes the confluence of the Sagana (Tana) and Thika rivers. The storage capacity of the reservoir is 1560 x 10^6 m^3 and the power output at full load is a total of 40MW from two generators drive by Kaplan turbines.

3 Base data

General description 3.1

3.1.1 In Feburary 1965, one month before the start of the Kindaruma project, TRDC commissioned Hunting Surveys Ltd. to fly an aerial survey covering all of the Seven Forks Project area which included the sites of the four dams now constructed. The result was a series of maps at a scale of 1:12 500 showing ground levels as contours drawn at 10ft (3.05 m) intervals. These maps were used by Engineering and Power Development Consultants Ltd (EPDC) – EAPL's consultants for these projects – to produce the design volumes and stage/capacity curves for all four reservoirs.

3.1.2 For the current study it was necessary to re-work the volumes as the summation of a series of segments, each one chosen to be approximately 500m long. These segments were defined in width by the plan position of the contour corresponding to the water surface level. Segment lengths were dictated by the location of range lines chosen for hydrographic surveys of the reservoirs to be carried out as part of the investigation (see paragraph 1.2).

Location of survey range lines 3.2

3.2.1 During a visit to Nairobi by ODU staff in March 1981, a drawing of Kamburu Reservoir (Figure 15) showing 29 range lines requiring 53 survey beacons (end-of-section markers) was handed to EAPL who had agreed to be responsible for their construction. Soon after this, a second drawing showing 13 range lines and 25 survey beacons on Kindaruma Reservoir (Figure 3) was also passed to EAPL. All the beacons were built by EPDC who completed the work by mid-July 1981.

3.2.2 After construction, the precise locations of the beacons were surveyed for EAPL 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 beacons are given for each section in Tables 1 and 3. It must be noted that the co-ordinates are related to a plane local engineering grid used during the dam construction, which is specific to each project site (i.e. the engineering grid at Kindaruma is not directly related to the engineering grid at Kamburu). EPDC found that it was not possible to tie the local engineering grids into the Kenya Survey Grid and so each beacon position was plotted relative to the local engineering grid, using the same scale as the reservoir drawings. This plot was then superimposed on the reservoir drawings and the position adjusted until all the beacons were above the maximum reservoir water level. The Kenya Survey Grid and the assumed plane local engineering grid are shown on Figures 3 and 15 for Kindaruma and Kamburu reservoirs respectively.

3.2.3 For each range line, the line length has been calculated using the grid co-ordinates as given and checked by measuring the plotted positions.

Cross-sections 3.3

3.3.1 The survey beacon positions as defined above were transferred to the contour maps supplied by Hunting Surveys Ltd. Each line was then traversed from the left-hand beacon (looking downstream) and the distance from the beacon to where the line cut each contour was noted. These distances and levels are listed in Tables 1 and 3 for Kindaruma and Kamburu reservoirs respectively. To ensure that the cross-sections are defined accurately at the beacons, the next contours to the left of the left-hand beacon (shown in the tables as a negative distance) and beyond the right-hand beacon are also included.

3.3.2 The cross-section data are shown graphically in figures 4 to 13 (Kindaruma reservoir) and 16 to 44 (Kamburu reservoir). It is not possible to interpolate ground levels below water using an aerial survey. In Figures 4 to 13, and 16 to 44, the bed levels have been shown as smooth transitions between the two known bank slopes. Since this constitutes only a small part of each section, any discrepancies in the total reservoir volumes will be negligible.

4 Data analysis

Method of calculation 4.1

4.1.1 During the feasibility or design stage of a reservoir project, it is considered to be good engineering practice to obtain a detailed contour map of the site, either by topographical surveying or (more commonly) aerial photography. However, because of the cost of mounting a large scale hydrographic survey to obtain directly comparable data after the reservoir has been impounded, it is usual to call for bed levels at discrete points, either on a fixed grid or along defined lines. Under normal field conditions, it is more straight-forward to locate the position of a boat moving along a line between two fixed beacons (Range Line) than it is to site a boat at fixed grid points. The Range Line technique is therefore the method recommended by ODU.

4.1.2 For a definition of terms used in this section see paragraph 4.1.5. Where only Range Line data are available, the volume contained between adjacent lines may be calculated using one of two basic approaches:

i) *Depth/area method*

The average depth of water between two Range Lines is evaluated, and the result is multiplied by the segment surface area to determine the segment volume.

ii) *End area/length method*

The average cross-sectional area below adjacent range lines is measured. The segment volume is obtained as the product of the average cross-sectional end area and a representative distance between the range lines.

The first method is only suitable for sites such as canals and rivers where the banks are nearly vertical and the water surface width does not vary dramatically between Range Lines. The second method has the advantage that it does not require any digital representation of the plan shape, but it does need an accurate assessment of a distance between range lines. This can only be evaluated by subjective judgement and becomes increasingly difficult as the reservoir shape becomes more complex.

4.1.3 Where a pre-impoundment contour plan is available, it is possible to refine the numerical techniques above without increasing the post-impoundment survey requirements. This approach involves contour-slicing to obtain the volume of each segment of a reservoir. Known as the *Constant Factor Method*, it is described in detail in Reference 3. In essence, the volume contained between successive contours is obtained from the pre-impoundment survey; this is then converted into a so-called "Constant Factor" by dividing the volume by the sum of the end areas. Subsequent volumes are calculated as the product of the "Constant Factor" and the intra-contour cross-sectional areas measured below the range lines. The principal advantages of this method are:

a) there is no need for subjective judgement to obtain any of the numerical input

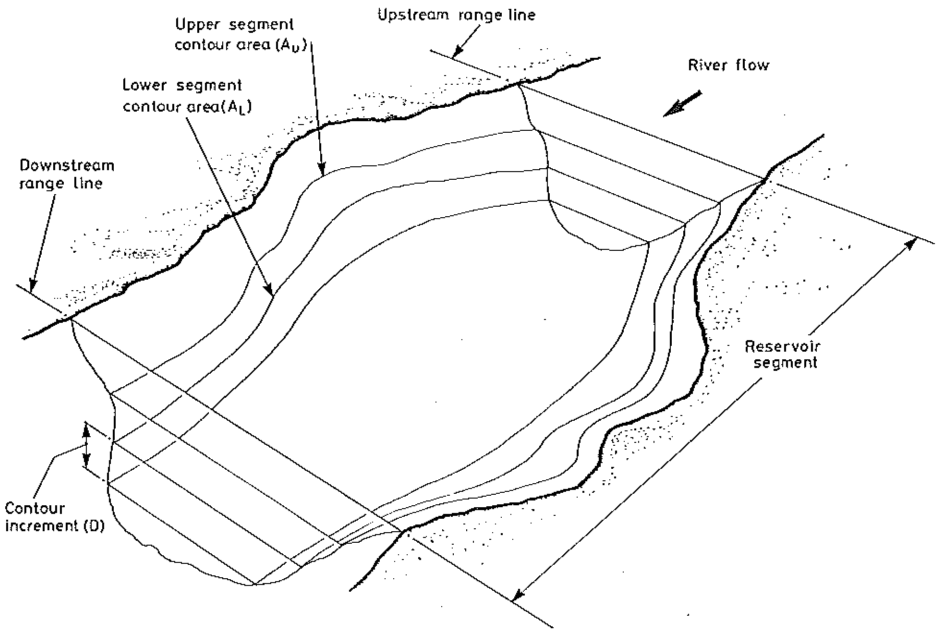
b) by using contours to obtain the base data, the accuracy of the calculated volumes is much greater than may be obtained by using Range Line data alone

c) this method allows much greater flexibility in the laying out of Range Lines with respect to reservoir shape and to each other — it is even possible to vary the location of Range Lines with depth if the situation justifies the extra site work involved.

4.1.4 This report covers the preparation and analysis of base data for Kindaruma and Kamburu reservoirs. The results given in Tables 2 and 4 show the initial design volumes of the reservoirs and the "Constant Factors" which will be used in future reports to calculate sediment volumes.

4.1.5 The terms used in this chapter 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

4.1.6 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:

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

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:

$$V_O = \Sigma V_{OS}$$

4.1.7 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 amount of sediment in the sub-segment.

4.1.8 The Constant Factor method has been used for Kindaruma and Kamburu reservoirs (using the Hunting's data for 1965) and the results are given in Tables 2 and 4 respectively. All the contour surface areas and the sub-segment end areas were measured at HRS using a Perex Digitising Table.

Accuracy of results 4.2

4.2.1 The contour maps were produced by Hunting Surveys Ltd. to a stated accuracy in levels of ± ½ (contour interval) which, in this instance, is ± 1.524 m. At first glance, this would seem to cast considerable doubt on the validity of any volumes or areas which are calculated from the plotted contours. However, the technique of contour slicing, by using each contour as the bottom of one slice and the top of the slice below, cancels out the errors for all but the top slice where the surface contour is used only once.

4.2.2 No information is available on the accuracy with which an experienced operator using the Perex Digitising Table is able to measure areas, but trials with measuring a known area have shown that consecutive measurements consistently give values to within ± 1% of the mean.

Kindaruma Reservoir 4.3

4.3.1 The maximum top water level was assumed to be +2563ft Kenya Datum (+781.20 m KD) and the location of this contour was drawn on the Hunting's maps by interpolation between the +2560ft and +2570ft contours. Data along each range line were collected as described in section 3.3 of this report, and the results are listed in Table 1 and plotted in Figures 4 to 13.

4.3.2 Table 2 lists all the areas taken from the contour map and the plotted cross-sections, together with the calculated sub-segment volumes and Constant Factors.

4.3.3 The total reservoir volume, obtained from a summation of the individual segment volumes measured on Hunting's contour maps, is seen to be 18.3 x 10^6 m^3 which compares favourably with the stated capacity of 16.2 x 10^6 m^3 (see paragraph 2.3). With a maximum water surface area of 2.5 x 10^6 m^2, this difference in volume represents a change in water level of 0.8 m. The average ground slope at top water level is about 7% and so a change in level of 0.8 m may be achieved by moving the water line approximately 5.7m horizontally. On the Hunting's maps, this would be equivalent to a distance of just over 0.4 mm and is well within the accuracy with which a line may be followed on the digitising table.

4.3.4 A stage/capacity curve has also been produced using the data given in Table 2, and it is included in this report as Figure 14.

Kamburu Reservoir 4.4

4.4.1 A similar desk exercise was carried out for Kamburu reservoir and the data are listed in Tables 3 and 4 from which it will be seen that the total capacity was calculated to be 133.2 x 10^6 m^3. The reservoir capacity quoted during the design phase was 150 x 10^6 m^3 (see paragraph 2.4); this shows the measured volume to be approximately 11% down on the given figure. A similar argument to that followed in paragraph 4.3.3 also applies in this case and so the data are considered to be within an acceptable tolerance.

4.4.2 A stage/capacity curve using data taken from Table 4 is given as Figure 45.

5 Conclusions

5.1 This report has given details of methods used in the production of base data taken from an aerial survey flown in 1965. The contour slicing technique described in Section 4 has produced reservoir data which compare favourably with those quoted during the design phases of Kindaruma and Kamburu reservoirs. It is therefore concluded that the "Constant Factors" computed using data abstracted from the 1965 survey by Hunting Surveys Ltd. may be used as a base for the analysis of reservoir sedimentation rates.

6 Acknowledgements

6.1 The desk study described in this report forms part of an investigation in collaboration with the Tana and Athi Rivers Development Authority, the Ministry of Water Development, and the East Africa Power and Lighting Co Ltd.

6.2 As part of a concurrent field study which will be discussed in later reports, TARDA have provided installation expenses for all the field equipment, and MOWD staff have carried out the data collection and instrument maintenance. EAPL have supplied historical data and their staff have participated in the reservoir surveys with ODU and MOWD.

6.3 The author acknowledges the value of discussions held with Engineering and Power Development Consultants Ltd and with Hunting Surveys Ltd.

6.4 Much of the data abstraction and analysis was carried out at the Hydraulics Research Station by Mr C R Talbot.

6.5 This work was carried out in Mr D W Holmes' section of the Hydraulics Research Station's Overseas Development Unit which is headed by Mr C L Abernethy. The ODU input to this project is funded by the Overseas Development Administration of the Foreign and Commonwealth Office, London.

7 References

1 Daily Nation. Nation Newspapers Ltd., Nairobi, Kenya. 2 December 1981.

2 WOOLDRIDGE R. Sedimentation in Reservoirs – Tana River Basin, Kenya: II Hydrographic surveys of Kindaruma, Kamburu and Masinga reservoirs in June/July 1981 with an analysis of the siltation rates since impoundment. Hydraulics Research Station Ltd., Wallingford. Report OD 46, December 1982.

3 MURTHY B N. Capacity Survey of Storage Reservoirs. Central Board of Irrigation and Power, New Delhi. Publication No 89, February 1968.

DDB Dd 650449 12/82

Tables & Figures

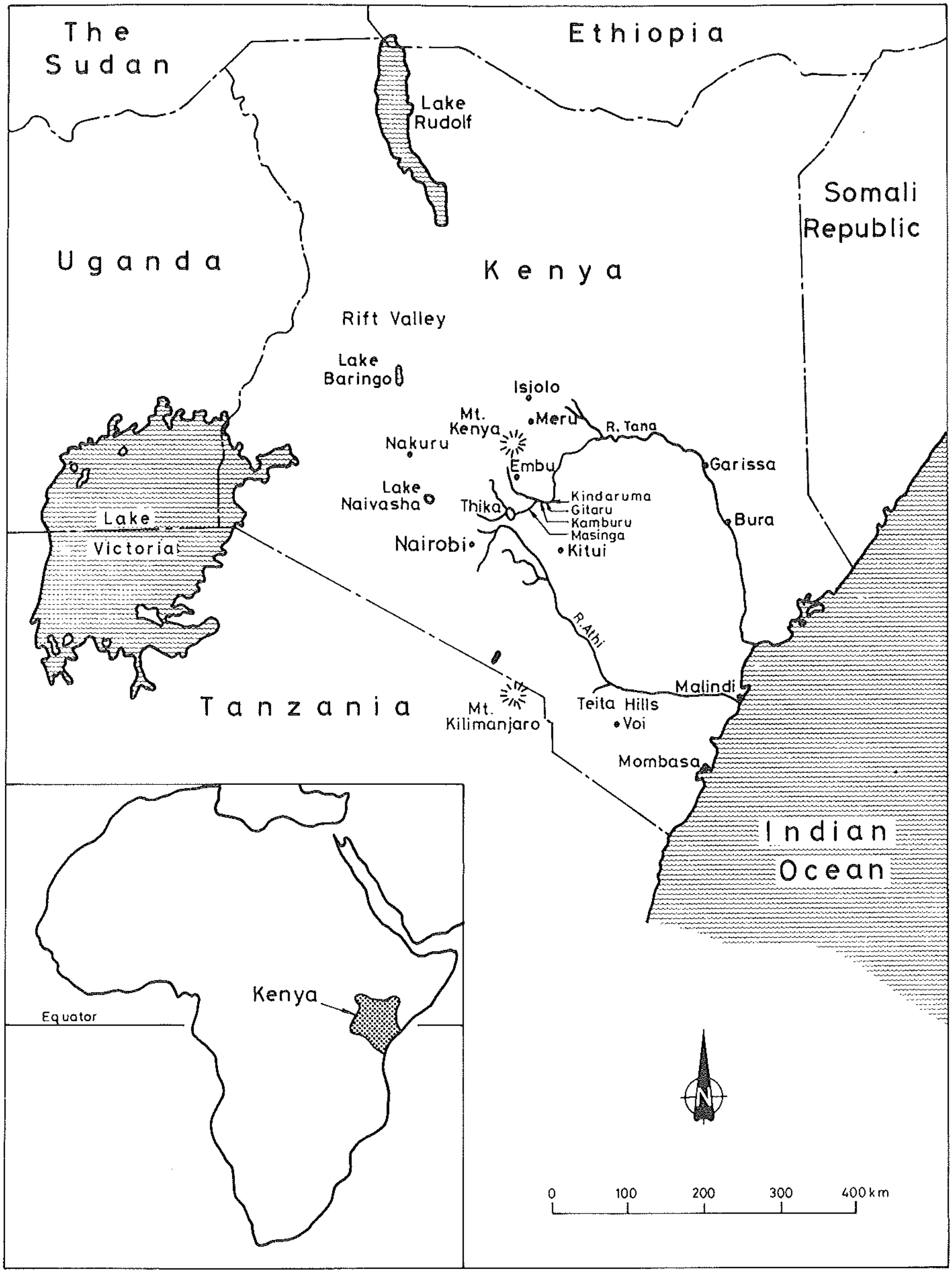


Fig 1 Location map

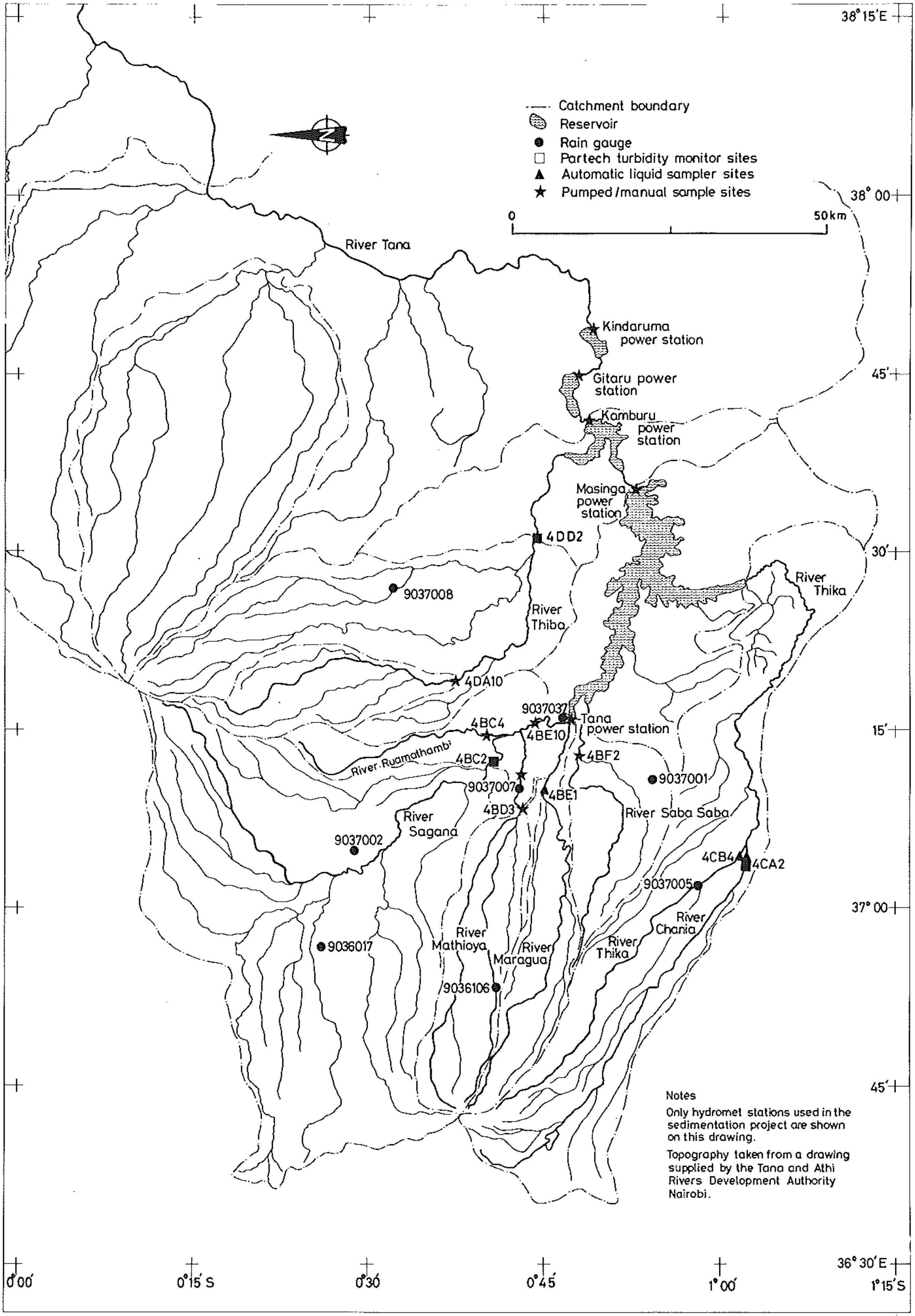


Fig 2 Tana River Basin

Kindaruma data

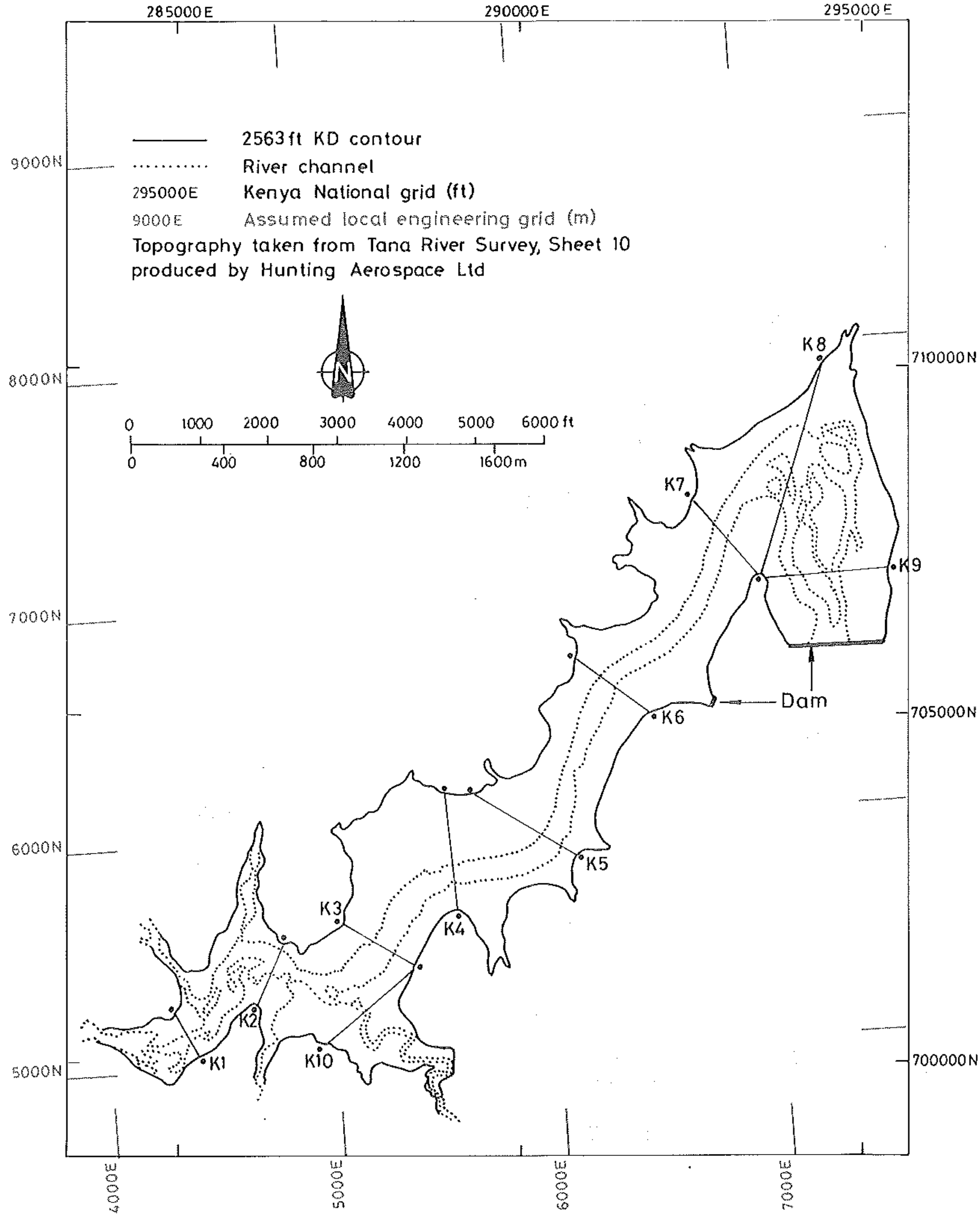


Fig 3 Kindaruma Reservoir

TABLE 1 Kindaruma base data survey, February 1965

Notes:

1. **Distances and levels taken from Hunting Surveys Ltd., Tana River Survey, Sheet 10, February 1965.**
2. **Sections as defined for hydrographic surveys started June 1981. (Ref 2)**
3. **Distances (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.**

Section K1

Length of section = 230.77m

Right-bank beacon co-ordinates = 4394.041, 5059.330
Left-bank beacon co-ordinates = 4288.175, 5261.382

Distance	Level	Distance	Level	Distance	Level
−23	783.34	100	771.14	201	774.19
+13	780.29	106	river	214	777.24
48	777.24	151		225	780.29
74	774.19	175	771.14	238	783.34

Section K2

Length of section = 301.42m

Right-bank beacon co-ordinates = 4658.181, 5258.709
Left-bank beacon co-ordinates = 4781.678, 5533.670

Distance	Level	Distance	Level	Distance	Level
− 9	783.34	32	river	162	771.14
+ 5	780.29	55		177	774.19
11	777.24	80	river	126	777.24
18	774.19	97		291	780.29
30	771.14	123	river	417	783.34
		142			

Section K3

Length of section = 386.87m

Right-bank beacon co-ordinates = 5372.964, 5394.913
Left-bank beacon co-ordinates = 5047.159, 5603.526

Distance	Level	Distance	Level	Distance	Level
−16	783.34	143	771.14	305	774.19
+ 8	780.29	160	river	341	777.24
30	777.24	279		373	780.29
56	774.19	286	771.14	411	783.34

TABLE 1 (cont'd)

Section K4

Length of section = 539.83m

Right-bank beacon co-ordinates = 5574.572, 5606.418
Left-bank beacon co-ordinates = 5540.887, 6145.196

Distance	Level	Distance	Level	Distance	Level
− 33	783.34	299	768.10	455	774.19
+ 11	780.29	313	river	475	777.24
48	777.24	400		523	780.29
75	774.19	404	768.10	578	783.34
288	771.14	443	771.14		

Section K5

Length of section = 551.36m

Right-bank beacon co-ordinates = 6131.429, 5825.573
Left-bank beacon co-ordinates = 5672.262, 6130.800

Distance	Level	Distance	Level	Distance	Level
− 29	783.34	350	river	571	777.24
+ 11	780.29	454		535	780.29
74	777.24	478	774.19	574	783.34
200	774.19				

Section K6

Length of section = 425.89m

Right-bank beacon co-ordinates = 6481.521, 6426.064
Left-bank beacon co-ordinates = 6154.345, 6698.721

Distance	Level	Distance	Level	Distance	Level
−17	783.30	144	771.14	349	774.19
+16	780.29	146	river	383	777.24
59	777.24	232		416	780.29
98	774.19	311	771.14	456	783.34

Section K7

Length of section = 458.25m

Right-hand beacon co-ordinates = 7000.000, 7000.000
Left-hand beacon co-ordinates = 6725.594, 7367.006

Distance	Level	Distance	Level	Distance	Level
−24	783.34	128	771.14	248	771.14
+10	780.29	138	768.10	316	774.19
48	777.24	139	river	376	777.24
89	774.19	230		430	780.29
		238	768.10	500	780.29

TABLE 1 (cont'd)

Section K8

Length of section = 997.52m

Right-bank beacon co-ordinates = 7000.000, 7000.000
Left-bank beacon co-ordinates = 7341.173, 7937.364

Distance	Level	Distance	Level	Distance	Level
− 34	783.34	326	river	660	river
+ 27	780.29	517		668	
57	777.24	580	river	672	768.10
121	774.19	592		687	771.14
293	771.14	610	river	755	774.19
315	768.10	641		932	777.24
				980	780.29
				1180	783.34

Section K9

Length of section = 593.28m

Right-bank beacon co-ordinates = 7000.000, 7000.000
Left-bank beacon co-ordinates = 7593.186, 7010.760

Distance	Level	Distance	Level	Distance	Level
−14	783.34	203	768.10	403	river
+16	780.29	226	768.10	465	
58	777.24	239	river	488	768.10
90	774.19	278		490	771.14
139	771.14	290	river	503	774.19
178	768.10	303		539	777.24
190	river	318	768.10	574	780.29
191		390	768.10	639	780.29

Section K10

Length of section = 525.05m

Right-bank beacon co-ordinates = 5372.964, 5394.913
Left-bank beacon co-ordinates = 4952.171, 5080.888

Distance	Level	Distance	Level	Distance	Level
− 19	783.34	212	771.14	317	774.19
+ 10	780.29	213	river	428	777.24
42	777.24	223		504	780.29
112	774.19	224	771.14	579	783.34

Table 2 Kindaruma Reservoir areas and volumes, 1965

Sections	Upper Contour (mKD)	Lower Contour (mKD)	End areas D/S (m^2)	End areas U/S (m^2)	Sum of end areas A_o' (m^2)	Contour surface areas upper (m^2)	Contour surface areas lower (m^2)	Capacity V_o' (m^3)	Constant factor $C = V_o'/A_o'$
U/S – K1	780.29	777.24	774	0	774	72867	54094	193489	250
	777.24	774.19	454	0	454	54094	37194	139123	306
	774.19	771.14	318	0	318	37194	14211	78341	246
	771.14	(769.62)	77	0	77	14211	0	10800	140
								421753	
K1 – K2	780.29	777.24	1045	774	1819	198507	158368	543878	299
	777.24	774.19	569	454	1023	158368	114226	415433	406
	774.19	771.14	447	318	765	114226	78691	294006	384
	771.14	(769.92)	109	77	186	78691	0	48002	258
								1301319	
K2 – K3	780.29	777.24	1363	1045	2408	334684	245794	884648	367
	777.24	774.19	863	569	1432	245794	158325	615877	430
	774.19	771.14	633	447	1080	158325	88907	376782	349
	771.14	(769.62)	148	109	257	88907	0	67569	263
								1944876	
K3 – K4	780.29	777.24	1898	1363	3261	294952	239573	814616	250
	777.24	774.19	1257	863	2120	239573	177506	635628	300
	774.19	771.14	819	633	1452	177506	71104	378882	261
	771.14	(768.10)	549	148	697	71104	0	108078	155
								1937204	
K4 – K5	780.29	777.24	1991	1898	3889	212023	173339	587292	151
	777.24	774.19	1127	1257	2384	173339	137775	474138	199
	774.19	771.14	610	819	1429	137775	61260	303329	212
	771.14	(768.40)	113	549	662	61260	0	83926	127
								1448685	
K5 – K6	780.29	777.24	1489	1991	3480	281723	220793	765834	220
	777.24	774.19	877	1127	2004	220793	157578	576637	288
	774.19	771.14	631	610	1241	157578	89085	375914	303
	771.14	(769.01)	337	113	450	89085	0	94876	211
								1813261	

Table 2 (Continued)

Sections	Upper Contour (mKD)	Lower Contour (mKD)	End areas D/S (m^2)	End areas U/S (m^2)	Sum of end areas A'_o (m^2)	Contour surface areas upper (m^2)	Contour surface areas lower (m^2)	Capacity V'_o (m^3)	Constant factor $C = V'_o/A'_o$
K6 – K7	780.29	777.24	1570	1489	3059	391175	294417	1044842	342
	777.24	774.19	871	877	1748	294417	207602	765077	438
	774.19	771.14	575	631	1146	207602	122462	503018	439
	771.14	768.10	334	337	671	122462	74073	299519	446
	768.10	(767.18)	120	14	134	74073	0	34074	254
								2646530	
K7 – K8	780.29	777.24	3735	1570	5305	213815	179583	599539	113
	777.24	774.19	2447	871	3318	179583	124666	463675	140
	774.19	771.14	1515	515	2030	124666	86877	322392	159
	771.14	768.10	1156	334	1490	86877	72032	242177	163
	768.10	(766.27)	386	120	506	72032	0	65909	130
								1693722	
K8 – K9	780.79	777.24	2274	3735	6009	359266	316030	1029151	171
	777.24	774.19	1372	2447	3819	316030	279997	908345	238
	774.19	771.14	1165	1515	2680	279997	235280	785282	293
	771.14	768.10	964	1156	2120	235280	197648	659782	311
	768.10	(765.96)	196	386	582	197648	0	211483	363
								3594043	
K9 – dam	780.79	777.24	*2274	2274	4548	169958	137873	469134	81
	777.24	774.19	*1372	1372	2744	137873	118118	390130	142
	774.19	771.14	*1165	1165	2330	118118	97394	328440	141
	771.14	768.10	*964	964	1928	97394	74974	262689	136
	768.10	(765.96)	*196	196	392	74974	0	80222	205
								1530615	

Total reservoir volume = 18.33×10^6 m^3

Notes

1. Contour levels shown in brackets are estimated from cross-section plots.
2. Cross-section areas at the dam (marked *) are assumed to be the same as at Section 9

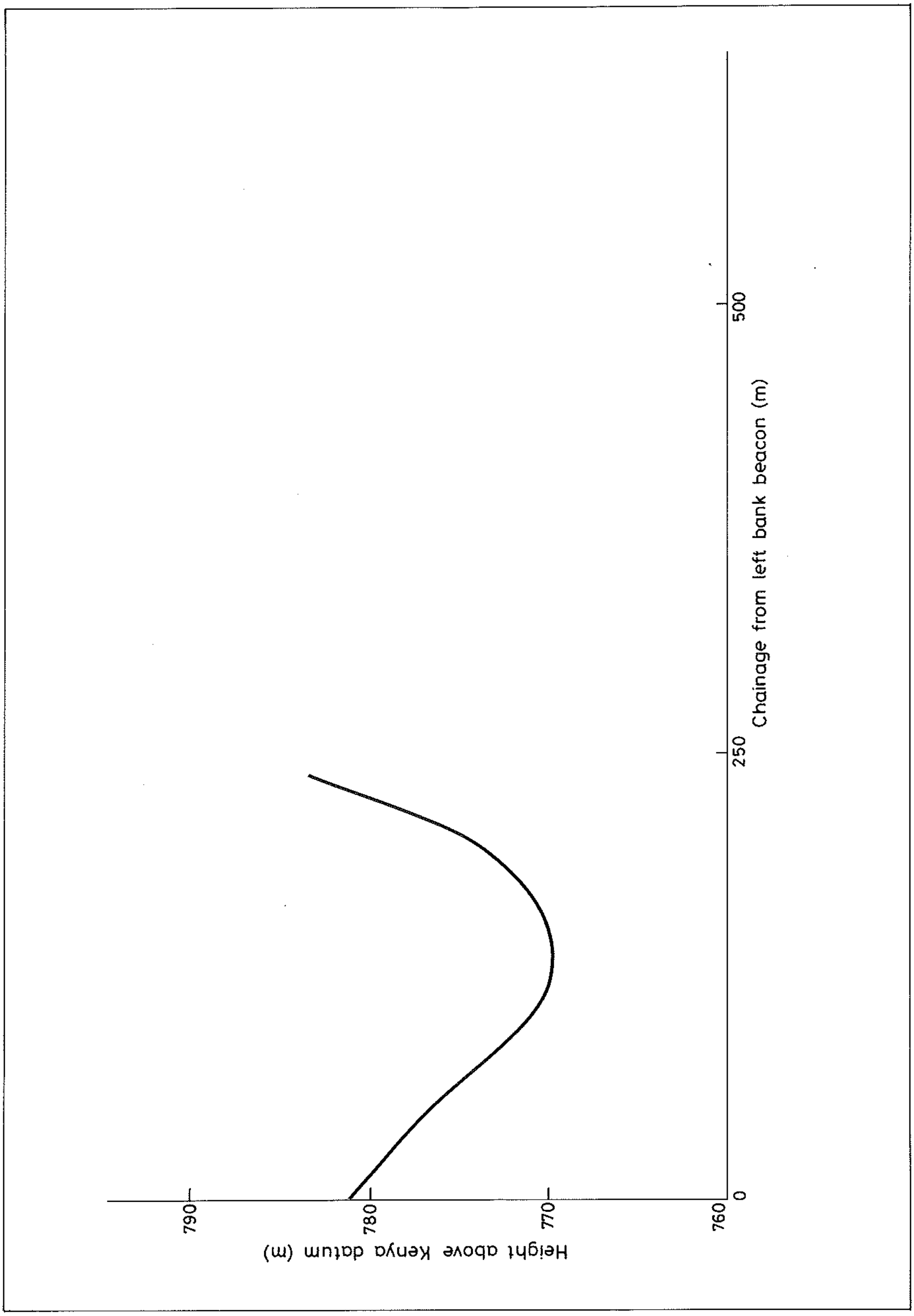


Fig 4 Kindaruma Reservoir section K1

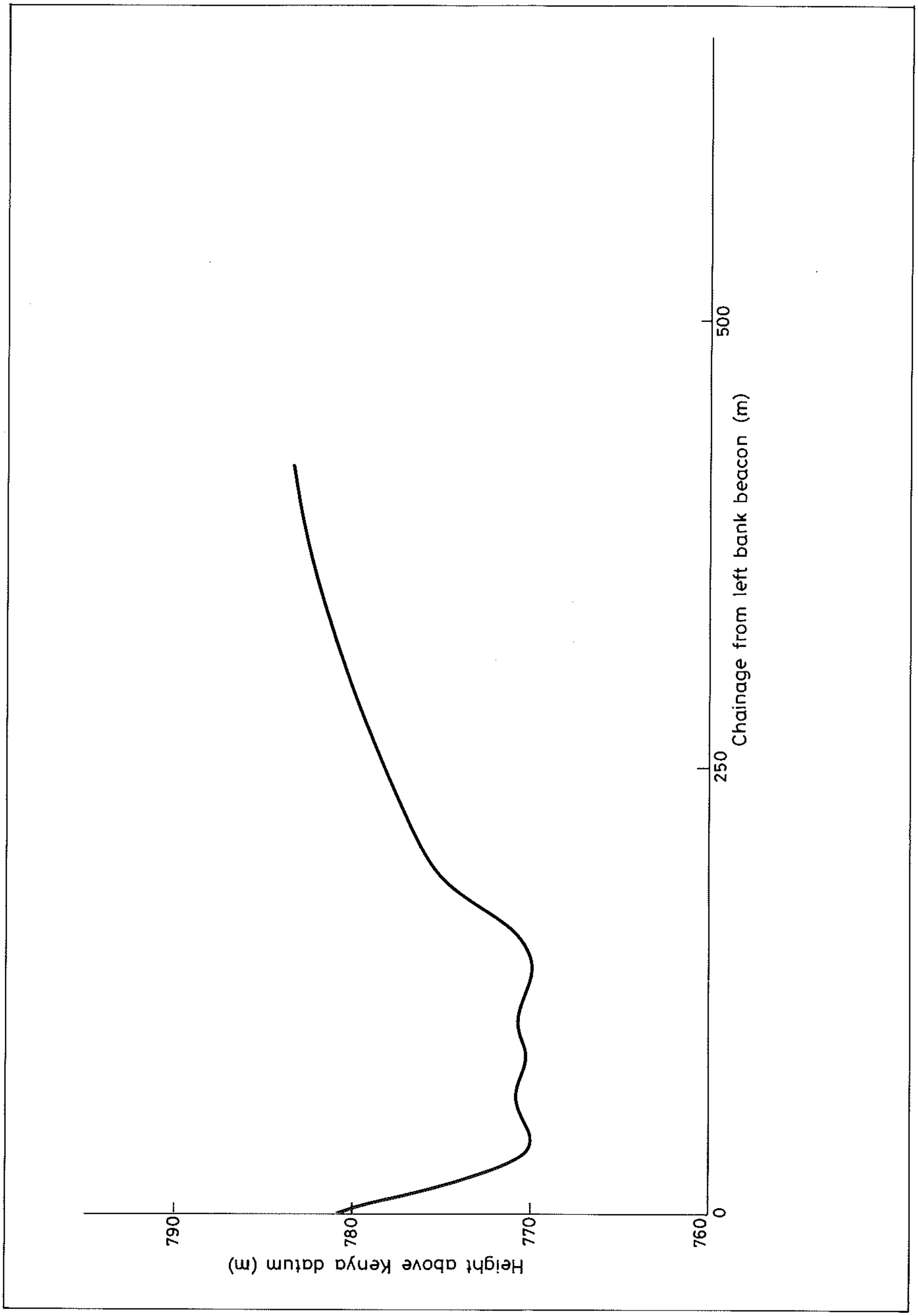


Fig 5 Kindaruma Reservoir section K2

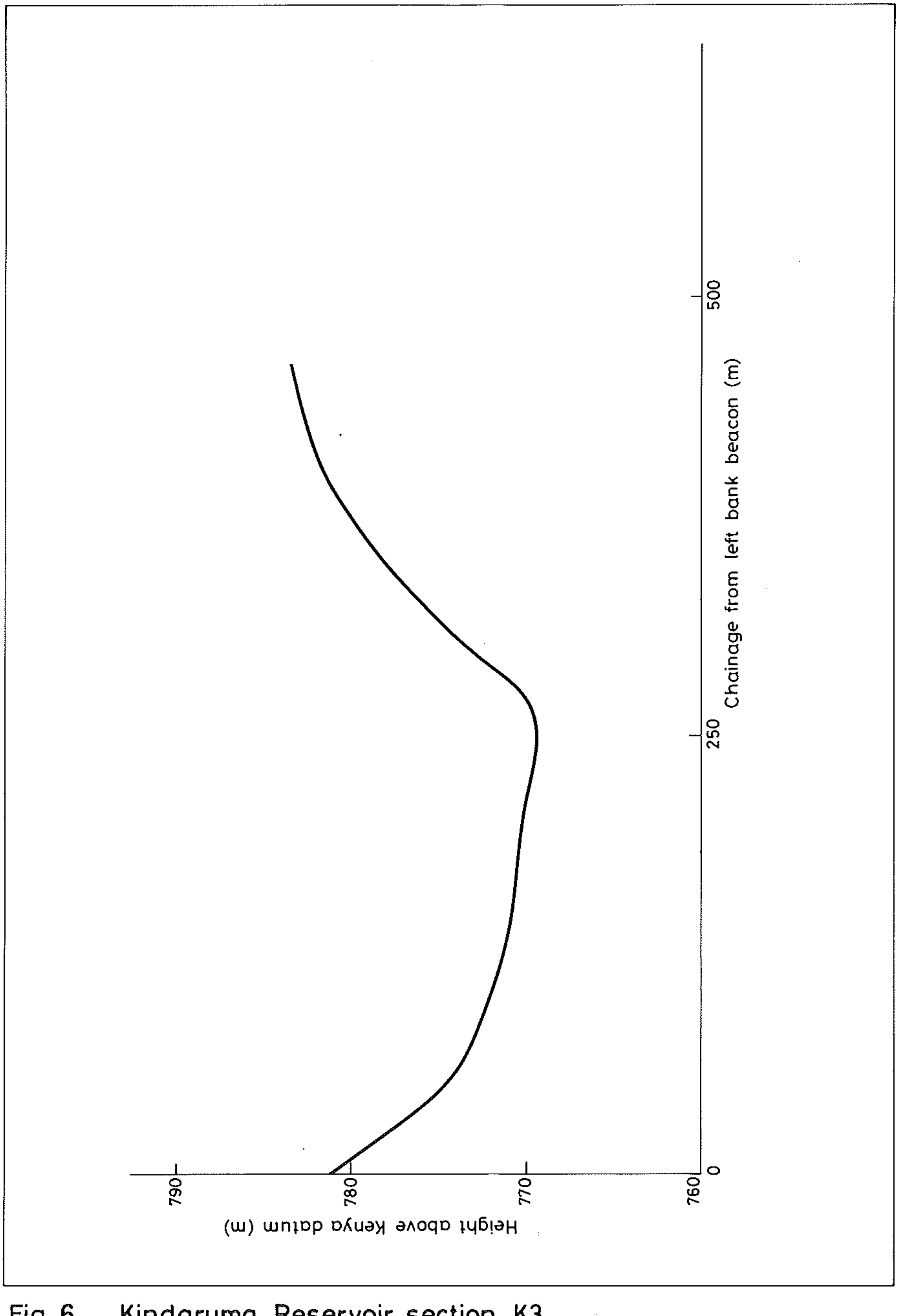


Fig 6 Kindaruma Reservoir section K3

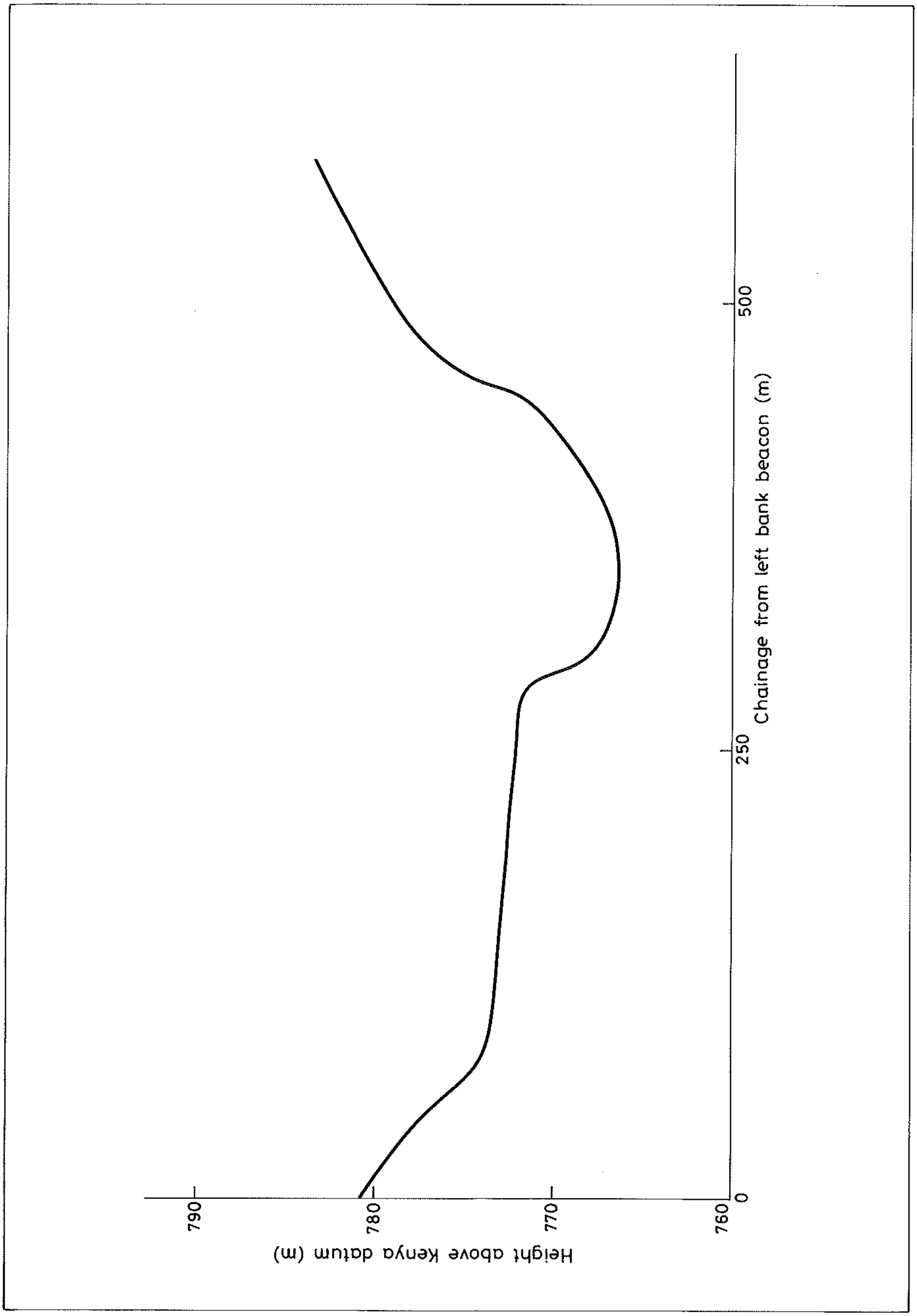


Fig 7 Kindaruma Reservoir section K4

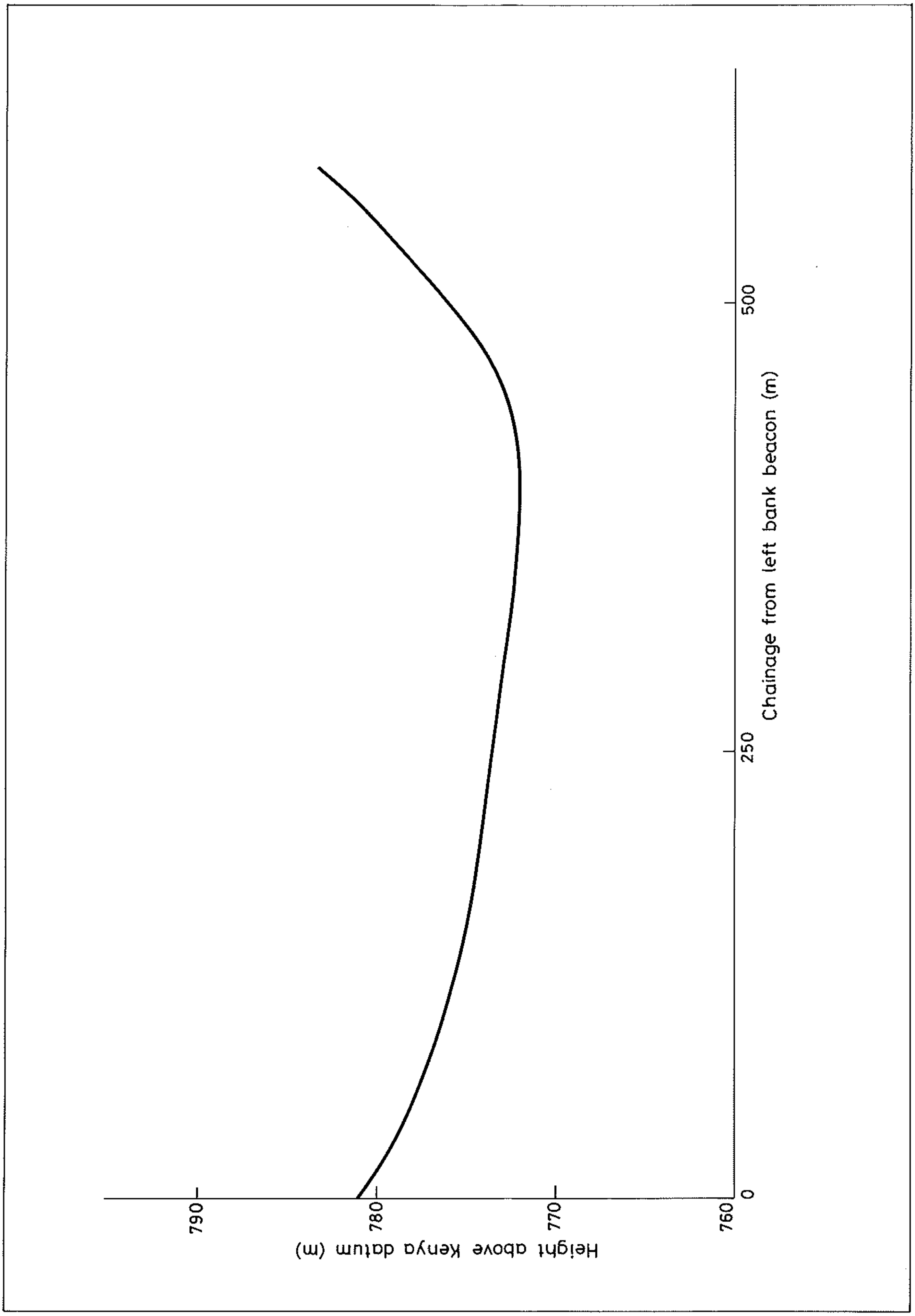


Fig 8 Kindaruma Reservoir section K5

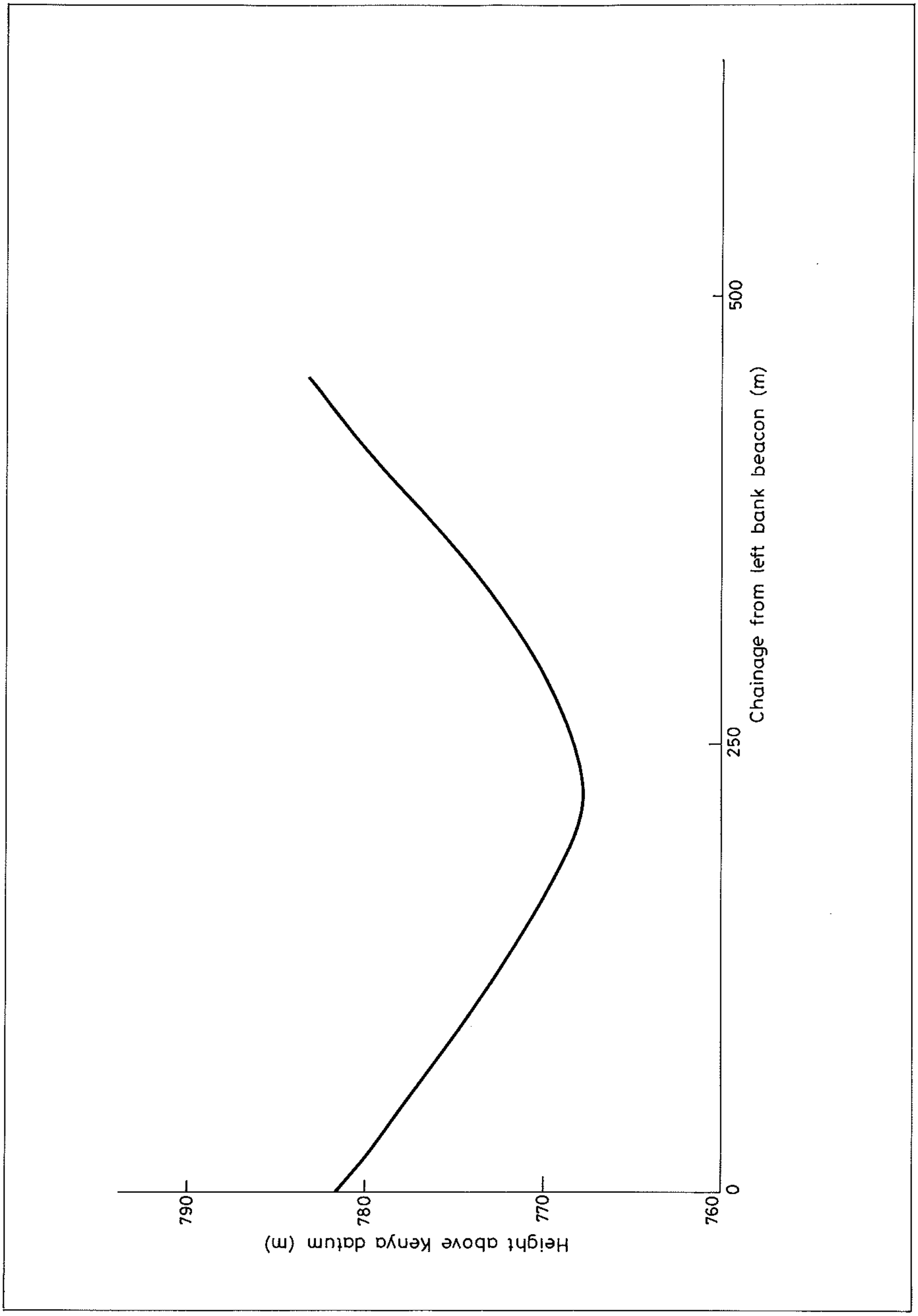


Fig 9 Kindaruma Reservoir section K6

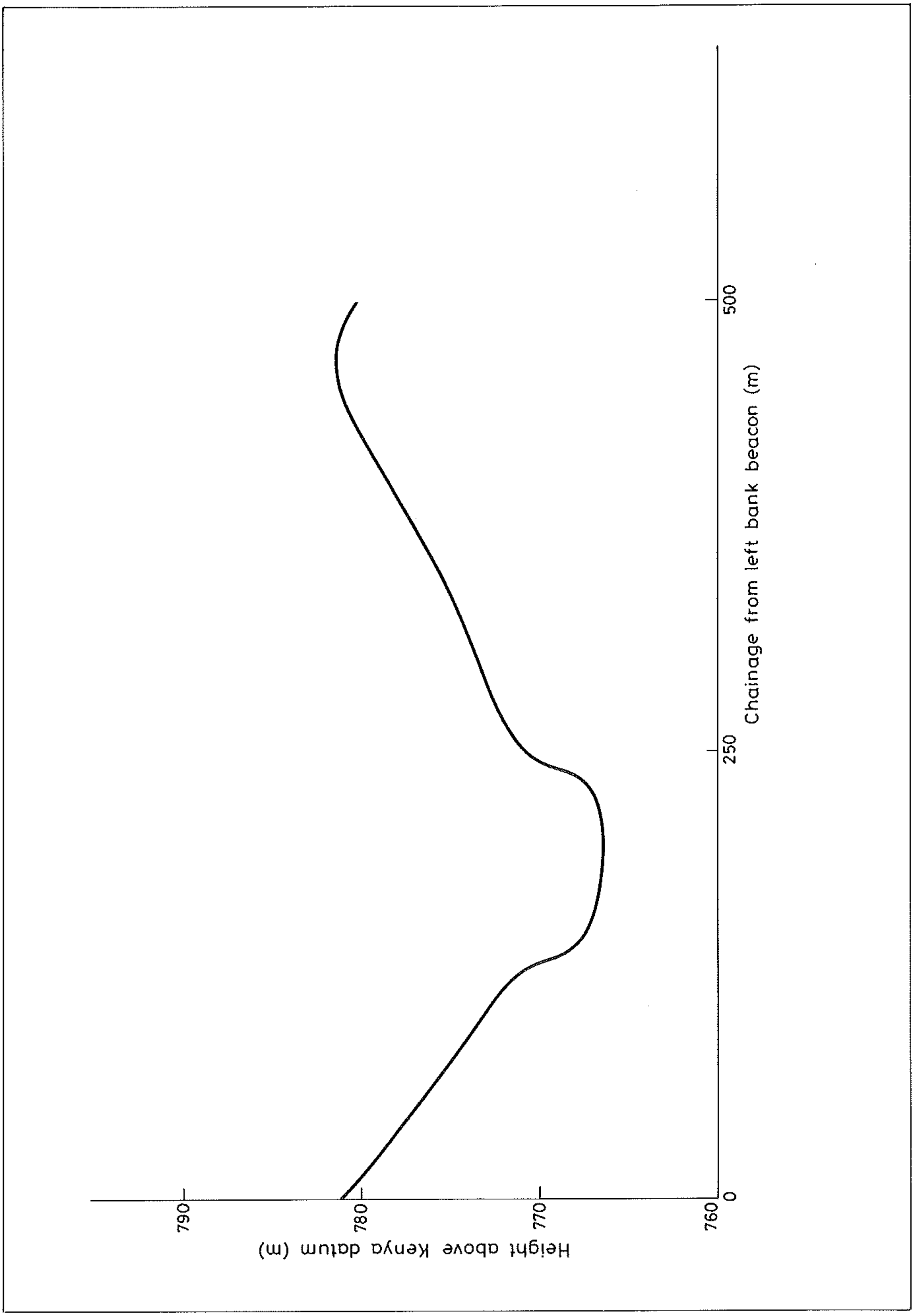


Fig 10   Kindaruma Reservoir section K7

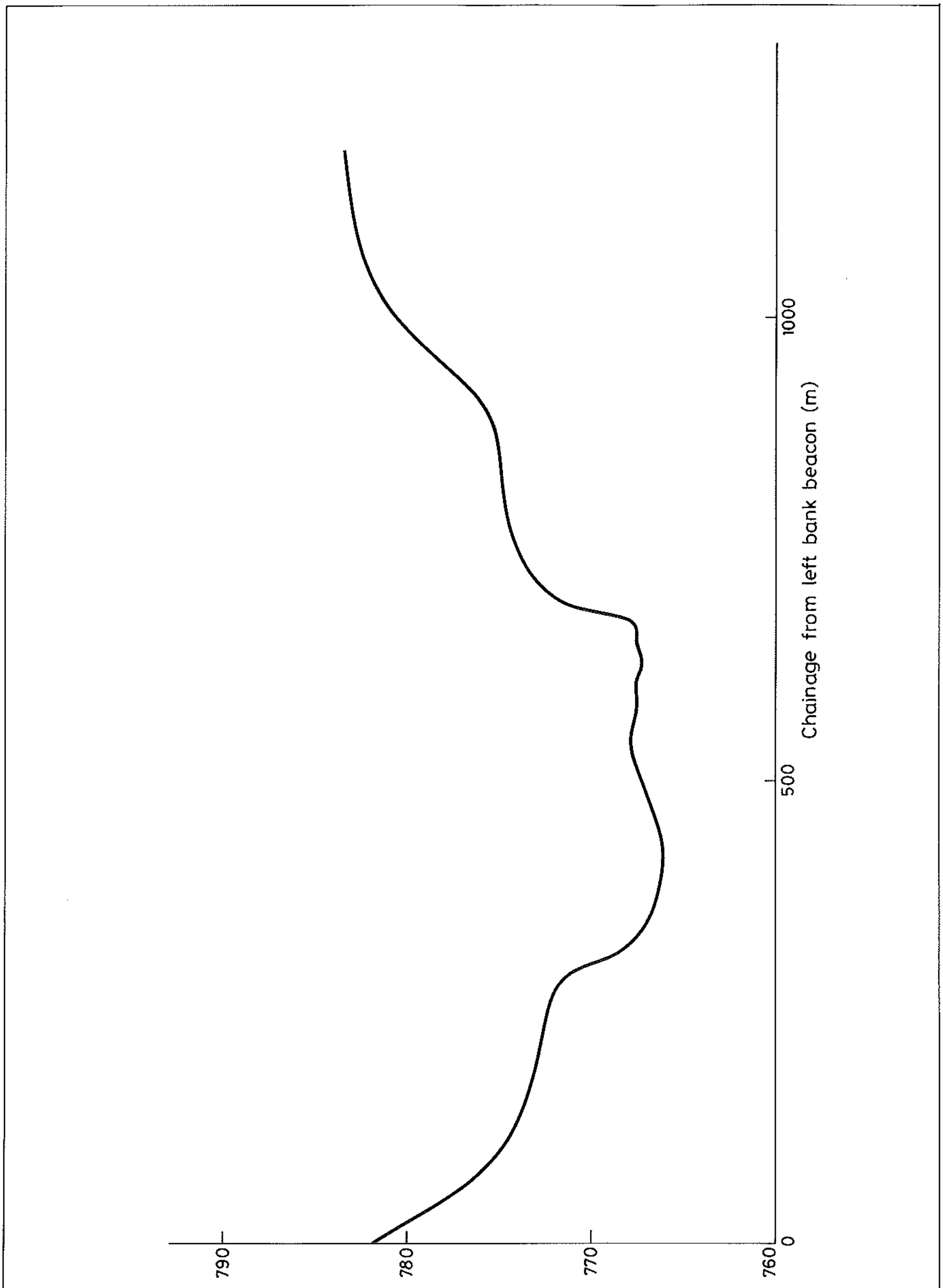


Fig 11   Kindaruma Reservoir section K8

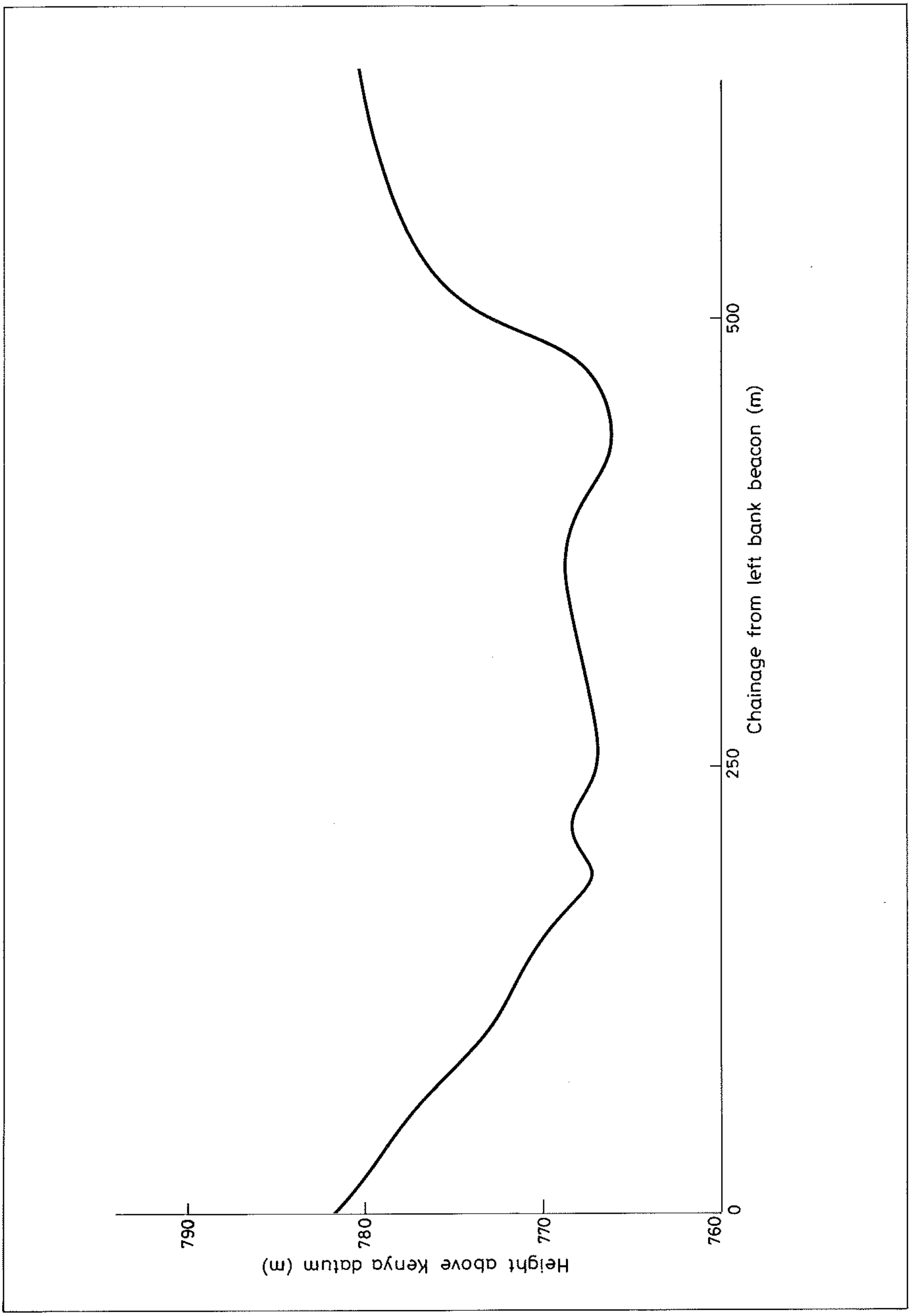


Fig 12 Kindaruma Reservoir section K9

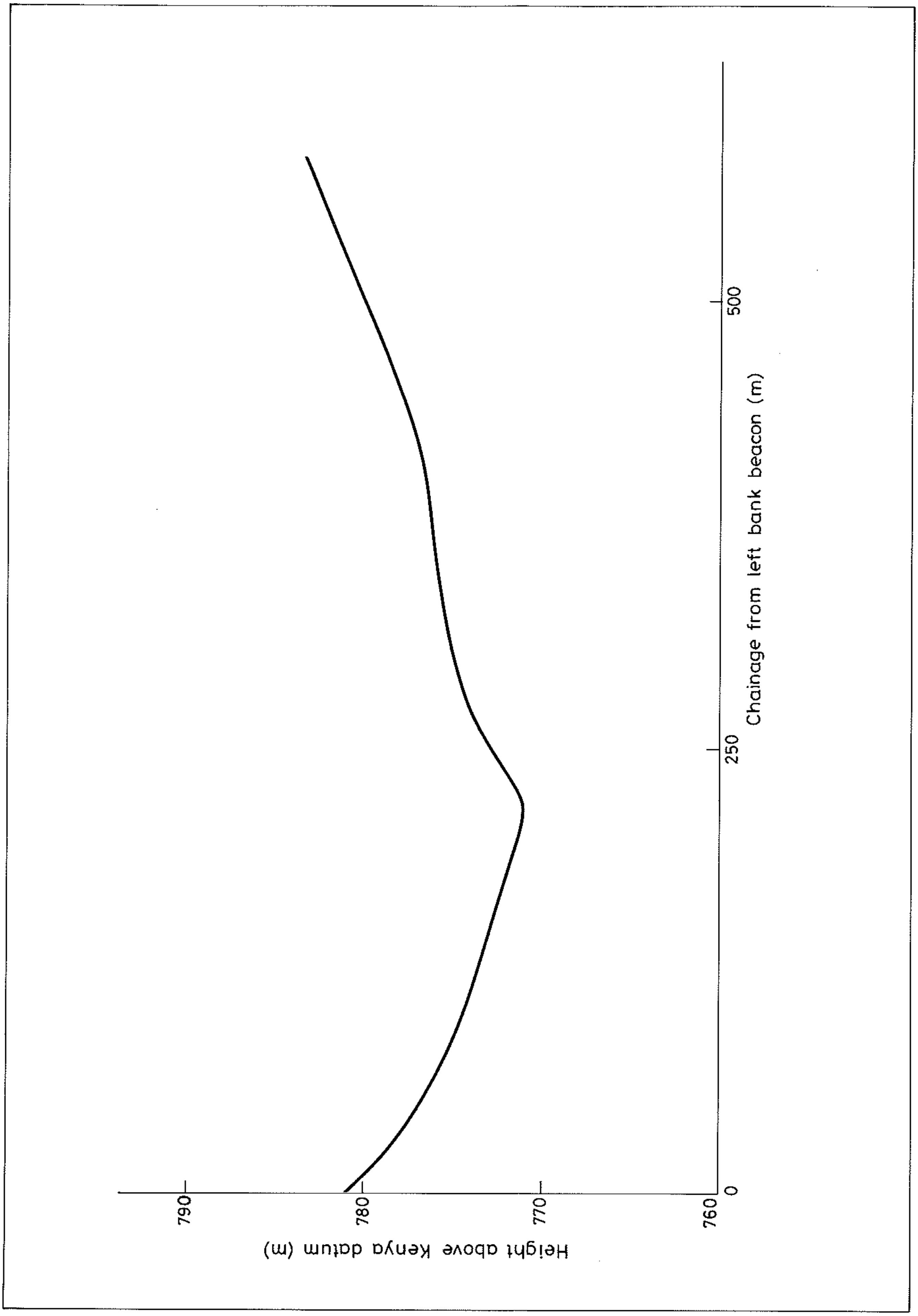


Fig 13 Kindaruma Reservoir section K10

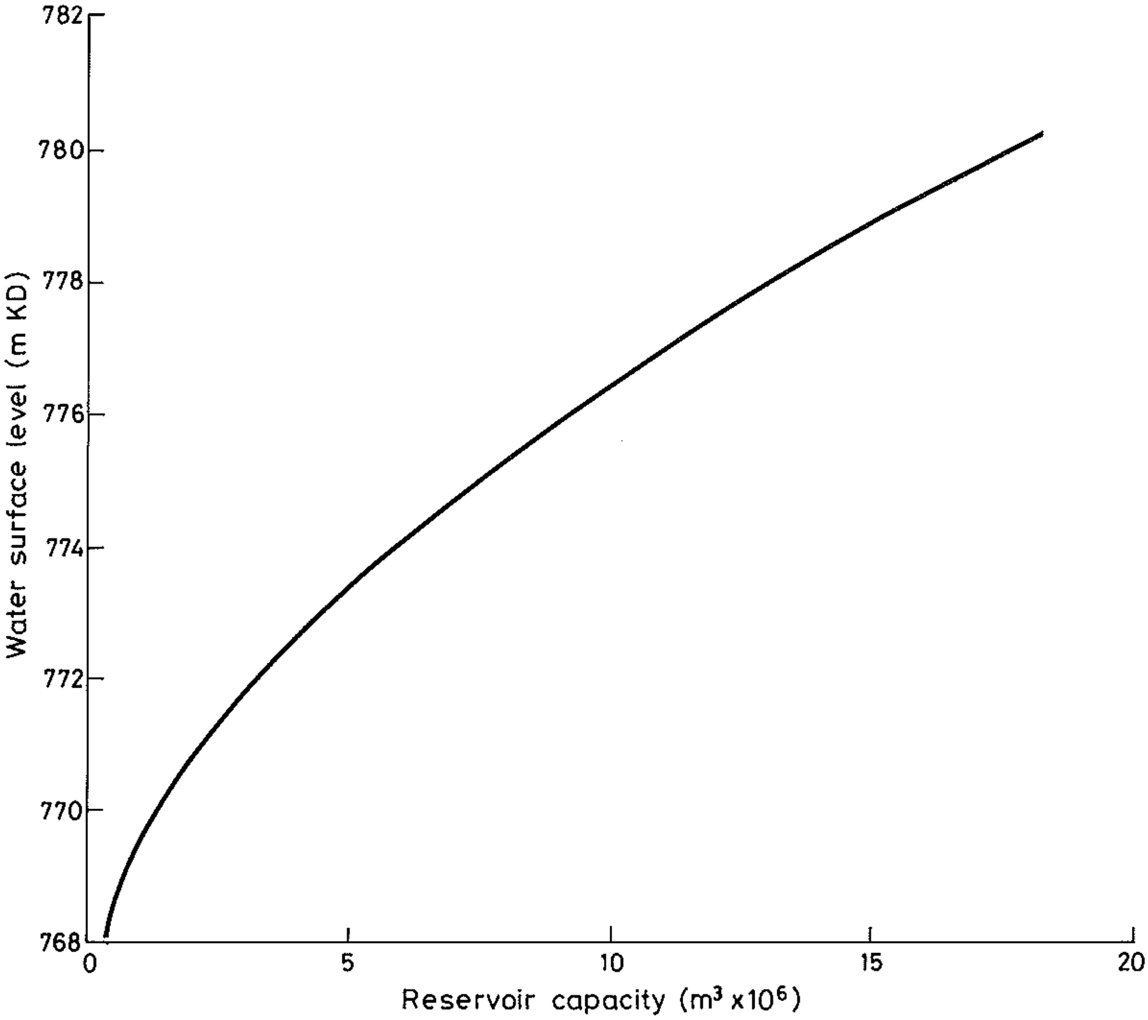


Fig 14 Kindaruma Reservoir stage/capacity curve

Kamburu data

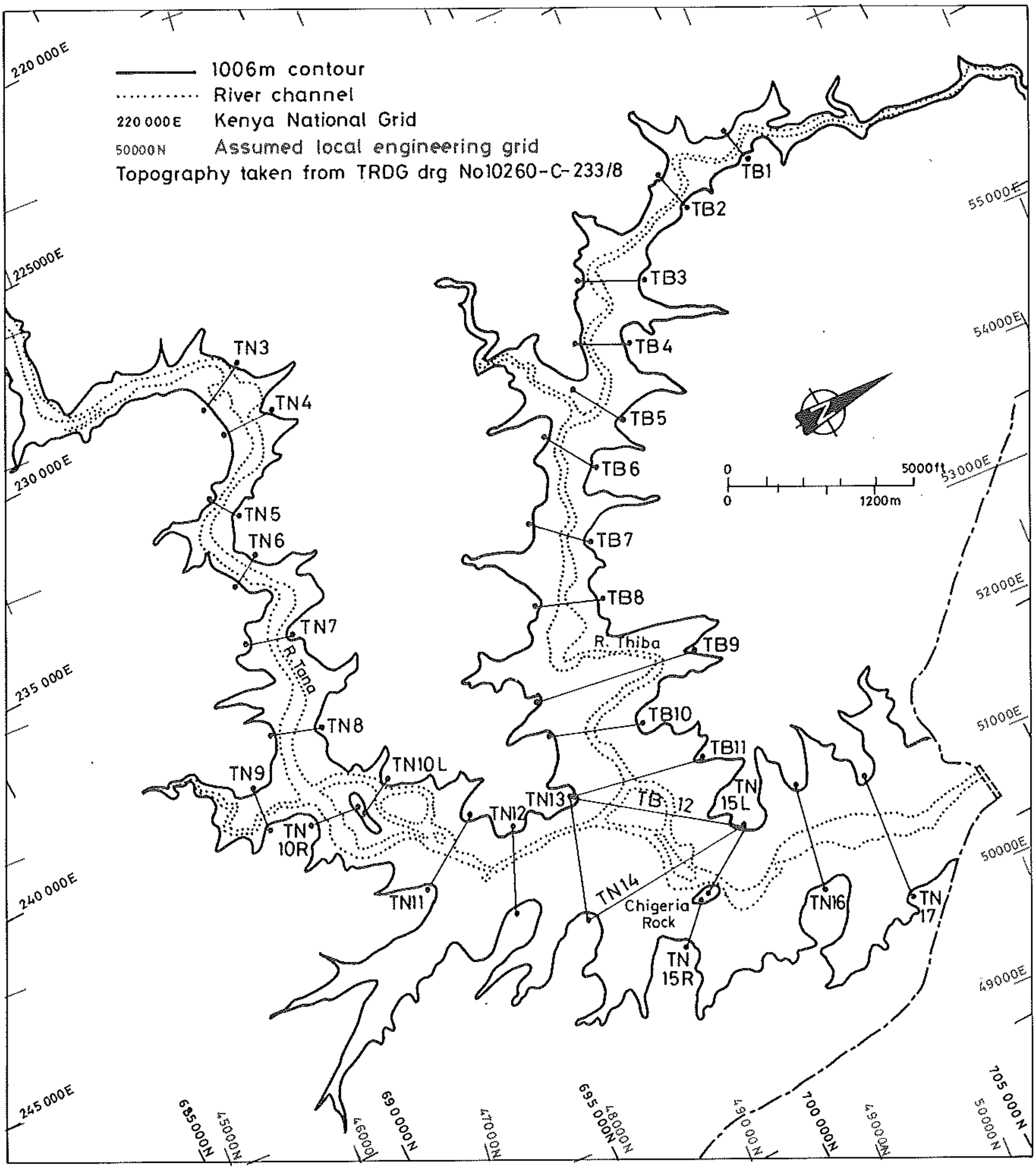


Fig 15 Kamburu Reservoir

TABLE 3 Kamburu base data survey, February 1965

Notes:

1. Distances and levels taken from Hunting Surveys Ltd., Tana River Survey, Sheets 7 & 8, February 1965.
2. Sections as defined for hydrographic surveys starting June 1981. (Ref 2)
3. Distances (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.

Section TN3

Length of section = 430.13m

Right-bank beacon co-ordinates = 46066.858, 55813.814
Left-bank beacon co-ordinates = 46434.584, 56036.950

Distance	Level	Distance	Level	Distance	Level
− 9	1008.89	31	river	279	1002.79
+ 7	1005.84	128		367	1005.84
22	1002.79	129	999.74	445	1008.89
30	999.74				

Section TN4

Length of section = 415.16m

Right-bank beacon co-ordinates = 46131.990, 55580.348
Left-bank beacon co-ordinates = 46546.838, 55596.497

Distance	Level	Distance	Level	Distance	Level
− 19	1008.89	136	river	343	1005.84
+ 36	1005.84	200		395	1008.89
113	1002.79	211	999.74	455	1011.94
126	999.74	216	1002.79		

Section TN5

Length of section = 190.15m

Right-bank beacon co-ordinates = 45898.043, 55100.831
Left-bank beacon co-ordinates = 46005.212, 54943.757

Distance	Level	Distance	Level	Distance	Level
−11	1008.89	93	999.74	186	river
+13	1005.84	118	996.70	189	1005.84
40	1002.79	126	river	203	1008.89

TABLE 3 (cont'd)

Section TN6

Length of section = 229.02m

Right-bank beacon co-ordinates = 45792.910, 54408.552
Left-bank beacon co-ordinates = 45984.136, 54534.572

Distance	Level	Distance	Level	Distance	Level
−29	1008.89	63	996.70	180	999.74
+9	1005.84	70	river	186	1002.79
25	1002.79	125		208	1005.84
50	999.74	143	996.70	237	1008.89

Section TN7

Length of section = 320.06m

Right-bank beacon co-ordinates = 45733.272, 53914.675
Left-bank beacon co-ordinates = 46048.696, 53860.411

Distance	Level	Distance	Level	Distance	Level
−28	1011.94	85	993.65	228	999.74
+13	1008.89	90	river	268	1002.79
25	1005.84	175		306	1005.84
49	1002.79	193	993.65	313	1008.89
70	999.74	200	996.70	365	1011.94
76	996.70				

Section TN8

Length of section = 387.75m

Right-bank beacon co-ordinates = 45619.031, 53173.360
Left-bank beacon co-ordinates = 45992.969, 53070.774

Distance	Level	Distance	Level	Distance	Level
− 11	1008.89	203	993.65	336	999.74
+ 15	1005.84	214	river	350	1002.79
44	1002.79	311		364	1005.84
88	999.74	314	993.65	376	1008.89
150	996.70	325	996.70	413	1011.94

Section TN9

Length of section = 304.61m

Right-bank beacon co-ordinates = 45333.109, 52784.194
Left-bank beacon co-ordinates = 45309.501, 52480.496

Distance	Level	Distance	Level	Distance	Level
− 9	1008.89	183	993.65	239	999.74
+ 8	1005.84	188	river	258	1002.79
30	1002.79	209		288	1005.84
50	999.74	214	993.65	300	1008.89
136	996.70	224	996.70	319	1011.94

TABLE 3 (cont'd)

Section TN10L

Length of section = 288.86m

Right-bank beacon co-ordinates = 46110.462, 52292.549
Left-bank beacon co-ordinates = 46345.034, 52461.159

Distance	Level	Distance	Level	Distance	Level
−15	1011.94	63	993.65	188	993.65
+5	1008.89	74	990.60	211	996.70
14	1005.84	75	river	220	999.74
36	1002.79	101		250	1002.79
50	999.74	163	990.60	286	1005.84
51	996.70				

Section TN10R

Length of section = 387.99m

Right-bank beacon co-ordinates = 45656.068, 52365.467
Left-bank beacon co-ordinates = 46043.449, 52343.933

Distance	Level	Distance	Level	Distance	Level
− 3	1008.89	125	river	313	996.70
+ 13	1005.84	145		325	999.74
34	1002.79	153	river	338	1002.79
49	999.74	288		358	1005.84
65	996.70	294	990.60	367	1008.94
86	993.65	300	993.65	399	1011.94
111	990.60				

Section TN11

Length of section = 701.11m

Right-bank beacon co-ordinates = 46318.403, 51521.417
Left-bank beacon co-ordinates = 46872.444, 51951.055

Distance	Level	Distance	Level	Distance	Level
− 36	1011.94	261	987.55	508	993.65
+ 13	1008.89	265	984.50	538	996.70
30	1005.84	283	river	570	999.74
75	1002.79	363		595	1002.79
113	999.74	368	984.50	644	1005.84
136	996.70	369	987.55	700	1008.89
150	993.65	449	990.60	748	1011.94
213	990.60				

TABLE 3 (cont'd)

Section TN12

Length of section = 645.25m

Right-bank beacon co-ordinates = 46951.680, 51104.348
Left-bank beacon co-ordinates = 47176.811, 51709.042

Distance	Level	Distance	Level	Distance	Level
− 3	1008.89	164	984.50	381	990.60
+ 20	1005.84	175	981.46	436	993.65
30	1002.79	200	river	475	996.70
60	999.74	270		526	999.74
88	996.70	283	981.46	575	1002.79
106	993.65	306	984.50	624	1005.84
125	990.60	326	987.55	700	1008.89
153	987.55				

Section TN13

Length of section = 1006.65m

Right-bank beacon co-ordinates = 47495.262, 50819.044
Left-bank beacon co-ordinates = 47712.954, 51801.874

Distance	Level	Distance	Level	Distance	Level
− 60	1005.84	255	984.50	623	999.74
+ 30	1008.89	274	981.46	654	1002.79
67	1008.89	289	river	749	1002.79
107	1005.84	349		787	999.74
134	1002.79	374	981.46	814	996.70
154	999.74	400	984.50	862	996.70
174	996.70	424	987.55	924	999.74
200	993.65	482	990.60	960	1002.79
213	990.60	537	993.65	1004	1005.84
239	987.55	574	996.70	1039	1008.89

Section TN14

Length of section = 1438.84

Right-bank beacon co-ordinates = 47495.262, 50819.044
Left-bank beacon co-ordinates = 48922.414, 51002.099

Distance	Level	Distance	Level	Distance	Level
− 11	1008.89	501	978.41	821	981.46
+ 40	1005.84	532	river	990	981.46
88	1002.79	591		1097	984.50
146	999.74	602	978.41	1140	987.55
190	996.70	615	981.46	1190	990.60
215	993.65	717	981.46	1235	993.65
236	990.60	728	978.41	1308	996.70
283	990.60	740	river	1339	999.74
365	990.60	763		1372	1002.79
415	987.55	767	978.41	1438	1005.84
452	984.50	775	981.46	1472	1008.89
480	981.46				

TABLE 3 (cont'd)

Section TN15L

Length of section = 602.53m

Right-bank beacon co-ordinates = 48440.060, 50641.568
Left-bank beacon co-ordinates = 48922.414, 51002.099

Distance	Level	Distance	Level	Distance	Level
− 16	1008.89	375	984.50	rises at a flat	
+ 11	1005.84	423	981.46	slope up to	
48	1002.79	431	978.41		
78	999.74	438	river	587	1005.84
113	996.70	450			
144	993.65	469	river	and beyond	
213	990.60	513			
356	987.55				

Section TN15R

Length of section = 388.04m

Right-bank beacon co-ordinates = 48133.317, 50301.086
Left-bank beacon co-ordinates = 48376.850, 50603.185

Distance	Level	Distance	Level	Distance	Level
+ 12	1005.84	260	993.65	362	1005.84
62	984.50	262	996.70	392	1008.89
187	987.55	303	999.74	437	1011.94
220	990.60	338	1002.79		

Section TN16

Length of section = 861.74m

Right-bank beacon co-ordinates = 49352.499, 50299.133
Left-bank beacon co-ordinates = 49430.834, 51157.308

Distance	Level	Distance	Level	Distance	Level
− 3	1008.89	365	978.41	566	984.50
+ 29	1005.84	379	975.36	610	987.55
33	1002.79	386	river	652	990.60
129	999.74	404		704	993.65
181	996.70	452	river	781	996.70
224	993.65	506		809	999.74
270	990.60	516	975.36	834	1002.79
305	987.55	524	978.41	854	1005.84
319	984.50	529	981.46	883	1008.89
347	981.46				

TABLE 3 (cont'd)

Section TN17

Length of section = 1035.14m

Right-bank beacon co-ordinates = 50000.000, 50000.000
Left-bank beacon co-ordinates = 50000.000, 51035.139

Distance	Level	Distance	Level	Distance	Level
− 1	1008.89	360	972.31	711	978.41
+ 50	1005.84	426	river	715	981.46
106	1002.79	450		750	984.50
157	999.74	510	972.31	786	987.55
193	996.70	514	975.36	813	990.60
228	993.65	538	978.41	847	993.65
253	990.60	564	981.46	888	996.70
283	987.55	616	981.46	920	999.74
294	984.50	636	978.41	963	1002.79
320	981.46	663	975.36	1025	1005.84
334	978.41	675	972.31	1110	1008.89
350	975.36	686	975.36		

TABLE 3 (cont'd)

Section TB1

Length of section = 288.99m

Right-bank beacon co-ordinates = 50896.304, 56346.697
Left-bank beacon co-ordinates = 50930.219, 56059.701

Distance	Level	Distance	Level	Distance	Level
− 5	1014.98	114	river	193	1002.79
+ 36	1008.89	154		278	1008.89
83	1002.79	155	996.70	400	1014.98
113	996.70				

Section TB2

Length of section = 330.13m

Right-bank beacon co-ordinates = 50262.878, 56190.396
Left-bank beacon co-ordinates = 50349.472, 55871.823

Distance	Level	Distance	Level	Distance	Level
−14	1014.98	113	996.70	153	996.70
+25	1008.89	114	river	233	1002.79
74	1002.79	152		349	1008.89

Section TB3

Length of section = 521.11m

Right-bank beacon co-ordinates = 49344.238, 55635.286
Left-bank beacon co-ordinates = 49831.657, 55450.965

Distance	Level	Distance	Level	Distance	Level
− 94	1014.98	338	996.70	418	996.70
+ 15	1008.89	339	river	421	1002.79
234	1002.79	417		528	1008.89

Section TB4

Length of section = 377.01m

Right-bank beacon co-ordinates = 49126.349, 55173.032
Left-bank beacon co-ordinates = 49476.381, 55032.986

Distance	Level	Distance	Level	Distance	Level
− 30	1008.89	274	993.65	331	996.70
+ 24	1005.84	286	river	338	999.74
78	1002.79	314		358	1002.79
149	999.74	325	993.65	413	1008.89
256	996.70				

TABLE 3 (cont'd)

Section TB5

Length of section = 472.17m

Right-bank beacon co-ordinates = 48946.234, 54858.508
Left-bank beacon co-ordinates = 49231.345, 54842.131

Distance	Level	Distance	Level	Distance	Level
− 25	1011.94	155	996.70	288	996.70
+ 5	1008.89	193	993.65	438	996.70
28	1005.84	200	river	456	996.70
68	1002.79	229		498	999.74
108	999.74	238	993.65		

Section TB6

Length of section = 411.73m

Right-bank beacon co-ordinates = 48597.509, 54559.585
Left-bank beacon co-ordinates = 48843.696, 54229.567

Distance	Level	Distance	Level	Distance	Level
− 29	1008.89	282	993.65	378	999.74
+ 14	1005.84	297	river	404	1002.79
50	1002.79	332		413	1005.84
98	999.74	342	993.65	438	1008.89
150	996.70	354	996.70		

Section TB7

Length of section = 473.72m

Right-bank beacon co-ordinates = 48240.387, 53960.459
Left-bank beacon co-ordinates = 48600.814, 53653.054

Distance	Level	Distance	Level	Distance	Level
− 15	1008.89	185	990.60	358	996.70
+ 15	1005.84	200	river	386	999.74
50	1002.79	238		423	1002.79
89	999.74	263	990.60	458	1005.84
130	996.70	293	993.65	493	1008.89
163	993.65				

Section TB8

Length of section = 475.00m

Right-bank beacon co-ordinates = 48011.752, 53322.934
Left-bank beacon co-ordinates = 48472.142, 53207.688

Distance	Level	Distance	Level	Distance	Level
+ 6	1005.84	255	987.55	392	996.70
30	1002.79	272	river	408	999.74
63	999.74	297		437	1002.79
131	996.70	301	987.55	463	1005.84
212	993.65	312	990.60	496	1008.89
236	990.60	380	993.65		

TABLE 3 (cont'd)

Section TB9

Length of section = 1252.90m

Right-bank beacon co-ordinates = 47741.689, 52616.207
Left-bank beacon co-ordinates = 48991.000, 52521.430

Distance	Level	Distance	Level	Distance	Level
0	1005.84	392	990.60	954	999.74
+ 48	1002.79	516	990.60	979	996.70
104	999.74	539	987.55	1011	993.65
134	996.70	569	987.55	1103	993.65
163	993.65	603	990.60	1121	996.70
183	990.60	629	993.65	1146	999.74
194	987.55	687	996.70	1191	1002.79
216	river	728	999.74	1238	1005.84
229		809	1002.79	1278	1008.89
256	987.55	928	1002.79	1334	1011.94

Section TB10

Length of section = 731.87m

Right-bank beacon co-ordinates = 47723.109, 52313.361
Left-bank beacon co-ordinates = 48433.034, 52135.834

Distance	Level	Distance	Level	Distance	Level
− 13	1008.89	338	984.50	514	990.60
+ 22	1005.84	363	981.46	542	993.65
76	1002.79	381	river	586	996.70
114	999.74	426		623	999.74
163	996.70	428	981.46	674	1002.79
204	993.65	463	981.46	710	1005.84
233	990.60	476	984.50	737	1008.89
262	987.55	488	987.55	779	1011.94

Section TB11

Length of section = 1092.07m

Right-bank beacon co-ordinates = 47712.954, 51801.874
Left-bank beacon co-ordinates = 48796.645, 51666.830

Distance	Level	Distance	Level	Distance	Level
− 99	1008.89	530	981.46	804	990.60
+ 25	1005.84	550	978.41	838	993.65
88	1002.79	567	river	918	996.70
139	999.74	599		950	999.74
175	996.70	609	978.41	1000	1002.79
204	993.65	678	981.46	1060	1005.84
250	990.60	714	984.50	1090	1008.89
295	987.55	765	987.55	1148	1011.94
367	984.50				

TABLE 3 (cont'd)

Section TB12

Length of section = 1449.95m

Right-bank beacon co-ordinates = 47712.976, 51801.861
Left-bank beacon co-ordinates = 48922.414, 51002.099

Distance	Level	Distance	Level	Distance	Level
−49	1005.84	549	984.50	1064	river
+100	1005.84	577	981.46	1112	
139	1002.79	583	978.41	1133	978.41
164	999.74	589	river	1152	981.46
182	996.70	652		1194	984.50
204	996.70	664	978.41	1229	987.55
239	999.74	706	981.46	1259	990.60
381	999.74	722	984.50	1288	993.65
415	996.70	737	987.55	1307	996.70
450	993.65	979	987.55	1342	999.74
489	990.60	1014	984.50	1370	1002.79
535	987.55	1030	981.46	1414	1005.84
		1052	978.41	1468	1008.89

Table 4 Kamburu Reservoir areas and volumes, 1965

Sections US D/S	Upper Contour (mKD)	Lower Contour (mKD)	End areas D/S (m^2)	End areas U/S (m^2)	Sum of end areas Áo (m^2)	Contour surface areas upper (m^2)	Contour surface areas lower (m^2)	Capacity Vó (m^3)	Constant factor C = Vó/Áo
TN3 TN4	1005.84	1002.79	639	961	1600	175705	99741	419780	262
	1002.79	999.74	289	545	834	99.741	73327	263756	316
	999.74	(998.00)	119	50	169	73327	0	63794	377
								747330	
TN4 TN5	1005.84	1002.79	474	639	1113	248281	160781	623410	560
	1002.79	999.74	343	289	632	160781	74440	358477	567
	999.74	996.70	178	119	297	74440	15090	136444	459
	996.70	(995.55)	37	–	37	15090	0	8677	235
								1127008	
TN5 TN6	1005.84	1002.79	530	474	1004	204199	147760	536386	534
	1002.79	999.74	455	343	798	147760	92344	365919	459
	999.74	996.70	290	178	468	92344	63919	238145	509
	996.70	(995.55)	19	37	56	63919	0	36753	656
								1177203	
TN6 TN7	1005.84	1002.79	774	530	1304	267473	205734	721167	553
	1002.79	999.74	573	455	1028	205734	146072	536152	522
	999.74	996.70	425	290	715	146072	95903	368770	516
	996.70	993.65	365	19	384	95903	73819	258656	674
	993.65	(991.70)	149	–	149	73819	0	71974	483
								1956719	
TN7 TN8	1005.84	1002.79	1024	774	1798	429824	325563	1151210	640
	1002.79	999.74	834	573	1407	325563	247266	872991	620
	999.74	996.70	643	425	1068	247266	148441	603057	565
	996.70	993.65	429	365	794	148441	82145	351413	443
	993.65	(991.00)	195	149	344	82145	0	108842	316
								3087513	

Table 4 (Continued)

Sections U/S	Sections D/S	Upper Contour (mKD)	Lower Contour (mKD)	End areas D/S (m^2)	End areas U/S (m^2)	Sum of end areas Áo (m^2)	Contour surface areas upper (m^2)	Contour surface areas lower (m^2)	Capacity Vó (m^3)	Constant factor C = Vó/Áo
TN8	TN10/10 A	1005.84	1002.79	1763	1024	2787	480536	425271	1380450	495
		1002.79	999.74	1494	834	2328	425271	364353	1203387	517
		999.74	996.70	1300	643	1943	364353	273543	972154	500
		996.70	993.65	1149	429	1578	273543	170044	676027	428
		993.65	990.60	940	195	1135	170044	110631	427749	377
		990.60	(988.80)	276	–	276	110631	0	99568	361
									4759335	
U/S	TN9	1005.84	1002.79	780	0	780	179687	122553	460614	591
		1002.79	999.74	627	0	627	122553	51542	265321	423
		999.74	996.70	506	0	506	51542	17801	105679	209
		996.70	993.65	286	0	286	17801	4799	34442	120
		993.65	(992.60)	18	0	18	4799	0	2519	140
									868575	
TN10/10A	TN11	1005.84	1002.79	1757	1763	3520	700361	619487	2011448	571
		1002.79	999.74	1491	1494	2985	619487	533341	1756910	589
		999.74	996.70	1310	1300	2610	533341	447123	1494227	573
		990.60	993.65	1185	1149	2334	447123	362721	1234202	529
		993.65	990.60	921	940	1861	362721	268433	961878	517
		990.60	987.55	523	276	799	268433	212673	733206	918
		987.55	984.50	315	–	315	212673	50421	400955	1273
		984.50	(983.30)	99	–	99	50421	0	30253	306
									8623079	

Table 4 (Continued)

Sections U/S	Sections D/S	Upper Contour (mKD)	Lower Contour (mKD)	End areas D/S (m^2)	End areas U/S (m^2)	Sum of end areas Aó (m^2)	Contour surface areas upper (m^2)	Contour surface areas lower (m^2)	Capacity Vó (m^3)	Constant factor C = Vó/Aó
TN11	TN12	1005.84	1002.79	1786	1757	3543	1069066	857841	2936606	829
		1002.79	999.74	1527	1491	3018	857841	662945	2317678	768
		999.74	996.70	1339	1310	2649	662945	518735	1800880	680
		996.70	993.65	1120	1185	2305	518735	383067	1374346	596
		993.65	990.60	895	921	1816	383067	264533	986942	543
		990.60	987.55	650	523	1173	264533	150953	633201	540
		987.55	984.50	483	315	798	150953	92788	371461	465
		984.50	981.46	391	99	490	92788	16445	166471	340
		981.46	(979.15)	179	–	179	16445	0	18994	106
									10606579	
TN12	TN13	1005.84	1002.79	2556	1786	4342	608245	506699	1699175	391
		1002.79	999.74	2021	1527	3548	506699	413425	1402269	395
		999.74	996.70	1663	1339	3002	413425	333931	1138971	379
		996.70	993.65	1159	1120	2279	333931	266111	914464	401
		993.65	990.60	910	895	1805	266111	200745	711489	394
		990.60	987.55	681	650	1331	200745	144933	526813	396
		987.55	984.50	507	483	990	144933	96853	368482	372
		984.50	981.46	367	391	758	96853	10617	163784	216
		981.46	(978.55)	226	179	405	10617	0	15448	38
									6940895	
TN13/TB12	TN14	1005-88	1002.79	4046	6541	10587	674072	666629	2043228	193
		1002.79	999.74	3852	5561	9413	666629	652025	2009628	213
		999.74	996.70	3648	4676	8324	652025	594414	1899573	228
		996.70	993.65	3234	3943	7177	594414	495233	1660622	231
		993.65	990.60	3024	3403	6427	495233	430356	1410598	219
		990.60	987.55	2346	2454	4800	430356	346647	1184153	247
		987.55	984.50	2101	1711	3812	346647	265544	932979	245
		984.50	981.46	1595	1296	2891	265544	175033	671439	232
		981.46	978.41	596	868	1464	175033	80208	388987	266
		978.41	(977.15)	129	150	279	80208	0	50531	181
									12251738	

Table 4 (Continued)

Sections U/S D/S	Upper Contour (mKD)	Lower Contour (mKD)	End areas D/S (m^2)	End areas U/S (m^2)	Sum of end areas Aó (m^2)	Contour surface areas upper (m^2)	Contour surface areas lower (m^2)	Capacity Vó (m^3)	Constant factor C = Vó/Aó
TN14 TN15/15A	1005.84	1002.84	2799	4046	6845	673714	583689	1916282	280
	1002.79	999.74	2490	3852	6342	583689	497513	1647752	260
	999.74	996.70	2260	3648	5908	497513	426530	1408242	238
	996.70	993.65	2010	3234	5244	426530	330006	1152961	220
	993.65	990.60	1791	3024	4815	330006	249362	882957	183
	990.60	987.55	1270	2346	3616	249362	186890	664848	184
	987.55	984.50	865	2101	2966	186890	129944	482855	163
	984.50	981.46	487	1595	2082	129944	76127	314052	151
	981.46	978.41	278	596	874	76127	50037	192274	220
	978.41	(976.70)	88	129	217	50037	0	42782	197
								8705005	
TN15/15A TN16	1005.84	1002.79	2458	2799	5257	1121292	1009033	3246615	618
	1002.79	999.74	2293	2490	4783	1009033	904883	2916808	610
	999.74	996.70	1964	2260	4224	904883	797121	2593854	614
	996.70	993.65	1700	2010	3710	797121	684887	2258580	609
	993.65	990.60	1273	1791	3064	684887	571163	1914220	625
	990.60	987.55	1041	1270	2311	571163	445435	1549295	670
	987.55	984.50	845	865	1710	445435	326489	1176412	688
	984.50	981.46	666	487	1153	326489	226245	842367	731
	981.46	978.41	505	278	783	226245	157991	585576	748
	978.41	975.36	474	88	562	157991	94911	385423	686
	975.36	(973.85)	97	–	97	94911	0	71658	739
								17540808	

TN17-DAM

783100
697000
613300
540800
463300
394500
324500
262700
196000
142700
91800
66100

Table 4 (Continued)

Sections U/S D/S	Upper Contour (mKD)	Lower Contour (mKD)	End areas D/S (m^2)	End areas U/S (m^2)	Sum of end areas Aó (m^2)	Contour surface areas upper (m^2)	Contour surface areas lower (m^2)	Capacity Vó (m^3)	Constant factor, C = Vó/Aó
TN16 TN17	1005.84	1002.79	2837	2458	5295	958551	842064	2744137	518
	1002.79	999.74	2529	2293	4822	842064	716771	2375665	493
	999.74	996.70	2262	1964	4226	716771	605849	2015673	477
	996.70	993.65	2049	1700	3749	605849	492758	1674277	447
	993.65	990.60	1816	1273	3089	492758	404268	1367068	443
	990.60	987.55	1631	1041	2672	404268	325378	1111981	416
	987.55	984.50	1484	845	2329	325378	250610	877806	377
	984.50	981.46	1275	666	1941	250610	185791	665075	343
	981.46	978.41	933	505	1438	185791	150889	513100	357
	978.41	975.36	723	474	1197	150889	109825	397328	332
	975.36	(968.55)	955	97	1052	109825	0	373954	355
								14116064	
TB1 TB2	1005.84	1002.79	579	418	997	254360	181249	663868	666
	1002.79	999.74	413	277	690	181249	89139	412071	597
	999.74	996.70	229	173	402	89139	13967	157134	391
	996.70	(995.85)	28	54	82	13967	0	5936	72
								1239009	
TB2 TB3	1005.84	1002.79	739	579	1318	315953	235525	840452	638
	1002.79	999.74	476	413	889	235525	161469	605019	681
	999.74	996.70	309	229	538	161469	73189	357619	665
	996.70	(994.20)	137	28	165	73189	0	91486	554
								1894576	

Table 4 (Continued)

Sections U/S D/S	Upper Contour (mKD)	Lower Contour (mKD)	End areas D/S (m^2)	End areas U/S (m^2)	Sum of end areas Aó (m^2)	Contour surface areas upper (m^2)	Contour surface areas lower (m^2)	Capacity Vó (m^3)	Constant factor C = Vó/Aó
TB3 TB4	1005.84	1002.79	971	739	1710	298733	224753	797793	467
	1002.79	999.74	725	476	1201	224753	158144	583535	486
	999.74	996.70	395	309	704	158144	62276	335920	477
	996.70	993.65	199	137	336	62276	33761	146360	436
	993.65	(991.75)	73	–	73	33761	0	32073	439
								1895681	
TB4 TB6	1005.84	1002.79	1144	971	2115	736426	546657	1955418	925
	1002.79	999.74	967	725	1692	546657	378366	1409735	833
	999.74	996.70	729	395	1124	378366	208628	894579	796
	996.70	993.65	509	199	708	208628	68372	422148	596
	993.65	(992.70)	41	73	114	68372	0	32477	285
								4714357	
TB6 TB7	1005.84	1002.79	1257	1144	2401	298284	239546	819653	341
	1002.79	999.74	1057	967	2024	239546	185096	647154	320
	999.74	996.70	797	729	1526	185096	128371	477724	313
	996.70	993.65	570	509	1079	128371	64114	293347	272
	993.65	990.60	315	41	356	64114	27585	139749	393
	990.60	(987.90)	139	–	139	27585	0	37240	268
								2414867	
TB7 TB8	1005.84	1002.79	1328	1257	2585	355643	288686	981957	380
	1002.79	999.74	1164	1057	2221	288686	230089	790613	356
	999.74	996.70	912	797	1709	230089	172373	613352	359
	996.70	993.65	640	570	1210	172373	113895	436272	361
	993.65	990.60	370	315	685	113895	66409	274783	401
	990.60	987.55	182	139	321	66409	9367	115483	360
	987.55	(985.35)	71	–	71	9367	0	10304	145
								3222764	

Table 4 (Continued)

Sections U/S D/S	Upper Contour (mKD)	Lower Contour (mKD)	End areas D/S (m^2)	End areas U/S (m^2)	Sum of end areas Áo (m^2)	Contour surface areas upper (m^2)	Contour surface areas lower (m^2)	Capacity Vó (m^3)	Constant factor C = Vó/Áo
TB8 TB9	1005.84	1002.79	3638	1328	4966	756095	675304	2181452	439
	1002.79	999.74	2713	1164	3877	675304	578739	1911162	493
	999.74	996.70	2310	912	3222	578739	479414	1612625	501
	996.70	993.65	1901	640	2541	479414	368145	1291680	508
	993.65	990.60	1529	370	1899	368145	236660	921723	485
	990.60	987.55	632	182	814	236660	112801	532579	654
	987.55	(985.70)	86	71	157	112801	0	104341	665
								8555562	
TB9 TB10	1005.84	1002.79	1994	3638	5632	442513	384668	1260624	224
	1002.79	999.74	1694	2713	4407	384668	321619	1076381	244
	999.74	996.70	1398	2310	3708	321619	258422	883982	238
	996.70	993.65	1198	1901	3099	258422	198381	696168	225
	993.65	990.60	940	1529	2469	198381	127645	496864	201
	990.60	987.55	804	632	1436	127675	71147	302959	211
	987.55	984.50	552	86	638	71147	38833	167610	263
	984.50	981.46	370	–	370	38833	6277	68748	186
	981.46	(980.25)	58	–	58	6277	0	3798	65
								4957134	
TB10 TB11	1005.84	1002.79	3008	1994	5002	464378	414985	1340149	268
	1002.79	999.74	2678	1694	4372	414985	360368	1181638	270
	999.74	996.70	2352	1398	3750	360368	306856	1016849	271
	996.70	993.65	2184	1198	3382	306856	249418	847762	251
	993.65	990.60	1842	940	2782	249418	190140	669886	241
	990.60	987.55	1578	804	2382	190140	135764	496678	208
	987.55	984.50	1298	552	1850	135764	88321	341506	185
	984.50	981.46	802	370	1172	88321	52191	214140	183
	981.46	978.41	320	58	378	52191	25994	119154	315
	978.41	(977.30)	48	–	48	25994	0	14427	301
								6242189	

Table 4 (Continued)

Sections U/S D/S	Upper Contour (mKD)	Lower Contour (mKD)	End areas D/S (m^2)	End areas U/S (m^2)	Sum of end areas A'_o (m^2)	Contour surface areas upper (m^2)	Contour surface areas lower (m^2)	Capacity V'_o (m^3)	Constant factor $C = V'_o/A'_o$
TB11 TB12	1005.84	1002.79	3985	1504	5489	356501	320829	1032251	188
	1002.79	999.74	3540	1339	4879	320829	288198	928157	190
	999.74	996.70	3013	1176	4189	288198	259433	834590	199
	996.70	993.65	2784	1092	3876	259433	224919	738152	190
	993.65	990.60	2493	921	3414	224919	188329	629790	184
	990.60	987.55	1773	789	2562	188329	150426	516263	201
	987.55	984.50	1204	649	1853	150426	110073	397000	214
	984.50	981.46	929	401	1330	110073	77644	286081	215
	981.46	978.41	642	160	802	77644	48543	192309	240
	978.41	(977.00)	150	24	174	48543	0	34223	197
								5588816	

Total reservoir volume = 133.2×10^6 m^3

Note

1. Contour levels shown in brackets are estimated from cross-section plots.
2. Where two sections are shown as the upstream and downstream limit, the end areas given are the sum of the two sections.

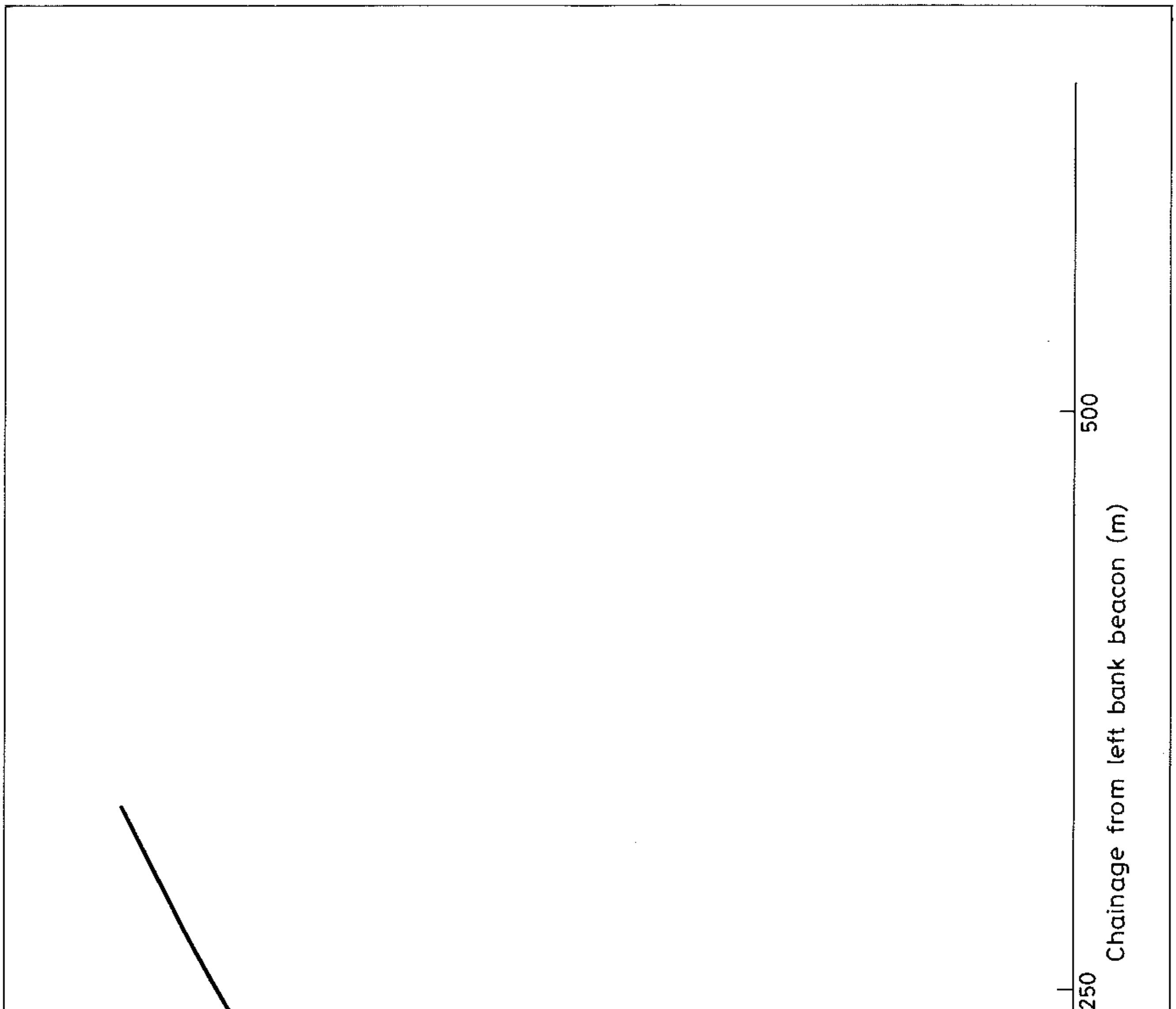


Fig 16 Kamburu Reservoir section TB1

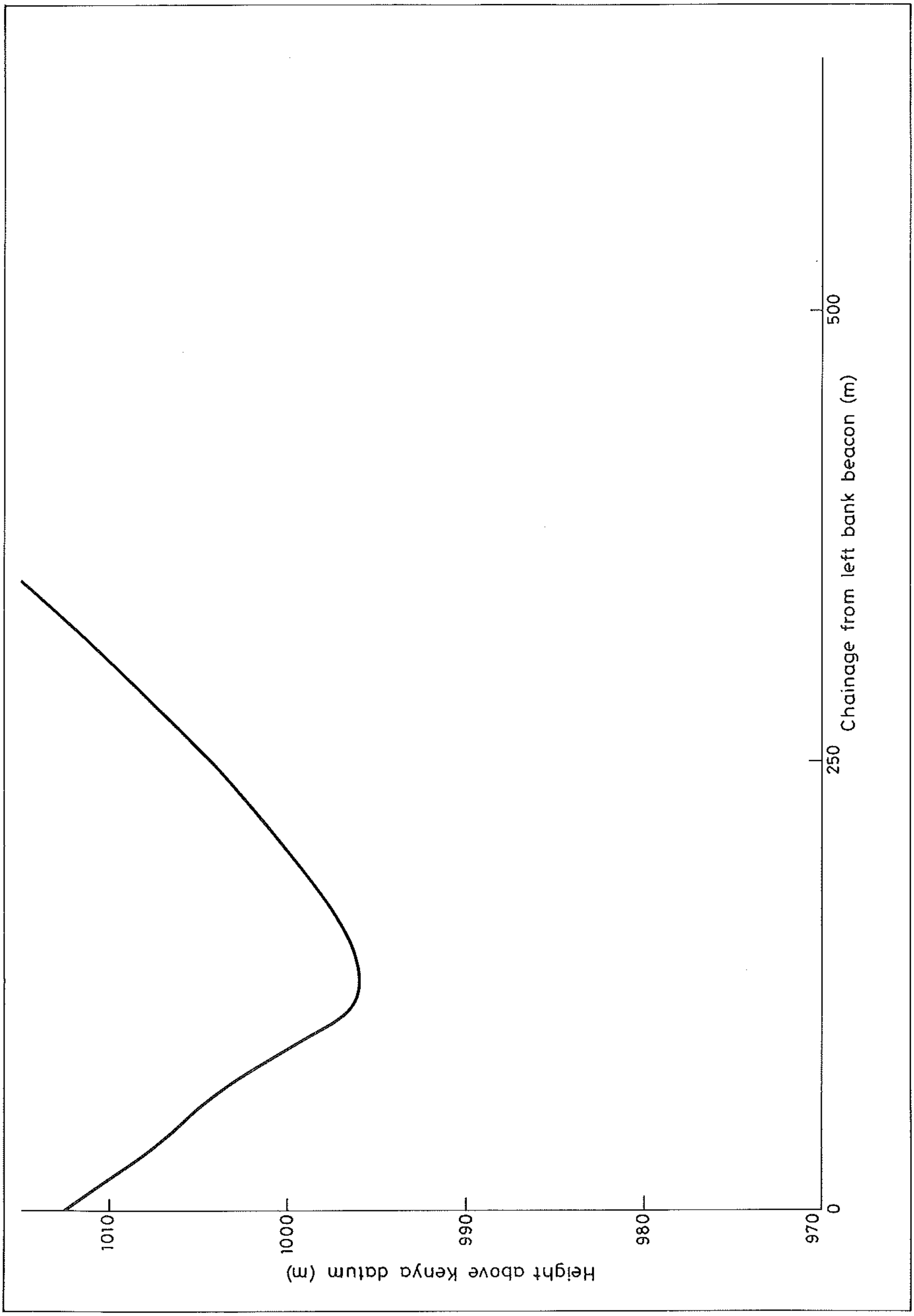


Fig 17 Kamburu Reservoir section TB2

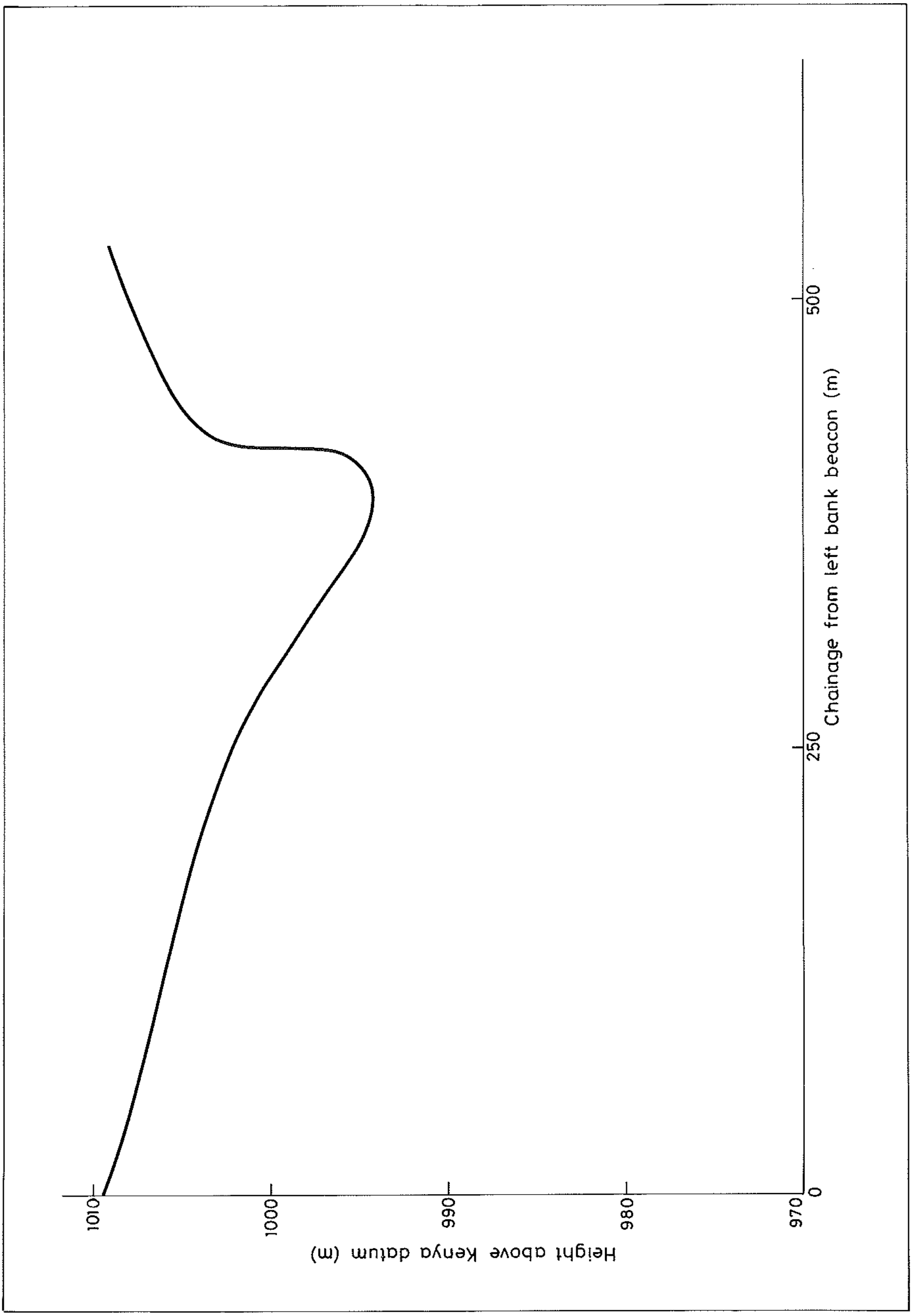


Fig 18 Kamburu Reservoir section TB3

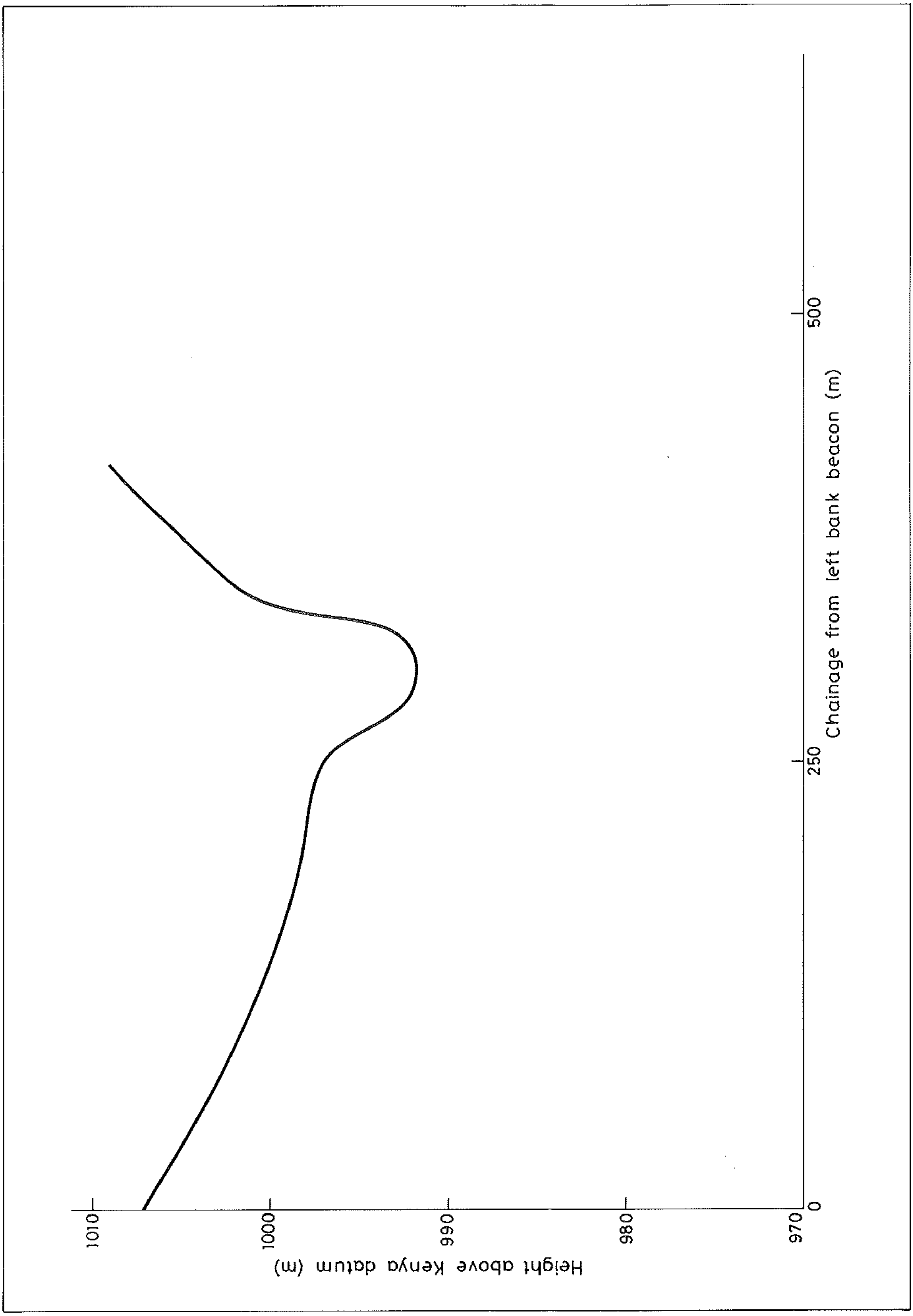


Fig 19 Kamburu Reservoir section TB4

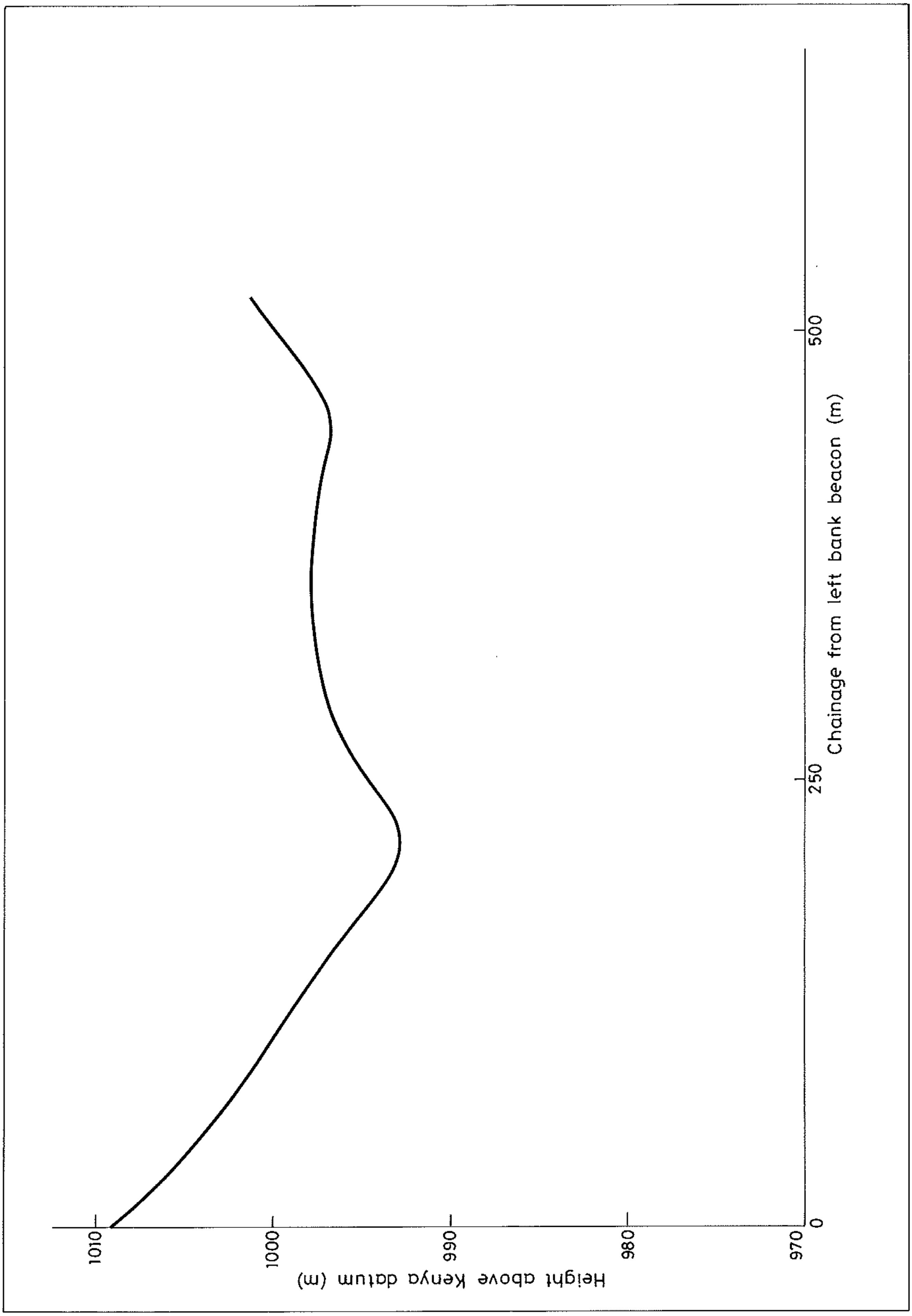


Fig 20 Kamburu Reservoir section TB5

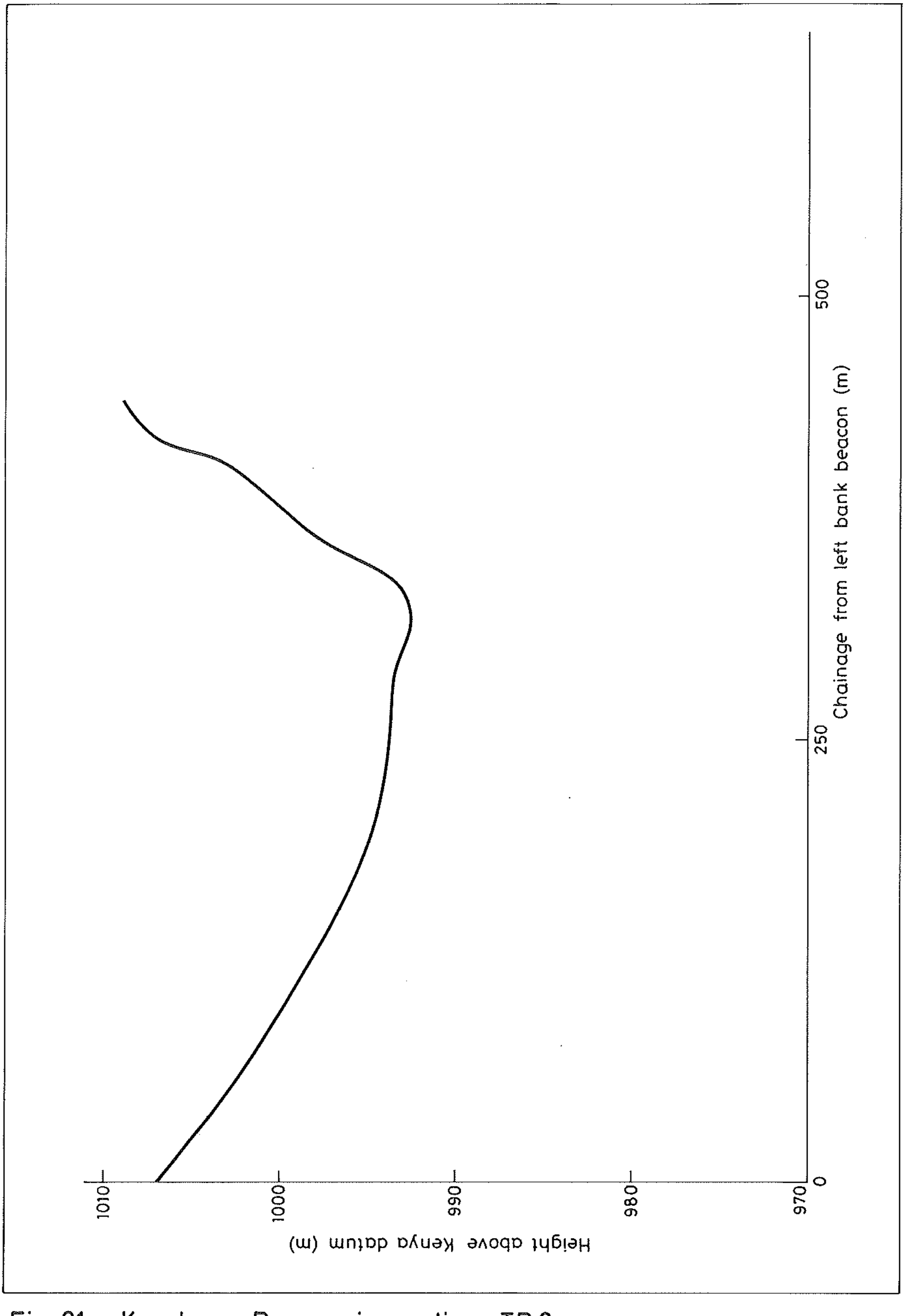


Fig 21 Kamburu Reservoir section TB6

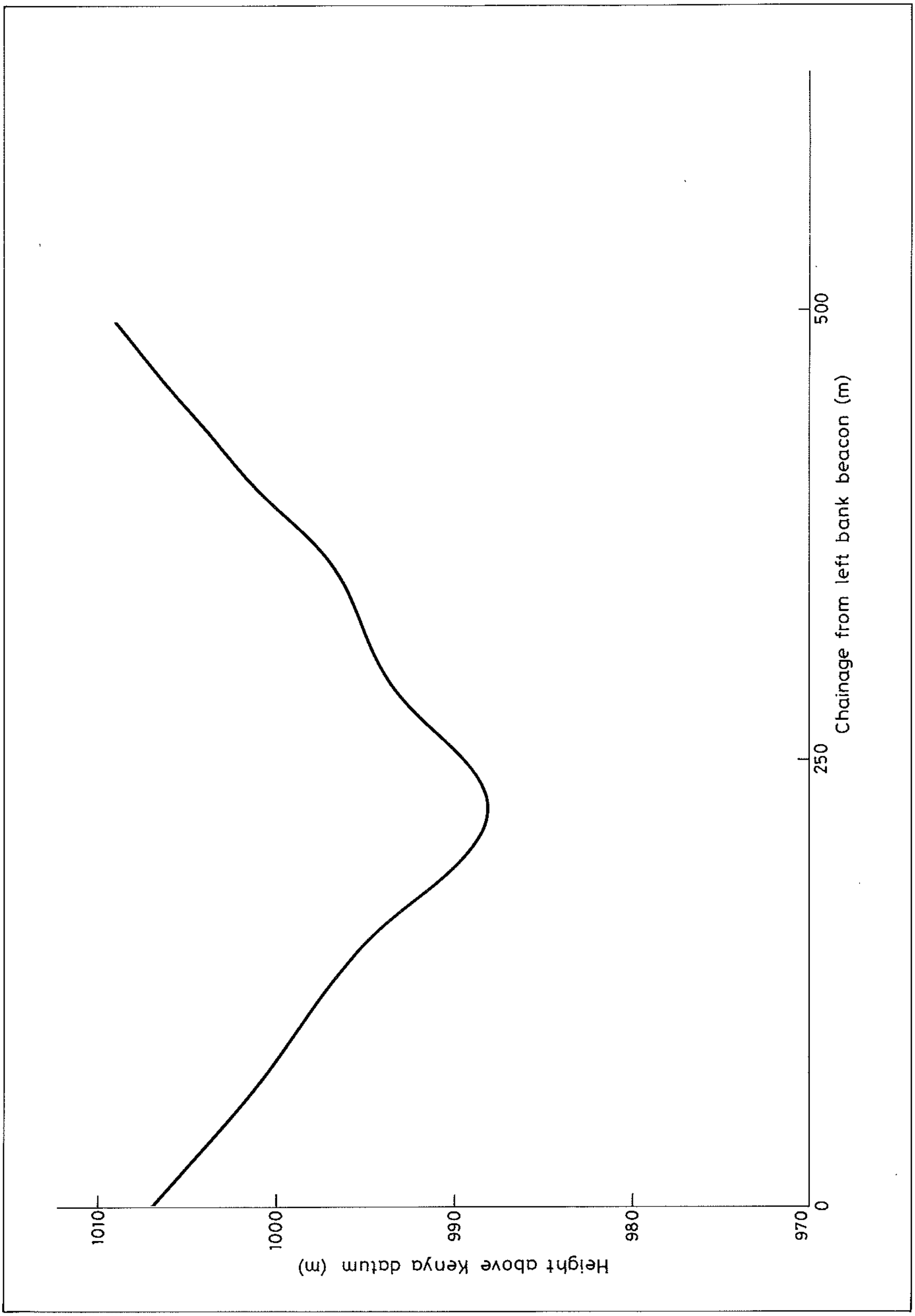


Fig 22 Kamburu Reservoir section TB7

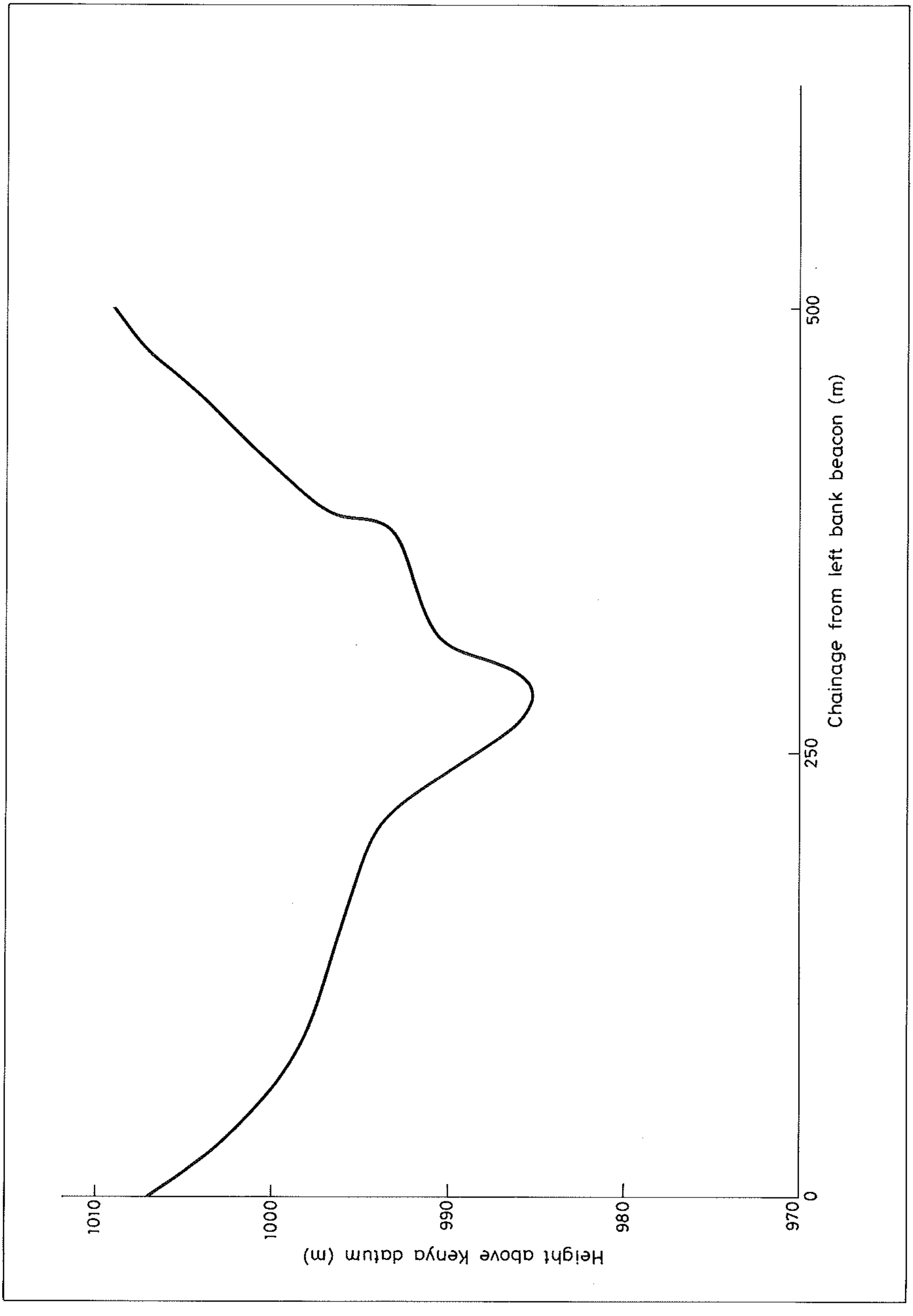


Fig 23 Kamburu Reservoir section TB8

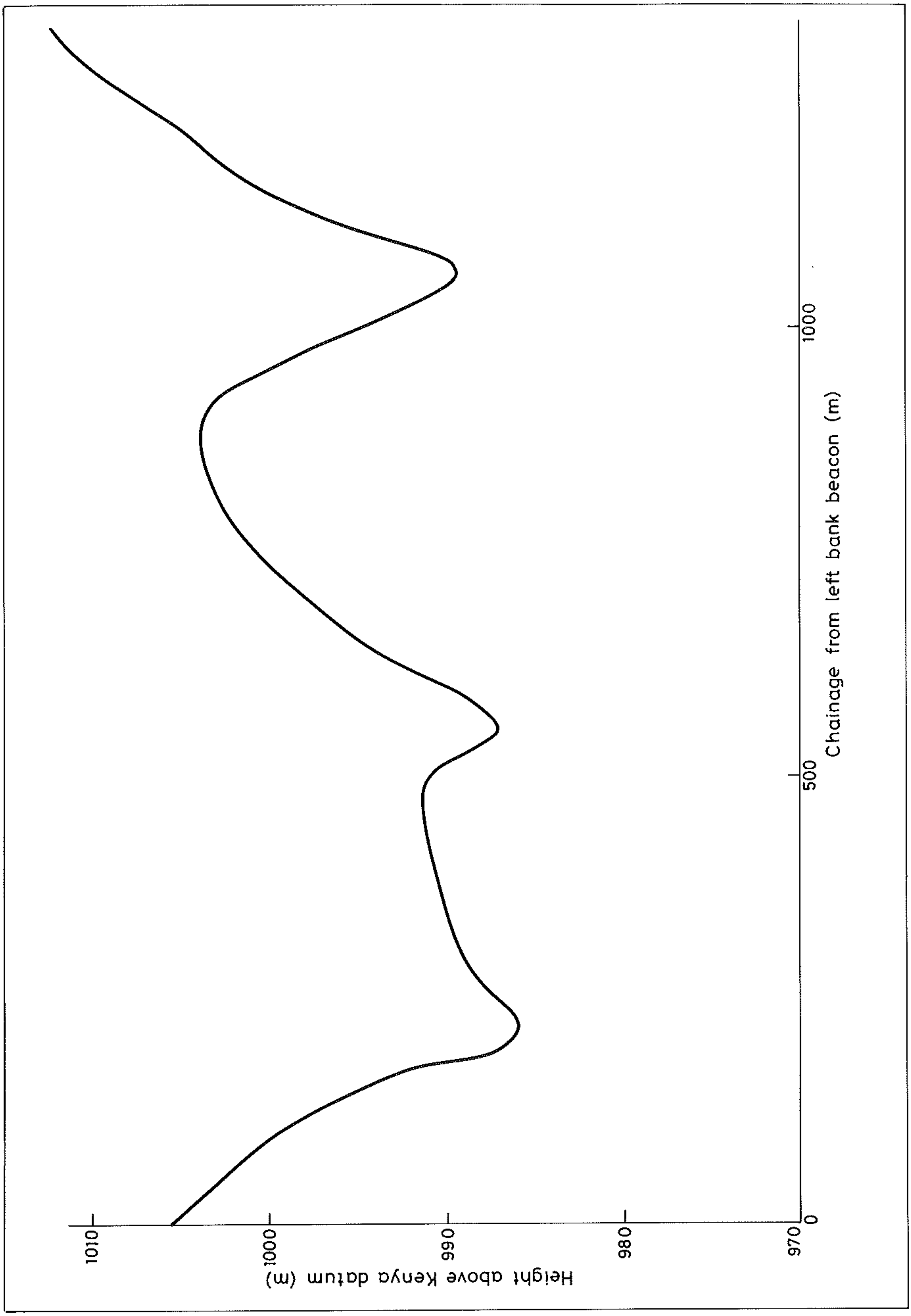


Fig 24 Kamburu Reservoir section TB9

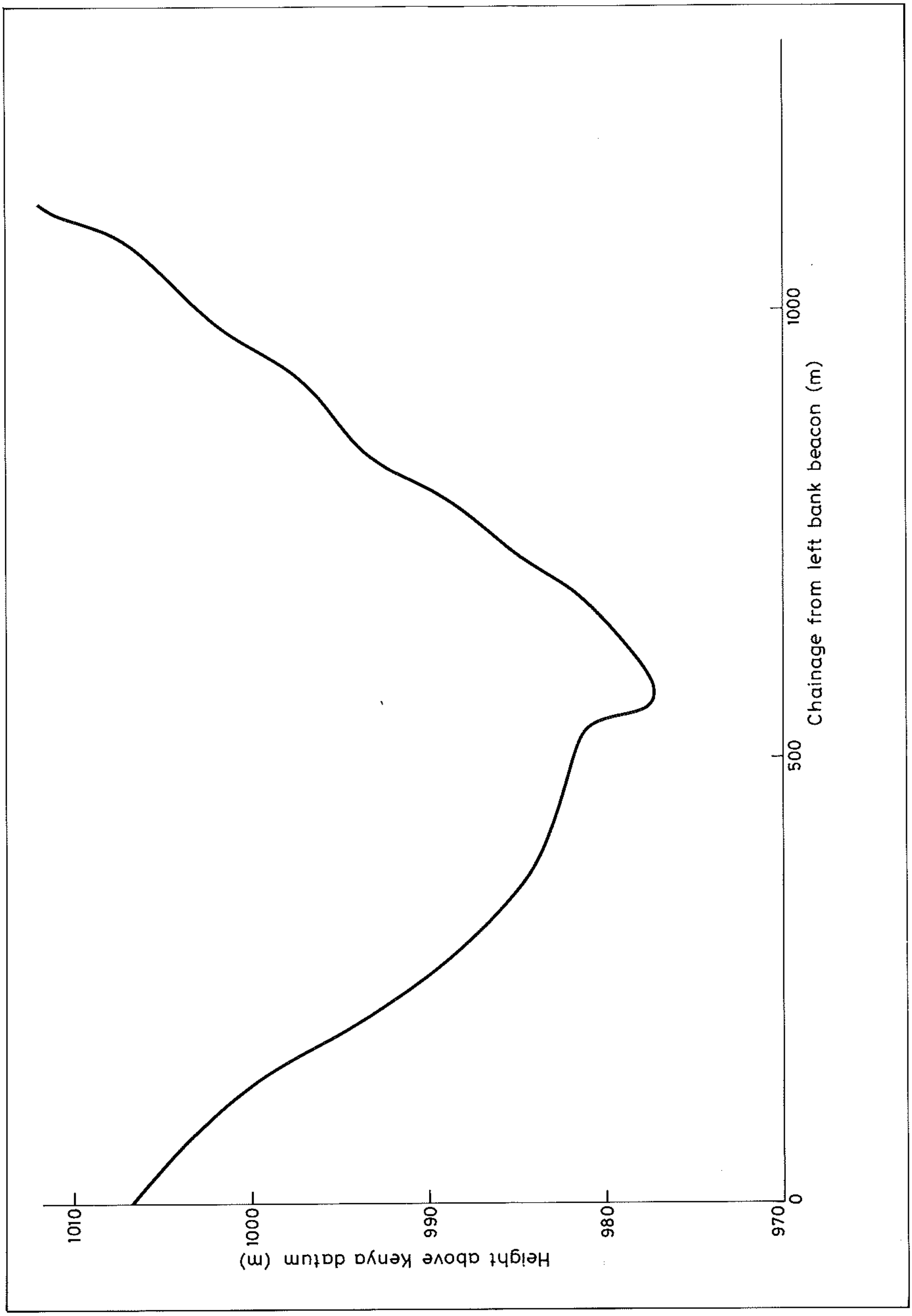


Fig 25 Kamburu Reservoir section TB11

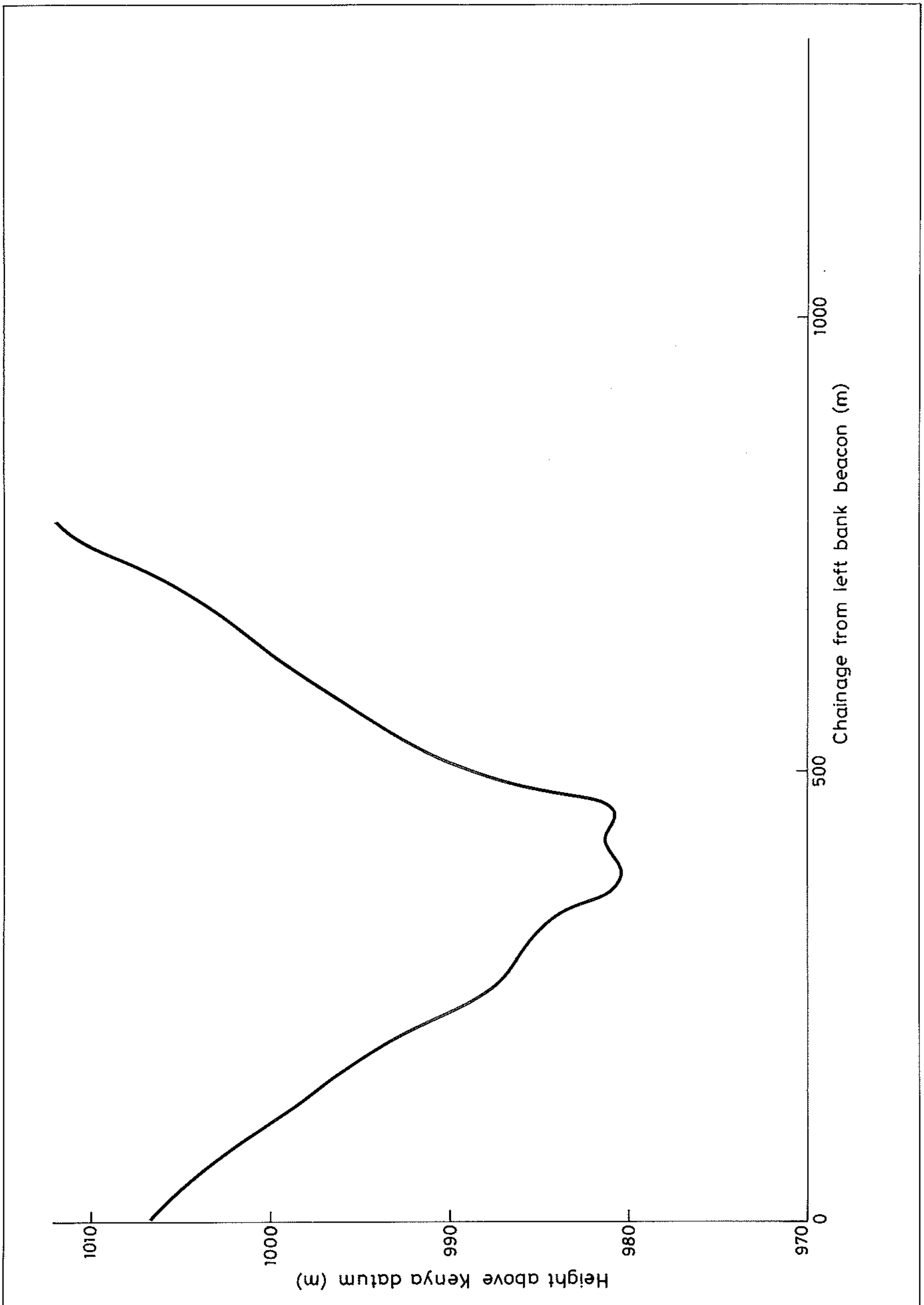


Fig 26 Kamburu Reservoir section TB10

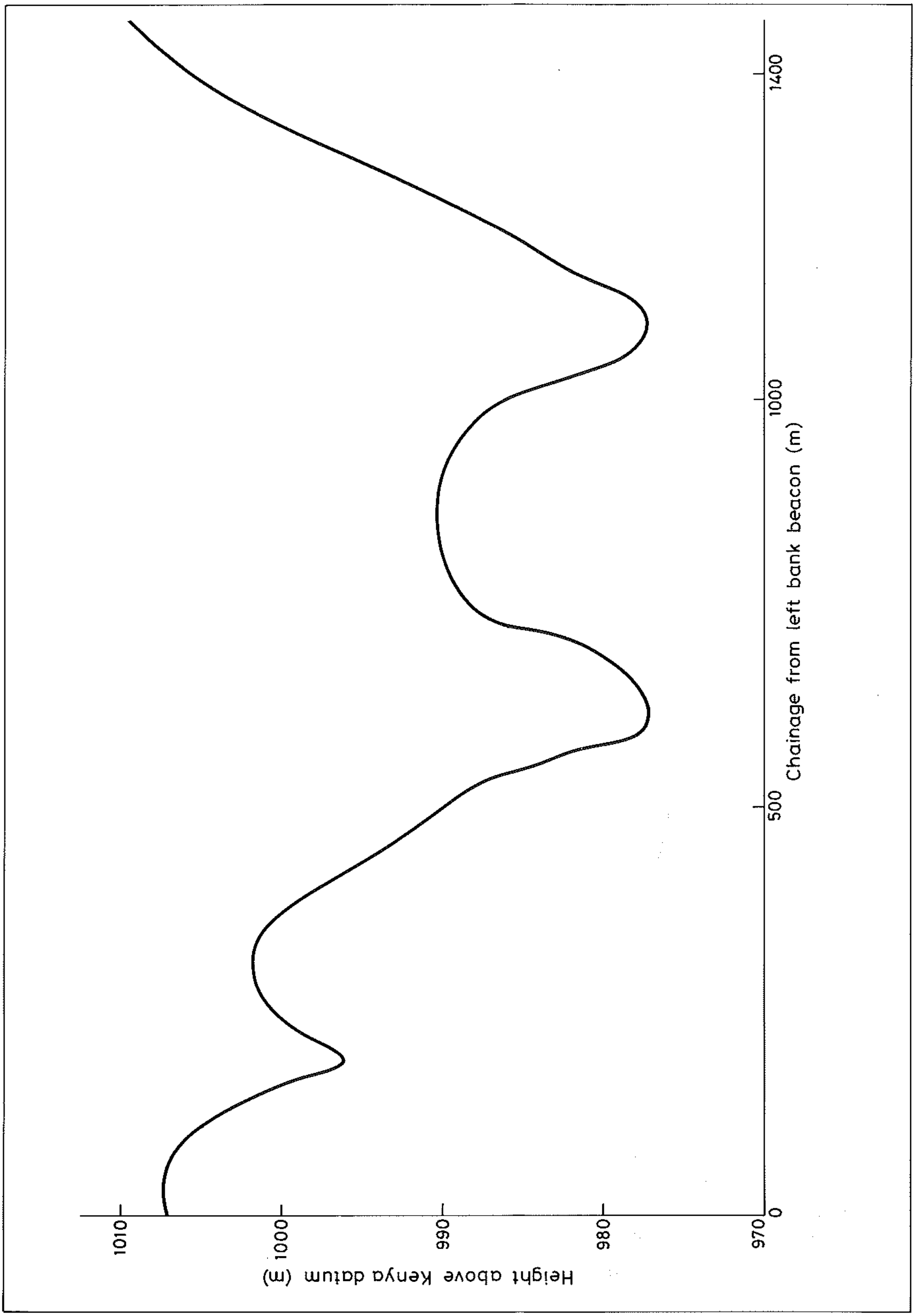


Fig 27 Kamburu Reservoir section TB12

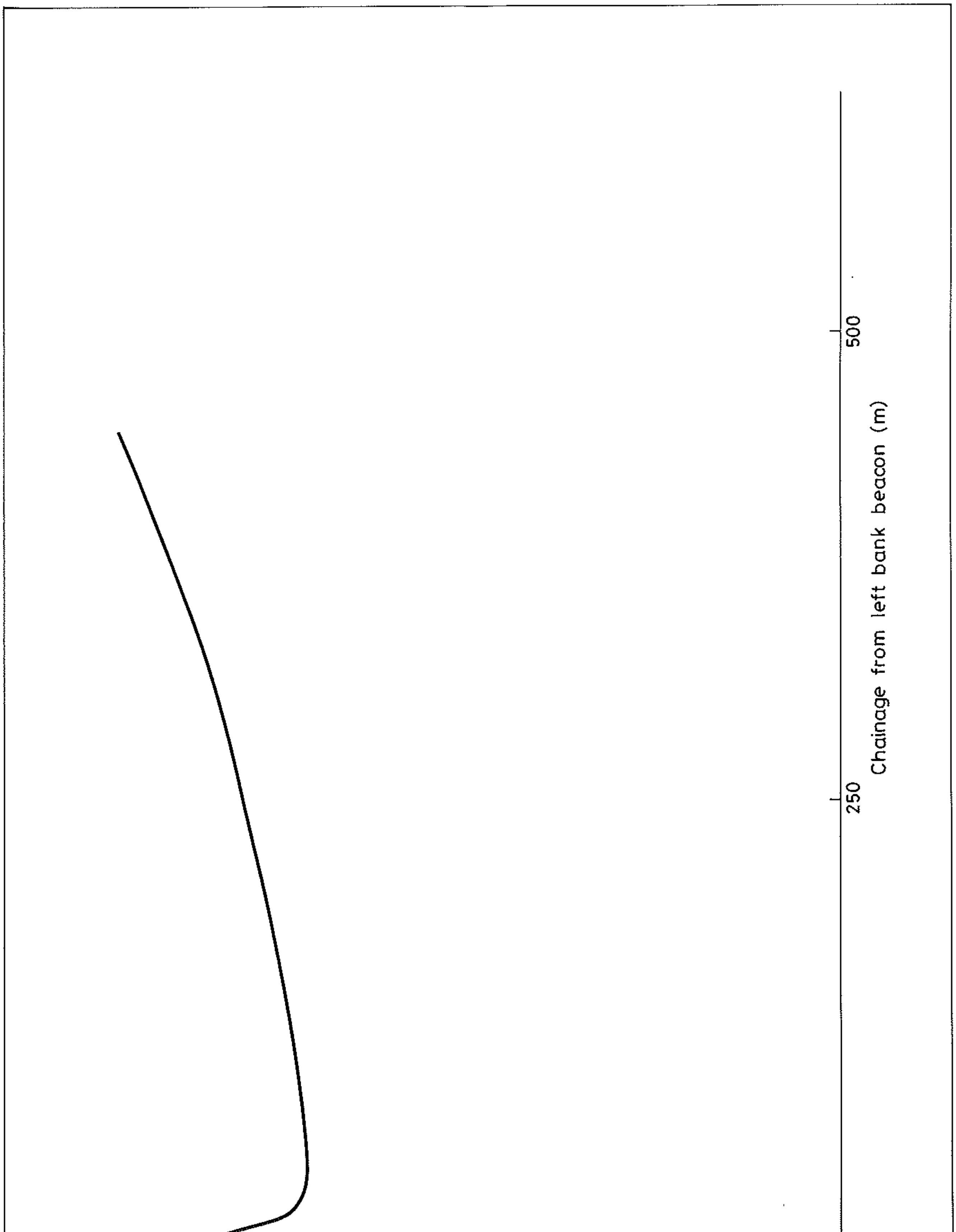


Fig 28 Kamburu Reservoir section TN3

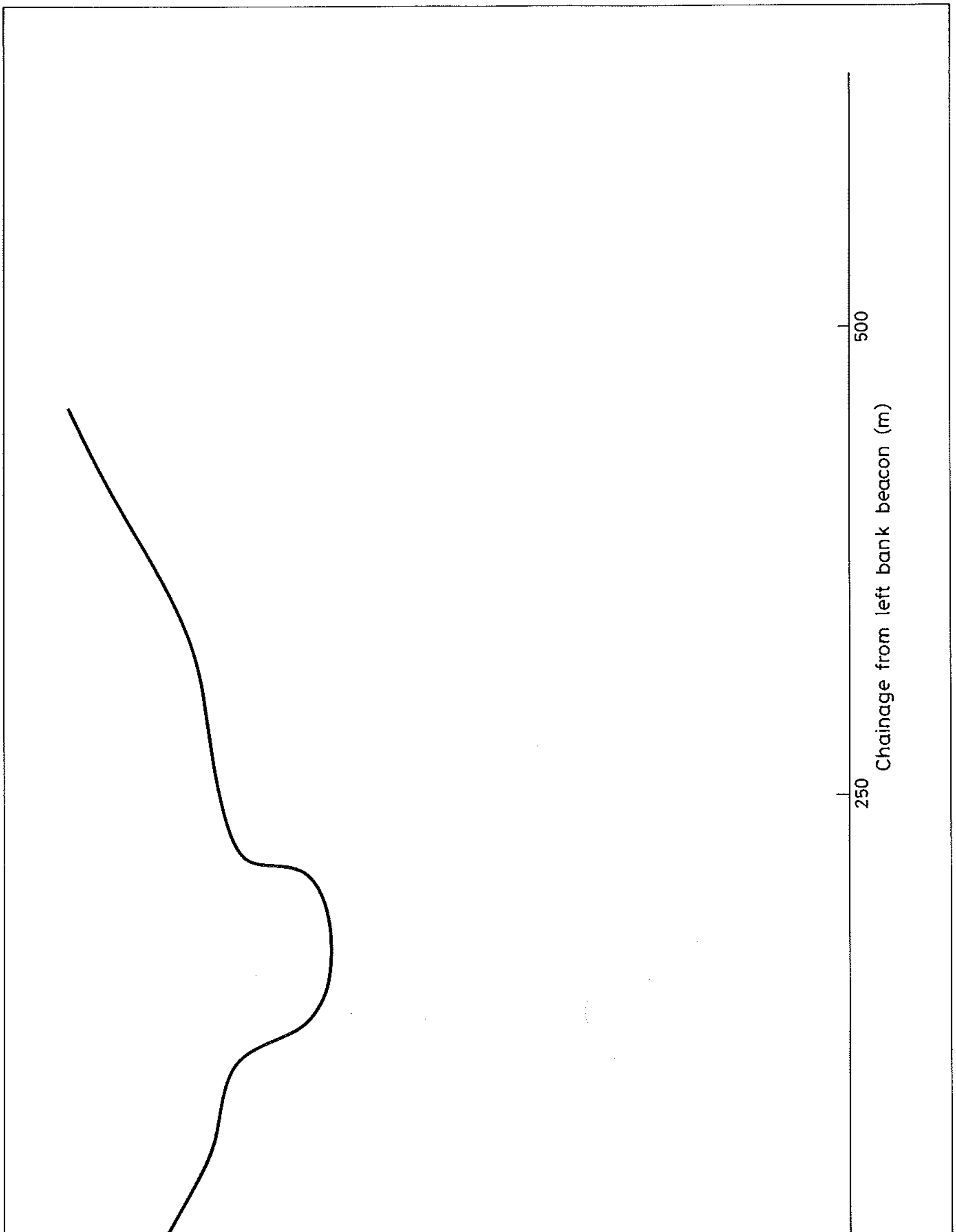


Fig 29 Kamburu Reservoir section TN4

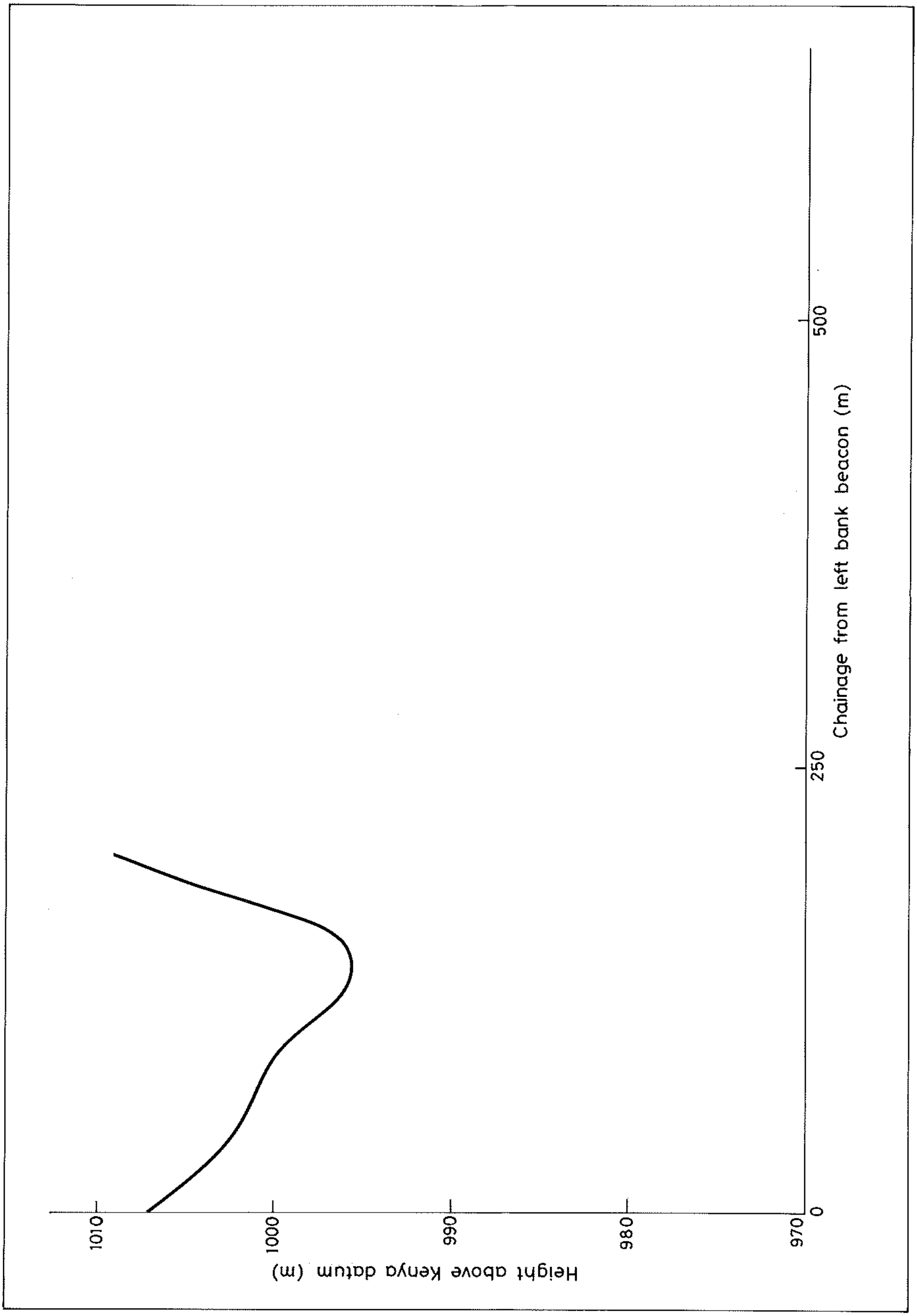


Fig 30 Kamburu Reservoir section TN5

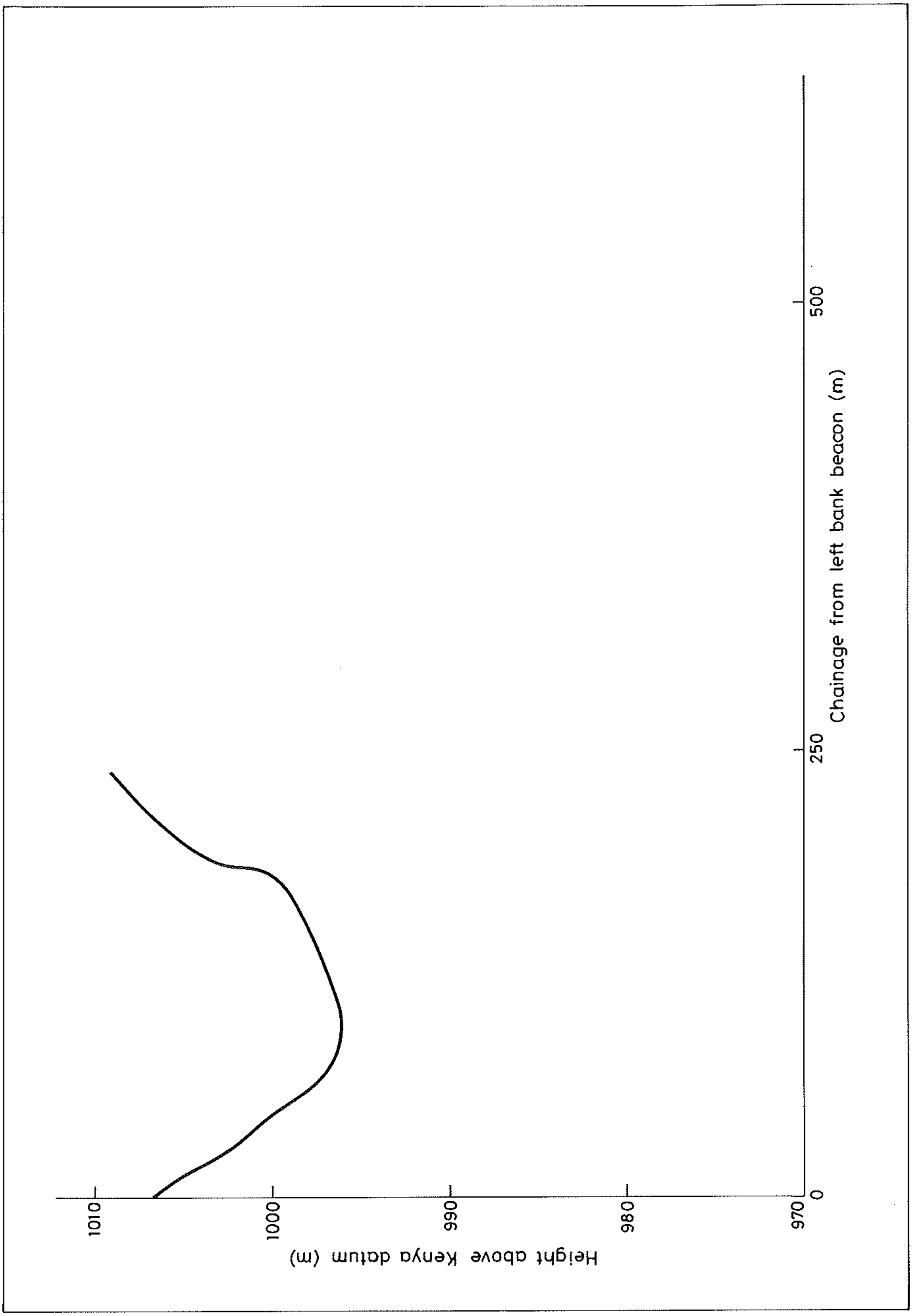


Fig 31 Kamburu Reservoir section TN6

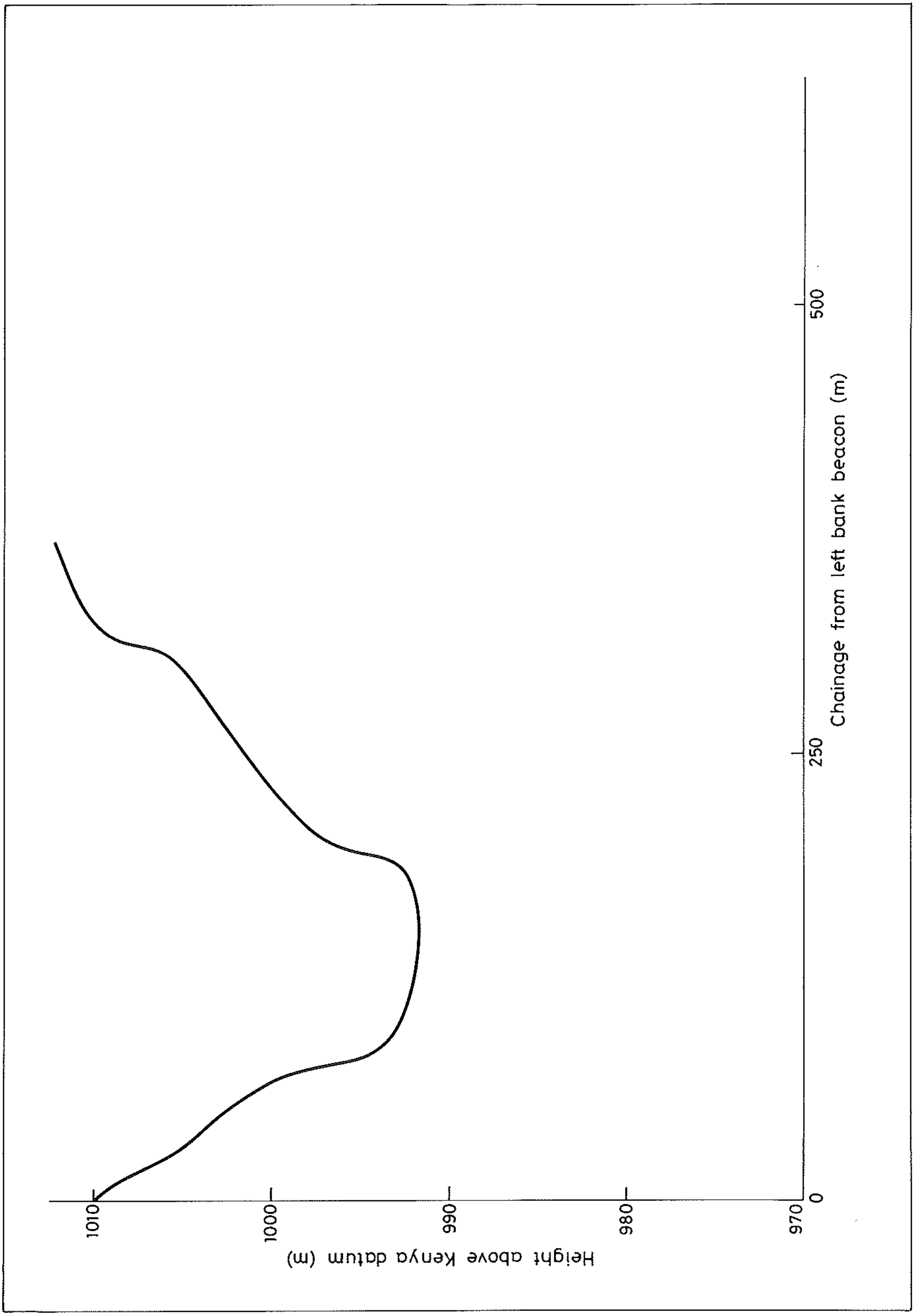


Fig 32   Kamburu Reservoir section TN7

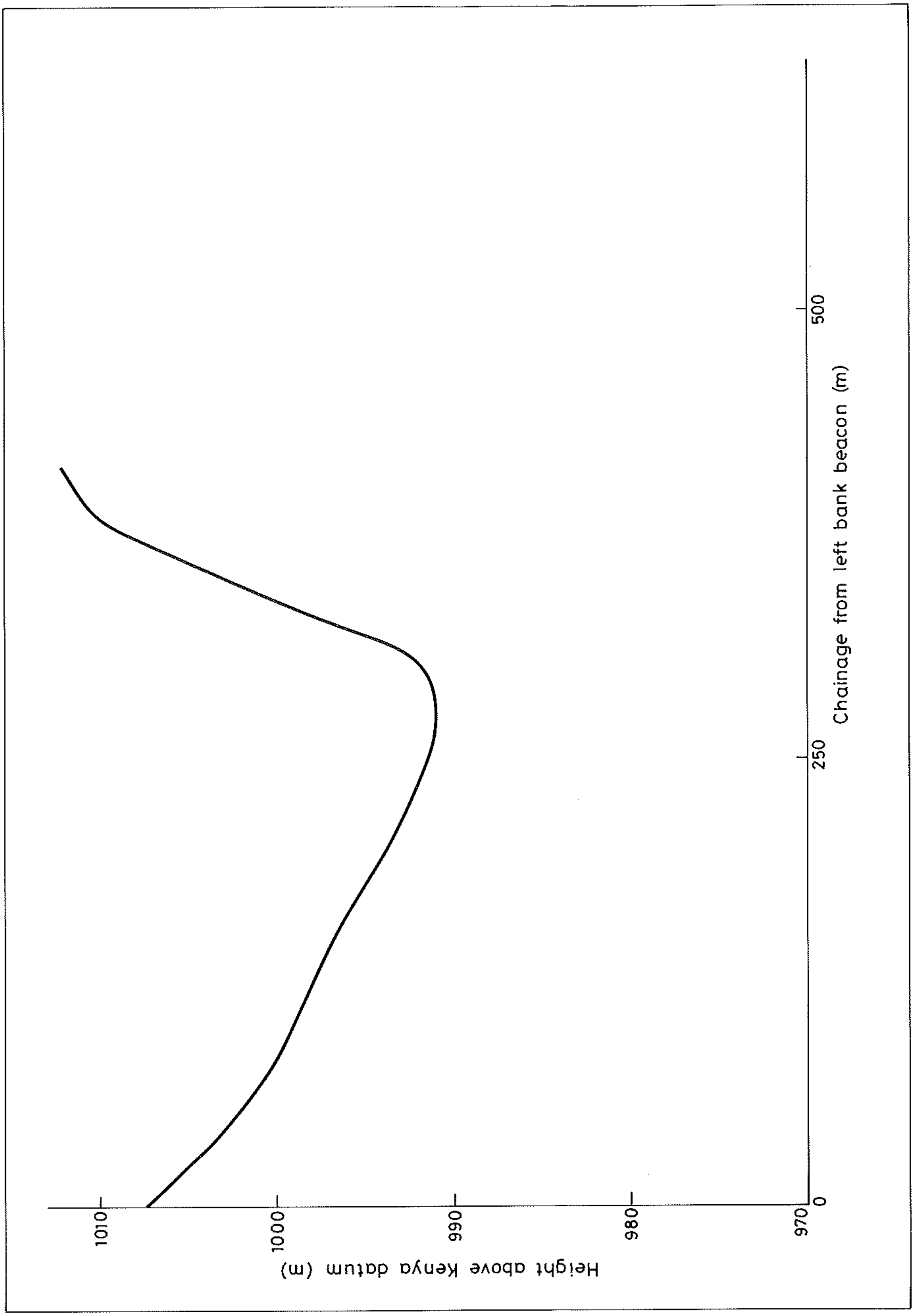


Fig 33 Kamburu Reservoir section TN8

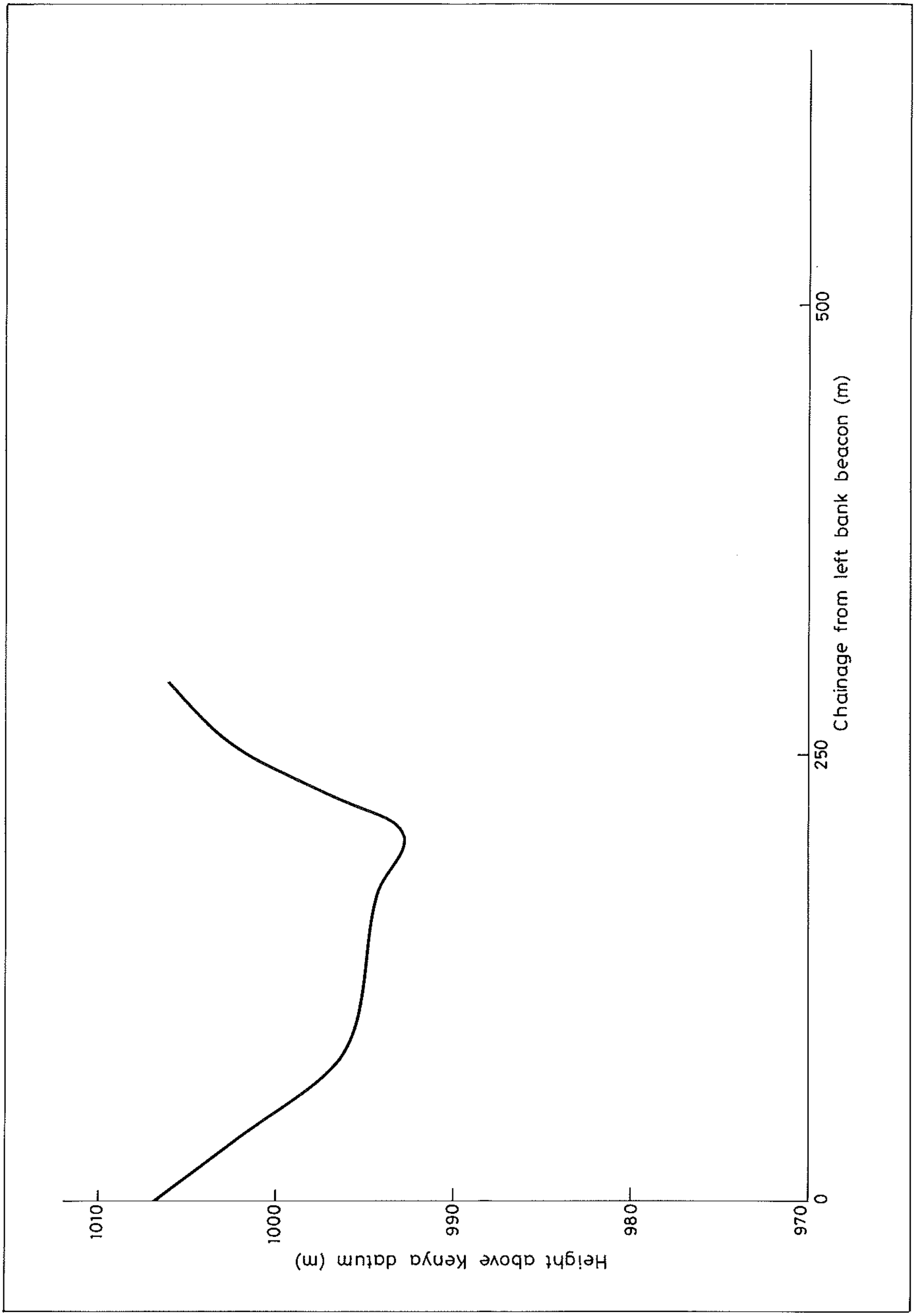


Fig 34 Kamburu Reservoir section TN9

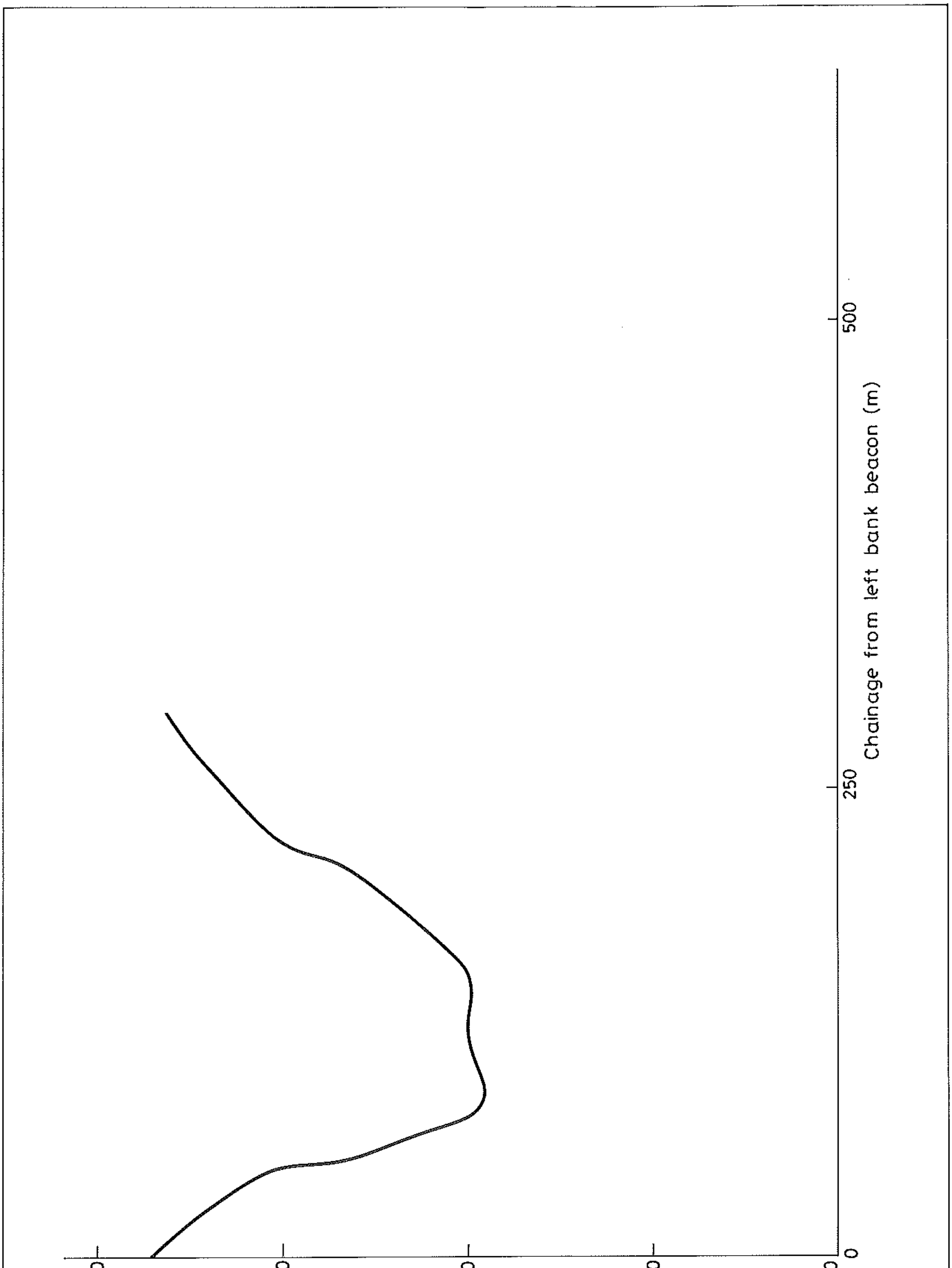


Fig 35 Kamburu Reservoir section TN10 (L)

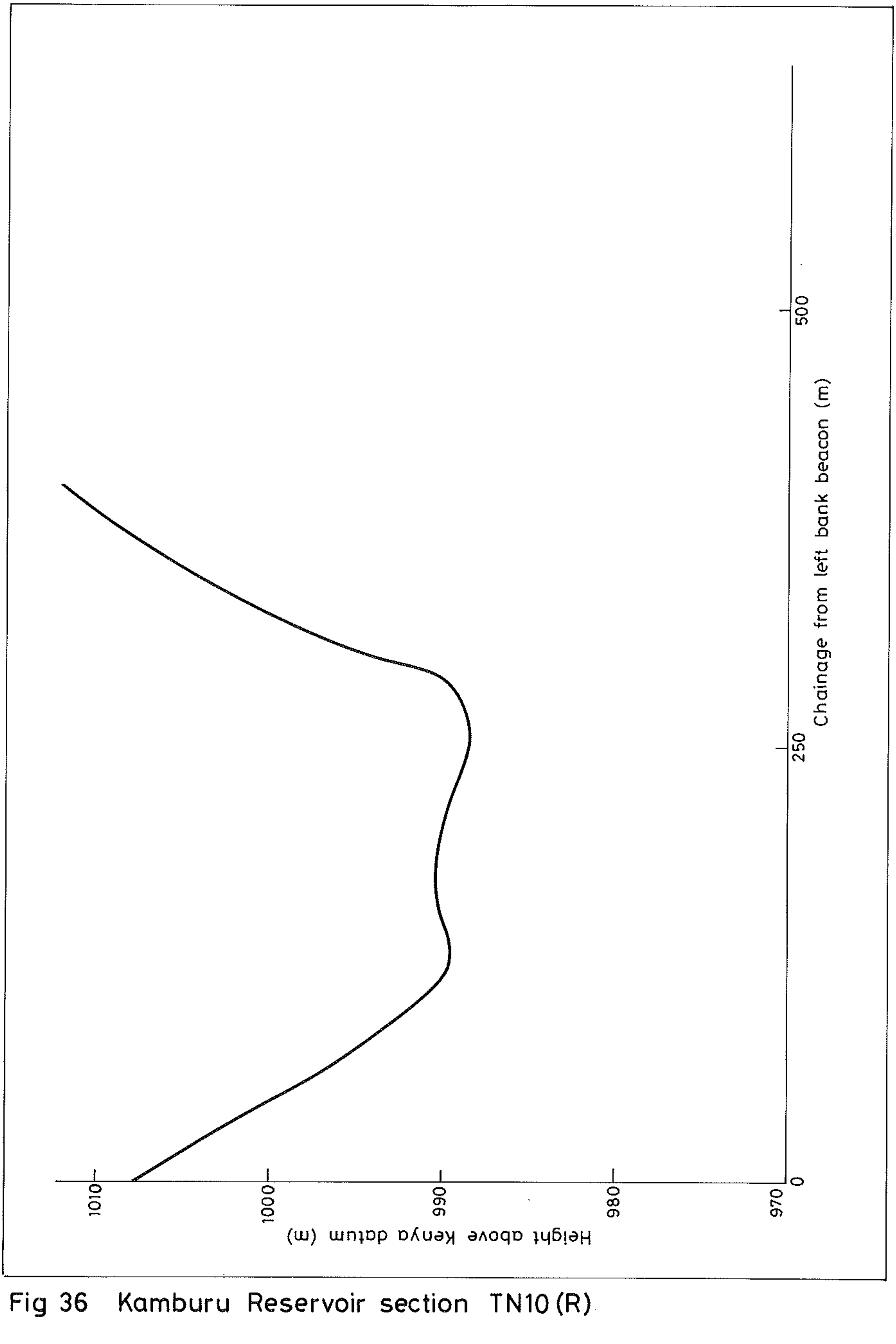


Fig 36 Kamburu Reservoir section TN10 (R)

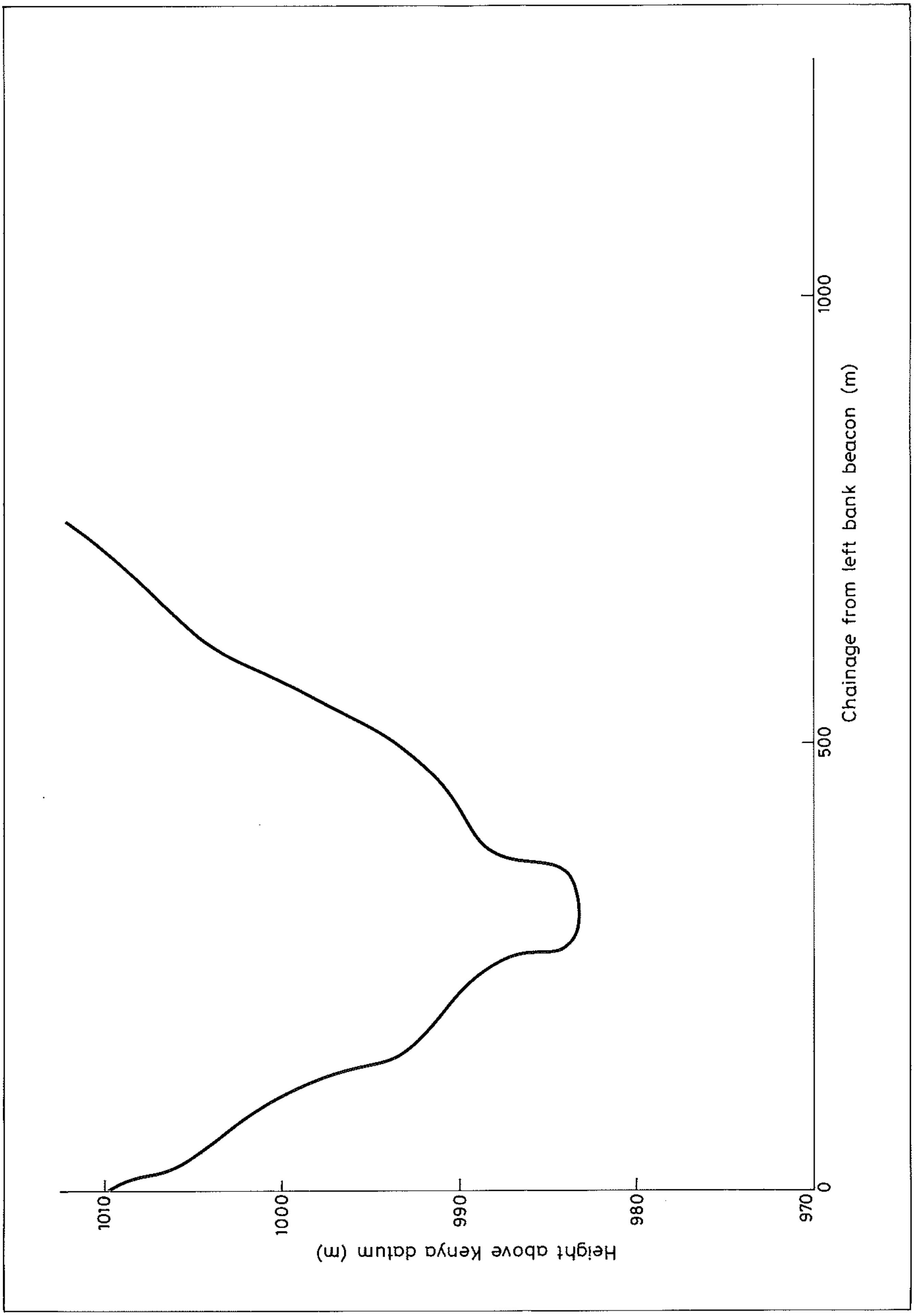


Fig 37 Kamburu Reservoir section TN11

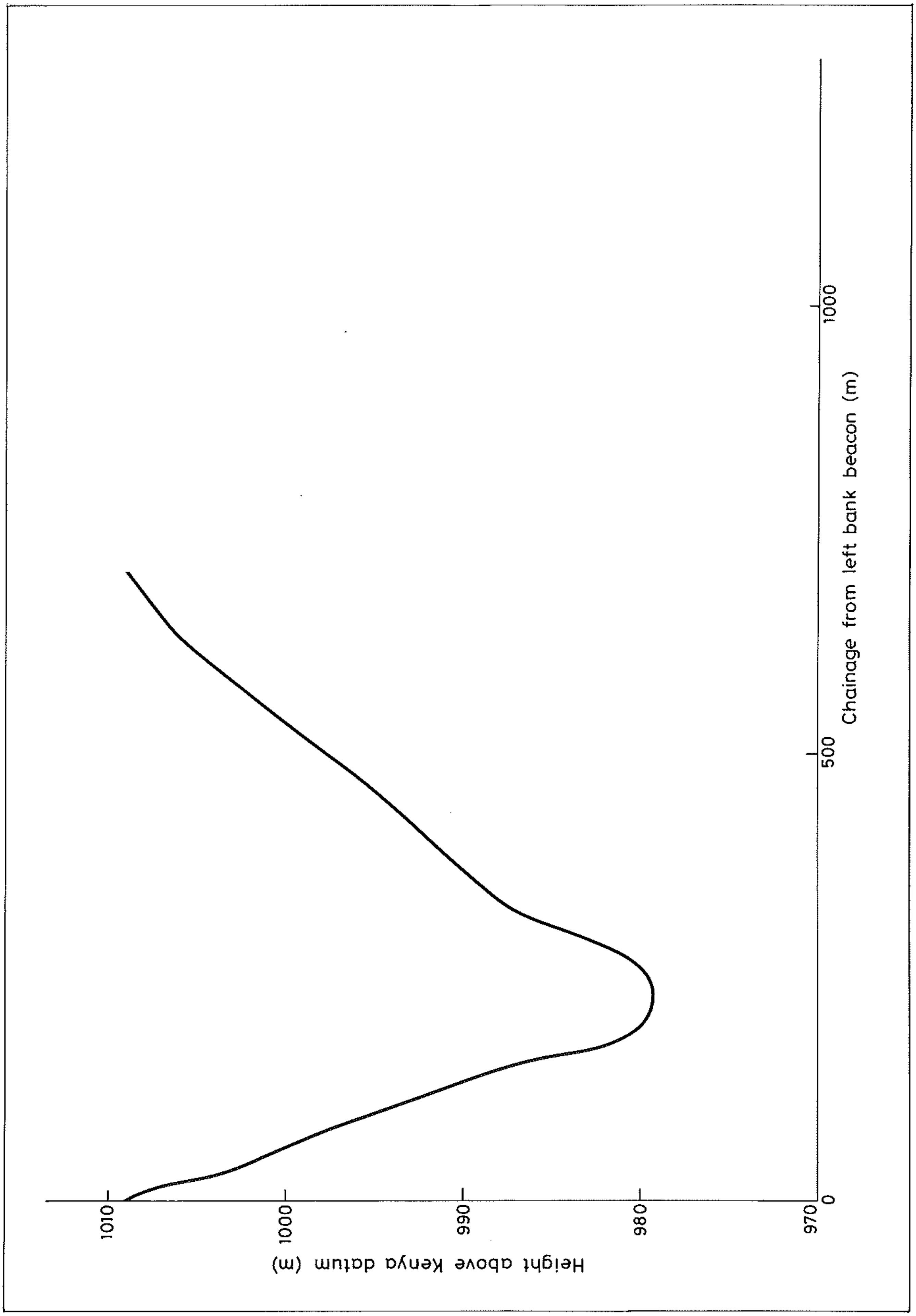


Fig 38 Kamburu Reservoir section TN12

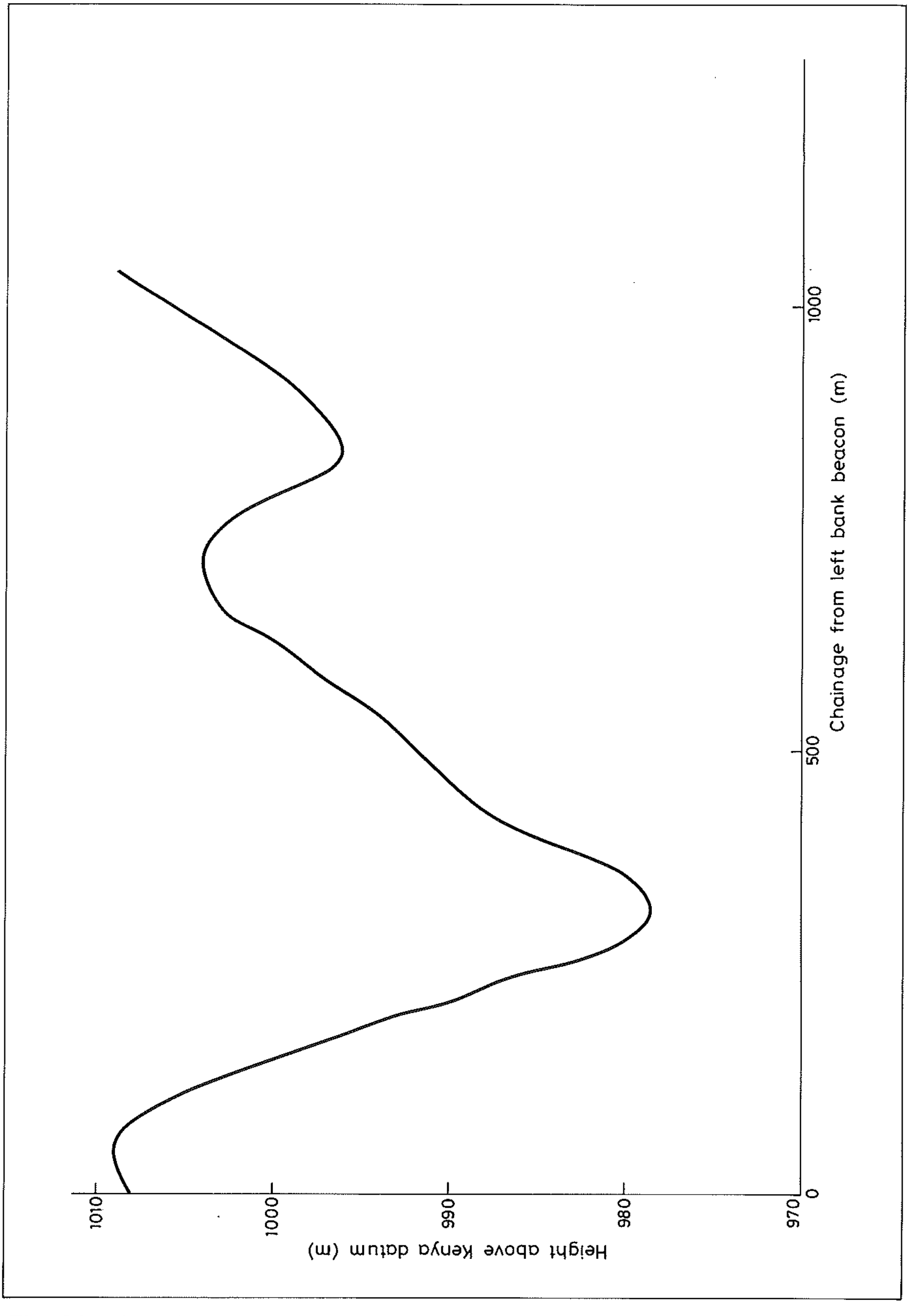


Fig 39 Kamburu Reservoir section TN13

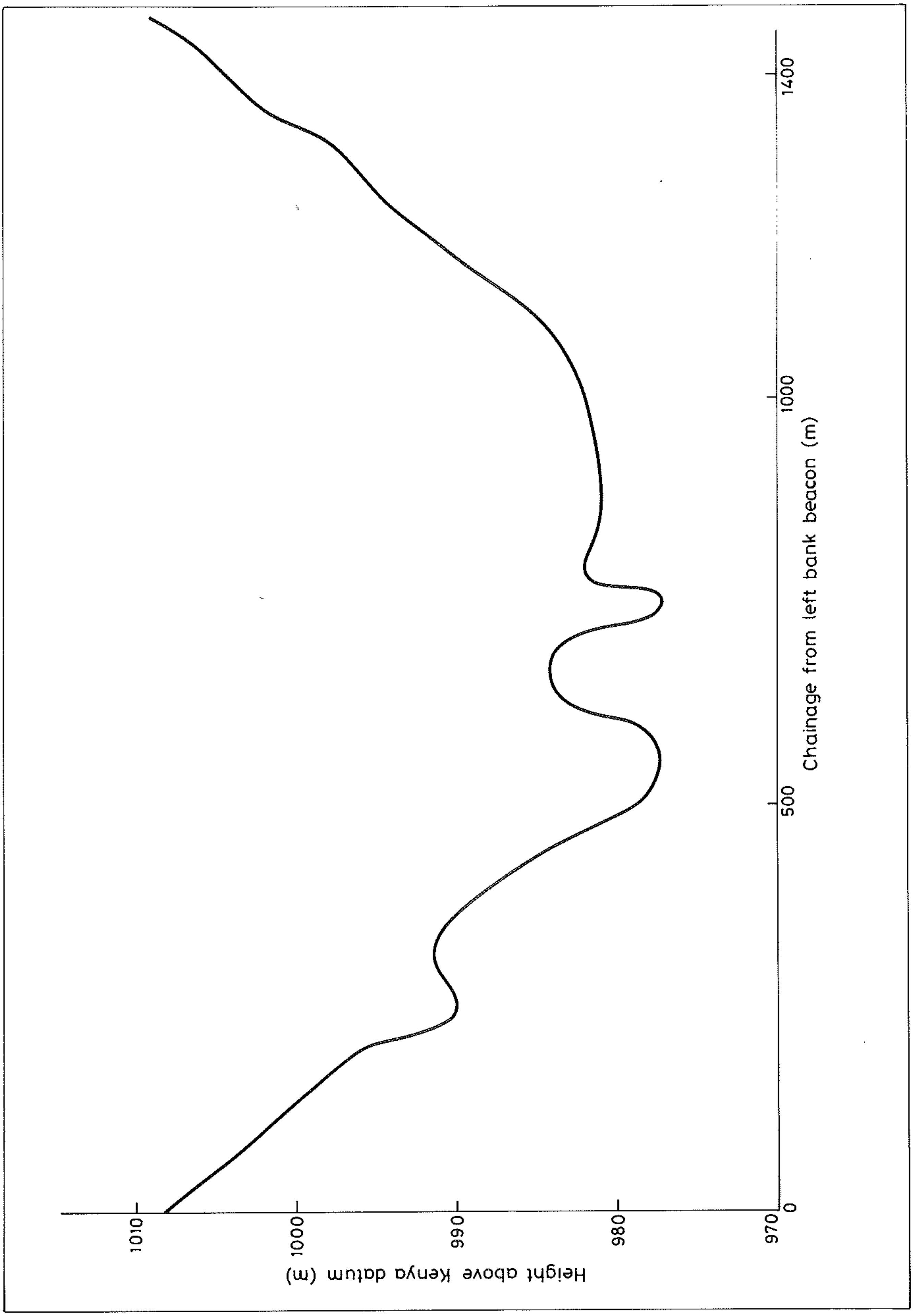


Fig 40 Kamburu Reservoir section TN14

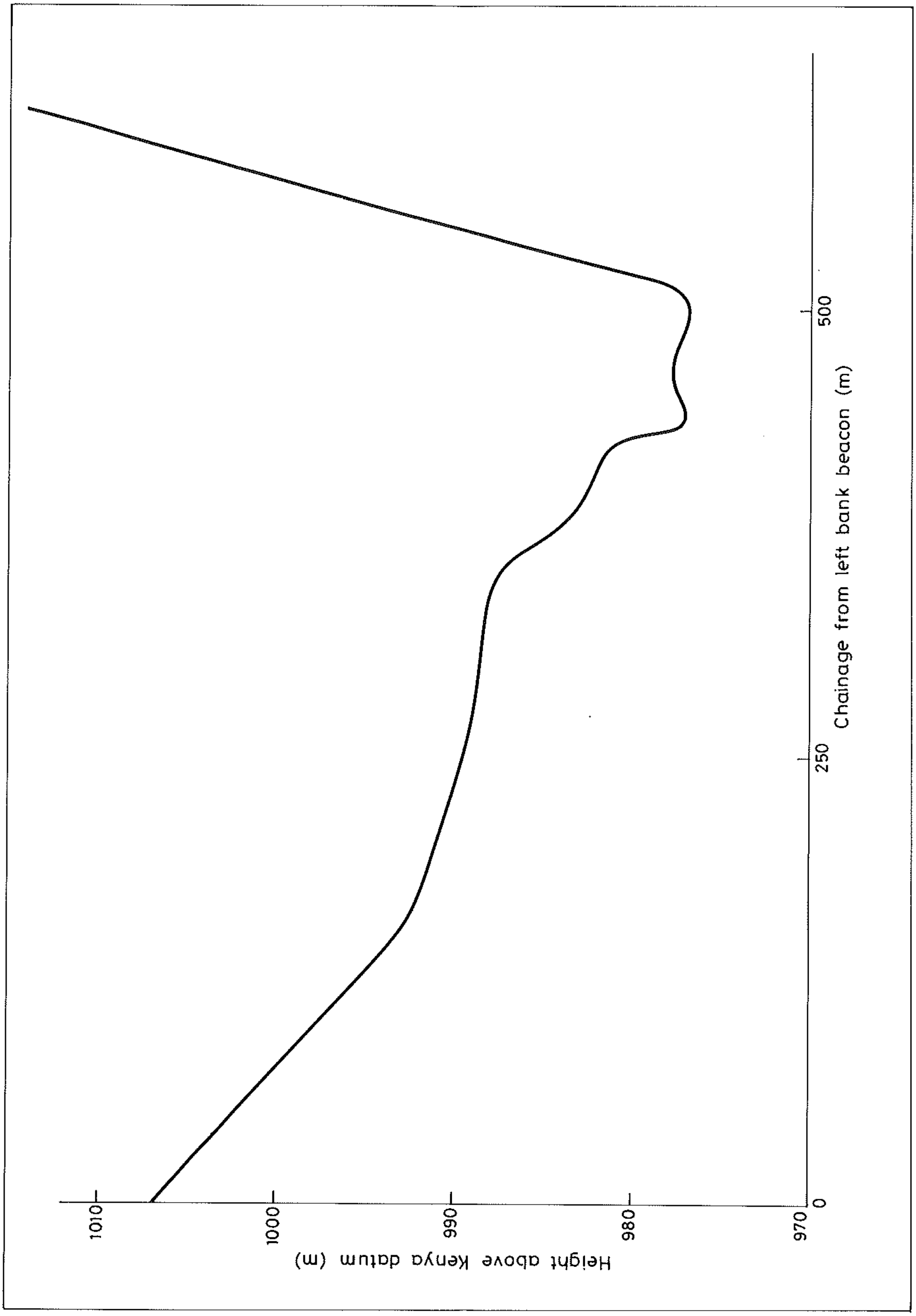


Fig 41   Kamburu Reservoir section TN15(L)

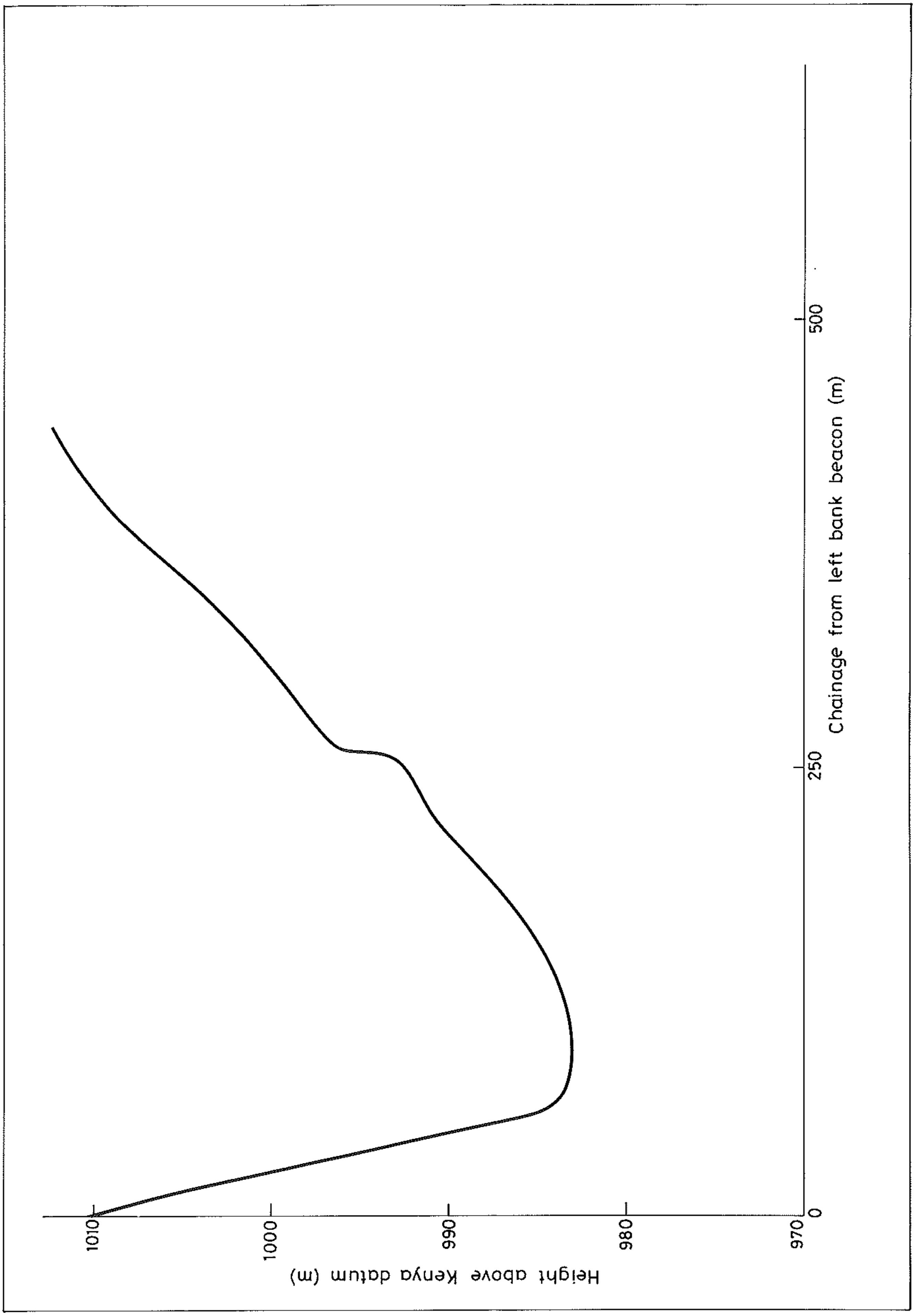


Fig 42 Kamburu Reservoir section TN15 (R)

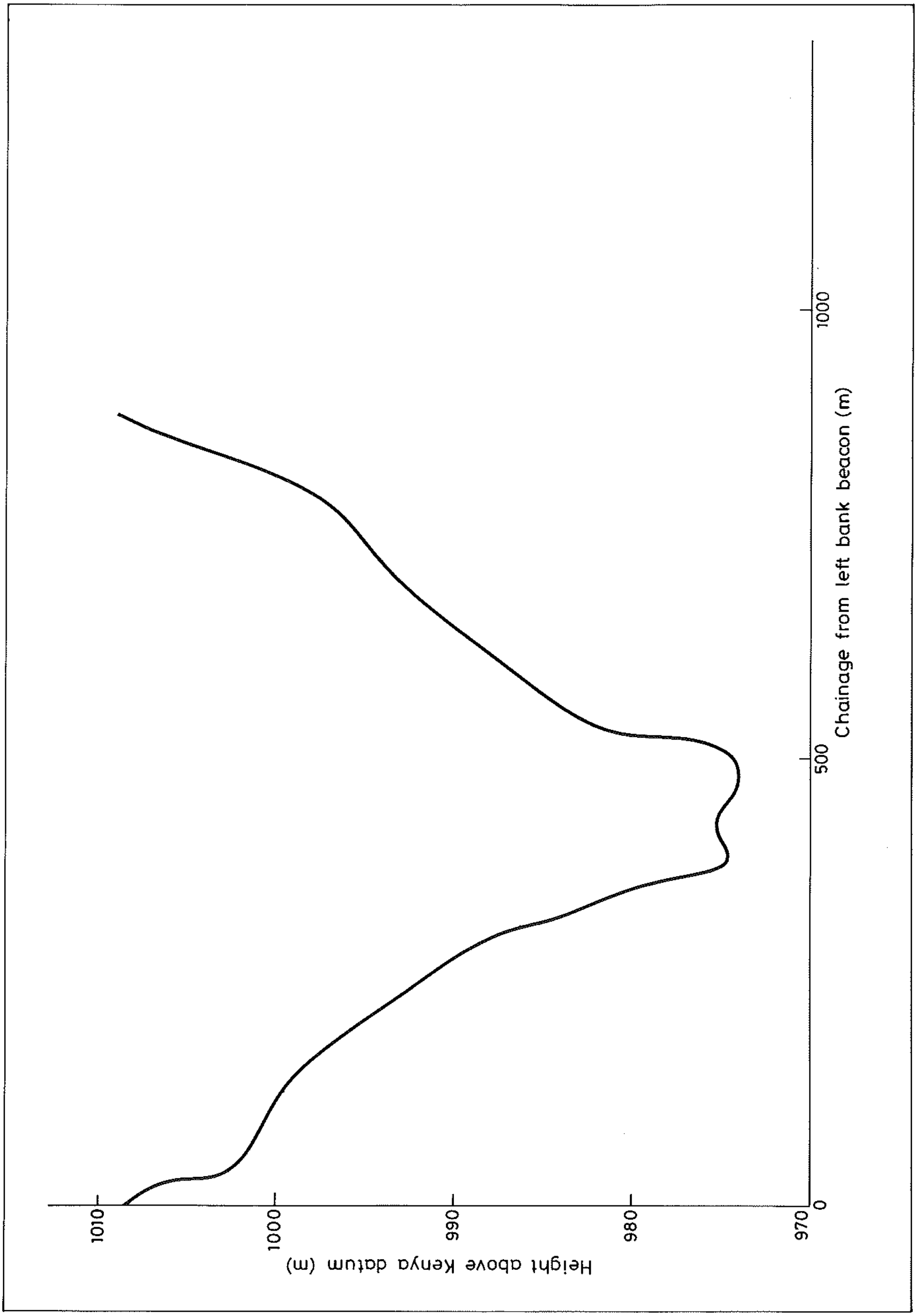


Fig 43 Kamburu Reservoir section TN16

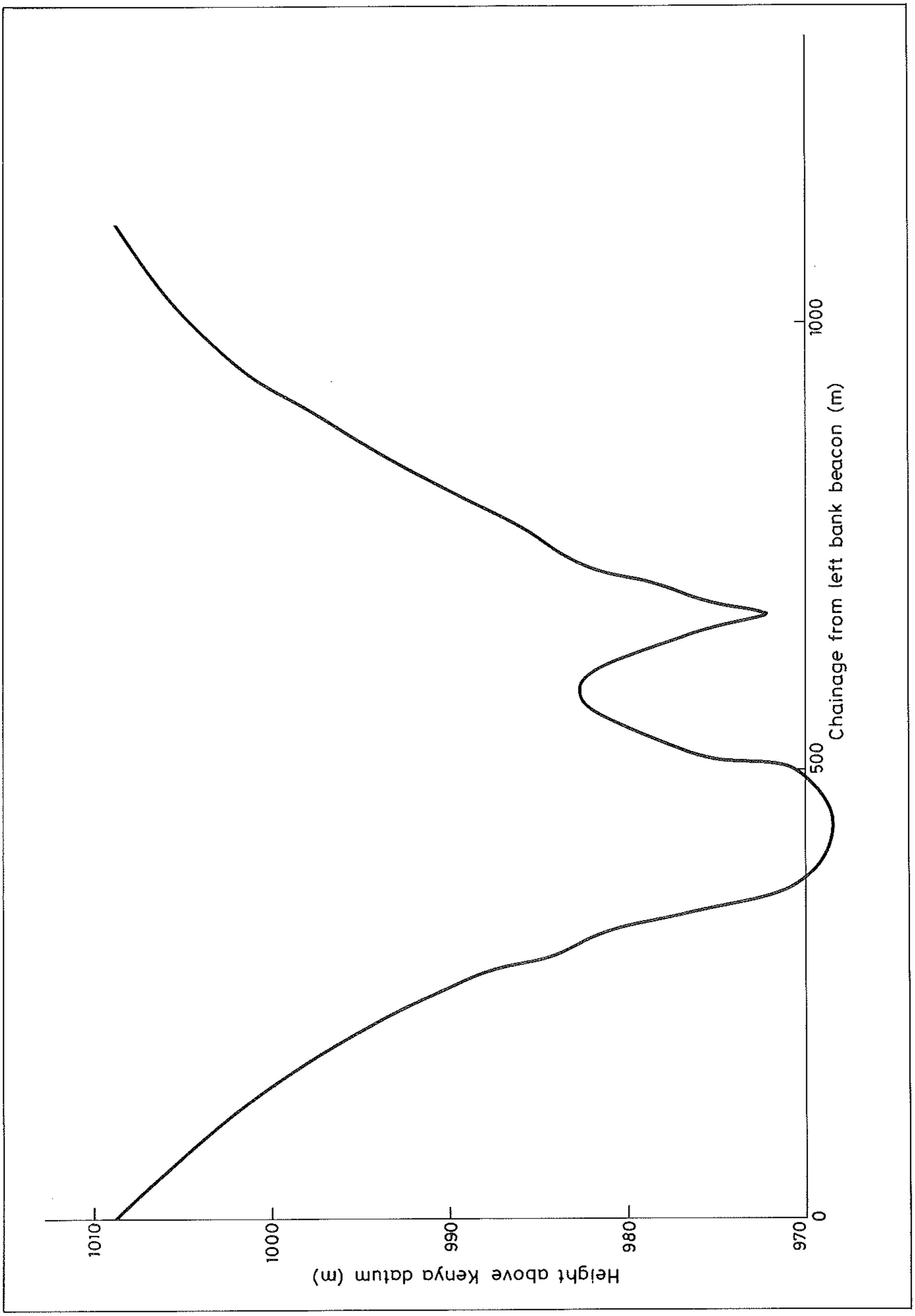


Fig 44 Kamburu Reservoir section TN17

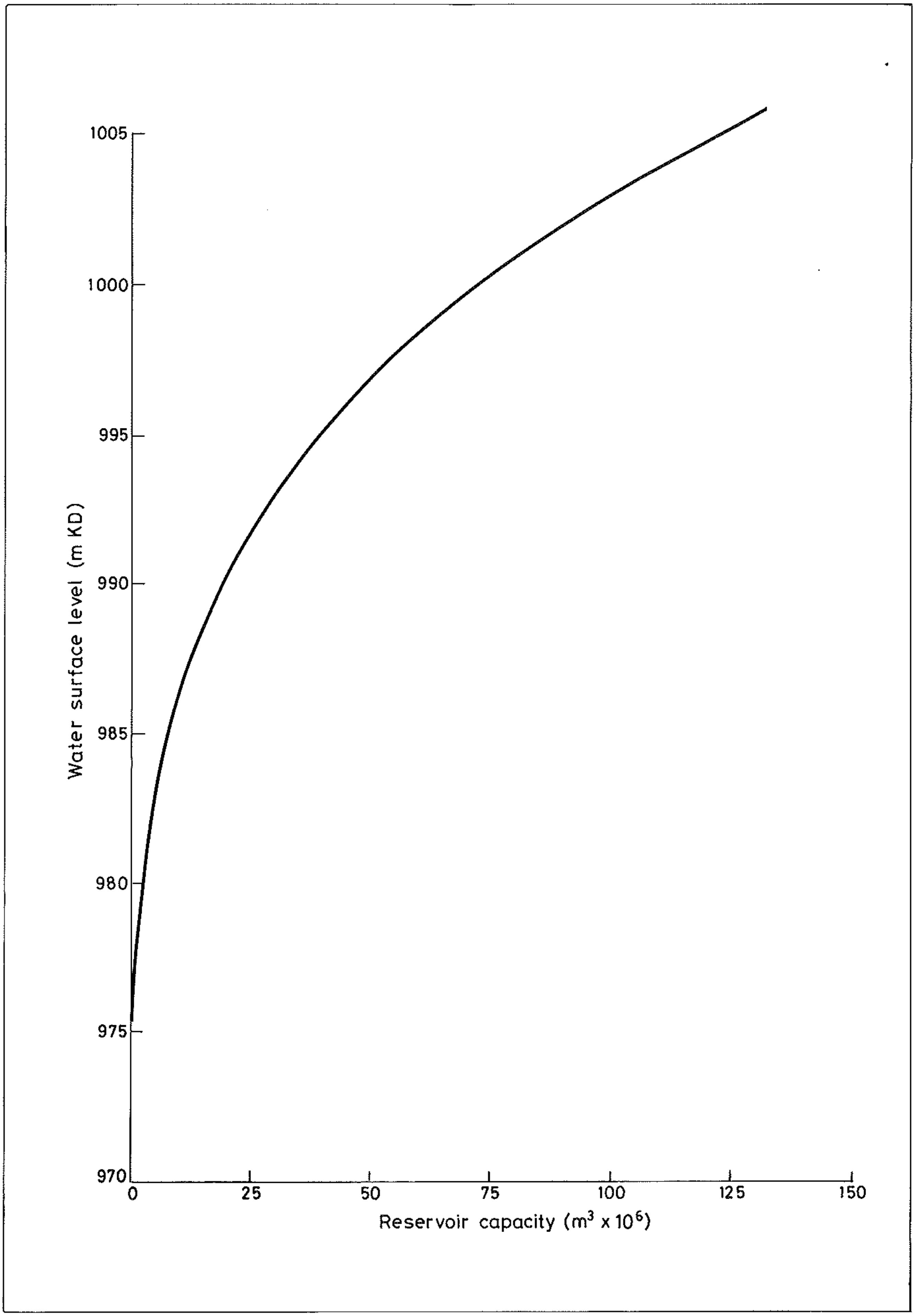


Fig 45 Kamburu Reservoir stage/capacity curve

This report is one of a series on topics of water resources and irrigation, prepared by the Hydraulics Research Station and funded by the British Overseas Development Administration.

Others in the series include:

OD 1 Canal linings and canal seepage
T J Yates, February 1975

OD 2 One-dimensional analysis of salinity intrusion in estuaries
K Sanmuganathan, May 1975

OD 3 Analysis of the discharge measurements carried out at Bansang, The Gambia, during March 1974
K Sanmuganathan and P J Waite, July 1975

OD 4 Reclamation of submerged saline lands in the northern Nile Delta: Draft proposals for a research programme
C L Abernethy, October 1975

OD 5 Minor irrigation in India: Research prospects to improve design and practice
J M A Pontin, September 1975

OD 6 Design of vortex tube silt extractors
K Sanmuganathan, March 1976

OD 7 Air-entraining vortices at a horizontal intake
M Amphlett, April 1976

OD 8 Rio Guayas, Ecuador: Field data for salinity study
P J Waite, September 1976

OD 9 Salinity intrusion in estuaries: Effects of vertical mixing
P J Waite, April 1980

OD 10 A study of hafir linings in Darfur Province, Western Sudan
J M A Pontin and R Wooldridge, August 1977

OD 11 Zawia Reclamation Project: I. Instrumentation and data collection
K Sanmuganathan and A L Taylor, January 1978

OD 12 Air bubbles for water quality improvement
H O Anwar, April 1978

OD 13 Principles of canal seepage measurement by bell-type bed penetration systems
J M A Pontin, April 1978

OD 14 Measurement of bed seepage from the Ismailia Canal
J M A Pontin and H S Elwan, May 1978

OD 15 Reservoir sedimentation study, Selorejo, East Java, Indonesia: Reservoir survey and field data
T Brabben, June 1978

OD 16 Reservoir sedimentation study, Selorejo, East Java, Indonesia: Reservoir survey — complete information on all forty-eight cross-sections of Selorejo reservoir
T Brabben, June 1978

OD 17 Air-entraining vortices at a vertically inverted intake
M B Amphlett, September 1978

OD 18 Gilbert Islands: Land reclamation and sea defences on Tarawa atoll
D W Holmes, January 1979

OD 19 Zawia reclamation project: II. Pumping test and ground water sampling
P J Waite, February 1979

OD 20 Abary River, Guyana: Salinity prediction model
P J Waite, March 1979

OD 21 Prediction of salinity intrusion in the Rio Guayas, Ecuador
K Sanmuganathan, May 1979

OD 22 Reservoir sedimentation study, Karangkates, East Java, Indonesia
T E Brabben, July 1979

OD 23 Design of water inflated tube dam
R Wooldridge, July 1979

OD 24 Stress measurement on low-cost well screens during the installation and pumping test
J Weller, July 1979

OD 25 Estimation of error in canal seepage derived by discharge measurement
J Weller, July 1979

OD 26 Water management study at Kaudulla Irrigation Scheme, Sri Lanka. I-Interim report on Yala season 1978 and Maha season 1978/79
D W Holmes and R J Dawson, HRS
H Gunston and C H Batchelor, IOH, July 1979

OD 27 Long term prediction of salinity intrusion in estuaries — program listing and user notes
J F Coles, October 1979

OD 28 Prediction of seepage loss from the enlarged Ismailia Canal
J M A Pontin, Laila Abed, J A Weller, December 1979

OD 29 Water Management Study at Kaudulla Irrigation Scheme, Sri Lanka. II-Interim report covering Yala season 1978 to Maha season 1979/80
D W Holmes , R Wooldridge, H Gunston and C H Batchelor, September 1980

OD 30 Guyana Coast. Recommendations for a future sea defence strategy
C L Abernethy, June 1980

OD 31 Performance and use of turbidity monitors in the Brantas river basin, East Java, Indonesia
T E Brabben, August 1980

OD 32 A field distortion principle for measuring the rate of seepage from canals
J M A Pontin, November 1980

OD 33 Pressure actuated constant discharge value for automatic water control
M Lusty and R Wooldridge, March 1981

OD 34 Matara Water Supply Scheme, Sri Lanka
P J Waite and M B Amphlett, March 1981

OD 35 Rio Guayas, Ecuador, Salt water intrusion study 3 — Analysis of flows
P J Waite, June 1981

OD 36 Soil salinity water table modelling
P J Waite, July 1981

OD 37 Design manual for vortex tube silt extractors
S White, December 1981

OD 38 Water management study at Kaudulla irrigation scheme, Sri Lanka III — interim report covering seasons Yala 1978 to Maha 1980/81
D W Holmes and J Weller, HRS
H Gunston and C H Batchelor, IOH

OD 39 A resistivity technique for detecting leaks in lined channels — preliminary investigation
N G Deacon, May 1982

OD 40 Laboratory verification of vortex tube design method — coefficient of discharge
P Lawrence

OD 41 Laboratory verification of vortex tube design method — trapping efficiency
R Wooldridge

OD 42 Warujayeng-Kertosono canal survey
D S Kadiro, T Santoso, June 1982

OD 43 Estimation of fresh water flow in the tidal reaches of the Berbice river, Guyana
M B Amphlett and I W Makin, June 1982

OD 44 A one-dimensional analysis of the tidal hydraulics of deltas
N V M Odd, July 1982

OD 45

OD 46 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 1965
R Wooldridge

OD 47 Solar powered irrigation pumps, Pakistan
Field trials of solar powered micro-irrigation units
G Pallett