

**Hydraulics Research**  
Wallingford

SEDIMENTATION IN RESERVOIRS  
TANA RIVER BASIN, KENYA

III - Analysis of hydrographic surveys  
of three reservoirs in June/July 1983

Part A - Text, Tables, Figures and Plates

by

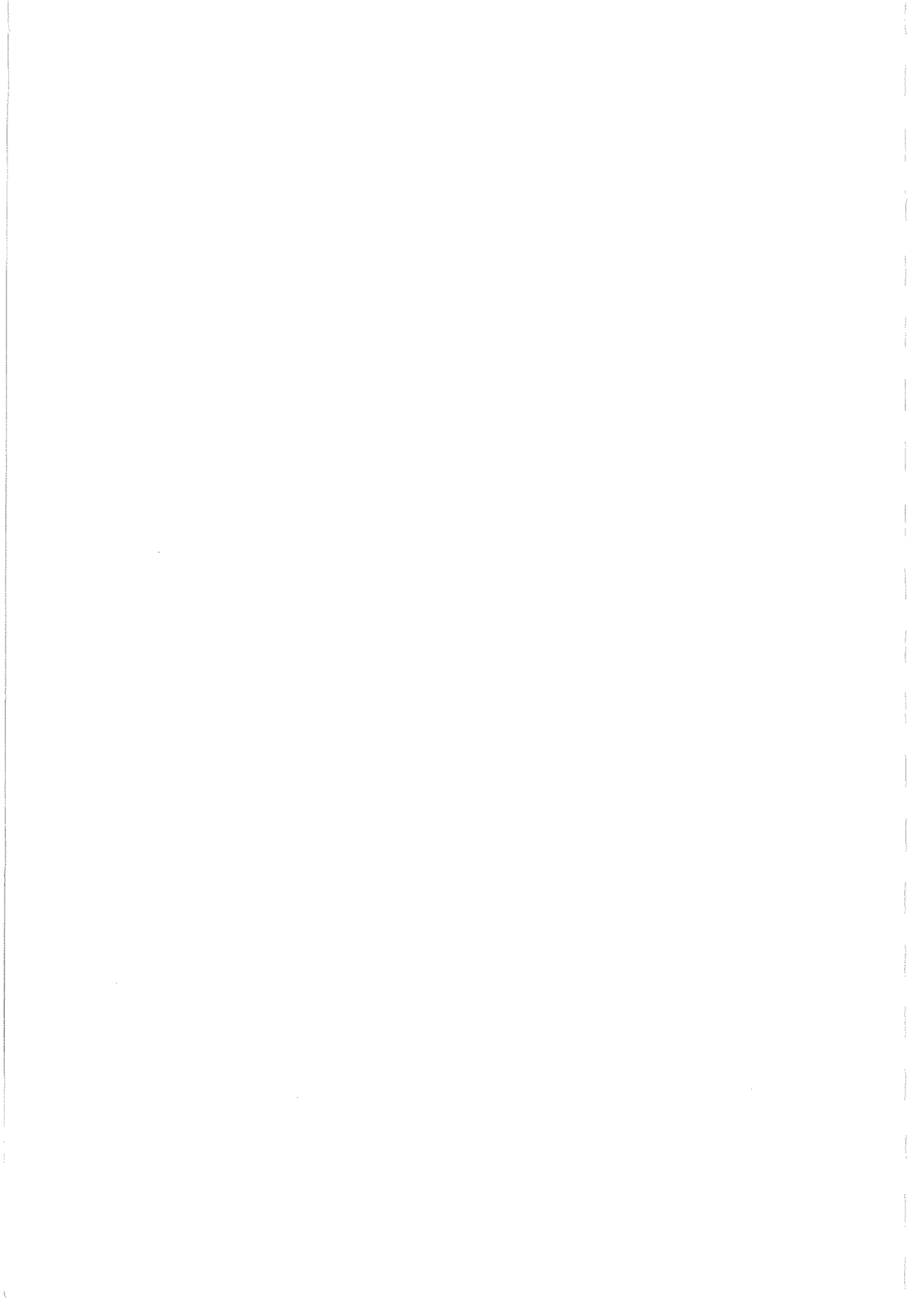
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In collaboration with :

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

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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 Kenya Power and Lighting Co Limited - are providing finances and staff to cover the Kenya end of the investigation.

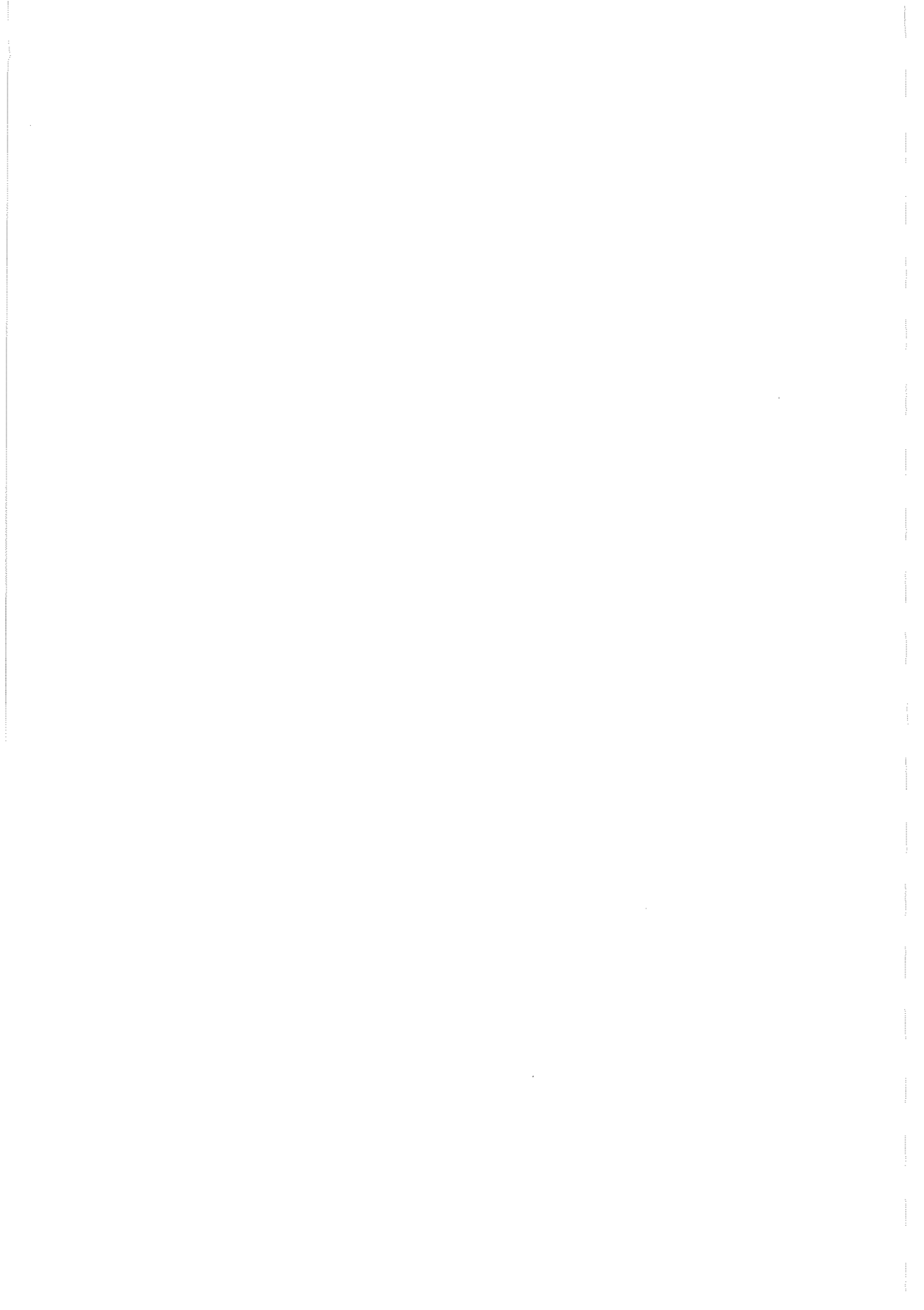
The first stage of the investigation was to produce a set of base data against which all future reservoir surveys will be compared. These data, which were abstracted from an aerial survey flown in 1965, are described in HR report OD 45.

An hydrographic survey was carried out in June/July 1981 and a number of analytical methods were tried on the results obtained. Details of these are given in HR report OD 46.

In June/July 1983, a second hydrographic survey was run and this time it included Masinga reservoir. Data were also collected on in-situ bed densities. A modification of the analytical method chosen in report OD 46 has been used but with refined input data. The results indicate that Kamburu reservoir capacity has been reduced by 11.7% since its impoundment in 1974 and Kindaruma has lost 38.8% since 1968.

Deduced catchment sediment yields show an annual increase of 2% averaged over the whole period from 1968 to 1983.

Limitations on the accuracy of such deductions are explained and a comparison is made with trial catchment data recorded in Malawi.



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## 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<sup>2</sup> - 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 reservoir schemes are in existence (Figure 2) or planned for the near future. Since the first reservoir was impounded in 1974 (Kamburu), the problems of erosion from the catchments and the subsequent deposition of sediment in successive reservoirs have been noted by the relevant Kenyan authorities. The magnitude of the problem in Kenya and the need for the Overseas Development Unit (ODU) of Hydraulics Research Limited to collect reliable field data over a number of years led to an investigation being undertaken by ODU in collaboration with the Tana and Athi Rivers Development Authority (TARDA), the Ministry of Water Development (MOWD) and the Kenya Power and Lighting Co. Ltd.(KP&L). Proposals for an investigation based on the upper Tana River were submitted following a visit to Kenya by a member of the ODU staff in December 1979<sup>(1)</sup>; a revised summary of these proposals was agreed after a series of meetings on site during July 1980<sup>(2)</sup>.
- 1.2 This investigation was expected to last three years but problems with the design and installation of field equipment resulted in the need for a twelve-month extension. The first report, published in September 1982<sup>(3)</sup> described a desk study of an aerial survey covering Kindaruma and Kamburu reservoir sites, flown by Hunting Surveys Ltd. The report used a contour-slicing technique to obtain data which later formed the basic input for a "Constant Factor" method of reservoir volume computation.
- 1.3 A second report - OD 46, published in June 1983<sup>(4)</sup> - made an assessment of the changes in reservoir volumes since impoundment, based on hydrographic surveys carried out in June/July 1981. The survey data were 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. At this time, the field work was expanded to include the collection of data from Masinga reservoir. As the data collection

techniques vary little from site to site, all three surveys are covered by this report. However, the detailed analysis and discussion only refer to Kindaruma and Kamburu reservoirs as originally proposed.

1.4 The agreed Proposals<sup>(2)</sup> included a list of recommended sediment transport monitoring sites which it was hoped would provide data on the volumes of sediment being carried into the reservoir by the major rivers in the Tana basin. The site at 4BC2 on the Sagana River (Figure 2 and Plate 1) was equipped with a continuously recording "Partech" turbidity monitor which was supplied by ODU on a three-year free loan. The installation was started in October 1981 by staff from MOWD with finance made available by TARDA and MOWD. Pumped samples were obtained on a regular basis from all the river sites, by MOWD with assistance from TARDA; samples from the five power stations were collected by local KP&L staff. All these samples were subjected to gravimetric analysis by the Water Quality and Pollution Control Centre of MOWD. During 1983, it became clear that the methods of collection and analysis of suspended sediment data being evolved at 4BC2 were sufficiently new and warranted their treatment as a separate topic. Details of this work will be published as a report in the OD series during 1985.

1.5 The reservoir study was continued with the collection of a second set of survey data from Kindaruma and Kamburu reservoirs and the first post-impoundment data for Masinga reservoir, during June/July 1983. As recommended in Section 12 of report OD 46, the field work was extended to include the collection of in-situ bed density data using a gamma probe. This report evaluates all the data obtained during the 1983 survey and compares them with the previously published results.

## 2 FIELD DATA COLLECTION

2.1 Section 2 of report OD 46 describes in some detail the parameters which have to be considered when locating the range lines to be used for a series of reservoir surveys. Following these parameters, the location of 10 range lines on Kindaruma, 29 on Kamburu and 71 on Masinga reservoirs were chosen (Figures 3, 4 and 5).

- 2.2 The end of section markers round Kindaruma and Kamburu reservoirs were constructed on behalf of KP&L by Engineering and Power Development Consultants (EPDC). They were designed to stand about 1.4m above ground level, were about 0.5m square and painted white (Plates 2 & 3). During the two-year period between the surveys, vegetation round the borders of the two older reservoirs - Kamburu and Kindaruma - had grown to such an extent that some of the markers were very difficult to locate and in some cases, they were never found. Due to the substantial nature of the markers none of them had been destroyed. However, a few of the markers on the right bank of the Thiba arm of Kamburu reservoir were in danger of being lost due to bank erosion (Plate 4).
- 2.3 Markers sited round Masinga reservoir for TARDA were made from concrete posts approximately 1.4m high and 0.1m square (Plate 5). The location of these beacons in relation to the reservoir top water level seemed to be somewhat random with the result that some were partially submerged, while others were set back some distance from the water's edge. A number of the markers were damaged and a few had been destroyed.
- 2.4 The hydrographic survey followed the same basic procedure as that described in Section 3 of OD 46<sup>(4)</sup>. In 1983, the original method of locating the boat's position by recording single sextant angles was superseded by the use of a direct reading laser rangefinder (Actif Hydro-Dista - HD4). After sorting out a few initial problems with the laser targets, this instrument was found to work very satisfactorily. It enabled the surveyor to increase the number of fix marks per range line, and the direct read-out of distance reduced the time required for data reduction. Data co-ordinates extracted from the echo-sounder charts are listed in Tables 1 (Kindarumma reservoir) and 2 (Kamburu reservoir). These data points were used for all the subsequent analysis described later in this report.
- 2.5 The "Hydro-Dista" provides distances which are accurate to 0.5m  $\pm$ 1m/km but the positional accuracy depends on how true a course the boat followed when crossing a range line. However, since the boat coxswain was being guided along the line by a shore-based observer, it is likely that the boat did not deviate by more than  $\pm$ 3m from the true line. Assuming this, the longitudinal error would be virtually negligible in comparison with the accuracy of the instrument.

2.6 On the assumption that reduced levels given for the end-of-section markers are correct, then the water levels relating to each range line are accurate to  $\pm 2$  cms.

2.7 Although the large size of the echo-sounder chart trace allows a depth resolution of better than 0.1m, the overall accuracy of the depth information is dependent on the following factors:

- (i) the care and frequency with which calibration (bar) checks are carried out.
- (ii) the clarity of the chart trace relating to the reflective nature of the reservoir bed
- (iii) physical conditions during the survey (e.g. wave action).

Taking the above factors into account, it may reasonably be assumed that the depth information obtained is accurate to about  $\pm 0.13$ m. This figure, when combined with the levelling accuracy, gives a value of  $\pm 0.15$ m for the overall accuracy of elevation relative to Kenya Datum ( $\pm 0.15$ m K.D).

### 3 SURVEY DATA ANALYSIS

3.1 Data obtained from a reservoir survey are usually studied in two distinct stages. The first stage is to plot the recorded reservoir cross-sections and thus identify the regions of erosion or deposition. Secondly, the cross-section data are used to calculate the reservoir capacity.

3.2 There is seen to be an increasing demand for reservoir surveys from many of the developing countries. ODU therefore decided that there was reasonable justifications for time to be spent in the production of computer programs to plot the reservoir cross-sections and to calculate the volume of water stored. The programs, which are listed in Appendices 1 and 2 have been written to be run on an ICL 2972 computer using Fortran 77. The graph plotting requirements make use of the GHOST-80 Graphical Output System<sup>(5)</sup>. In both cases, the data are presented in similar formats to those used in previous reports for ease of comparison.

- 3.3 The location of sediment range lines for Kindaruma, Kamburu and Masinga reservoirs are shown in Figures 3, 4 and 5 respectively. Computer plots of the hydrographic survey data collected in 1981 and 1984, together with the 1965 "base data", are reproduced in Part II to this report.
- 3.4 One effect of any major civil engineering works in a fluvial environment, such as the construction of a dam, is an enforced variation in the quantity of suspended material transported by the river. During the construction period, which for a dam is typically three to four years, there is an increase in the quantity of material available for transport by the river as "suspended load" and "bed load". The amount of suspended load that a river is able to carry is normally only constrained by the availability of supply and so during this construction phase it is reasonable to expect larger than average volumes of fine material being transported from the site for deposition downstream. The movement of suspended bed material load (usually taken to have a mean particle size greater than 63 microns) is considered to be limited by the carrying capacity of the river and so is unlikely to vary significantly throughout the construction period.
- 3.5 After the dam is closed, much of the suspended material which would previously have passed the site will be trapped; the river downstream of the dam will therefore be carrying a reduced sediment load during this period until sediment equilibrium is restored in the impounded reservoir.
- 3.6 The result, on a reservoir downstream, of this cycle of higher than average suspended sediment flux followed by a period of reduced flux is likely to be seen as an increased rate of accretion followed by erosion while the bed level is being regraded.
- 3.7 **Kindaruma reservoir** - accretion of the channel entering from the right bank between sections K2 and K3 meant that it was not possible to survey the correct line for section K10; a line was surveyed from K10(L) to K3(R) but as it is not directly comparable with the 1965 and 1981 data for K10, it has not been included. An examination of the remaining sections shows that section K1 displays a trend towards erosion (as a result of the process described in the paragraphs above) while the remaining sections indicate accretion ranging from a maximum

at section K2 to a minimum close to the dam. When examining the hydrographic survey results, it must be remembered that the vertical accuracy of the data is  $\pm 0.15\text{m}$ .

3.8 **Kamburu reservoir** - the Tana River limb of the Kamburu reservoir, shows a tendency to erosion as far down as section TN8. This is the result of the construction of Masinga Dam as described above, combined with a period of low reservoir levels prior to the 1983 long rains - in March 1983 the reservoir was virtually dry above section TN8. The maximum accretion on this limb occurs at section TN11 just upstream of a large inlet on the right bank and about 1.4km above the confluence with the Thiba River limb. The effect of reduced reservoir water levels can also be seen at sections TB1 and TB2 on the Thiba River limb of Kamburu reservoir which was not effected by Masinga Dam construction. Section TB3 indicates accretion in the order of one to two metres and the remaining sections show a gradual reduction in accretion until the final section, TB12.

3.9 **Masinga reservoir** - like Kamburu reservoir, Masinga reservoir has two limbs, one of which is fed by the Tana River and the other by the Thika River. It is reasonable to expect that the first major effect of the impoundment of a new reservoir would be a sudden deposition of fluvial sediments at the upstream end. This is seen to have happened on both limbs of Masinga with the greater depth of sediment being deposited adjacent to the Tana River road bridge near section TA32; the bed had been raised to such an extent that it was not possible to survey sections TA33 and TA34. However, within only a short distance of the upstream limits, on both limbs, the accretion has reduced to less than a metre in the old river channels. From then on, the layer of settled sediment averaged out at about 0.2m or less on each section and the difference in bed level that was recorded was less than the stated accuracy of the echo-sounder (see paragraph 2.7). The plotted sections therefore serve to give a qualitative guide to the areas subjected to accretion, but cannot be quantified to produce any accurate assessment of catchment erosion or reservoir accretion rates.

#### 4 RESERVOIR CAPACITIES

4.1 As for the preceding reports<sup>(3,4)</sup>, storage volumes for Kindaruma and

Kamburu reservoirs are calculated using a contour slicing technique which is defined in Appendix 3 of this report. Tables 3 and 4 give Kindaruma and Kamburu reservoir design capacities (based on aerial survey data recorded in 1965) together with calculated capacities for 1981 and 1983 obtained from hydrographic survey data. Computed capacities are shown below with the previously published values<sup>(4)</sup> shown in brackets.

	Masinga (m <sup>3</sup> x 10 <sup>6</sup> )	Kamburu (m <sup>3</sup> x 10 <sup>6</sup> )	Kindaruma (m <sup>3</sup> x 10 <sup>6</sup> )
Capacity from 1965 survey		146.01 (146.00)	18.34 (18.33)
1981 capacity	1488	129.84 (127.46)	11.55 (11.59)
1983 capacity	1418	128.98	11.22
Reduction in capacity since impoundment	4.7%	11.7%	38.8%

4.2 Minor differences between the capacity data published in 1983<sup>(4)</sup> and those produced for the present study are the result of a change in the method of calculation. In the earlier work, cross-sectional areas below the sediment range lines were measured using a digitising table; the computer analysis program given in Appendix 2 has been developed to calculate each area using the trapizoidal method applied to hydrographic survey data points. There is, of course, still a need to measure the surface area of each contour in each reservoir segment as part of the base data input. Because Masinga reservoir was not impounded when this project was started, it was not explicitly included in the proposals. However, since hydrographic survey data were collected, a simplified analysis has been carried out and the values have been given above. The impoundment capacity shown is about 4.6% less than the design volume of 1560 10<sup>6</sup> m<sup>3</sup> given by TARDA. It is likely that some of this variation may be attributed to the method of calculation employed and should not necessarily be taken to represent a genuine reduction in volume. Comments on the accuracy of the original data have already been made in paragraph 3.7.

- 4.3 Using the volumetric data as given in Tables 3 and 4, stage/capacity curves have been produced for Kindaruma and Kamburu reservoirs; these are reproduced as Figures 6 and 7.
- 4.4 The catchment area upstream of Kamburu reservoir is 9520 km<sup>2</sup> of which some 7335 km<sup>2</sup> drain into Masinga reservoir. If it is assumed that the quantity of sediment passing through Masinga dam is insignificant then it may also be assumed that the impoundment of Masinga reservoir in 1981 effectively reduced the area of catchment capable of supplying sediment to Kamburu reservoir to 2185 km<sup>2</sup>. Taking data from paragraph 4.1 above, during the period 1981 to 1983, Kamburu reservoir capacity was reduced by  $0.86 \times 10^6 \text{ m}^3$  which implies an annual decrease of  $0.43 \times 10^6 \text{ m}^3$ . On the assumption that this value is equivalent to the volume of material eroded from the reduced catchment, then the yield is  $197 \text{ m}^3/\text{km}^2/\text{year}$  or 0.2 mm/year over the whole area. A similar calculation for the seven-year period 1974 to 1981, assuming a catchment area of 9520 km<sup>2</sup>, results in a catchment sediment yield of 0.24 mm/year.
- 4.5 It must be stressed, however, that hydrographic surveys of reservoirs are specifically designed to locate the water-sediment interface and thus enable the change in capacity to be calculated. Any analysis of the change in sediment volume such as that carried out above assumes that there is no compaction or consolidation of the sediments in the intervening period and thus results in an under estimate of the catchment erosion rate.

## 5 CONSOLIDATION OF SEDIMENTS

- 5.1 In an attempt to take this analysis a stage further, the 1983 hydrographic survey included a series of in-situ bed density measurements using a "Harwell" type gamma transmission probe. The sensing head consisted of two prongs, one of which housed the gamma source and the other, a detector (Plate 8). A series of laboratory tests at Wallingford have shown that the attenuation of the gamma rays by the intervening sediment is a function of the sediment density. It is therefore possible to convert the readings or counts recorded on site into bulk densities by reference to a calibration curve obtained through use of the Hydraulic Research calibration facility. To the top of the probe is attached a profiler which consists of a precision depth

meter and pitch/roll indicator. The whole system weighs about 50 kg and can be used in water depths up to 50 m.

- 5.2 In order to obtain a profile, the sediment/water interface had to be located. This was found by carefully lowering the probe through the water until a slight change in probe detector reading was noted on the count rate meter. A 10-second count was recorded at this level which became the datum level for the profile. The probe was then lowered into the bed in steps of about 5 cm and further 10 second counts were made at each level until maximum bed penetration was reached. A 0.5 kg grab sediment sample was taken from each site at which a density profile was recorded (Plate 9).
- 5.3 One set of readings was taken at the deepest parts of each of twenty two sections in Masinga reservoir. The maximum bulk density of 1.71 was recorded on section TA4 and the maximum penetration achieved was 0.95 m on section TH10 with a bulk density of 1.4. (The bulk density is defined as the total weight of a sample divided by the total volume).
- 5.4 A second set of readings was taken at the deepest parts of sections K1 to K9 on Kindaruma reservoir. The maximum bulk density recorded was 1.83 on section K3 and the maximum penetration achieved was 0.40 m on section K9 with a bulk density of 1.43.
- 5.5 Data were collected from all the sections of Kamburu reservoir. The maximum bulk density recorded was 1.9 on sections TN7 and TN10 (R), and the greatest penetration recorded was 1.5 m at section TB4. The average penetration depth achieved on the Tana River limb was 0.22m and that for the Thiba River was 0.75 m.
- 5.6 With all this data available, an attempt was made to construct a mathematical (theoretical) model to predict the behaviour of settled sediments. Details of this model are given in Appendix 4. The main conclusion is that although the numerical model has produced some encouraging results, no firm decisions can yet be reached about the behaviour of sediment deposits because the site data covers only a small proportion of the total depth of the sediment layer.

6 CALCULATION OF SEDIMENT YIELD

6.1 Because of the amount of pre-1981 data which were available, the analysis given in report OD46 was based on Kamburu reservoir and the same procedure will first be followed here.

6.2 The data obtained in 1983 from Kamburu reservoir and quoted in section 4.1 above may be sub-divided to show the decrease in stored water volume for the Thiba River and Tana River limbs.

Date	Volume ( $\times 10^6 \text{m}^3$ )	Reduction in volume ( $\times 10^6 \text{m}^3$ )	Annual loss ( $\times 10^6 \text{m}^3$ )
<b>THIBA RIVER</b>			
Design	40.73		
1981	38.38	2.35	0.34
1983	37.84	0.54	0.27
<b>TANA RIVER</b>			
Design	105.29		
1981	91.46	13.83	1.98
1983	91.14	0.32	0.16
<b>WHOLE RESERVOIR</b>			
Design	146.02		
1981	129.84	16.18	2.31
1983	128.98	0.86	0.43

It will be seen from these values that subsequent to the closure of Masinga Dam in 1981, the storage volume of the Thiba River limb was reduced by about 1.4% while the equivalent figure for the Tana River limb was about 0.4% (prior to 1981 the reductions were 5.8% and 13.1% respectively). These values serve to confirm the earlier statement in section 3.5 - that Masinga Dam will trap much of the sediment which would otherwise be deposited in Kamburu reservoir and will thus serve to prolong the projected life of the older reservoirs downstream.

6.3 The procedure used here to obtain an estimate of the catchment erosion rate is based on work by Lane and Koelzer<sup>(6)</sup>, and Trask<sup>(7)</sup>. They

assumed that the density of settled sediments increased logarithmically with respect to time such that:

$$W = W_1 + K \log_{10} T$$

where:

$W$  = unit weight after  $T$  years

$W_1$  = initial unit weight

They studied sets of data obtained from a large number of reservoirs in the United States of America and produced a range of values for  $W_1$  and  $T$  covering four reservoir operating conditions. A sediment sample taken from Kamburu reservoir and subjected to a size grading analysis, was found to consist of 16% clay, 62% silt and 22% sand. Using the equation above with this sediment composition, indicated that the density of the settled material would increase by a factor of 1.05 over a seven year period, and by 1.06 over nine years.

6.4 Lane and Koelzer also quoted some work carried out at Lake Niedersoutholfen in Bavaria from which they deduced the variation in density with depth. Taking an initial density of  $1026.1 \text{ kg/m}^3$  - the value calculated from the equation in paragraph 6.3 above - it is possible to plot a line following the same trend as the Lake Niedersoutholfen data (Figure 8). A mean depth of sediment is obtained for each segment of Kamburu reservoir by dividing the segment sediment volume by the average contour area. Using Lane and Koelzer's reservoir work, it is then possible to deduce a mean sediment density for the given reservoir segment.

6.5 Having deduced an age factor, the initial sediment density and a density at the mean depth for each segment, it is now possible to determine a more valid estimate of the catchment sediment yield for Kamburu reservoir. The ratio of the actual sediment volume ( $V_{act}$ ) to the initial volume ( $V_o$ ) of the sediment at the unconsolidated density ( $\rho_o$ ) is calculated as follows. Consider a column of unit area of material varying in density from  $\rho_o$  at the surface to  $\rho_D$  at depth  $D$ , and if density at depth  $d$  is  $\rho_d$ , then:

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

hence:

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

and:

$$\text{actual volume } V_{\text{act}} = D \times l \times l$$

If this mass had all been deposited at density  $\rho_o$  (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:

$$\frac{V_o}{V_{\text{act}}} = \frac{\int_0^D \rho_d \cdot dd}{\rho_o \times D}$$

By idealising the shape of the curve given in Figure 8, the above equation may be reduced to:

$$\frac{V_o}{V_{\text{act}}} = 0.5 + \frac{\rho_d \cdot AF}{2 \cdot \rho_o}$$

where AF is the age factor.

6.6 Tables 5 and 6 have followed this procedure through and show calculated "unconsolidated" sediment volumes for the Tana River and Thiba River limbs of Kamburu reservoir. The results are summarised as follows:

	1974 - 81 (x10 <sup>6</sup> m <sup>3</sup> )	1974 - 83 (x10 <sup>6</sup> m <sup>3</sup> )
TANA LIMB	15.77	16.26
THIBA LIMB	2.59	3.20
TOTAL	18.36	19.46

The mean annual increase in the unconsolidated volume for 1974 - 81 was therefore:

$$\frac{18.37 \times 10^6}{7} = 2.62 \times 10^6 \text{ m}^3/\text{year}$$

Following a similar process for Kindaruma reservoir, the total unconsolidated sediment volume for the period 1968 to 1981 was calculated to be  $7.57 \times 10^6 \text{ m}^3$ .

- 6.7 The above calculation only takes account of the volume of material which is trapped within the reservoir. However, some of the eroded material will remain in suspension and will pass through the dam. The proportion of material trapped to material supplied is termed the 'trap efficiency' of a reservoir, and Brune<sup>(8)</sup> showed this to be closely related to the reservoir capacity/inflow ratio. The reservoir capacity is the volume of water stored as quoted in paragraph 4.1. Estimated reservoir inflows for the three periods were based on data published by TARDA<sup>(9)</sup>. In the leaflet, the long term average annual river flows for Masinga and Kamburu were given as  $2586 \times 10^6 \text{ m}^3$  and  $3406 \times 10^6 \text{ m}^3$  respectively. Taking the catchment areas to be  $7335 \text{ km}^2$  and  $9520 \text{ km}^2$ , it is possible to deduce a mean catchment run-off of  $0.36 \times 10^6 \text{ m}^3/\text{km}^2/\text{year}$ . Applying this value to Kindaruma catchment implies a mean annual reservoir inflow of  $3560 \times 10^6 \text{ m}^3$ . Using stream discharge data taken from river gauging stations 4DE2 and 4DD2, the inflow to Kindaruma reservoir in 1968 is seen to be  $2393 \times 10^6 \text{ m}^3/\text{year}$ . Assuming that the reservoir inflow is proportional to catchment area, the inflows at impoundment for Kamburu and Gitaru reservoirs were  $2305 \times 10^6 \text{ m}^3/\text{year}$  and  $5858 \times 10^6 \text{ m}^3/\text{year}$  respectively. Using these river flow data it is possible to calculate the following reservoir trap efficiencies:

	Kindaruma	Gitaru	Kamburu	Masinga
<u>Design</u>				
Inflow (x10 <sup>6</sup> m <sup>3</sup> /year)	2393	5858	2305	2586
Capacity (x10 <sup>6</sup> m <sup>3</sup> )	18.34	12	146.01	(1488)
Trap Efficiency	38%	4%	81%	96%
<u>1981</u>				
Inflow (x10 <sup>6</sup> m <sup>3</sup> /year)	3560	-	3406	-
Capacity (x10 <sup>6</sup> m <sup>3</sup> )	11.55	-	129.84	-
Trap Efficiency	16%	-	73%	-
<u>1983</u>				
Inflow (x10 <sup>6</sup> m <sup>3</sup> /year)	3560	-	3406	2586
Capacity (x10 <sup>6</sup> m <sup>3</sup> )	11.22	-	128.98	(1418)
Trap Efficiency	14%	-	73%	96%

Continuing the calculation started in paragraph 6.6, if the annual increase in the volume of unconsolidated sediment in Kamburu reservoir over the period 1974 - 81 was  $2.62 \times 10^6 \text{ m}^3$ , then the sediment input rate (i.e. the catchment erosion rate) was:

$$\frac{2.62 \times 10^6}{0.77} = 3.40 \times 10^6 \text{ m}^3/\text{year}$$

which is equivalent to:

$$\frac{3.40 \times 10^6}{9520} = 357 \text{ m}^3/\text{km}^2/\text{year}$$

averaged over the whole catchment. By the same process, it must be assumed that  $0.23 \times (3.40 \times 10^6) \text{ m}^3/\text{year} = 0.78 \times 10^6 \text{ m}^3/\text{year}$  passed through Kamburu dam to Gitaru and Kindaruma reservoirs.

- 6.8 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

Looking at these dates it is possible to divide the time into four distinct periods as shown:

- (i) 1968-1974 Kindaruma reservoir only, trapping a proportion of the sediment yield from approximately 10 000 km<sup>2</sup>
- (ii) 1974-1978 Kamburu reservoir trapping part of the sediment produced by a 9520 km<sup>2</sup> catchment - Kindaruma collecting some of sediment passing Kamburu and from 480 km<sup>2</sup> catchment
- (iii) 1978-1981 Gitaru reservoir intercepting some of input to Kindaruma reservoir and reducing Kindaruma catchment to 250 km<sup>2</sup>
- (iv) 1981-1983 Masinga reservoir traps part of sediment yield from 7335 km<sup>2</sup> catchment and reduces the Kamburu reservoir catchment area to 2185 km<sup>2</sup>

Each of these periods will now be considered in turn.

#### 6.9 1968-1974

Let  $y$  m<sup>3</sup>/km<sup>2</sup>/year be the average catchment yield for Kindaruma reservoir. Then the sediment input rate would be  $y \times 10\ 000$  m<sup>3</sup>/year. Assuming an average trap efficiency over this period to be 33%, then the volume of sediment trapped would be:

$$6 \times \frac{y}{100} \times 33\% \times 10^6 \text{ m}^3$$

$$= 0.020 y \times 10^6 \text{ m}^3 \text{ for } 1968-74$$

The value of  $y$  will have to be defined later.

#### 6.10 1974-1978

The catchment yield for Kamburu reservoir (averaged over the period 1974-1981) was calculated (paragraph 6.7) to have been  $357 \text{ m}^3/\text{km}^2/\text{year}$  with  $0.78 \times 10^6 \text{ m}^3/\text{year}$  passing downstream. Assuming the trap efficiency of Kindaruma reservoir for the period 1974-1978 to be 25%, the total sediment input was therefore:

$$\begin{aligned} & 4 (0.78 \times 10^6 \times 25\%) + 4 (357 \times 480 \times 25\%) \\ & = 0.95 \times 10^6 \text{ m}^3 \text{ for } 1974-78 \end{aligned}$$

#### 6.11 1978-81

As for the previous period, the output from Kamburu reservoir was assumed to be  $0.78 \times 10^6 \text{ m}^3/\text{year}$ .

Hence:

Output from Gitaru reservoir

$$\begin{aligned} & = 3 (0.78 \times 10^6 \times 96\%) + 3 (357 \times 230 \times 96\%) \\ & = 2.48 \times 10^6 \text{ m}^3 \text{ for } 1978 - 81 \end{aligned}$$

And

Sediment trapped in Kindaruma reservoir for the three year period was

$$\begin{aligned} & (2.48 \times 10^6 \times 19\%) + 3 (357 \times 250 \times 19\%) \\ & = 0.522 \times 10^6 \text{ m}^3 \text{ for the period } 1978-81 \end{aligned}$$

6.12 Using the data produced in paragraphs 6.9, 6.10 and 6.11 above, it is now possible to evaluate the annual catchment sediment yield for the period 1968 to 1974 based on Kindaruma reservoir. By extrapolation from the 1981 hydrographic survey data, the equivalent "unconsolidated" sediment volume trapped in Kindaruma reservoir was  $7.57 \times 10^6 \text{ m}^3$  (see paragraph 6.6). The preceding calculations shown that this sediment volume is represented by the sum of:

$$(0.02y + 0.95 + 0.52) \times 10^6 \text{ m}^3$$

from which it can be seen that

$$y = 305 \times 10^6 \text{ m}^3/\text{km}^2/\text{year} \text{ for the period 1968 to 1974.}$$

### 6.13 1981-83

Masinga Dam was closed in the first part of 1981 and so impounded the most upstream reservoir of the series. Following the same procedure as for the previous calculations, the calculation of catchment yield will be based on Kamburu reservoir. However, the output from Masinga only enters the Tana River limb of Kamburu reservoir and so, using data from paragraph 6.6 above, the volume of unconsolidated sediment accreted in Tana River limb during this period is  $0.49 \times 10^6 \text{ m}^3$  which is equivalent to  $0.245 \times 10^6 \text{ m}^3/\text{year}$ . Assuming a trap efficiency of 73%, this represents an inflow of:

$$\frac{0.245 \times 10^6}{0.73} = 0.336 \times 10^6 \text{ m}^3/\text{year}$$

The trap efficiency of Masinga reservoir was calculated to be 96%, hence the total volume of sediment from the catchment is seen to be:

$$\frac{0.336 \times 10^6}{0.04} = 8.40 \times 10^6 \text{ m}^3/\text{year}$$

and the volume trapped is  $8.06 \times 10^6 \text{ m}^3/\text{year}$ . The catchment area for Masinga reservoir was stated by TARDA to be  $7335 \text{ km}^2$  and so the catchment sediment yield is calculated as:

$$\frac{8.06 \times 10^6}{7335} = 1099 \text{ m}^3/\text{km}^2/\text{year}$$

6.14 The results of the preceding five paragraphs may be combined to show calculated catchment sediment yields as:

1968 to 1974	$305 \text{ m}^3/\text{km}^2/\text{year}$
1974 to 1981	$357 \text{ m}^3/\text{km}^2/\text{year}$

The catchment sediment yield for 1981-83 is shown above to be  $1099 \text{ m}^3/\text{km}^2/\text{year}$ . However, not too much reliance should be placed on

this value which is discussed in more detail in the following paragraphs.

## 7 DISCUSSION OF RESULTS

- 7.1 Since the production of report OD 46 in June 1983, the methods whereby hydrographic survey data are analysed have been modified such that a large proportion of the work can be carried out using a digital computer. It has thus been possible to look again at all the data which have been collected since this project was started.
- 7.2 The second important step which has been taken is the collection of reservoir bed samples and the attempt to record in-situ bed density measurements. Both sets of data, while not giving a complete answer as had originally been hoped, nevertheless have enabled more accurate values of bed density to be used in the consolidation calculations.
- 7.3 The calculated catchment sediment yields show an increase over the period 1968-1981 of just under 2% per year with a maximum yield of  $357 \text{ m}^3/\text{km}^2/\text{year}$ ; this converts to 0.4mm averaged over the whole catchment. Report OD 46<sup>(4)</sup> showed in paragraph 11.7, catchment sediment yields of 416, 715 and  $330 \text{ m}^3/\text{km}^2/\text{year}$  for the three periods 1968-74, 1974-78 and 1978-81 respectively.
- 7.4 At the time of writing report OD 46, complete surveys of Kindaruma and Kamburu reservoirs were only available from pre-impoundment aerial survey maps and the 1981 hydrographic surveys. Attempts were made to identify trends in sedimentation rates by extrapolating values from limited surveys of Kamburu reservoir carried out for TARDA by Engineering and Power Development Consultants. Although based on a number of major assumptions, it was thought that the values given were of the right order.
- 7.5 The 1983 hydrographic surveys have enabled the analytical techniques to be refined so that the number of assumptions and estimates involved in the calculation of catchment sediment yield are considerably reduced. The time periods over which yields are calculated in this report have therefore been changed to cover the years between surveys without any attempt being made to evaluate erosion rates at intervening times.

7.6 The calculated catchment sediment yield for the period 1981-83 must be treated with considerable caution. Paragraph 4.2 explains that a simplified method was employed to calculate the Masinga reservoir volumes and so the results are less accurate than those obtained for the other reservoirs. Because of this, an attempt was made to evaluate the catchment yield using data from the Tana river limb of Kamburu reservoir; but the method still required an estimate of trap efficiency based on the volume of Masinga reservoir. The resulting value of  $1099 \text{ m}^3/\text{km}^2/\text{year}$  should therefore not be taken as an accurate representation of the field condition. If the calculations are based on the Thiba river limb of Kamburu reservoir (which was not affected by the closure of Masinga dam) then a catchment sediment yield of  $210 \text{ m}^3/\text{km}^2/\text{year}$  is indicated. However, since the Thiba river flows through a large irrigation scheme near to the reservoir, it is likely that a proportion of the sediment would be dropped out of suspension prior to entering the reservoir resulting in a reduced estimate of catchment sediment yield. If the catchment sediment yield continues to increase by about 2% per year, then it is reasonable to expect a yield of about  $392 \text{ m}^3/\text{km}^2/\text{year}$  for the period 1981-83.

7.7 As a check on these values, a comparison was made with data obtained from a study of catchments in Malawi which have been subjected to various levels of land management<sup>(10)</sup>. The Malawi studies have shown that farming using traditional methods could be expected to lose up to 1.17mm of soil per year while the operation of physical conservation measures could reduce this to 0.14mm per year. The Kenyan catchments cover a wide range of land use types from fairly intense farming to sparsely cultivated land and so it seems reasonable that the erosion rate in the Upper Tana River catchments should fall between these two extremes.

7.8 The comparison mentioned above between relatively small catchments in Malawi ( $0.05$  to  $0.13 \text{ km}^2$ ) and the large Kenyan catchments ( $2185$  to  $10000 \text{ km}^2$ ) raises a question which is fundamental to all catchment erosion studies: what is the relationship between soil loss from a defined area of a catchment, and the sediment yield at the reservoir - the so-called Sediment Delivery Ratio? Many attempts have been made to examine this phenomenon and they generally show a reduction in the ratio with increasing catchment area. For the Kenyan catchments, the ASCE<sup>(11)</sup> indicate delivery ratios of 2-10% which if applied to the

Malawi data, implies sediment yields ranging from 0.12 mm/year down to 0.002 mm/year, which are clearly under estimates. Any further discussion of the mechanism whereby sediments are transported within a catchment is beyond the scope of this report and is the subject of a separate collaborative study by Hydraulics Research in the Philippines.

7.9 The data given in paragraph 4.1 shows that by June 1983, the capacity of Kamburu reservoir had been reduced by 11.7% and that for Kindaruma had reduced by 38.8%. The equivalent data for Masinga reservoir indicates a reduction in capacity of 4.7%. However the subsequent paragraph explains that the method by which the volume of Masinga reservoir was calculated was a gross over-simplification and too much reliance should not be put on these values.

7.10 An examination of the survey data shows that there is very little variation between two data sets obtained over a relatively short time period. When small changes in bed level are being experienced, it is likely that the inaccuracies inherent in such a data collection system may become significant in terms of the calculated results. It is now recommended that a limited survey should be carried out every two years to check that no large changes in reservoir bed level have occurred. A full scale survey should be run after six years unless an intermediate survey indicates the need earlier.

## 8 CONCLUSIONS

8.1 The preceding sections have described the methods by which hydrographic and sediment density data were obtained for these reservoirs in Kenya during 1983. It was emphasised that hydrographic surveys are designed to define the volume of water stored within the reservoir and that any extrapolation of the results to indicate catchment sediment yields must be treated with some caution.

8.2 Using a contour-slicing technique which was initially devised for the 1981 Kenya surveys, the reservoir volumes were calculated to be:

Masinga       $1418 \times 10^6 \text{ m}^3$  (4.7% reduction since 1981)

Kamburu       $128.98 \times 10^6 \text{ m}^3$  (11.7% reduction since 1974)

Kindaruma  $11.22 \times 10^6 \text{ m}^3$  (38.8% reduction since 1968)

- 8.3 The calculation of catchment sediment yields was based on data obtained from Kamburu reservoir since its impoundment in 1968, together with more recent data from Kindaruma and Masinga reservoirs. In each case, an allowance was made for the reservoir trap efficiency, and an estimated sediment density was used. The catchment sediment yields were calculated to be:

1968 to 1974  $305 \text{ m}^3/\text{km}^2/\text{year}$

1974 to 1981  $357 \text{ m}^3/\text{km}^2/\text{year}$

1981 to 1983  $1099 \text{ m}^3/\text{km}^2/\text{year}$

The first two values compared favourably with soil loss rates measured from study catchments in Malawi.

- 8.4 On the basis of the data obtained from the 1981 and 1983 surveys, it is recommended that a limited survey (e.g. 10 sections on Kamburu reservoir, 4 sections on Kindaruma and 15 sections on Masinga) should be carried out every two years with a full, detailed survey at six year intervals.

## 9 ACKNOWLEDGEMENTS

- 9.1 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 Kenya Power and Lighting Co Ltd (KP & L).
- 9.2 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 under the control of Mr M M Gateri.
- 9.3 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

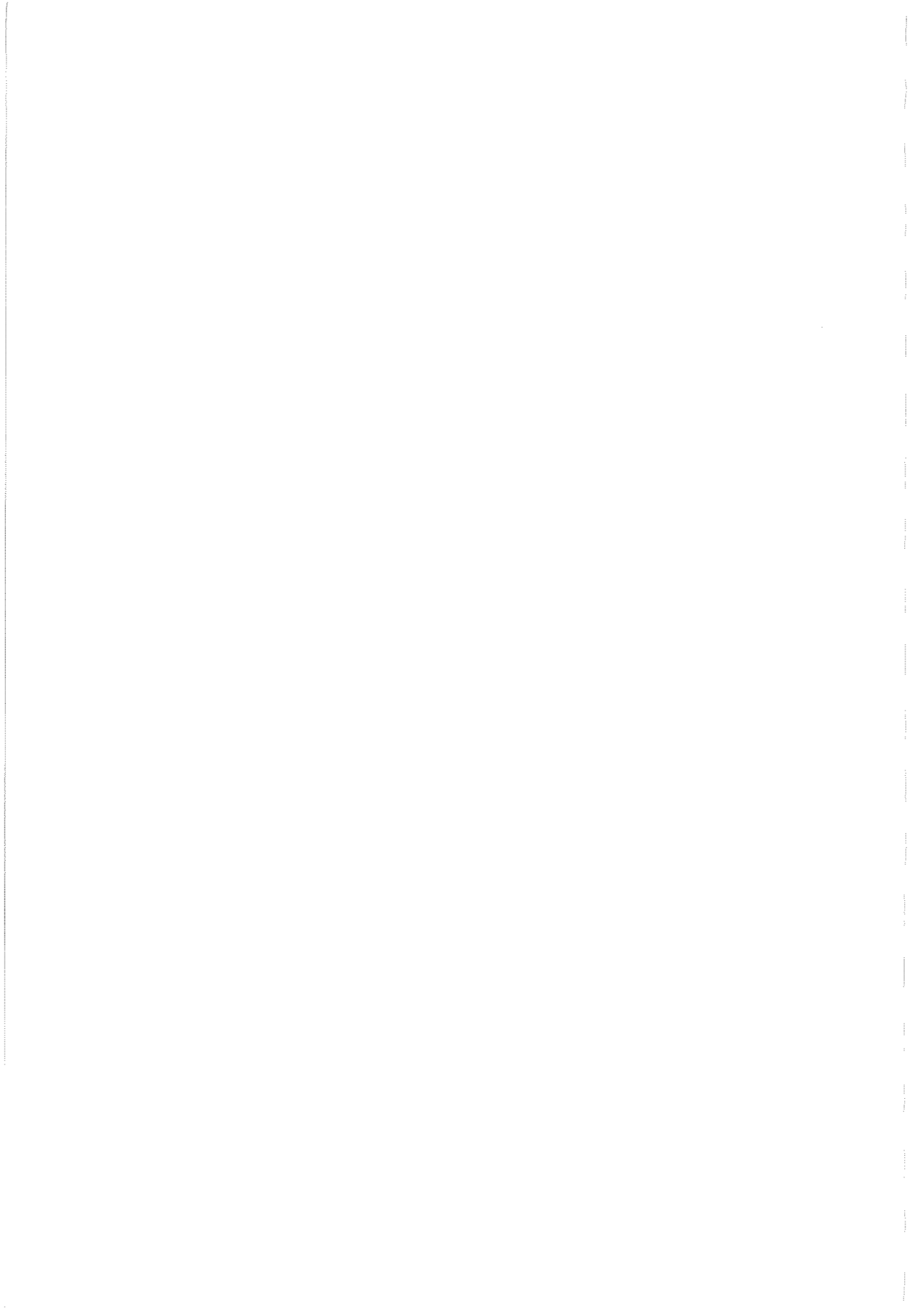
Hydrologist, Mr S H Charania, have carried out the fluvial data collection and instrument maintenance. MOWD staff also took part in the reservoir surveys.

- 9.4 KP & L 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 KP & L interest was led by Mr N K Gichuki.
- 9.5 All of the collaborative organisations have supplied valuable advice and assistance throughout the investigation which would not be possible without their full co-operation.
- 9.6 The hydrographic surveys were carried out in 1981 and 1983 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 and Mr A P E Green.
- 9.7 Appendix 4 was researched and written by Mr E Atkinson at Hydraulics Research and the author expresses his thanks to Mr Atkinson for this work.
- 9.8 This project was carried out by the Overseas Development Unit at Hydraulics Research Limited, 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

Reservoir cross-section plotting program

```

1      PROGRAM PLOTD1
2      C *****
3      C *           A program to read in X and Y coordinates along section(s) *
4      C *           of a river/reservoir, and plot the section(s). *
5      C *
6      C *****
7      C
8      DIMENSION XCOORD(300),YCOORD(300),NDATE(5),NCHANN(5)
9      CHARACTER*80 REFNAM,PLOTQ*5,NAME*20
10     REAL MAXWID
11     C
12     C           Read in general reservoir data
13     C
14         READ(1,400)NAME
15         READ(1,*)NYEARS
16         READ(1,*)NLIMBS
17         READ(1,*)NSECT
18         READ(1,460)
19         READ(1,*)CINCRE
20         READ(1,*)WL
21         READ(1,*)WLCINC
22     DO 5 M = 1,NYEARS
23         READ(1,*)NDATE(M),NCHANN(M)
24     5 CONTINUE
25     NCOUNT = 0
26     C
27     C           Initial plot instructions. Call routine to
28     C           set plotting paper.
29     C
30     CALL PAPER(1)
31     C           Set up plotting area for each X-section to
32     C           be plotted.
33     C
34     DO 99 NN = 1,NSECT
35         NCOUNT = NCOUNT + 1
36         IF(NCOUNT.EQ.1) CALL PSPACE (0.08,1.0,0.66,0.99)
37         IF(NCOUNT.EQ.2) CALL PSPACE (0.08,1.0,0.33,0.66)
38         IF(NCOUNT.EQ.3) CALL PSPACE (0.08,1.0,0.0,0.33)
39     C
40     DO 98 I=1,NYEARS
41     C
42     15     READ(NCHANN(I),400)REFNAM
43         READ(NCHANN(I),*)WIDTH
44     18     READ(NCHANN(I),*,ERR=20)(XCOORD(LL),YCOORD(LL),LL=1,300)
45     20     NFIX = LL-1
46         IF(NFIX.LT.1)GO TO 98
47         XCOORD(NFIX+1) = WIDTH
48         YSMALL = 99999.0
49         DO 25 L = 1,NFIX
50             IF(YSMALL.GT.YCOORD(L))YSMALL = YCOORD(L)
51     25     CONTINUE
52     C
53     IF(I.GT.1) GO TO 30
54     C
55     DIFF=WL-YSMALL-5.0
56     YMAX = AINT(WL/10.0)*10.0+10.0
57     C
58     IF(DIFF.LE.0.0)YMAX=YMAX+30.0
59     C
60     YINC = YMAX - YSMALL
61     YAINT = AINT(YINC/40.1)+1.0

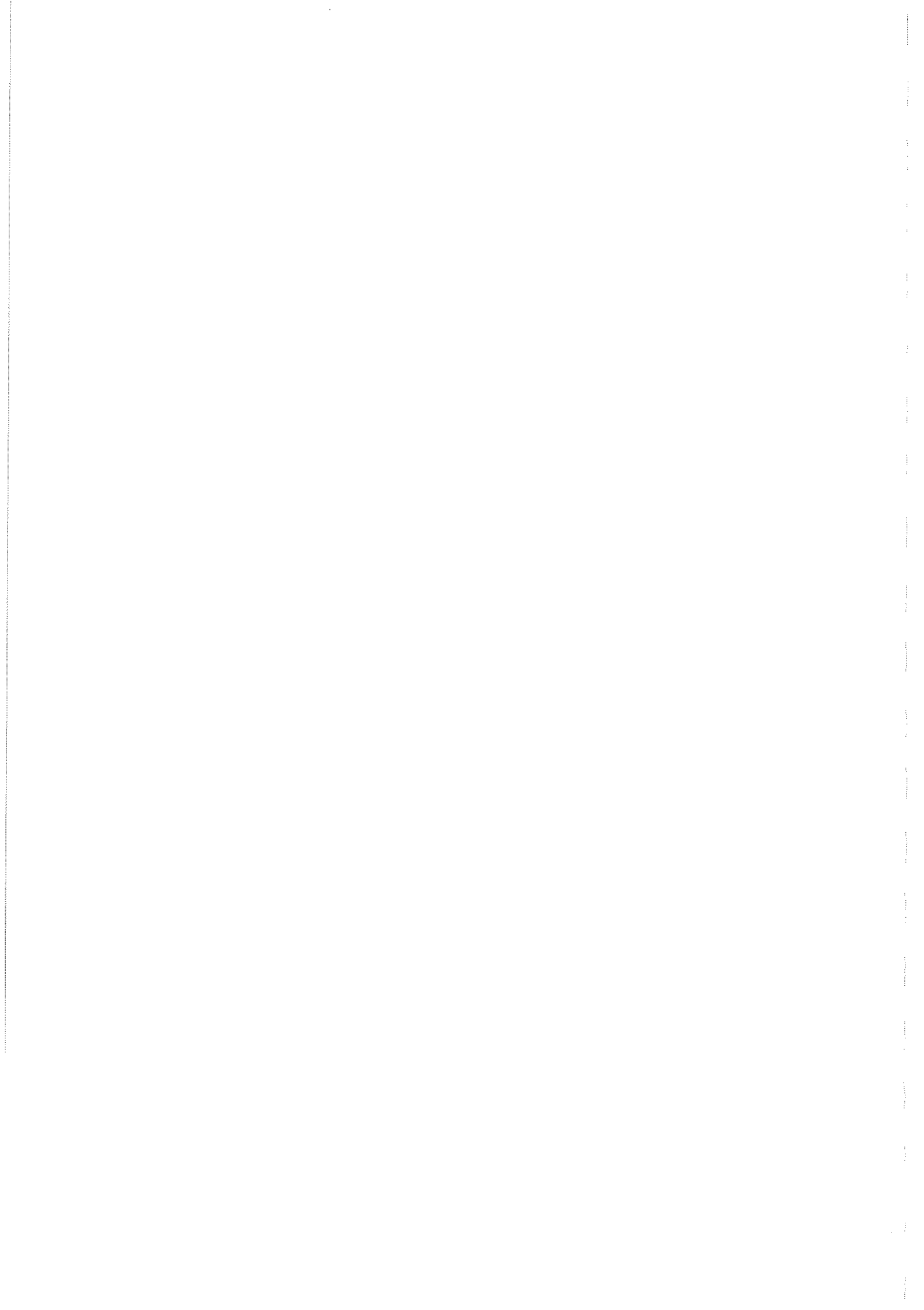
```

```

62      YMIN = YMAX - (YAIN*40.0)
63      XAIN* = AINT(WIDTH/600.1)+1.0
64      XMAX = 600.0*XAIN*
65      C
66      C
67      MAXWID = 1456.0*XAIN*
68      YMAP = YMIN - (14.0*YAIN*)
69      CALL MAP (0.0,MAXWID,YMAP,YMAX)
70      CALL WINDOW (0.0,XMAX,YMIN,YMAX)
71      CALL CTRMAG(6)
72      CALL POSITN(0.0,(YMIN-(7.0*YAIN*)))
73      CALL TYPECS('SECTION ',8)
74      CALL TYPECS(REFNAM,10)
75      CALL TYPECS(': ',2)
76      CALL TYPECS(NAME,20)
77      CWL = WIDTH/4.0
78      CALL POSITN(CWL,(WL+1.0))
79      IF(XMAX.LT.400)THEN
80          CALL TYPENF(WL,2)
81      ELSE
82          CALL TYPECS('Reservoir T.W.L.= ',17)
83          CALL TYPENF(WL,2)
84      ENDIF
85      C
86      CALL BROKEN(2,2,2,2)
87      CALL POSITN(0.0,WL)
88      CALL JOIN(XMAX,WL)
89      CALL FULL
90      CALL CTRMAG(5)
91      CALL AXESSI(100.0,10.0)
92      C
93      30 YK = (6-I)*2*YAIN*
94      CALL POSITN((XAIN*460.0),(YMIN+YK))
95      CALL CTRMAG(4)
96      CALL TYPENI(NDATE(I))
97      CALL POSITN((XAIN*515.0),(YMIN+YK))
98          IF(I.EQ.2) CALL BROKEN(3,2,3,2)
99          IF(I.EQ.3) CALL BROKEN(5,2,2,2)
100         IF(I.EQ.4) CALL BROKEN(4,4,4,4)
101      CALL JOIN((XAIN*590.0),(YMIN+YK))
102         IF(I.GT.1) CALL FULL
103      C
104         IF(I.GT.1)GO TO 40
105      C
106      CALL POSITN ((XMAX/4.0),(YMIN-YAIN*5.0))
107      CALL TYPECS ('Distance from left bank beacon (m)',34)
108      CALL CTRORI (90.0)
109      CALL POSITN ((-55.0*XAIN),(YMIN+YAIN*8.0))
110      CALL TYPECS('Reduced Level (m)',18)
111      CALL CTRORI (0.0)
112      C
113      C
114      40  IF(I.EQ.2)CALL BROKEN(3,2,3,2)
115         IF(I.EQ.3)CALL BROKEN(5,2,2,2)
116         IF(I.EQ.4)CALL BROKEN(4,4,4,4)
117      CALL PTJOIN(XCOORD,YCOORD,1,NFIX,0)
118         IF(I.GT.1)CALL FULL
119      C
120      98 CONTINUE
121
122         IF(NCOUNT.EQ.3)CALL FRAME
123      C

```

```
124 C           Return to read and plot data for another
125 C           section if this is applicable.
126 C
127 C           IF(NCOUNT.EQ.3)NCOUNT = 0
128 C
129 C           99 CONTINUE
130 C           1000 CALL GREND
131 C
132 C           STOP
133 C
134 C           400 FORMAT(A)
135 C           450 FORMAT(/)
136 C           460 FORMAT(//)
137 C           500 FORMAT (I4)
138 C           END
```



APPENDIX 2

Reservoir sediment evaluation program

```

1
2 PROGRAM SVPRO3
3 C
4 C *****
5 C *
6 C *           Hydraulics Research Ltd,Wallingford,Oxon.
7 C *           Program begun by C.R.Talbot,continued
8 C *           by Tony G.      1984
9 C *
10 C *****
11 C
12 C A program to read survey data in the form of X and Y coordinates
13 C (i.e distances and reduced levels) along reservoir X-sections.The
14 C program calculates the X-sectional areas using the Trapezium Rule
15 C and,after calculating initial"Constant Factors" for the sections,
16 C new volumes of each segment and the complete reservoir are
17 C calculated using the new survey data.
18 C
19 C The program has two main parts.The first part reads in survey
20 C data and calculates X-sectional areas for each section.This is
21 C done for both the original and recent surveys.Constant factors
22 C and design volumes are calculated in the second part and finally
23 C new volumes are calculated.
24 C
25 C The program can deal with reservoirs containing any specified no.
26 C of limbs.This is specified (as 'NLIMBS'), and each limb is consid-
27 C -ered separately, starting with the main limb, which will include
28 C the segment between the final (downstream) section and the dam.
29 C Care in defining'upstream' and'downstream'is required,the program
30 C assumes upstream values to be input before downstream.
31 C
32 C It is assumed the user has a knowledge of the ' Constant Factor '
33 C method for calculating reservoir volumes.
34 C
35 C ***** Glossary of Variable names *****
36 C
37 C (r) read in
38 C (c) calculated
39 C
40 C          AO (C) = Sum of end areas of segment.
41 C          AREA (c) = Area of trapezium within sub-section,defined
42 C                   by XCOORD's and YCOORD's.
43 C          CFAC (r) = Constant Factor.AO/VO
44 C          CINCRE (r) = Increment between contours.(Area calcs)
45 C          CONT (r) = Higher contour in sub-segment
46 C          CONTL (c) = Lower contour in sub-segment
47 C          DSTRM (r) = Is program to include volume of segment d/s
48 C                   of final section? (YES/NO)
49 C          DMAX (c) = Maximum depth along a defined section.'DMAX'
50 C                   is calculated using 'XSMALL'.
51 C          H (c) = Height of water level/upper contour above
52 C                reduced level of bed at point 'XCOORD'.
53 C          INC (c) = Increment between contours.(Vol calcs)
54 C          NFIX (c) = No of fixes (ie XCOORD's and YCOORD's) along
55 C                   a defined section.
56 C          NLIMBS (r) = No of limbs in reservoir.
57 C          NSECT (r) = No of sections in reservoir/reservoir limb.
58 C          NSUBS (c) = No of sub-sections in a defined section.
59 C          NQUAT (c) = A number, written out to monitor file, which
60 C                   indicates which equation was used to calcul-
61 C                   -ate the area of a defined trapezium.Useful

```

```

62 C                                     for checking against possible data errors.
63 C     REFNAM (r) = Reference name of section/segment.
64 C     SAREA (c) = Area of a defined sub-section.
65 C     SED (r) = Volume of defined sub-segment(previous survey)
66 C
67 C     SEDSUM (r) = Volume of defined segment(previous survey)
68 C     SEDX (c) = Present volume of defined sub-segment.
69 C     SEDXM (c) = Present volume of defined segment.
70 C     SUMSEG (c) = Total reservoir volume (at design).
71 C     SUMVO (r) = Volume of defined segment (at design).
72 C     TOTSED (c) = Total reservoir volume (previous survey).
73 C     TSEDXM (c) = Present Total reservoir volume.
74 C     UPSTRM (r) = Is program to include volume of segment u/s
75 C                 of first section? (YES/NO)
76 C     VO (r) = Volume of a defined sub-section (at design).
77 C     WIDTH (r) = Width of defined section (beacon to beacon).
78 C     XSMALL (c) = see 'DMAX'.
79 C     XCOORD (r) = Distance(m) of fix from left bank beacon.
80 C     YCOORD (r) = Reduced level of bed at 'XCOORD'.
81 C     WL (r) = Water level.
82 C     WLCINC (r) = Increment between 'WL', and contour which
83 C                 defines lowest part of uppermost sub-sect
84 C                 -ion in the reservoir.
85 C

```

```

86 C     The program creates two files; a results file (channel 3),and
87 C     a monitor file (channel 6) to which are written intermediate
88 C     values whilst the program is running.This is useful for detect
89 C     -ing data errors.
90 C

```

```

91 C     *****
92 C     *****
93 C

```

```

94 CHARACTER*80 REFNAM,TEST,LINST,UPSTRM*5,DNSTRM*5,TITLE*120,
95 1NAME*25
96 DIMENSION XCOORD(300),YCOORD(300),H(300),SAREA(25,100,5),
97 1 SED(25),VO(25),SEDX(25),AOSEDX(25),NSUBS(25),CONTH(25),
98 2 SAUPP(25),SALOW(25),AO(25),CONTL(25),INCRE(25),NDATE(25),
99 3 CONT(25),INC(25),RSALOW(25),RSAUPP(25),NCHANN(25),CFAC(25),
100 4 TOAREA(100,5),CVOL(25,5),DSAREA(25),USAREA(25)
101 INTEGER DS,US,DATE
102 REAL INC,INCRE
103 LOGICAL XXX

```

```

104 C
105 READ(4,*)SWIT
106 READ(4,*)DATE
107 READ(4,*)NSEGS
108 READ(4,*)MCONTS
109 READ(4,*)(CONT(M),M=1,MCONTS)

```

```

110 C
111 C     Initialisation
112 C

```

```

113 XXX = .FALSE.
114 SUMSEG = 0.0
115 TOTSED = 0.0
116 TSEDXM = 0.0
117 MNCNT = 1.0

```

```

118 C
119 C
120 C     Read in general parameters (channel 1)
121 C

```

```

122 READ(1,350)NAME
123 READ(1,*)NYEARS

```

```

124         READ(1,*)NLIMBS
125         READ(1,*)NSECT
126         READ(1,350)UPSTRM
127         READ(1,350)DNSTRM
128         READ(1,340)
129         READ(1,*)CINCRE
130         READ(1,*)WL
131         READ(1,*)WLCINC
132     DO 5 N = 1,NYEARS
133         READ(1,*)NDATE(N),NCHANN(N)
134     5 CONTINUE
135 C
136         DO 2 I=1,25
137             DO 2 K=1,NYEARS
138                 CVOL(I,K)=0.0
139     2 CONTINUE
140 C
141     III = NLIMBS
142 C
143         If more than one limb exists,XXX is set to 'TRUE'
144 C
145     33 IF(III.GT.1) XXX = .TRUE.
146 C
147         DO 18 J = 1,100
148             DO 18 I = 1,25
149                 DO 18 K=1,NYEARS
150                     SAREA(I,J,K) = 0.0
151                     TOAREA(J,K) = 0.0
152     18 CONTINUE
153     WRITE(6,*)NSECT,CINCRE,WL
154 C
155 C
156 C     *****
157 C     This first part reads in the new survey data and calculates
158 C     X-sectional areas for each section.
159 C     *****
160 C
161         DO 101 K=1,NYEARS
162         DO 100 MSECT = 1,NSECT
163         WRITE(6,920)MSECT
164         READ(NCHANN(K),350)REFNAM
165         READ(NCHANN(K),*)WIDTH
166 C
167 C     'REFNAM' is the reference name of the section
168 C
169     3     READ(NCHANN(K),*,ERR=4)(XCOORD(LL),YCOORD(LL),LL=1,300)
170     4     NFIX = LL-1
171         XCOORD(NFIX+1)=WIDTH
172 C
173     XSMALL = 99999.0
174         DO 6 I = 1,NFIX
175             IF(XSMALL.GT.YCOORD(I))XSMALL = YCOORD(I)
176     6     CONTINUE
177     DMAX = (WL-XSMALL)
178         IF((DMAX-WLCINC).LE.0.0)THEN
179             NSUBS(MSECT)=1
180         ELSE
181             NSUBS(MSECT) =((DMAX-WLCINC)/CINCRE)+1.9999
182         ENDIF
183 C
184 C     Note above equation.0.9999 is added to left-hand side to ensure
185 C     that rounding is always (in effect) upwards to nearest integer.

```

```

186 C
187 WRITE(6,600)REFNAM
188 WRITE(6,*)XSMALL,NFIX,XCOORD(NFIX+1)
189 C
190 C Calculate 'H(I)' i.e the depth of reservoir at each fix.
191 C
192 DO 7 I=1,NFIX
193 H(I) = WL-YCOORD(I)
194 7 CONTINUE
195 C
196 STORE = CINCRE
197 C
198 DO 10 J = 1,NSUBS(MSECT)
199 IF(J.EQ.1) CINCRE = WLCINC
200 IF(J.GE.2) CINCRE = STORE
201 WRITE(6,405)CINCRE
202 C
203 C This section defines each trapezium and decides how to calculate
204 C the area of that trapezium.
205 C
206 DO 25 I = 1,NFIX
207 H(NFIX+1) = 0.0
208 IF(H(I).LE.0.0.AND.H(I+1).LE.0.0)GO TO 25
209 C
210 C Note 'NQUAT' is set to an integer value,in the range 1 to 6
211 C depending on which equation is used to calculate 'AREA' for
212 C each trapezium.
213 C
214 IF(H(I).GE.CINCRE.AND.H(I+1).GE.CINCRE)THEN
215 AREA = CINCRE*(XCOORD(I+1)-XCOORD(I))
216 NQUAT = 3
217 GO TO 20
218 ENDIF
219 C
220 IF (H(I).LT.0.0.AND.H(I+1).GT.0.0)THEN
221 X = ((XCOORD(I+1)-XCOORD(I))*H(I+1))/(H(I+1)-H(I))
222 AREA = (H(I+1)/2.0)*X
223 NQUAT = 4
224 IF(H(I+1).GT.CINCRE)THEN
225 X2 = ((XCOORD(I+1)-XCOORD(I))*(H(I+1)-CINCRE))
226 / (H(I+1)-H(I))
227 1 AREA2 = ((H(I+1)-CINCRE)/2.0)*X2
228 AREA = AREA - AREA2
229 NQUAT = 1
230 ENDIF
231 GO TO 20
232 ELSEIF(H(I+1).GT.CINCRE.AND.H(I).LT.CINCRE)THEN
233 X = ((XCOORD(I+1)-XCOORD(I))*(H(I+1)-CINCRE))
234 1 / (H(I+1)-H(I))
235 AREA = (((H(I)+H(I+1))/2.0)*(XCOORD(I+1)-XCOORD(I)))-
236 1 ((H(I+1)-CINCRE)/2.0)*X
237 NQUAT = 5
238 GOTO 20
239 ENDIF
240 C
241 IF(H(I).GT.0.0.AND.H(I+1).LT.0.0)THEN
242 X = (((XCOORD(I+1)-XCOORD(I))*(H(I))))/
243 1 (H(I)-H(I+1))
244 AREA = (H(I)/2.0)*X
245 NQUAT = 6
246 IF(H(I).GT.CINCRE)THEN
247 X2 = ((XCOORD(I+1)-XCOORD(I))*(H(I)-CINCRE))

```

```

248      1      / (H(I)-H(I+1))
249      AREA2 = ((H(I)-CINCRE)/2.0)*X2
250      AREA = AREA - AREA2
251      NQUAT = 2
252      ENDIF
253      GO TO 20
254      ELSEIF(H(I).GT.CINCRE.AND.H(I+1).LT.CINCRE)THEN
255      X = ((XCOORD(I+1)-XCOORD(I))*(H(I)-CINCRE))
256      1      / (H(I)-H(I+1))
257      AREA = (((H(I)+H(I+1))/2.0)*(XCOORD(I+1)-XCOORD(I)))-
258      1      ((H(I)-CINCRE)/2.0)*X
259      NQUAT = 7
260      GO TO 20
261      ENDIF
262      C
263      AREA = ((H(I)+H(I+1))/2.0)*(XCOORD(I+1)-XCOORD(I))
264      NQUAT = 8
265      C
266      <0 CONTINUE
267      C
268      IF (AREA.LT.0.0)AREA = 0.0
269      C
270      SAREA(J,MSECT,K) = SAREA(J,MSECT,K)+AREA
271      25 CONTINUE
272      WRITE(6,750)SAREA(J,MSECT,K),NQUAT
273      DO 21 L = 1,NFIX
274      H(L) = H(L) - CINCRE
275      21 CONTINUE
276      TOAREA(MSECT,K)=TOAREA(MSECT,K)+SAREA(J,MSECT,K)
277      10 CONTINUE
278      WRITE(6,760)TOAREA(MSECT,K)
279      100 CONTINUE
280      101 CONTINUE
281      C
282      C      *****
283      C      This second main part reads in contour data and calculates
284      C      Constant Factors' using previously calculated Xsectn areas.
285      C      *****
286      C
287      WRITE(3,300)DATE
288      WRITE(3,310)
289      WRITE(3,340)
290      WRITE(3,320)
291      NSECT = NSECT + 1
292      DO 228 MSECT = 1,NSECT
293      IF (UPSTRM.EQ.'NO'.AND.MSECT.EQ.1)GO TO 228
294      IF (DNSTRM.EQ.'NO'.AND.MSECT.EQ.NSECT)GO TO 228
295      C
296      C      As each end area may (eg if UPSTRM=YES)require an extra set of
297      C      contour data,the assumed value of UP/DOWNSTRM is YES and the
298      C      extra'read in'is operated unless NO is specified.
299      C
300      C
301      C      SET K=1 I.E. USE ORIGINAL SURVEY DATA FOR CALCULATING CFAC
302      C
303      K=1
304      SUMVO = 0.0
305      SEDSUM = 0.0
306      SUMSIL = 0.0
307      C
308      104 READ(5,350)LINST
309      IF(LINST.EQ.' ')GO TO 104

```

```

310 C          READ IN ORIGINAL RESERVOIR DATA
311 C          READ(5,*) NCONTS
312 C          READ(5,*) BINCRE
313 C          READ(5,*) (SAUPP(J),J=1,NCONTS)
314 C
315 C
316 C          DO 108 M=1,NCONTS
317 C          IF(M.EQ.NCONTS)GO TO 109
318 C          CONTL(M) = CONT(M+1)
319 C
320 C          Incre could be activated if contours are unevenly spaced
321 C          this would require further program modification.
322 C          INCRE(M) = CONT(M)-CONTL(M)
323 C
324 C          GO TO 108
325 C          109 CONTL(NCONTS) = CONT(NCONTS) - BINCRE
326 C          108 CONTINUE
327 C
328 C          Assign top and bottom areas for each contour slice
329 C
330 C          DO 118 L = 1,NCONTS
331 C          IF(L.EQ.NCONTS)GO TO 119
332 C          SALOW(L) = SAUPP(L+1)
333 C          GO TO 118
334 C          119 SALOW(NCONTS) = 0
335 C          118 CONTINUE
336 C
337 C          Assign vertical increments between contours,water level and bottom
338 C
339 C          DO 122 N = 1,NCONTS
340 C          IF(N.EQ.1)THEN
341 C             INC(N) = WLCINC
342 C          ELSEIF(N.EQ.NCONTS)THEN
343 C             INC(N) = BINCRE
344 C          ELSE
345 C             INC(N) =CINCRE
346 C          ENDIF
347 C          122 CONTINUE
348 C          IF(NCONTS.GE.MNCONT)MNCONT=NCONTS
349 C
350 C          Calculate Original Volumes and hence Constant Factors
351 C
352 C          DO 129 J = 1,NCONTS
353 C          IF(MSECT.EQ.1)THEN
354 C             AO(J)=SAREA(J,MSECT,K)
355 C          ELSEIF(MSECT.GT.1.AND.MSECT.LT.NSECT)THEN
356 C             AO(J)=SAREA(J,MSECT,K)+SAREA(J,MSECT-1,K)
357 C          ELSEIF(MSECT.EQ.NSECT)THEN
358 C             AO(J)=SAREA(J,MSECT-1,K)*2
359 C          ENDIF
360 C          VO(J)=((SAUPP(J)+SALOW(J))/2)*INC(J)
361 C          CFAC(J)=VO(J)/AO(J)
362 C          SUMVO = SUMVO+VO(J)
363 C
364 C          CVOL(J,K)=CVOL(J,K)+VO(J)
365 C          129 CONTINUE
366 C
367 C          Optional Info to moniter file
368 C
369 C          IF(SWIT.EQ.0.0)GO TO 111
370 C          WRITE(6,210) LINST
371 C          WRITE(6,620)

```

```

372      WRITE(6,230)(CONTH(J),CONTL(J),SAREA(J,MSECT,K),
373      1SAREA(J,MSECT-1,K),AO(J),SAUPP(J),SALOW(J),VO(J),CFAC(J),
374      2J=1,NCONTS)
375      WRITE(6,240)SUMVO
376      111 CONTINUE
377      C
378      C
379      DO 199 K = 2,NYEARS
380      C      Normally there will only be 2 years data processed simultaneously
381      C
382      SEDXM=0.0
383      C
384      DO 117 J = 1,NCONTS
385      C
386      C      Calculate sum of end areas 'AOSEDX'
387      C
388      IF(MSECT.EQ.1)THEN
389      AOSEDX(J) = SAREA(J,MSECT,K)
390      ELSEIF(MSECT.GT.1.AND.MSECT.LT.NSECT)THEN
391      AOSEDX(J) = SAREA(J,MSECT,K)+SAREA(J,MSECT-1,K)
392      ELSEIF(MSECT.EQ.NSECT)THEN
393      C
394      AOSEDX(J) = SAREA(J,MSECT-1,K)*2
395      ENDIF
396      C
397      C      Multiply 'AOSEDX' by Constant Factor 'CFAC'.
398      C
399      SEDX(J) = CFAC(J)*AOSEDX(J)
400      SEDXM = SEDXM + SEDX(J)
401      C
402      CVOL(J,K)=CVOL(J,K)+SEDX(J)
403      C
404      117 CONTINUE
405      C
406      PCENT = 100.0-((SEDXM/SUMVO)*100.0)
407      SEDSUM=SUMVO-SEDXM
408      C
409      C      Write to results file(channel 3)
410      C
411      C
412      WRITE(3,340)
413      WRITE(3,250)LINST
414      C
415      DO 138 J = 1,NCONTS
416      IF(MSECT.EQ.1)THEN
417      NSLAST = 0.0
418      ELSE
419      NSLAST = INT(SAREA(J,MSECT-1,K))
420      ENDIF
421      IF (MSECT.EQ.NSECT) THEN
422      NSAREA=NSLAST
423      ELSE
424      NSAREA=INT(SAREA(J,MSECT,K))
425      ENDIF
426      SVO=VO(J)-SEDX(J)
427      WRITE(3,150)CONT(J),CONTL(J),NSAREA,NSLAST,AOSEDX(J),
428      1CFAC(J),VO(J),SEDX(J),SVO
429      138 CONTINUE
430      C
431      C
432      WRITE(3,340)
433      C      WRITE(3,200)SUMVO,SEDXM,SEDSUM,PCENT

```

```

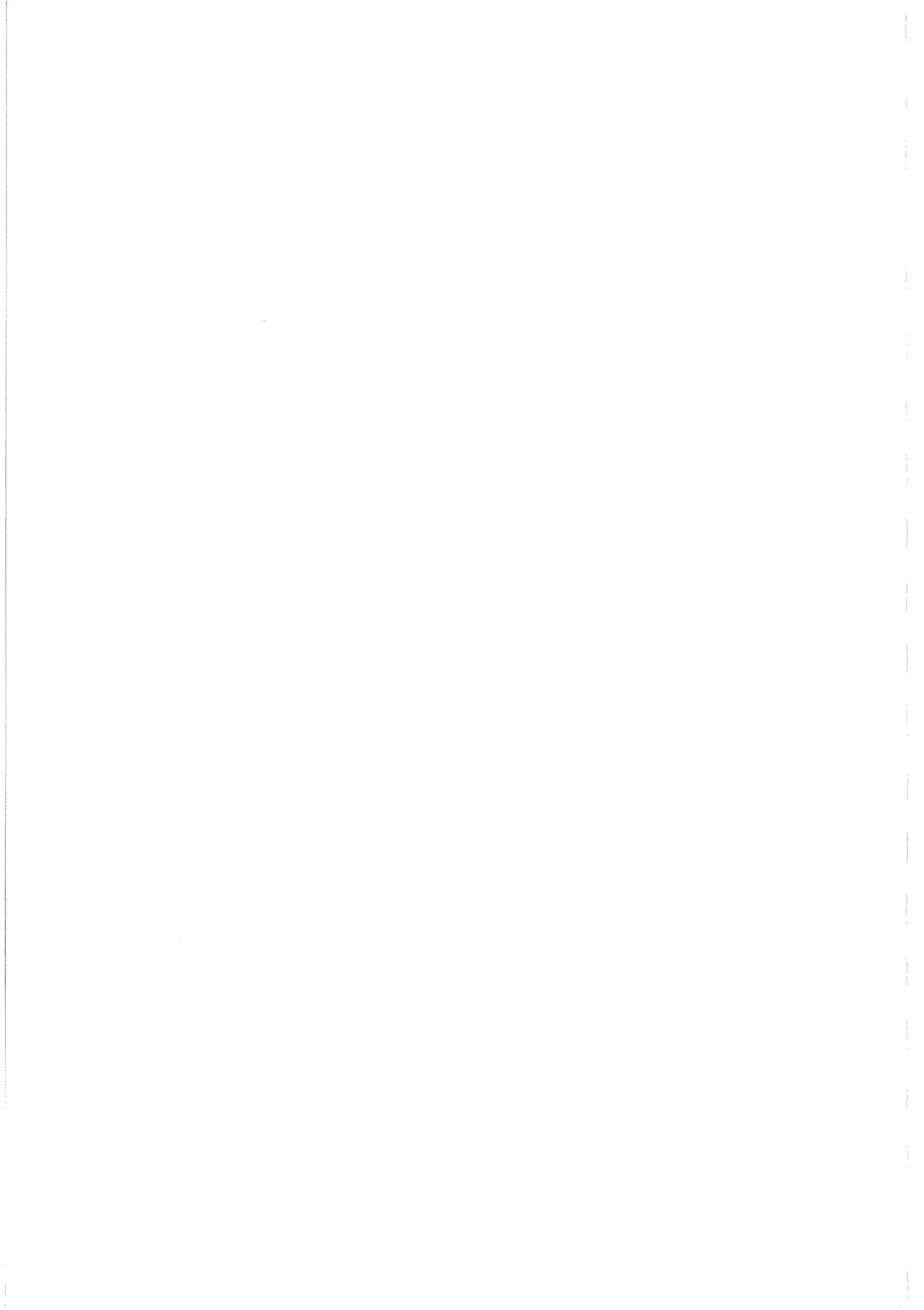
434 199 CONTINUE
435 C
436 SUMSEG = SUMSEG+SUMVO
437 TOTSED = TOTSED+SEDSUM
438 TSEDXM = TSEDXM+SEDXM
439 C
440 228 CONTINUE
441 C
442 C Check whether there are any further limbs in reservoir to be
443 C considered.If 'yes' then return to read more survey data.
444 C
445 IF(XXX)THEN
446 III = III - 1
447 XXX = .FALSE.
448 READ(1,*)NSECT
449 READ(1,350)UPSTRM
450 READ(1,350)DNSTRM
451 GO TO 33
452 ENDIF
453 C
454 TPCENT = 100.0-((TSEDXM/SUMSEG)*100.0)
455 WRITE(3,340)
456 WRITE(3,340)
457 WRITE(3,403)SUMSEG,TSEDXM,TOTSED,TPCENT
458 C
459 C Sum the reservoir volumes below each contour
460 C
461 DO 238 K=1,NYEARS
462 C
463 RUNTOT=0.0
464 C
465 DO 238 J=MNCONT,1,-1
466 RUNTOT=RUNTOT+CVOL(J,K)
467 WRITE(3,780)NDATE(K),CGNT(J),RUNTOT
468 238 CONTINUE
469 STOP
470 C
471 110 FORMAT(A119)
472 120 FORMAT(A116)
473 130 FORMAT(A120)
474 150 FORMAT(14X,F7.2,2X,F7.2,4X,I4,5X,I4,6X,F7.1,4X,F7.1,1X,
475 1F11.1,3X,F11.1,2X,F11.1)
476 200 FORMAT(73X,F10.1,1X,F13.1,F13.1,2X,F6.2)
477 250 FORMAT(/1X,A)
478 340 FORMAT()
479 341 FORMAT(///)
480 350 FORMAT(A)
481 402 FORMAT(16X,F11.1,2X,F11.1,2X,F11.1)
482 403 FORMAT(56X,'TOTAL RESERVOIR ',F12.1,2X,F11.1,3X,F12.1,2X,F6.2)
483 405 FORMAT(/5X,'CINCRE = ',F5.3)
484 600 FORMAT(/5X,'REFNAM = ',A)
485 660 FORMAT(/5X,'H(L) = ',5(F6.3,1X))
486 700 FORMAT(5X,'AREA = ',F10.4)
487 750 FORMAT(5X,'SAREA( RUNNING TOTAL ) = ',F11.4,6X,I2)
488 760 FORMAT(5X,'TOTAL XSECTN AREA = ',F11.2)
489 920 FORMAT(/2X,'MSECT = ',I3)
490 930 FORMAT(/2X,'J = ',I3)
491 300 FORMAT(1X,' SECTIONS UPPER LOWER END AREAS SU
492 1M OF CONSTANT DESIGN ',I4,' CHANGE IN % LOSS'
493 1)
494 310 FORMAT(1X,' U/S D/S CONTOUR CONTOUR D/S U/S END
495 1 AREAS FACTOR CAPACITY CAPACITY VOLUME OF')

```

```

496 320 FORMAT(33X,'[SQ.M] [SQ.M] AO [SQ.M] [C] [CU.M]
497 1 [CU.M] [CU.M] CAPACITY')
498 220 FORMAT(/)
499 210 FORMAT(/1X,A)
500 620 FORMAT(1H1///4X,'UPPER LOWER END AREAS SUM OF
501 1 CONTOUR SURFACE AREAS CAPACITY CONSTANT')
502 630 FORMAT(3X,'CONTOUR CONTOUR D.S U.S END AREAS
503 1 UPPER LOWER VO FACTOR')
504 640 FORMAT(5X,'[M] [M] [SQ.M] [SQ.M] AO [SQ.M] [S
505 1Q.M] [SQ.M] [CU.M] [CFAC]')
506 240 FORMAT(/56X,'VOLUME OF SEGMENT [CU.M] = ',F12.1)
507 230 FORMAT(4X,F7.2,4X,F7.2,3X,15,4X,15,6X,15,7X,17,9X,17,5X,F10.1,7X,1
508 14)
509 780 FORMAT(/5X,15,' VOLUME BELOW ',F7.2,' = ',F12.0,' CU.M')
510 END

```



APPENDIX 3

Contour slicing technique

A3.1 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.

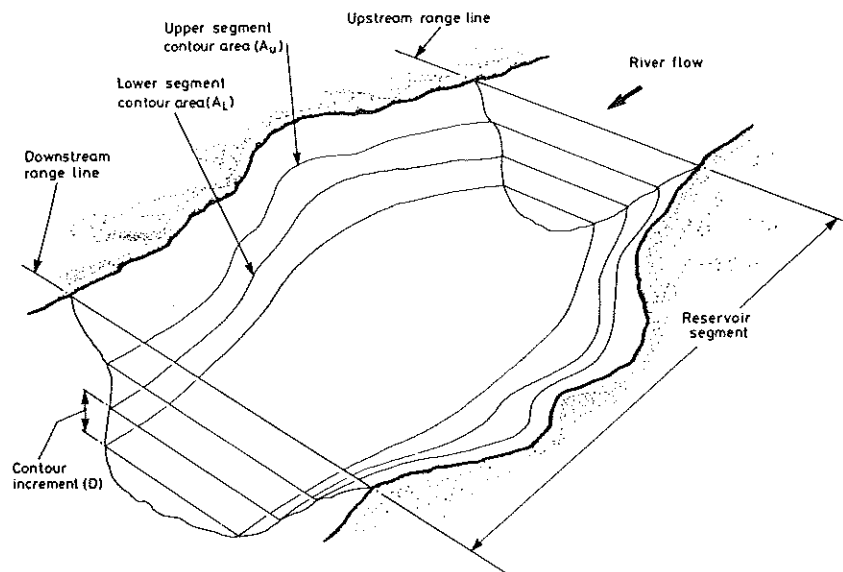
Segment volume the volume of part of a reservoir contained between two given cross-sections and below a defined contour.

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.



A3.2 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:

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

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

A3.2 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 4

### Prediction of the behaviour of a self-consolidating sediment

#### A4.1 SURVEY DATA

##### A4.1.1 Measurement of density

The figures referred to in this appendix immediately follow the text. During the reservoir surveys in the summer of 1983 measurements of bed density were taken using a density probe. This probe was either pushed into the bed on the end of a long pole or was lowered into the bed under its own weight by a rope and winch. The probe had two prongs, one emitted gamma rays and the other measured their intensity after attenuation by any intervening sediment, and so a measure of density was obtained.

The bed surface was arbitrarily taken as the point at which the density reading just started to increase, although the probe could only take accurate readings once it was a few centimetres into the bed.

The depth of penetration was taken as the vertical distance the rope or pole moved after the density reading had started to increase from its pure water value.

##### A4.1.2 Analysis of the density profiles

The density/depth data described above were used to plot a density against depth profile for each measuring point.

For each density profile the following information was available :

- A soil sample.
- Knowledge of the local conditions at that point, for example, whether it was above the original river bed.

With this information an attempt was made to understand the form of individual density profiles and the vast variation between them (specific bulk densities - defined in Section A4.2.1 - at 50 cm depth varying from 1.1 to 1.9).

The following pattern emerged. Measuring positions above the original river bed, gave the most varied density profiles and the highest specific bulk densities. The corresponding soil samples were found to contain high proportions of sand. Profiles taken at points away from the deepest part of a cross section were more regular with smaller bulk densities. The corresponding soil samples comprised almost entirely silt and clay particles. Since the principal purpose of this study is to determine density changes through a consolidating layer of soil, profiles whose soil samples were largely composed of sand were discounted. Details of the profiles obtained in each reservoir branch are as follows :

#### Kindaruma

- of the 8 density profiles obtained, one corresponded to a sandy soil sample and was discounted, the remaining 7 were averaged to obtain the plot shown in Fig 4.1.

#### Kamburu, Tana Branch

- of the 15 samples taken, 6 were very sandy and one was taken from a section across a side branch. The remaining 8 density profiles were averaged and plotted in Fig A4.2.

#### Thiba Branch

- of the 11 density profiles, 3 were taken at the deepest part of a cross section and their form appeared to indicate the presence of a high proportion of sand. However the soil samples taken from the surface at these positions comprised mainly clay or silt. The 3 profiles were nevertheless discounted on the assumption that the surface clay was overlying a sandy soil. One further profile was discounted because the soil sample was sandy. The remaining 7 profiles were averaged and plotted in Fig A4.2.

#### Masinga - All branches

- of 23 samples taken only one was found to be sandy. Also one profile seemed to indicate only a thin layer of sediment

over the original ground soil. This probably arose because the section (MAIO) is set across a tight constriction in the flooded valley. The 21 remaining profiles are plotted as averages for the Tana, Thika and joint branches in Fig A4.3.

#### A4.1.3 Discussions of these results

In the six averaged density profiles obtained, a clear trend can be seen : a rapid rate of increase of density in the top 10 cm of the soil is followed by a more steady rise below that depth where densities in the 1.3 - 1.5 range were measured. It is not clear, however, whether the rapid rise represents actual density increases or whether it is due to edge effects as the probe enters the bed.

Within the overall trend two other effects can be seen. Firstly two of the reservoir branches, the Tana branch of both Kamburu and Kindaruma reservoirs, have reservoirs upstream which have reduced deposition rates in recent years. Both show higher bed densities. These profiles probably represent sediment which has been consolidating over several years without appreciable quantities of fresh sediment being added.

Secondly the Thiba branch of Kindaruma reservoir has a different form of density profile than any of the other reservoir branches. Instead of a quick rise for a small depth followed by a gradual rise, the density rises more continuously. This seems to be due to the different sediment entering this branch, which is carried in the Thiba river, whose water passes through an irrigation scheme.

Many of the density profiles showed smaller variations away from their overall trend and this can be seen on the density profile from the Thiba branch of Kamburu. It is possible that they represent the different soil properties or rates of deposition through a year, however some of the density profiles from Masinga reservoir (which is only 2 years old) have up to 4 such 'bumps'.

## A4.2 A THEORETICAL COMPUTER MODEL

### A4.2.1 The basis for the model

In order to understand the trends shown in the density profiles obtained from the Tana River reservoirs, a comparison was made with theoretical predictions. Results have been published on research into the consolidation of loose clays and silts under their own weight, for example Been and Sills<sup>(11)</sup>. However, no simple theoretical model is available which can predict the behaviour of a continuously accreting and consolidating bed of clay and silt. To explain how the present model is derived it is necessary to introduce some common soil mechanics terms

#### Voids ratio, e

Voids ratio is defined for a completely saturated soil as:

$$e = \frac{\text{volume of water}}{\text{volume of solids}} \quad (1)$$

#### Permeability, k

Permeability provides a measure of the resistance of soil to the passage of water. Permeability is defined as:

$$k = \frac{v}{i} \quad (2)$$

where  $v$  = artificial flow velocity of the water

$$= \frac{\text{volumetric flow rate}}{\text{total area (including both particles and pores)}}$$

$i$  = hydraulic gradient

$$= \frac{\text{difference in head between 2 points}}{\text{distance between the points}} \quad (3)$$

$$= \frac{\Delta h}{\Delta s}$$

Permeability is measured in units of velocity, m/s.

#### Excess Pore Water Pressure, $u$

Excess pore water pressure is the pressure of water in the soil voids in excess of hydrostatic pressure.

#### Total and Effective Stress, $\sigma$ and $\sigma'$

Total stress is the stress acting on the soil; if a layer of soil in a reservoir bed were to be replaced by a rigid impermeable surface then the pressure on that surface in excess of hydrostatic pressure would be the total stress. The soil supports the stress partly by the excess pore pressure,  $u$ , and partly by the forces between the soil grains. This inter-particle stress is termed the effective stress. The following equation summarises the basic relation:

$$\sigma = \sigma' + u \quad (4)$$

#### Specific Bulk Density

Specific bulk density is defined as:

$$\frac{\text{Bulk density of the soil}}{\text{Density of Water}} \quad (5)$$

To develop a model which can approximately predict the behaviour of a bed of self-consolidating soil, 3 simplifying assumptions are made:

- that there is a unique relationship between the voids ratio and the permeability for a particular soil, whatever its history, see Fig A4.4
- that there is a similar unique relationship between the voids ratio and the effective stress, see Fig A4.4.
- that the bed of consolidating soil can be considered to be made up of layers, each with a certain voids ratio (and

therefore unique values of  $k$ ,  $\sigma'$  and density) and pore pressure. This is shown diagrammatically in Fig A4.5.

The flow of water out of layer  $j$  and into layer  $(j + 1)$  in Fig A4.5 can be taken approximately as :

$$v_j = \text{Artificial velocity of water leaving layer } j$$

$$= \frac{k_j (U_j - U_{j+1})}{x_j \gamma_w} \quad (6)$$

where  $\gamma_w$  = specific weight of water.

This is derived from equations (2) and (3) where

$$\Delta h = \frac{(U_j - U_{j+1})}{\gamma_w} \quad (7)$$

and

$$\Delta s = x_j \quad (8)$$

After a short timestep,  $\Delta t$ ,  $x_j$  has changed slightly so that its new value becomes:

$$(x_j)_{\text{new}} = (x_j)_{\text{old}} - (V_j - V_{j-1}) \Delta t \quad (9)$$

The total quantity of soil in the layer has not changed so a new voids ratio can be found because

$$(e_{j+1}) \text{ is proportional to } x_j \quad (10)$$

Therefore,

$$e_j = \frac{x_j (1 + e_o)}{x_o} - 1 \quad (11)$$

where  $e_o$  and  $x_o$  are the initial conditions.

Density and voids ratio are clearly related for a given soil, the function may be expressed as:

$$\text{Specific bulk density} \frac{G_s + e}{1 + e} \quad (12)$$

$$\text{where } G_s = \frac{\text{density of solids}}{\text{density of water}} = \text{specific gravity of solids} \quad (13)$$

The effective stress and permeability of a soil layer with a given voids ratio can be determined on the basis of the assumed relations

$$\sigma' = \text{function}(e) \quad (14)$$

$$\text{and } k = \text{function}(e) \quad (15)$$

Also, the total stress at any layer may be found by integrating the densities of all layers above it, and multiplying by  $g$  ( $=9.81 \text{ m/s}^2$ ). The new pore pressures may then be determined by rewriting equation (4) as:

$$u = \sigma - \sigma' \quad (16)$$

Thus, by applying equations (6) to (16) a new set of pore pressures can be determined after the passage of a small time interval.

To operate the model suitable boundary conditions must be selected. The upper boundary conditions, where the deposition of fresh sediment is occurring, is set by two parameters; firstly, the initial voids ratio,  $e_0$  and secondly the water pressure at the surface,  $U_0 = 0$ . The lower boundary condition can be taken as a rigid impermeable surface, that is  $V = 0$ . Whether seepage is, in fact, negligible will depend on the soil below the deposited bed. If it were sand it would be unsafe to regard it as impermeable.

#### A4.2.2 Using the model to make density predictions

To obtain a reasonably accurate solution using this method a vast number of calculations is required. The analysis was, therefore, undertaken by computer. The computer program requires the following information :

- the form of the  $k : e$  function
- the form of the  $\sigma' : e$  function
- the rate of soil deposition in  $\text{kg/m}^2/\text{yr}$
- the voids ratio of the soil at deposition ( $e_0$ )

- the age of the reservoir at which the simulation stops.

The  $k : e$  and  $\sigma' : e$  functions were obtained from Been and Sills<sup>(11)</sup>, Figs 14 and 16. However, their data include values of  $e$  ranging from 3 to 16, whereas, in the present study mean bulk specific densities in the range 1.2 to 1.5 need to be considered (that is values of  $e$  between 2.3 and 7). There is therefore insufficient information available to determine values of  $e$ ,  $k$  and  $\sigma'$  in the lower layers of the bed where the simulation gave values of  $e$  as low as 0.8 in some circumstances. The values adopted in such cases were based on extrapolation of the published data and should be treated with caution.

Figs 14 and 16 in Been and Sills<sup>(11)</sup> are presented in Fig A4.4. Two sample functions have been fitted to the original data points on both the permeability and effective stress plots. These have the following mathematical forms :

$$k = 0.1 \times 10^{(\log_{10} e - 2.5)/0.3} \text{ m/s}$$

$$k = 10^{(\log_{10} 3 - 2.5)/0.3} \text{ m/s}$$

and  $\sigma' = 3/e^2 \text{ KN/m}^2$

$$\sigma' = 3/(e-2)^2 \text{ KN/m}^2$$

Since the precise rate of soil deposition is unknown, a range of suitable values was adopted. Assuming that the layer of soil increases in thickness by about 0.5 m/year and has a mean specific bulk density of about 1.65 then the rate of deposition would be about 500 kg/m<sup>2</sup>/yr; the values 200, 500 and 1,000 kg/m<sup>2</sup>/yr were, therefore, applied.

The initial specific bulk density from the density probe measurements appears to be 1.02, but this merely reflects the first noticeable increase in density from 1.0. It is clearly impossible to make a reasonable estimate of the initial voids ratio from this. A wide range of possibilities was, therefore, investigated by applying values of  $e_0$  of 4, 10 and 20.

The reservoirs under study range in age from 2 to 15 years. The computer simulation was applied over periods of 1, 3 and 10 years.

#### A4.2.3 The results of the computer simulation

The following set of conditions was adopted for the 'standard' case:

$$k = 0.1 \times 10^{(\log_{10} e - 2.5)/0.3} \text{ m/s}$$

$$\sigma' = 3/e^2 \text{ KN/m}^2$$

$$\text{rate of deposit} = 500 \text{ kg/m}^2/\text{yr}$$

$$\text{initial voids ratio} = 10$$

$$\text{age of reservoir} = 3 \text{ years}$$

After running the simulation for this set of conditions one quantity at a time was varied keeping the rest at their standard values. The results are plotted in Figs A4.6, A4.7, A4.8, A4.9.

It can be seen immediately that the trends shown in the observed reservoir density profiles are matched by those of the simulation, despite the uncertainty in choosing its input. This provides support for the use of such a model despite the important simplifications which have been incorporated.

Varying the inputs to the simulation produces effects which can largely be understood in terms of physical processes. Firstly, an increase in the rate of deposition for a given permeability in the surface layer, results in a reduction in the mean rate of consolidation and, therefore, the mean bulk density. Secondly, an increase in the age of the deposit results in relatively lower densities in the upper sediment layers. This arises because water seeping from lower layers enters the upper layers causing a reduction in their net rate of water loss and, consequently, in their rate of consolidation. Thirdly, an increase in initial voids ratio produces larger voids ratios at all depths although this has a negligible effect for values of  $e_0$  greater than 10 except in the top 20 cm. Finally, changes in the functions for both permeability

and effective stress cause changes in the density profile; an increase in permeability for a given  $e$  allows more rapid consolidation and so produces higher densities, while an increase in effective stress for a given  $e$  implies that the soil structure is relatively stronger and that consolidation will, therefore, proceed at a slower rate for a given overburden.

#### A4.3 CONCLUSIONS AND RECOMMENDATIONS

##### A4.3.1 Conclusions

The depth to which the density readings were taken is only a small fraction of the total depth of the sediment layer. Furthermore, the theoretical model is based on two unknown functions; those for  $k$  and  $\sigma'$ . Consequently no firm conclusions can yet be reached about the general behaviour of sediment deposits. Therefore, for the present, the analysis of the echo-sounder survey data must be based on predictions using the empirical work of Lane and Koelzer<sup>(6)</sup> or Trask<sup>(7)</sup>.

The numerical model described has, however, produced some encouraging results which suggest that accurate predictions of the behaviour of reservoir deposits may be possible in due course. Close agreement was found between observed soil densities and those obtained from the computer simulation in the two cases in which the rate of deposition was relatively constant and for which suitable input values could be estimated.

##### A4.3.2 Recommendations

For the further development of such a numerical model and the accurate analysis of reservoir survey data, more field measurements are required.

- (i) Density profiles through the full depth of a bed of consolidating sediment should be obtained so that simulation results can be verified more comprehensively.

- (ii) Borehole samples from the reservoir bed should be taken
  - (a) to examine possible changes in particle size and determine whether there is sand in the bed,
  - (b) to verify the depth of the sediment deposit and,
  - (c) to provide information on the soil just below the deposits.
- (iii) A series of density measurements should be taken across each reservoir section to identify clearly any lateral variations in sediment particle size and locate any areas of sand.
- (iv) Pore pressure measurements are required so that the relationship between effective stress and voids ratio can be determined by calculating the total stress as the integral of density with depth and applying equation (4). The pore pressure profile can also be checked against computer predictions.
- (v) Direct measurements of permeability in a consolidating soil layer are required to establish the relationship between permeability and voids ratio.
- (vi) An investigation of the bottom boundary condition is required as indicated at the end of section A4.2.1. Borehole samples such as those required for section (ii) above will give a particle size distribution of the material in the original reservoir bed soil. If the soil is found to be high in clay it will not be inflexible so Young's modulus must also be found; however this pore pressure does not have a unique value since it varies with reservoir level.

Once this field work is completed a check of the theoretical model can be made, and so eventually we aim to:

- be able to predict future bed levels of a reservoir
- calculate the mass of soil deposited between two surveys. This is not possible at present because the soil on the surface at the first survey settle an unknown distance by the next survey.

However our more short term aims are to:

- compare the mean density predictions with those of Lane and Koelzer;
- determine how many bed density profiles are required to give accurate information on the bed consolidation for a reservoir;
- determine the accuracy of our computer model.

At present the computer simulation can only model a continuous rate of deposition and not the conditions in a reservoir branch in which deposition rates are greatly reduced by a recently impounded reservoir upstream. So, initially, the bed density profiles from only Masinga reservoir and the Thiba branch of Kamburu can be compared to profiles computed using the simulation. In these examples the ages of the reservoirs are known, a reasonable estimate of the initial voids ratio may be taken as  $e_0 = 6$ , and the standard functions selected for  $k$  and  $\gamma$  give realistic results. Only the rate of deposition is unassigned. Close agreement is found between the simulated and observed density profiles in these reservoirs if the rate of deposition is taken as  $600 \text{ kg/m}^2/\text{yr}$  in Masinga and  $300 \text{ kg/m}^2/\text{yr}$  in Kamburu, Thiba branch. See Figs A4.2 and A4.3.

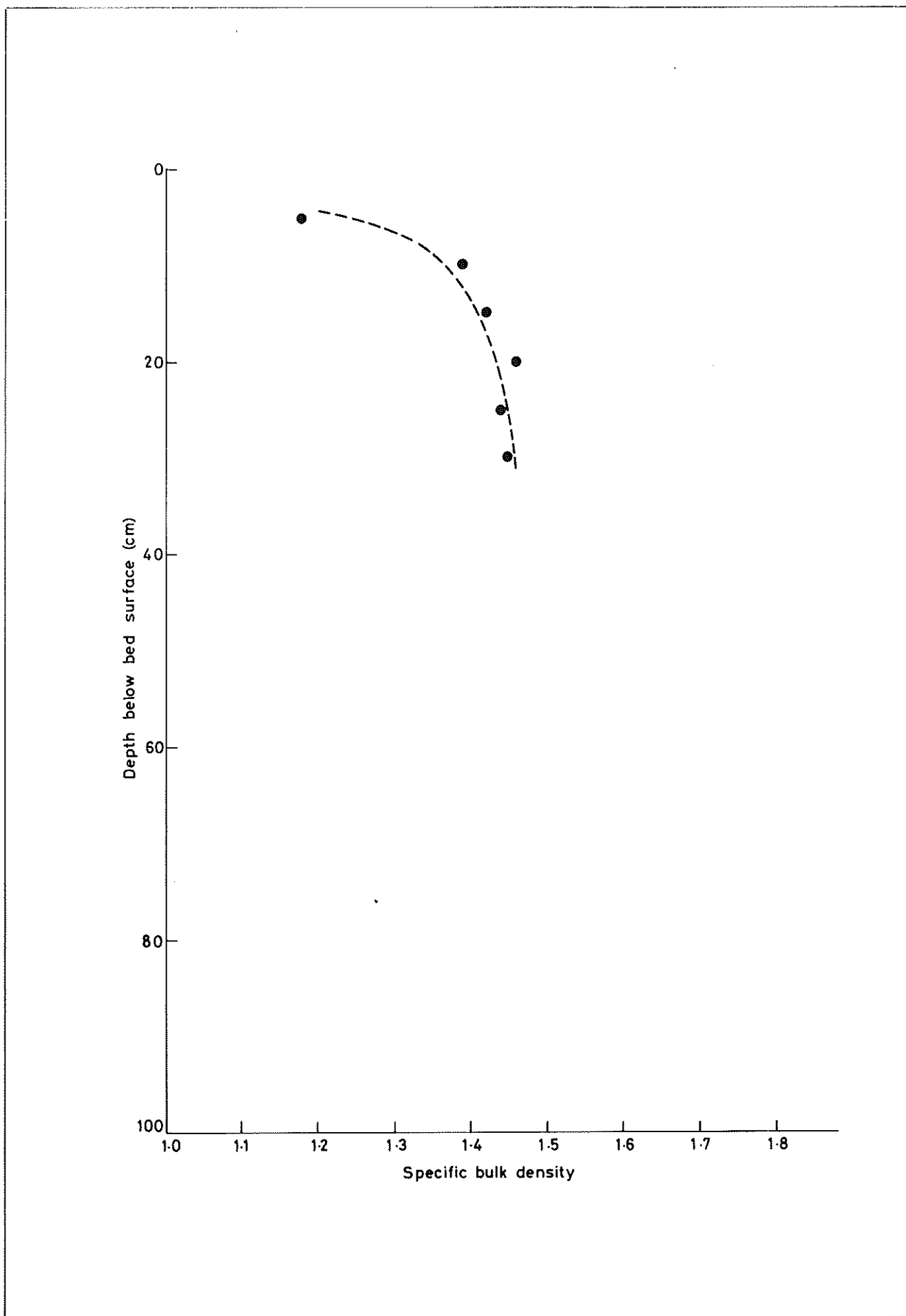


Fig A4.1 Kindaruma Reservoir bed density profile

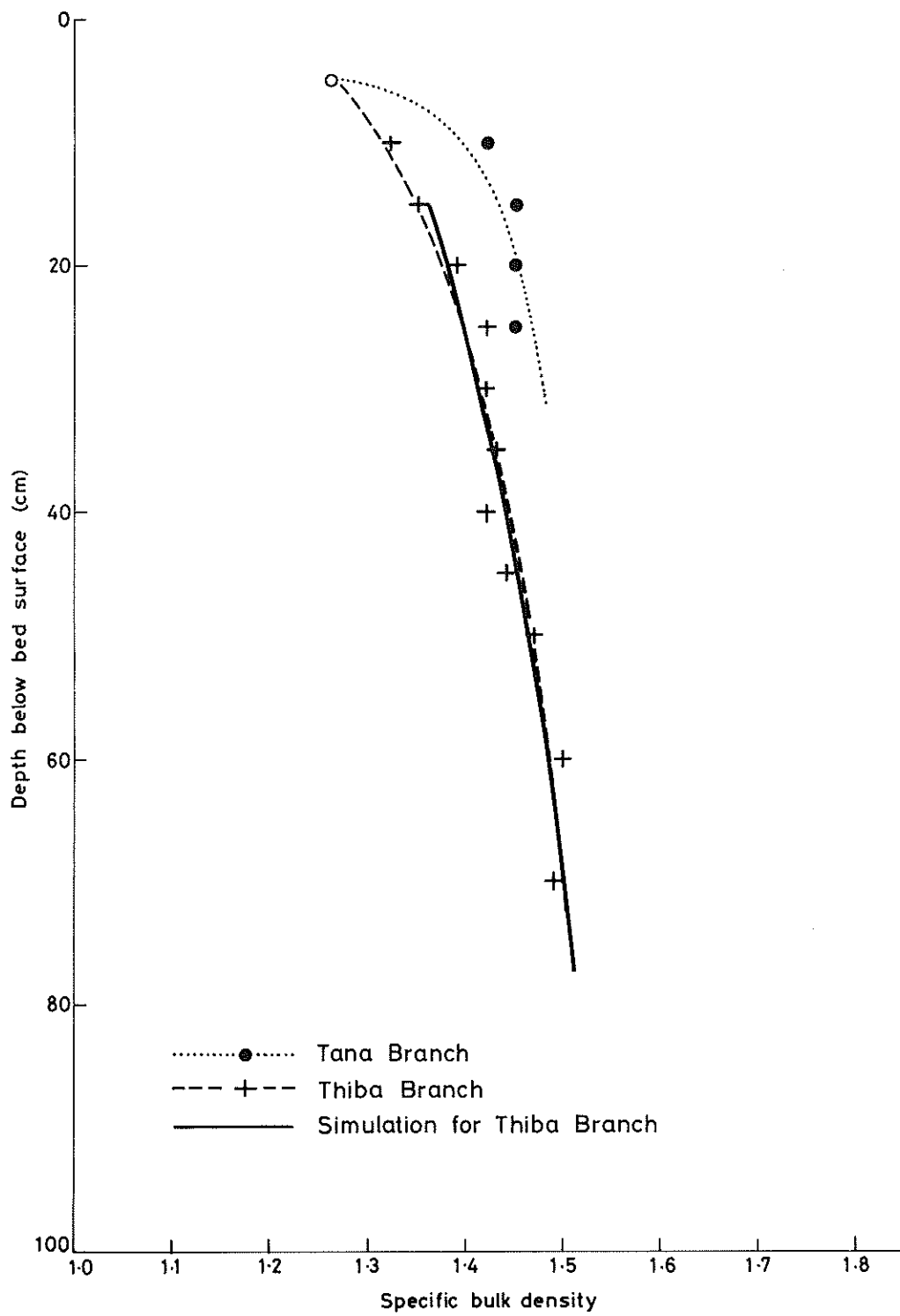


Fig A4-2 Kambara Reservoir bed density profiles

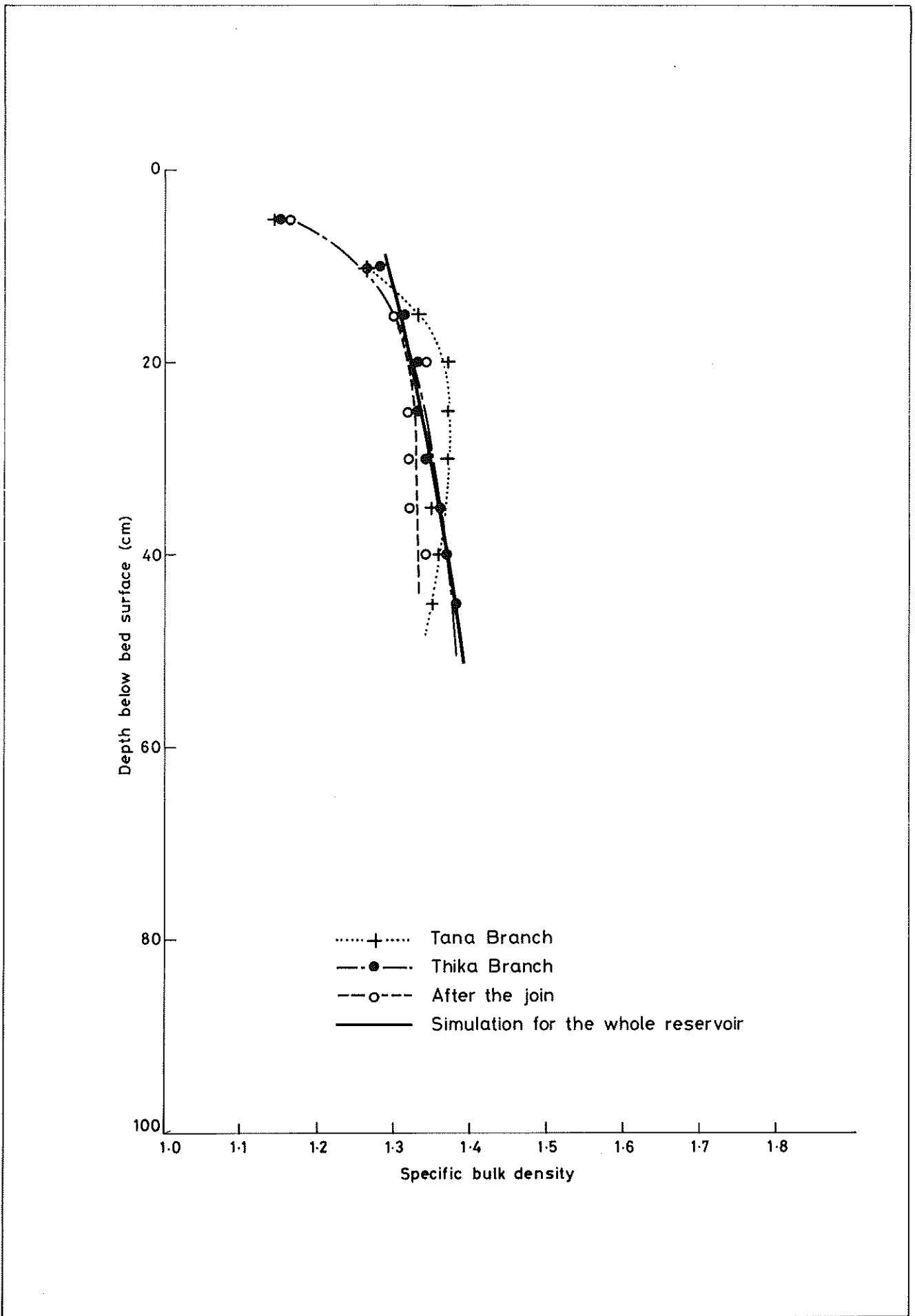


Fig A4-3 Masinga Reservoir bed density profiles

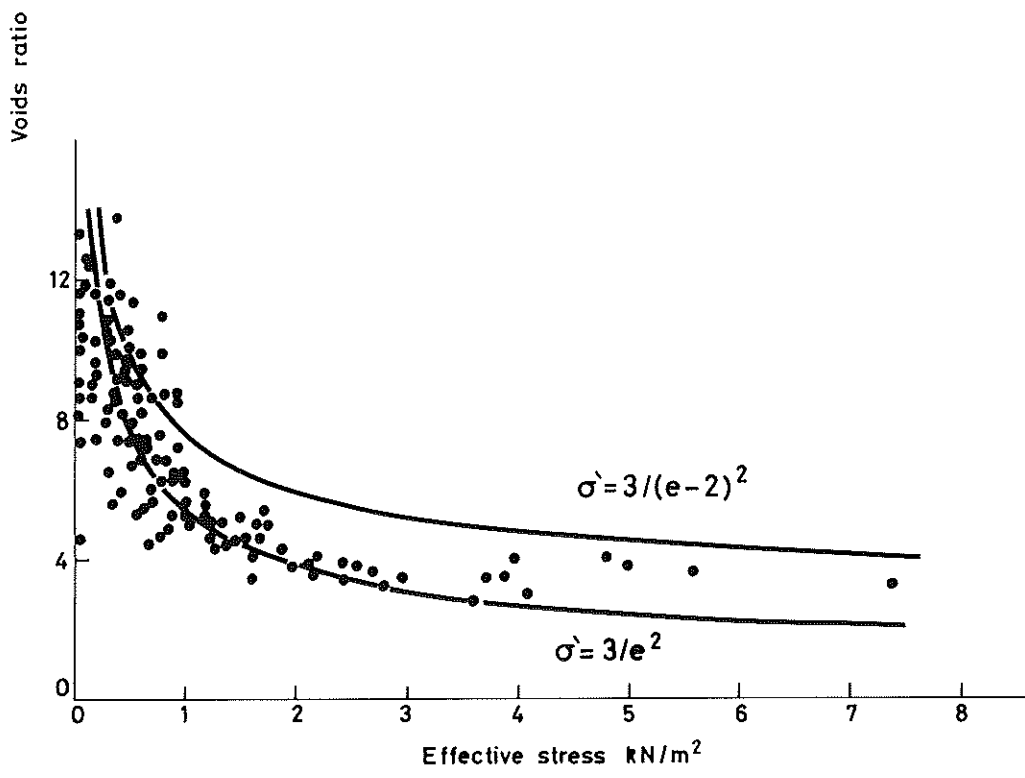
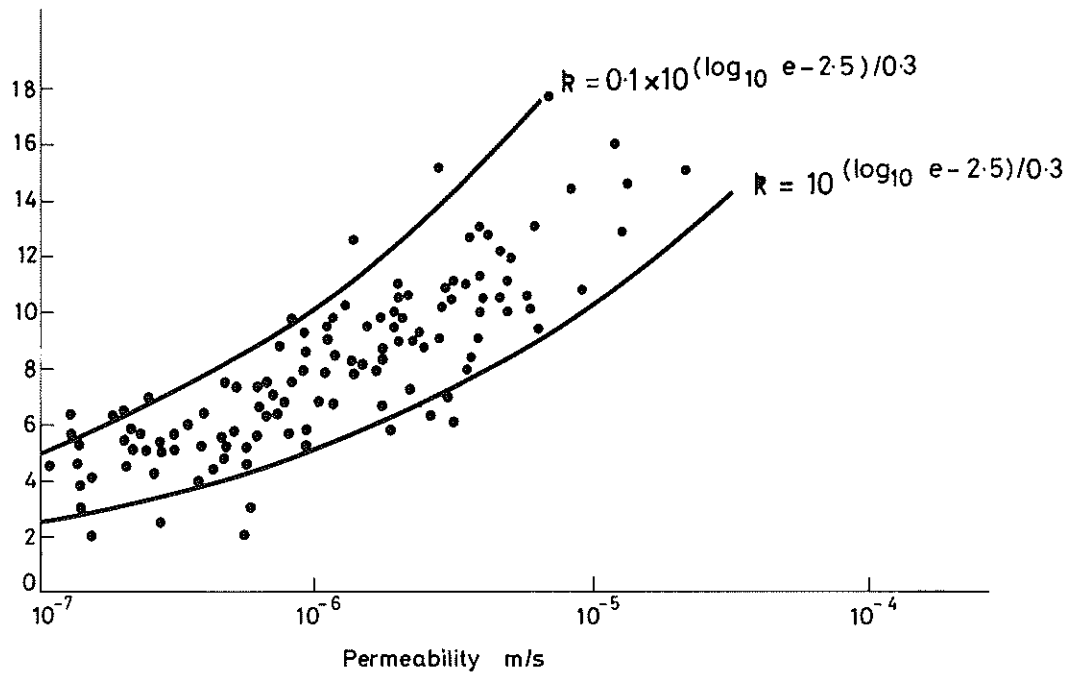


Fig A4.4 The permeability and effective stress functions

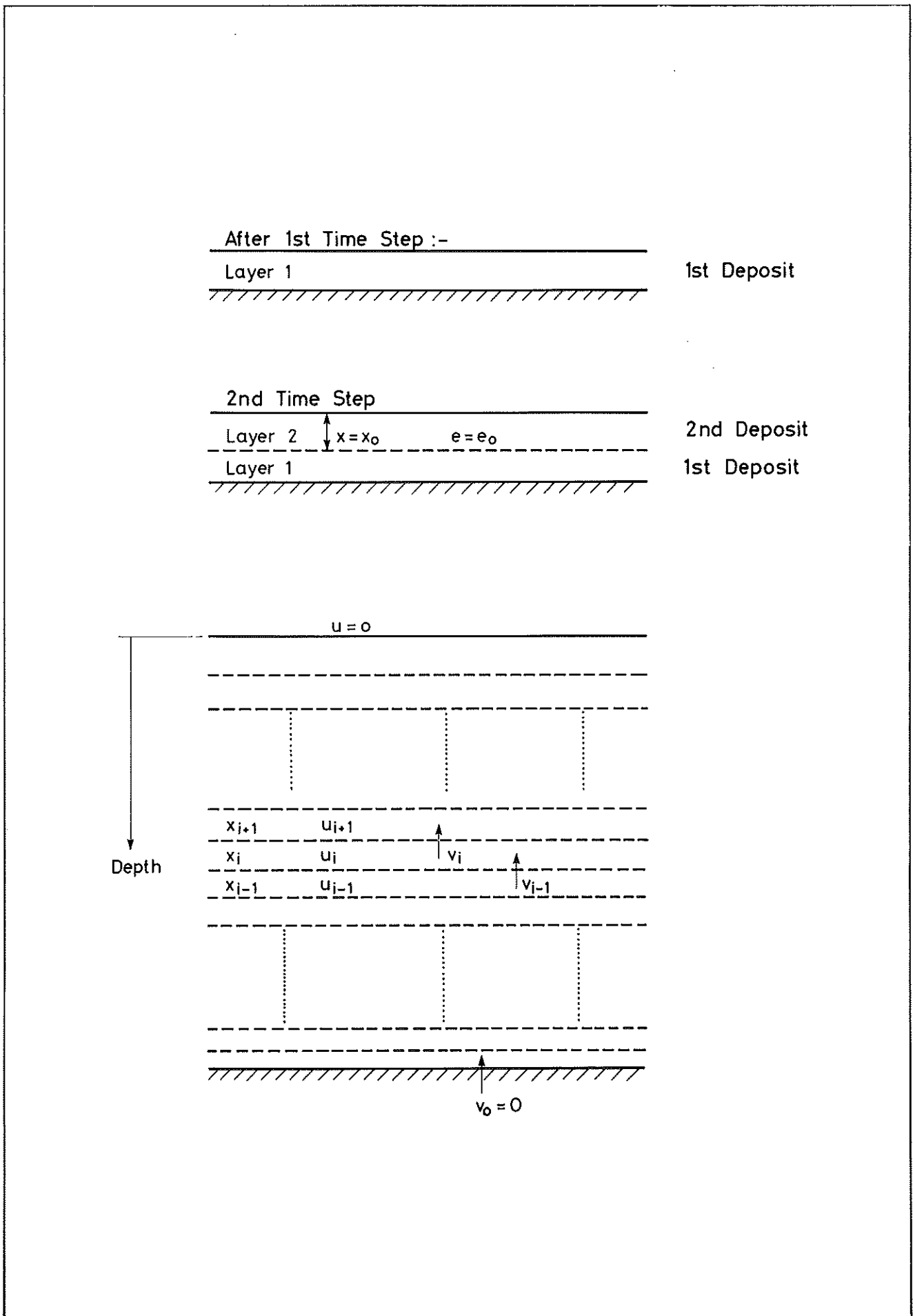


Fig A4.5 Splitting the reservoir bed into layers

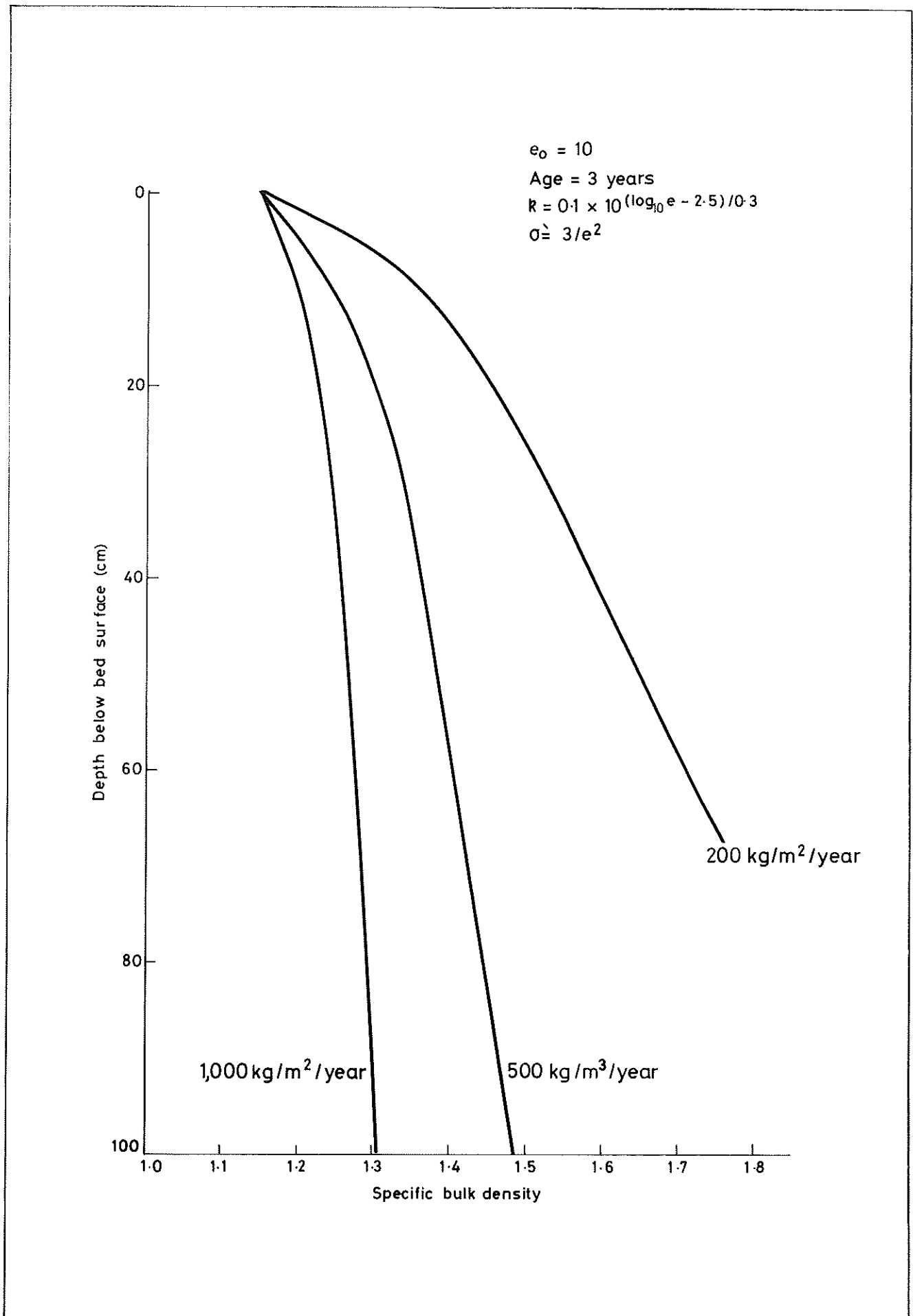


Fig A4.6 Results of simulation, varying deposition rate

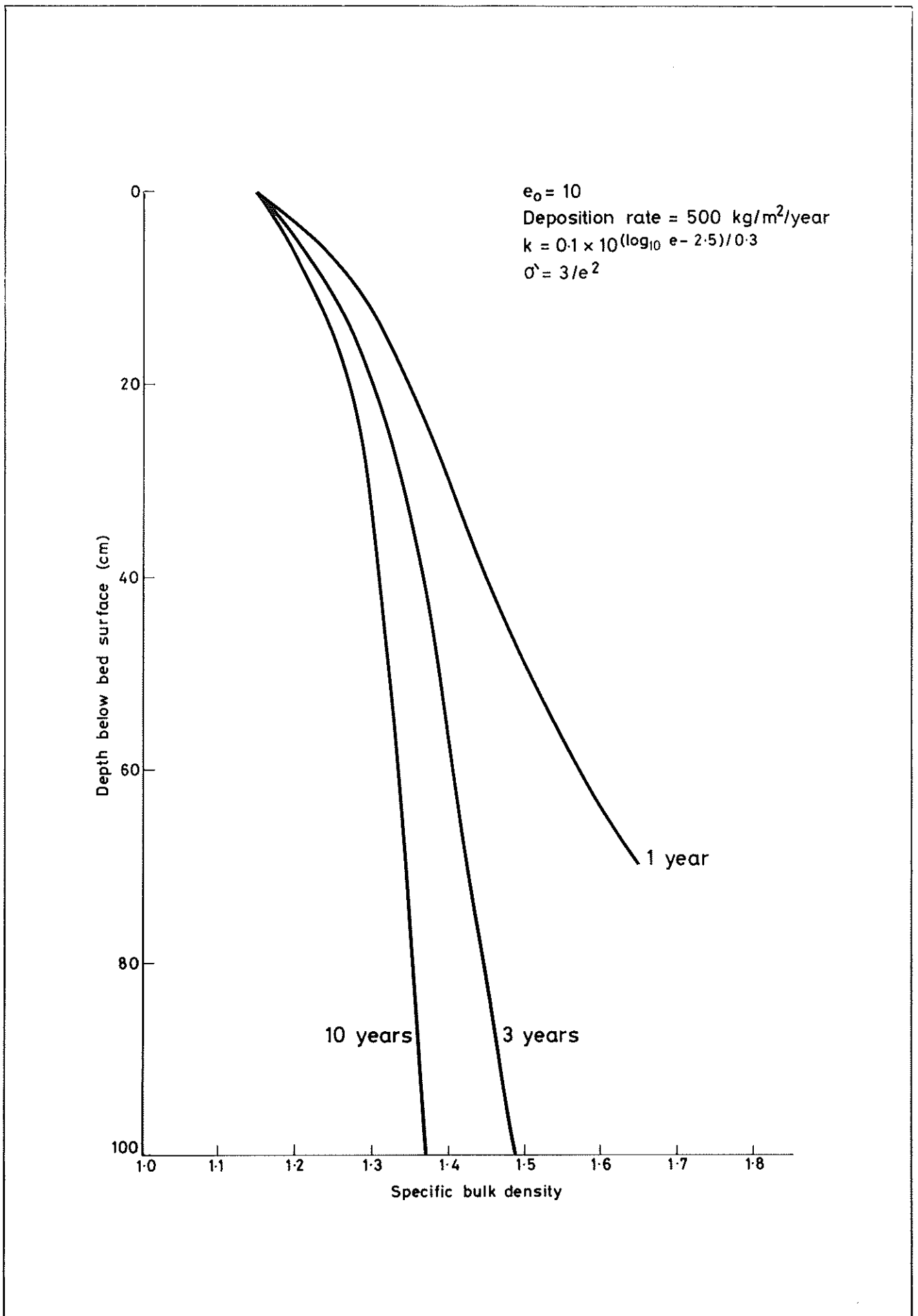


Fig A4-7 Results of simulation, varying deposit age

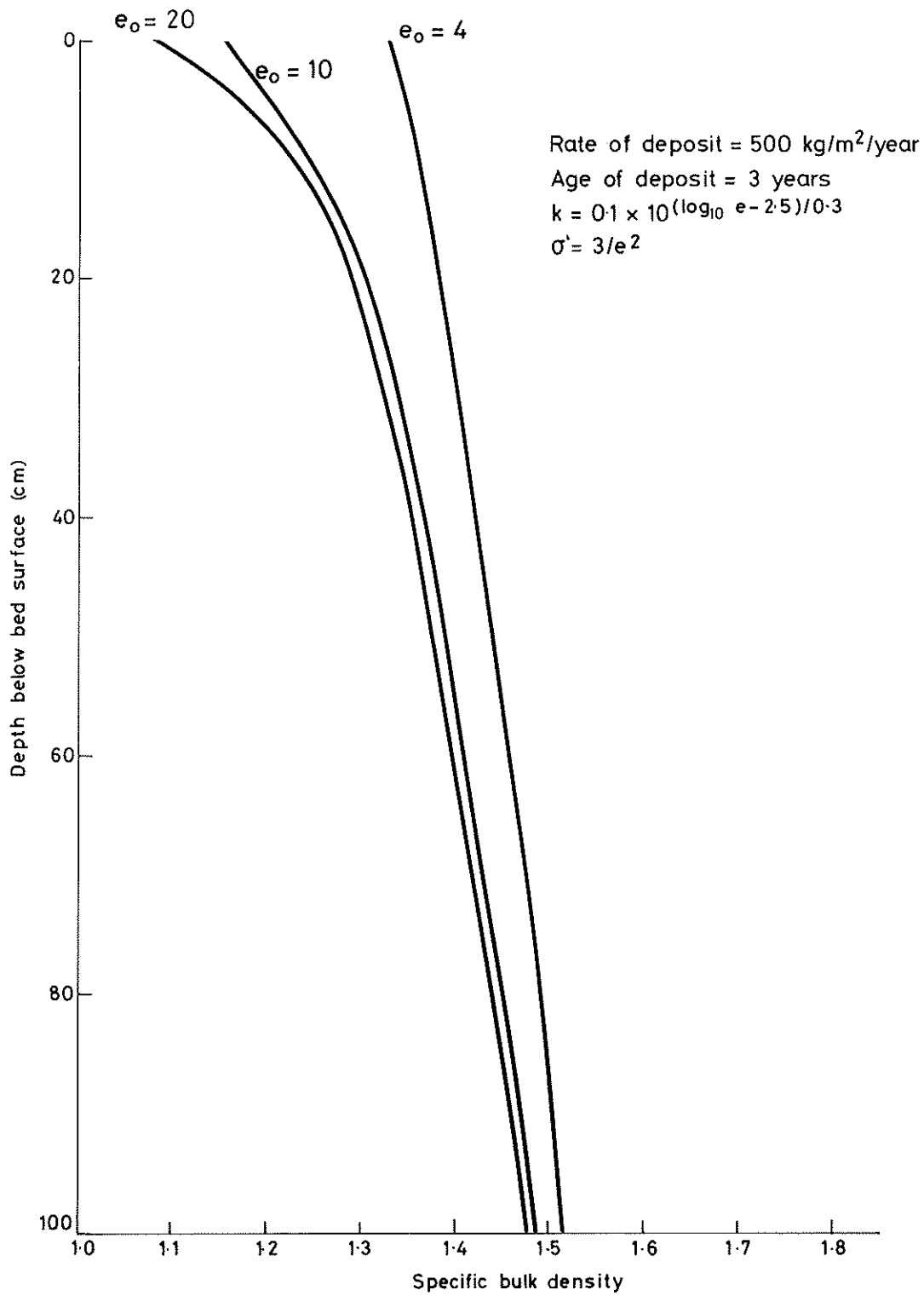


Fig A4.8 Results of simulation, varying initial voids ratio

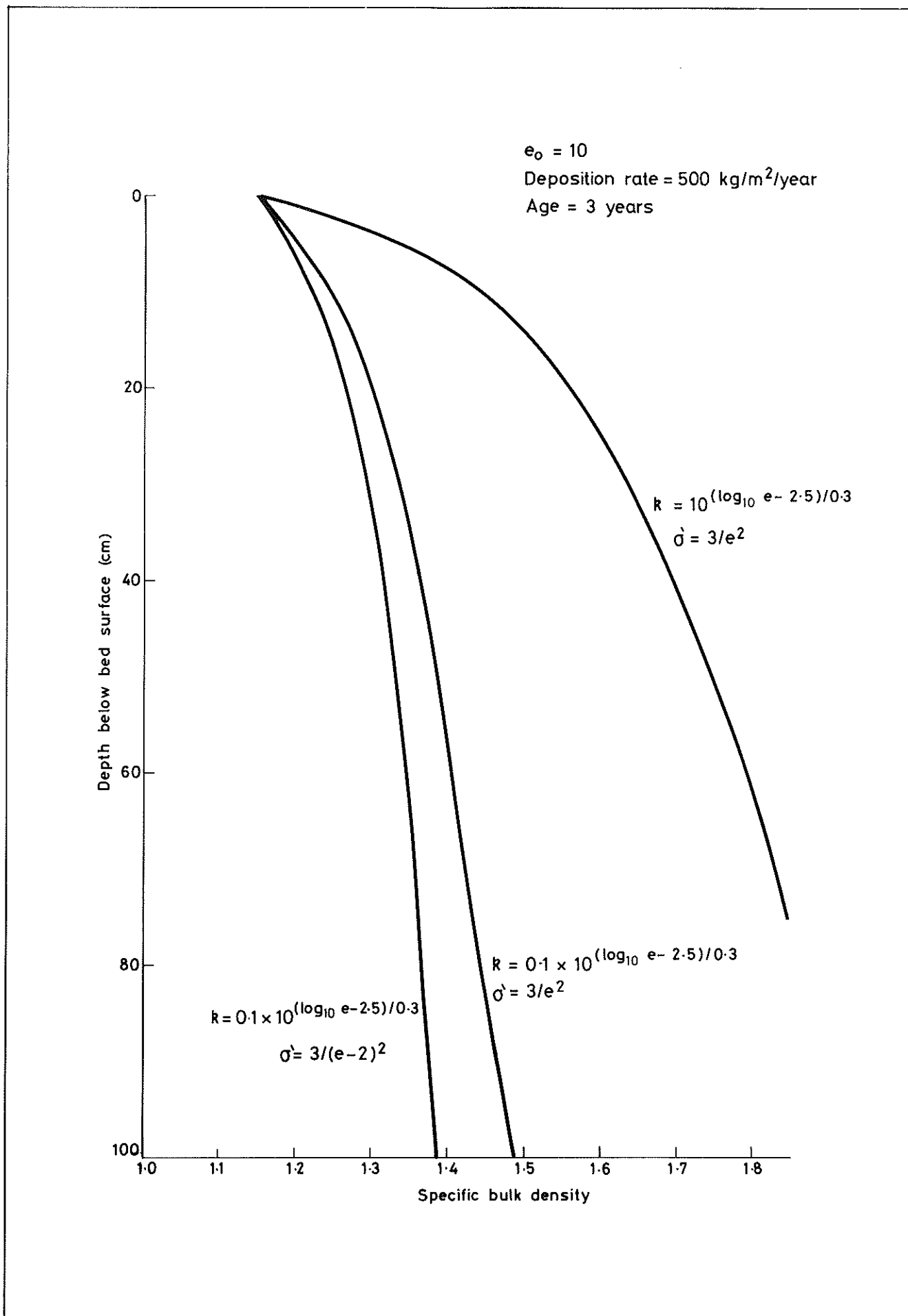


Fig A4-9 Results of simulation, varying the permeability and effective stress functions



## Tables

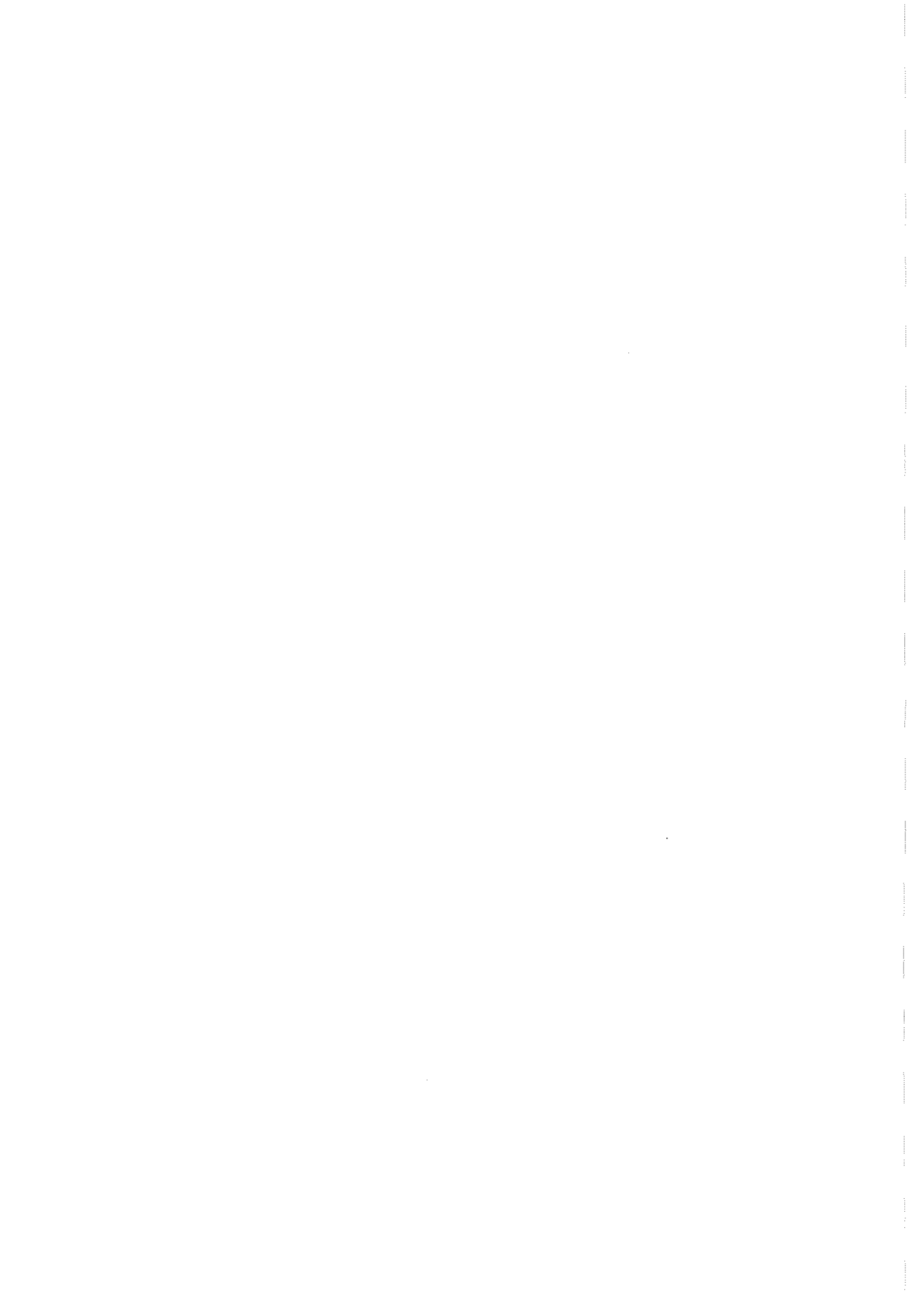


TABLE 1 - Kindaruma reservoir survey data - June/july 1983

Section K1

Length of Section = 230.8m

Distance	Level	Distance	Level	Distance	Level
0	780.80	88	779.30	174	778.70
19	780.10	92	779.60	181	778.80
24	779.80	99	779.20	189	778.50
31	779.60	106	779.30	197	778.10
39	779.40	114	779.00	205	777.30
46	779.40	123	778.30	212	776.70
54	779.30	135	778.00	219	776.30
61	779.60	143	778.30	222	775.80
68	780.40	151	778.50	224	777.70
76	779.00	159	778.60	227	780.70
83	779.80	167	778.70		

Section K2

Length of Section = 301.4m

Distance	Level	Distance	Level	Distance	Level
0	781.90	109	775.40	228	777.60
3	780.80	116	775.60	236	777.80
8	779.20	124	775.80	241	778.10
13	779.10	134	776.20	247	778.30
19	779.10	142	776.40	251	778.60
26	779.10	151	776.60	254	778.50
33	779.30	159	776.80	260	778.80
41	779.30	167	777.10	266	779.20
50	779.20	177	777.30	272	779.70
58	778.20	184	777.50	277	780.00
65	777.40	192	777.60	281	780.30
73	776.40	200	777.40	288	780.50
80	775.30	207	777.20	295	780.70
87	775.10	212	777.00	301	781.20
95	775.10	214	777.50		
102	775.30	220	777.40		

Section K3

Length of Section = 386.9m

Distance	Level	Distance	Level	Distance	Level
2	781.50	96	778.30	282	775.90
3	781.20	104	778.20	293	776.00
5	780.70	111	778.00	301	776.00
9	780.40	119	777.70	310	776.00
11	780.20	129	777.30	318	776.20
14	780.00	139	776.70	324	776.70
18	779.60	146	776.70	332	778.10
23	779.10	159	776.70	340	778.60
28	778.50	169	776.70	348	779.20
33	778.20	182	776.90	355	779.30
40	778.20	194	777.20	362	779.60
48	778.20	203	777.40	365	779.30
54	778.50	215	777.40	368	779.60
61	778.40	226	777.60	372	779.90
67	778.40	237	777.30	375	780.10
73	778.40	252	777.00	381	780.80
80	778.40	262	776.40	384	781.70
87	778.40	272	776.00		

Section K4

Length of Section = 539.8m

Distance	Level	Distance	Level	Distance	Level
0	781.50	168	777.80	412	773.80
6	781.10	177	778.10	421	773.80
7	780.80	179	778.60	432	774.00
10	780.30	181	778.80	437	774.00
13	780.00	189	778.80	441	775.20
19	779.60	203	778.80	449	776.20
23	779.20	218	778.80	457	776.70
28	778.80	231	779.00	465	776.90
34	778.30	252	779.10	472	777.40
40	777.80	263	779.10	479	778.00
45	777.50	266	778.80	486	778.60
48	777.80	276	778.10	492	778.70
55	777.80	286	777.70	499	779.20
63	777.70	300	777.40	505	779.30
73	777.10	310	776.50	512	779.80
82	776.80	322	775.70	517	780.10
94	776.80	334	775.30	522	780.30
104	777.10	346	775.00	527	780.40
113	777.30	358	774.70	530	780.60
123	777.40	368	774.50	532	780.80
134	777.50	382	774.20	540	781.30
147	777.70	392	774.00		
157	777.80	402	773.90		

Section K5

Length of Section = 551.4m

Distance	Level	Distance	Level	Distance	Level
0	781.50	127	776.30	403	776.20
3	781.20	141	776.60	409	776.10
6	780.80	153	776.80	416	776.30
8	780.60	164	777.10	428	777.00
12	780.40	173	777.00	440	777.50
17	780.10	182	777.20	450	777.60
23	779.80	193	777.00	461	777.70
29	779.40	205	776.60	466	777.60
35	779.20	239	775.60	472	776.80
42	779.00	265	773.60	482	776.60
48	778.80	272	773.90	490	776.80
57	778.60	289	774.20	499	776.90
65	778.50	308	774.50	508	777.20
73	778.30	331	774.70	516	777.80
81	777.80	341	774.70	526	778.60
89	777.10	351	774.90	535	779.60
100	776.80	362	775.80	546	780.70
110	776.70	375	776.00	551	781.50
120	776.50	390	776.20		

Section K6

Length of Section = 425.9m

Distance	Level	Distance	Level	Distance	Level
0	781.60	127	774.60	308	772.70
6	781.10	136	774.30	316	773.20
6	780.70	144	773.50	327	774.20
13	780.10	153	773.60	336	775.00
18	779.60	161	774.10	346	775.50
25	779.20	172	774.20	355	776.00
32	778.60	183	774.10	363	776.40
39	778.20	193	774.00	371	777.00
45	777.70	199	773.90	380	777.70
53	777.30	206	773.20	389	778.20
61	777.00	222	772.70	396	778.70
68	776.50	231	772.50	402	779.30
75	776.30	243	772.50	409	779.80
83	776.20	253	772.50	414	780.10
91	776.20	262	772.50	418	780.30
99	776.30	271	772.50	422	780.70
106	776.50	281	772.60	422	780.90
112	776.50	290	772.60	426	781.10
118	775.70	299	772.60		

Section K7

Length of Section = 458.3m

Distance	Level	Distance	Level	Distance	Level
6	780.30	146	771.80	305	774.30
12	780.00	154	771.80	317	774.90
17	779.50	162	771.80	332	775.80
23	779.20	172	771.70	349	776.30
30	778.70	175	771.60	362	776.80
38	778.20	183	771.20	372	777.30
47	777.60	197	770.90	381	777.60
54	777.20	207	770.70	391	778.10
61	776.70	227	770.50	400	778.60
66	776.20	239	770.40	407	778.90
73	775.90	244	770.40	413	779.30
80	775.50	251	771.70	420	779.60
87	775.30	255	772.10	425	779.90
95	775.10	258	771.70	430	780.10
103	775.10	263	772.20	435	780.50
113	774.80	272	772.50	440	780.70
122	773.90	277	772.20	450	781.10
127	773.30	282	772.60	458	781.30
131	773.20	285	773.20		
137	772.10	292	773.80		

Section K8

Length of Section = 997.5m

Distance	Level	Distance	Level	Distance	Level
0	781.70	319	768.80	743	775.50
5	781.50	324	769.70	757	775.70
7	781.00	329	769.20	768	775.90
11	780.70	334	769.30	781	776.00
18	780.10	346	770.20	790	776.20
25	779.90	357	770.60	800	776.50
32	779.60	369	770.80	808	776.60
39	779.30	381	771.00	815	776.60
46	779.10	394	771.20	825	776.50
53	778.80	405	771.30	836	776.20
60	778.50	416	771.70	844	776.20
66	778.20	428	771.90	851	776.10
73	777.80	441	772.00	859	775.60
82	777.50	452	772.10	866	775.50
90	777.10	463	772.20	873	775.30
100	776.50	474	772.30	879	775.20
109	776.20	487	772.40	887	775.40
120	775.90	499	772.50	895	775.60
131	775.50	512	772.50	902	775.80
142	775.10	525	772.40	909	776.20
149	774.60	538	772.10	915	776.60
154	774.50	548	772.00	923	777.00
166	774.50	559	771.90	929	777.30
176	774.30	571	771.70	936	777.70
187	774.20	582	771.60	942	778.20
203	774.00	596	771.50	948	778.40
220	773.70	610	771.50	954	778.70
229	773.60	624	771.50	961	779.00
238	773.60	638	771.50	966	779.40
253	773.50	644	771.20	970	779.50
268	773.30	650	771.40	974	779.80
281	773.20	663	771.70	979	780.00
290	773.30	679	773.70	983	780.20
294	772.20	692	774.10	986	780.40
297	772.20	702	774.30	989	780.50
302	772.50	710	774.50	992	780.70
307	771.60	721	774.90	992	781.00
314	770.90	731	775.20	998	781.30

Section K9

Length of Section = 593.3m

Distance	Level	Distance	Level	Distance	Level
0	782.00	176	770.20	446	770.20
2	781.40	186	770.30	450	769.40
9	780.80	196	770.40	458	769.30
19	779.50	205	770.60	468	769.40
24	779.20	215	770.60	472	769.40
30	778.70	226	770.40	477	770.50
38	778.20	240	770.10	487	770.90
46	777.70	255	769.90	496	774.80
52	777.30	267	770.20	503	775.50
59	776.80	285	770.60	511	776.20
66	776.30	291	770.40	518	776.50
73	775.60	297	770.30	524	776.90
80	775.30	302	770.50	531	777.30
89	774.70	317	770.80	537	777.70
96	774.40	331	770.80	544	778.30
104	774.10	343	770.70	551	778.60
110	773.60	353	770.80	558	778.80
119	773.20	364	770.80	563	779.30
128	772.90	376	770.80	568	779.50
134	772.70	386	770.80	574	779.90
135	771.70	398	770.70	579	780.20
143	770.90	410	770.40	588	780.90
151	770.30	418	770.40	593	781.30
158	770.10	430	770.40		
167	769.90	441	770.30		

TABLE 2 - Kamburu reservoir survey data - June/July 1983

Section TN1

Length of Section = 115.3m

Distance	Level	Distance	Level	Distance	Level
9	1005.70	57	1004.30	96	1004.50
14	1005.20	62	1004.30	99	1004.50
18	1004.70	67	1004.30	100	1005.10
22	1004.80	72	1004.30	101	1005.90
28	1004.60	77	1004.30	102	1006.10
40	1004.40	82	1004.40	105	1006.30
45	1004.40	87	1004.40		
52	1004.30	92	1004.50		

Section TN2

Length of Section = 145.1m

Distance	Level	Distance	Level	Distance	Level
9	1003.60	59	1003.60	88	1003.80
20	1003.60	65	1003.60	93	1004.50
29	1003.60	68	1003.90	96	1004.20
36	1003.60	74	1003.90	98	1004.60
41	1003.60	79	1003.80	101	1004.80
47	1003.70	83	1004.00	105	1005.30
54	1003.60	86	1003.60	107	1006.30

Section TN3

Length of Section = 430.1m

Distance	Level	Distance	Level	Distance	Level
3	1006.20	26	1002.00	59	1002.70
6	1005.50	27	1001.00	64	1003.00
9	1005.00	31	1001.30	69	1003.20
11	1004.10	37	1001.50	74	1003.20
12	1003.20	41	1001.80	76	1003.30
16	1003.30	46	1002.20	78	1004.40
21	1002.60	53	1002.50	80	1006.60

Section TN4

Length of Section = 415.2m

Distance	Level	Distance	Level	Distance	Level
12	1006.60	41	1005.00	88	1002.50
15	1006.50	46	1004.60	95	1002.40
19	1006.40	50	1004.40	101	1002.50
22	1006.10	54	1004.20	110	1002.40
27	1005.90	59	1003.80	122	1002.40
30	1005.60	64	1003.50	126	1002.40
34	1005.40	70	1003.30	127	1003.40
36	1005.10	77	1002.80	131	1006.10
37	1005.20	83	1002.50	356	1006.10

Section TN5

Length of Section = 190.2m

Distance	Level	Distance	Level	Distance	Level
0	1007.40	82	1001.60	146	1005.40
16	1005.00	91	1001.40	152	1005.40
29	1003.90	100	1001.80	157	1005.40
34	1004.10	106	1001.70	162	1005.50
38	1003.40	108	1001.40	166	1005.50
43	1003.30	114	1001.80	170	1005.40
53	1002.50	119	1001.60	174	1005.40
59	1002.10	120	1001.90	178	1005.50
65	1002.10	126	1005.60	182	1005.80
74	1001.90	132	1005.50	184	1006.00
78	1001.60	139	1005.40		

Section TN6

Length of Section = 229.0m

Distance	Level	Distance	Level	Distance	Level
92	1005.50	118	1001.90	154	1000.90
96	1005.40	122	1001.70	164	1000.90
102	1005.50	127	1001.60	174	1001.60
108	1005.70	132	1001.50	196	1003.40
111	1005.60	138	1000.90	201	1003.50
113	1003.40	147	1000.90	204	1004.40

Section TN7

Length of Section = 320.1m

Distance	Level	Distance	Level	Distance	Level
5	1006.50	111	999.50	223	1006.30
8	1006.00	122	999.20	231	1006.20
16	1005.80	124	999.40	237	1006.10
20	1005.20	132	998.90	242	1005.90
32	1004.00	135	998.70	250	1004.90
38	1003.50	142	999.50	258	1004.20
41	1003.50	145	1000.10	266	1004.00
47	1001.90	151	999.90	273	1004.10
51	1001.50	157	1000.90	279	1004.30
59	1000.70	163	1003.50	284	1004.40
62	1000.80	168	1006.10	291	1004.80
66	1000.90	173	1006.30	298	1005.20
72	1000.10	182	1006.30	302	1005.60
76	999.90	190	1006.30	307	1005.90
85	1000.20	199	1006.30	310	1006.00
89	1000.50	207	1006.30	312	1006.30
100	1000.00	215	1006.30		

Section TN8

Length of Section = 387.8m

Distance	Level	Distance	Level	Distance	Level
5	1006.20	82	1003.90	285	1003.00
6	1006.00	91	1004.00	298	1002.70
9	1005.80	101	1004.00	311	999.90
12	1005.60	111	1004.00	316	998.10
16	1005.40	120	1004.00	321	997.80
20	1004.90	130	1004.20	326	996.90
24	1004.50	143	1004.30	331	997.00
30	1004.20	155	1004.40	335	996.40
36	1003.90	167	1004.30	340	999.50
42	1003.30	193	1004.40	344	1002.90
49	1002.90	207	1004.30	362	1004.90
54	1002.40	218	1004.10	369	1005.60
58	1002.50	232	1003.70	374	1006.00
65	1002.90	243	1003.30		
74	1003.50	262	1003.30		

Section TN9

Length of Section = 304.6m

Distance	Level	Distance	Level	Distance	Level
11	1006.10	135	1003.80	236	1001.50
20	1005.20	147	1003.70	240	1001.50
37	1003.20	158	1003.10	248	1002.20
52	1002.50	168	1002.70	257	1002.90
67	1002.30	173	1002.60	266	1003.60
72	1002.50	179	1001.90	273	1004.10
84	1002.20	182	1001.80	277	1004.40
89	1002.10	190	1001.60	281	1004.80
100	1002.40	200	1001.60	285	1005.30
115	1003.20	213	1001.50	288	1005.80
127	1003.50	224	1001.50		

Section TN10 (L)

Length of Section = 288.9m

Distance	Level	Distance	Level	Distance	Level
3	1006.30	102	992.80	215	999.80
10	1005.10	106	991.90	225	1001.30
13	1004.80	113	992.00	234	1002.40
17	1004.40	117	992.60	243	1002.90
19	1004.00	126	994.50	251	1003.30
24	1003.30	143	994.90	258	1003.80
27	1002.70	152	994.80	264	1004.20
34	1002.00	163	994.20	269	1004.40
48	1000.80	174	994.90	274	1004.80
60	999.60	181	995.30	278	1005.10
70	997.80	185	996.00	281	1005.30
83	995.80	196	997.00	284	1005.60
93	993.80	205	998.40	289	1007.10

Section TN10 (R)

Length of Section = 388.0m

Distance	Level	Distance	Level	Distance	Level
15	1005.10	99	1000.20	271	997.70
19	1004.60	108	1000.40	275	997.90
25	1003.90	117	1000.60	285	998.00
30	1003.30	126	1000.70	296	998.70
37	1002.60	151	1000.80	311	1000.10
43	1002.20	161	1000.90	324	1000.50
49	1001.70	171	1000.70	333	1001.20
54	1001.40	183	1000.60	345	1002.50
61	1000.90	197	1000.60	355	1003.80
66	1000.50	207	1000.50	365	1004.70
73	1000.30	222	999.90	388	1006.90
81	1000.20	233	998.60		
89	1000.10	247	997.70		

Section TN11

Length of Section = 701.1m

Distance	Level	Distance	Level	Distance	Level
20	1005.40	286	991.80	551	997.20
30	1004.70	296	991.90	561	997.60
38	1003.60	309	992.10	572	997.90
52	1002.50	322	992.20	582	998.30
66	1001.40	339	992.50	592	999.00
80	1000.10	356	993.00	602	999.70
94	999.30	371	993.60	609	1000.20
107	998.10	387	993.90	617	1001.10
124	997.00	405	993.70	625	1001.60
136	996.00	419	993.50	633	1002.50
148	995.20	430	993.50	639	1003.50
163	994.40	441	993.50	643	1003.80
177	993.60	443	993.50	646	1003.90
192	993.30	451	994.20	652	1004.00
204	993.20	481	995.50	658	1004.20
208	993.30	496	996.10	665	1004.50
224	992.90	500	996.30	672	1004.90
238	992.80	507	996.40	680	1005.20
252	993.00	517	996.50	684	1005.50
264	992.90	530	996.70	688	1005.80
274	992.10	541	996.80	691	1006.00
278	991.80	545	996.80		

Section TN12

Length of Section = 645.3m

Distance	Level	Distance	Level	Distance	Level
17	1005.50	261	985.30	504	998.60
40	1002.90	273	985.50	518	999.40
53	1001.00	281	985.60	533	1000.40
68	999.20	286	986.30	544	1001.10
92	997.00	295	988.10	557	1001.90
107	996.50	300	988.30	567	1002.40
121	993.50	313	989.20	577	1002.90
138	991.50	326	989.70	587	1003.40
155	989.50	339	990.00	594	1003.90
179	988.30	350	990.20	602	1004.30
183	988.00	364	990.70	608	1004.60
187	987.50	374	991.30	613	1005.00
194	987.40	390	992.10	618	1004.70
199	987.10	415	994.00	621	1005.40
203	985.70	430	994.70	623	1005.60
208	985.50	448	995.60	625	1005.70
221	985.30	460	996.20	627	1005.90
237	985.30	474	996.90		
252	985.30	487	997.80		

Section TN13

Length of Section = 1006.7m

Distance	Level	Distance	Level	Distance	Level
24	1006.10	385	987.20	761	1000.90
43	1005.70	396	987.60	789	999.60
57	1005.20	407	988.60	795	999.50
72	1004.60	422	990.00	801	999.80
92	1003.10	439	990.70	807	999.60
117	1000.80	455	992.10	823	998.50
133	999.40	468	993.00	839	998.20
150	997.60	483	993.70	853	998.40
170	996.00	492	994.30	864	998.40
183	994.60	507	995.20	867	998.60
203	992.50	523	996.60	879	999.10
221	990.60	534	998.20	890	999.60
237	988.60	537	998.40	901	1000.20
253	987.40	543	998.30	915	1001.10
270	985.10	549	999.20	928	1002.00
275	984.20	563	999.90	939	1002.70
283	983.50	581	1001.00	947	1003.60
291	983.40	594	1002.00	961	1004.30
301	983.50	610	1003.00	968	1004.80
313	983.60	632	1003.90	975	1005.10
319	983.60	651	1004.60	981	1005.30
325	983.90	666	1004.50	986	1005.50
328	984.20	682	1004.20	994	1005.80
338	984.30	698	1003.80	998	1006.10
350	984.50	710	1003.30	1001	1006.30
361	986.70	726	1002.60		
367	986.80	739	1001.90		

Section TN14

Length of Section =1438.8m

Distance	Level	Distance	Level	Distance	Level
16	1005.60	506	981.50	978	986.30
18	1005.30	511	981.10	996	986.60
54	1003.80	528	980.70	1009	986.70
74	1002.90	551	980.50	1022	986.60
87	1002.20	569	980.70	1041	986.50
91	1002.10	588	981.00	1078	986.50
110	1001.00	603	981.40	1091	987.00
129	1000.00	617	984.50	1103	987.00
144	999.20	635	986.30	1113	988.20
162	997.40	645	986.60	1139	989.60
186	995.50	654	986.60	1158	990.60
213	993.10	671	986.60	1179	991.50
240	990.40	686	985.90	1196	992.70
258	989.10	694	985.00	1232	994.10
268	988.70	702	984.80	1252	995.10
278	989.30	717	984.40	1268	995.90
290	990.00	735	982.00	1284	996.50
300	991.20	754	981.60	1298	997.30
303	991.20	772	986.10	1313	998.00
327	991.10	783	985.50	1327	998.50
361	990.10	788	985.40	1339	999.10
380	989.00	809	984.70	1350	999.70
406	987.70	815	984.30	1363	1000.80
428	986.20	828	984.10	1376	1001.60
433	984.90	848	984.30	1388	1002.50
445	984.70	869	984.70	1398	1003.30
463	984.80	891	985.20	1409	1004.20
471	984.90	905	985.60	1419	1005.00
479	983.90	911	985.50	1425	1005.50
490	981.30	935	985.60	1429	1006.00
495	981.30	955	986.00		

Section TN15(L)

Length of Section = 602.2m

Distance	Level	Distance	Level	Distance	Level
7	1006.10	239	988.70	466	981.10
11	1006.00	246	989.10	470	980.60
15	1005.60	253	989.50	478	980.50
21	1005.30	267	988.80	480	979.90
28	1004.90	275	988.60	504	979.50
37	1004.10	283	989.00	513	979.10
48	1003.00	285	989.40	522	978.60
60	1002.00	287	989.00	530	978.30
70	1001.50	303	988.70	532	978.60
81	1000.20	323	988.60	538	982.60
92	999.20	334	989.30	547	989.60
103	998.40	349	988.30	561	1003.00
114	997.40	366	988.20	565	1002.10
122	996.60	378	988.10	569	1002.60
133	995.60	387	987.60	572	1005.10
157	994.30	403	986.60	576	1005.10
168	993.40	419	985.60	579	1004.50
186	992.30	445	984.20	582	1004.60
207	990.50	457	983.60	586	1005.70
213	990.30	460	982.10	595	1006.00
219	989.50	464	981.90		

Section TN15 (R)

Length of Section = 388.0m

Distance	Level	Distance	Level	Distance	Level
5	1006.50	167	986.70	297	998.50
20	1004.70	183	987.90	304	1000.00
30	1000.40	198	988.90	310	999.90
40	997.30	214	989.90	320	1000.90
50	995.50	222	991.10	332	1001.80
74	992.90	229	990.80	340	1002.90
91	990.40	233	990.60	348	1003.50
111	988.00	244	992.50	356	1004.10
129	986.40	263	995.00	362	1004.80
137	986.50	276	996.20	368	1005.20
144	985.50	281	997.00	373	1005.60
155	986.00	287	997.30	376	1006.10

Section TN16

Length of Section = 861.7m

Distance	Level	Distance	Level	Distance	Level
7	1006.50	346	981.60	606	988.00
15	1004.90	364	980.70	620	989.10
22	1004.80	377	980.20	640	990.30
25	1004.60	381	979.00	659	991.50
42	1004.20	390	978.40	673	992.50
51	1003.20	398	977.90	699	994.00
60	1002.70	415	978.40	711	994.60
68	1002.30	429	978.80	722	995.00
78	1001.80	442	979.00	735	995.70
83	1001.50	447	978.20	748	996.40
86	1001.50	451	977.80	756	997.30
89	1001.40	460	977.80	760	997.80
97	1000.70	467	977.50	767	998.20
111	999.70	474	976.90	776	999.40
128	998.60	479	976.90	781	999.90
147	997.50	482	977.90	801	1000.70
164	996.50	489	977.90	809	1001.50
191	995.00	496	977.90	817	1002.10
210	993.30	511	979.40	825	1002.40
241	991.00	535	981.30	833	1003.50
265	989.30	566	982.70	836	1003.80
281	988.40	582	984.50	837	1004.10
297	986.80	588	985.60	841	1004.60
326	983.70	594	987.00	850	1005.30
340	982.00	600	987.40		

Section TN17

Length of Section = 1035.1m

Distance	Level	Distance	Level	Distance	Level
26	1005.80	436	976.30	770	985.70
42	1005.00	439	976.50	776	985.50
69	1003.80	462	975.40	793	986.70
94	1002.10	475	973.80	811	988.20
119	1000.40	495	976.00	828	989.70
135	999.20	506	975.50	843	991.00
165	997.60	517	975.20	859	992.70
185	996.00	527	975.10	877	994.40
205	994.70	536	976.50	894	996.00
226	993.10	548	978.00	914	997.60
250	991.30	553	978.20	931	999.80
270	989.00	576	979.50	949	1001.00
291	987.00	594	980.50	956	1001.40
313	984.80	603	980.50	962	1001.90
333	982.90	625	980.10	973	1002.50
346	981.00	648	980.50	982	1003.10
358	978.50	660	979.50	990	1003.70
365	977.70	671	979.00	998	1004.20
380	977.80	688	977.90	1005	1004.70
386	978.20	697	977.40	1011	1005.10
392	977.60	710	977.30	1017	1005.40
397	977.50	722	979.10	1022	1005.60
418	977.30	735	981.00	1025	1005.90
428	977.00	747	981.50		

Section TB1

Length of Section = 289.0m

Distance	Level	Distance	Level	Distance	Level
4	1006.00	78	1002.60	187	999.90
8	1005.60	84	1002.40	190	1000.00
10	1005.00	90	1002.30	198	1000.60
14	1004.70	96	1002.20	206	1003.00
18	1004.50	103	1002.20	213	1003.10
22	1004.20	111	1002.40	219	1003.10
27	1003.70	118	1002.60	227	1003.40
30	1003.30	125	1001.80	233	1004.10
32	1003.30	137	1001.30	240	1004.40
37	1003.30	141	1001.10	246	1004.60
43	1003.30	145	1001.20	253	1004.90
48	1003.30	157	1001.20	259	1005.00
53	1003.30	161	1001.20	264	1005.10
59	1003.20	168	1000.90	270	1005.30
64	1002.90	176	1000.40	273	1005.40
71	1002.70	183	1000.20		

Section TB2

Length of Section = 330.1m

Distance	Level	Distance	Level	Distance	Level
13	1005.60	114	999.50	222	1001.40
15	1005.50	119	999.40	229	1001.30
17	1005.40	124	999.50	238	1001.20
24	1004.80	130	999.70	246	1001.30
30	1004.20	138	1000.00	254	1001.80
38	1003.60	142	1000.10	263	1002.10
43	1003.00	146	1001.40	269	1002.40
51	1002.30	153	1001.30	276	1002.70
59	1001.10	159	1001.30	283	1003.10
64	1000.00	168	1001.30	289	1003.40
72	1000.20	178	1001.40	297	1004.20
79	1000.20	185	1001.50	304	1004.80
86	1000.20	192	1001.60	310	1005.20
94	1000.10	201	1001.50	315	1005.70
100	999.90	207	1001.50	319	1006.00
108	999.80	214	1001.40	322	1006.20

Section TB3

Length of Section = 521.1m

Distance	Level	Distance	Level	Distance	Level
19	1005.70	177	1000.40	389	999.40
25	1005.30	183	999.60	399	999.40
31	1004.80	193	999.50	407	999.40
39	1004.50	204	999.20	415	999.40
48	1004.20	217	999.40	422	998.20
54	1004.00	242	999.40	426	997.60
61	1003.60	265	999.60	431	998.20
68	1003.30	278	999.70	440	999.70
75	1003.00	295	999.70	449	1000.70
83	1002.60	307	999.60	457	1001.30
92	1002.20	317	999.50	465	1002.00
100	1001.70	327	999.50	471	1002.70
110	1001.30	336	999.50	478	1003.30
121	1001.00	344	999.50	484	1003.90
131	1000.70	354	999.50	491	1004.50
141	1000.70	363	999.60	496	1004.90
153	1000.20	373	999.50	501	1005.40
164	1000.40	382	999.40	506	1005.70

Section TB4

Length of Section = 377.0m

Distance	Level	Distance	Level	Distance	Level
21	1005.80	135	1001.10	281	997.50
24	1005.70	144	1000.70	290	997.60
27	1005.60	153	1000.40	296	997.50
33	1005.40	161	999.90	302	997.60
40	1005.00	171	999.50	310	997.90
47	1004.70	183	999.20	317	998.00
55	1004.40	197	999.30	324	998.90
63	1004.00	208	999.30	329	1000.20
70	1003.70	216	999.30	335	1001.00
78	1003.40	224	999.10	342	1002.30
86	1003.00	235	998.70	353	1003.90
94	1002.70	242	998.20	359	1004.40
101	1002.40	250	998.10	366	1005.40
110	1002.10	257	997.90	369	1005.90
119	1001.80	266	997.60		
127	1001.40	273	997.30		

Section TB5

Length of Section = 472.2m

Distance	Level	Distance	Level	Distance	Level
9	1006.10	153	998.20	358	999.60
12	1005.60	167	998.10	368	1000.10
19	1004.90	182	998.20	378	1000.70
29	1003.90	199	998.20	387	1001.20
37	1003.10	218	998.40	396	1001.80
47	1002.30	229	998.50	405	1002.50
58	1001.30	239	998.40	414	1003.10
68	1000.20	260	998.20	422	1003.60
80	999.30	281	998.10	430	1004.10
89	998.90	294	997.60	437	1004.70
100	998.50	303	997.50	444	1005.10
112	998.10	313	997.90	450	1005.60
123	997.70	325	998.40	456	1006.50
129	997.60	336	998.80	462	1006.70
138	997.90	347	999.10	466	1006.80

Section TB6

Length of Section = 411.7m

Distance	Level	Distance	Level	Distance	Level
15	1005.40	137	996.50	302	996.30
21	1004.70	140	996.30	312	996.40
29	1004.20	148	996.70	317	996.60
38	1003.70	160	996.90	321	998.00
47	1003.00	172	997.00	331	999.70
53	1002.40	185	997.10	340	1000.70
61	1002.00	195	997.00	347	1001.80
68	1001.50	209	997.10	355	1002.10
71	1001.00	225	997.10	362	1003.00
80	1000.70	241	997.10	369	1003.70
89	1000.00	252	997.00	377	1004.30
100	999.30	262	996.70	383	1005.00
108	999.00	272	996.60	389	1005.40
117	998.20	283	996.60	395	1005.90
125	997.70	292	996.50	400	1006.20

Section TB7

Length of Section = 473.7m

Distance	Level	Distance	Level	Distance	Level
21	1006.20	135	995.50	324	996.30
27	1005.00	145	995.20	338	997.00
34	1004.20	153	994.50	353	997.20
40	1003.70	168	992.30	365	997.80
47	1003.20	173	992.20	376	998.20
54	1002.50	184	992.10	384	999.00
63	1001.70	200	992.10	394	1000.20
71	1001.10	217	992.00	406	1001.30
80	1000.40	231	992.00	422	1002.20
90	999.70	237	992.00	434	1003.50
99	999.00	244	992.80	448	1004.50
109	997.80	274	994.90	454	1005.00
118	997.00	294	995.30	459	1005.30
125	996.30	311	995.80	462	1005.50

Section TB8

Length of Section = 474.6m

Distance	Level	Distance	Level	Distance	Level
12	1005.20	203	993.70	381	998.70
19	1004.40	217	993.70	388	999.30
24	1004.00	230	992.90	396	999.90
41	1002.90	244	992.30	407	1000.80
59	1001.30	254	991.60	415	1001.50
67	1000.00	264	990.00	422	1002.00
78	999.00	270	989.30	428	1003.00
91	997.20	275	989.30	434	1003.50
106	996.40	293	989.30	440	1004.00
121	995.30	304	989.80	446	1004.50
134	994.40	312	993.30	452	1004.90
147	994.00	330	994.40	457	1005.20
159	993.70	344	995.00	461	1005.50
174	993.50	354	996.00	466	1005.70
185	993.80	365	996.90	470	1005.90
194	993.80	373	997.70		

Section TB9

Length of Section =1252.9m

Distance	Level	Distance	Level	Distance	Level
13	1005.60	469	992.30	1009	993.30
19	1005.20	487	991.70	1025	991.30
25	1004.90	500	991.10	1043	990.50
33	1004.60	517	990.10	1047	990.30
55	1003.70	533	989.70	1057	990.40
86	1002.20	552	989.40	1071	991.50
106	1001.10	568	989.90	1080	993.20
126	1000.00	585	990.30	1083	993.80
138	998.40	598	991.30	1085	993.40
156	996.80	615	992.40	1105	994.30
172	995.20	635	993.40	1111	995.20
196	991.30	659	994.80	1117	996.80
215	985.30	677	995.80	1121	997.10
220	984.50	689	996.40	1129	1000.00
232	984.50	701	997.20	1137	1001.10
241	984.50	711	997.70	1138	1000.80
244	984.80	724	998.30	1149	1000.10
249	985.80	739	998.60	1152	1000.30
259	989.10	762	999.60	1162	1001.20
262	989.10	775	1000.20	1169	1002.30
277	989.20	788	1000.80	1172	1002.10
288	989.30	805	1001.60	1176	1002.10
298	990.00	820	1002.00	1184	1002.50
307	990.30	836	1002.40	1194	1002.80
315	990.20	852	1002.80	1204	1003.30
329	990.10	869	1002.80	1211	1003.80
348	990.00	890	1002.50	1219	1004.40
362	990.10	907	1001.70	1226	1004.60
383	990.50	930	1000.60	1232	1005.00
402	991.10	941	999.40	1237	1005.20
421	991.80	957	997.80	1242	1005.50
438	992.50	970	996.10	1245	1005.80
452	992.50	988	994.30		

Section TB10

Length of Section = 731.9m

Distance	Level	Distance	Level	Distance	Level
25	1005.20	371	987.20	575	993.80
51	1003.20	379	984.00	585	994.60
72	1002.20	387	984.70	596	995.30
91	1002.00	388	984.20	606	996.30
111	1001.20	390	983.70	616	997.10
131	999.20	400	983.70	627	997.90
156	998.00	410	983.70	637	998.70
181	996.20	421	984.00	645	999.50
195	994.20	431	984.20	654	1000.10
209	992.90	442	987.70	664	1001.00
228	992.00	447	988.00	672	1001.50
243	990.30	451	988.00	679	1002.10
256	989.30	462	988.00	687	1002.50
269	988.40	472	987.70	693	1003.20
282	987.70	484	987.40	699	1003.80
299	987.40	496	987.40	704	1004.20
312	987.20	502	988.20	709	1004.40
317	987.30	508	988.50	713	1004.70
336	987.70	519	989.50	719	1005.20
349	987.70	534	990.20	723	1005.50
353	987.70	546	991.30	729	1005.90
359	987.10	563	992.30		

Section TB11

Length of Section =1092.1m

Distance	Level	Distance	Level	Distance	Level
16	1005.90	372	987.20	710	986.50
17	1005.80	385	986.90	731	987.30
20	1005.60	398	986.40	746	988.10
23	1005.50	413	986.20	764	988.80
26	1005.30	428	986.00	780	989.90
31	1005.10	444	985.70	797	990.90
60	1003.90	460	985.30	817	992.10
81	1002.40	473	985.20	842	993.00
94	1001.70	489	985.20	858	994.00
110	1001.10	504	985.40	877	994.90
126	999.50	518	985.70	892	995.70
148	998.00	534	986.30	909	996.40
169	996.70	550	987.00	924	997.60
186	995.50	564	986.30	935	998.20
205	994.30	570	986.20	947	998.40
221	993.20	580	983.10	960	998.90
236	992.40	594	982.00	974	999.30
247	991.50	597	982.10	986	1000.10
261	990.70	609	982.20	1000	1001.00
273	990.40	625	982.30	1015	1001.50
276	990.40	638	985.80	1024	1002.20
281	990.40	653	986.20	1034	1002.70
286	989.90	660	986.20	1044	1003.30
306	989.10	667	986.60	1054	1004.10
318	988.70	670	986.70	1063	1005.00
329	988.20	682	986.30	1070	1005.30
346	987.90	694	986.10	1083	1005.90
358	987.50	705	986.20	1090	1008.90

Section TB12

Length of Section =1450.0m

Distance	Level	Distance	Level	Distance	Level
52	1005.60	589	982.30	1002	986.40
61	1005.60	596	982.30	1006	986.00
75	1005.40	612	981.60	1041	986.10
86	1005.10	627	980.90	1051	983.10
93	1004.90	640	980.90	1062	983.00
101	1004.50	648	980.90	1087	982.10
133	1003.20	653	981.70	1095	982.10
152	1001.30	656	981.60	1103	982.60
185	998.30	661	981.60	1118	985.60
199	997.00	671	984.40	1132	986.50
212	997.10	677	985.10	1149	986.90
220	998.40	687	984.90	1164	987.40
222	998.40	700	986.70	1176	987.10
238	999.20	703	986.60	1224	987.70
262	1000.70	713	986.10	1237	989.90
275	1001.60	723	986.90	1255	991.30
296	1001.80	738	988.60	1269	993.10
318	1001.50	752	990.10	1290	994.90
334	1001.00	771	990.60	1314	996.90
355	1000.20	785	991.00	1324	997.90
370	999.40	802	991.20	1338	998.90
398	998.10	824	991.20	1351	999.40
418	996.60	839	991.50	1362	1000.20
438	995.10	866	991.40	1374	1001.10
457	993.60	881	991.20	1385	1001.70
471	992.10	893	991.30	1395	1002.40
492	990.10	904	991.10	1406	1003.10
510	988.40	917	991.00	1414	1003.60
528	986.90	930	992.10	1421	1004.10
542	985.60	948	990.20	1427	1004.40
564	985.10	968	989.10	1432	1004.80
579	985.60	981	987.90	1438	1005.40
583	985.10	992	987.60	1443	1005.80

TABLE 3 - Kindaruma reservoir - areas and volumes

SECTIONS U/S	D/S	UPPER CONTOUR	LOWER CONTOUR	[SQ.F]	[SQ.M]	U/S	D/S	END AREAS U/S	SUM OF END AREAS	CONSTANT FACTOR	DESIGN CAPACITY	1761 CAPACITY	CHANGE IN VOLUME	% LOSS OF CAPACITY
									AC [SQ.M]	[C]	ECU.M	ECU.M	ECU.M	
<b>U/S-K1</b>														
		780.29	777.24	307	0				307.6	335.5	123432.6	103170.9	90317.6	
		777.24	774.19	11	0				11.6	311.1	139122.9	3691.7	135521.2	
		774.19	771.14	0	0				0.0	253.6	73341.2	0.0	73341.2	
		771.14	769.62	0	0				0.0	180.9	10200.4	0.0	10200.4	
											421752.9	106772.6	314980.4	74.68
<b>K1-K2</b>														
		780.29	777.24	648	307				955.7	405.4	543877.5	387477.7	156399.8	
		777.24	774.19	130	11				142.3	408.0	415433.2	53067.0	357366.2	
		774.19	771.14	0	0				0.0	390.5	294005.5	0.0	294005.5	
		771.14	769.62	0	0				0.0	286.2	48001.5	0.0	48001.5	
											1301317.0	445544.6	855772.4	65.76
<b>K2-K3</b>														
		780.29	777.24	382	648				1531.1	492.6	884648.6	754271.7	130376.8	
		777.24	774.19	107	130				237.2	432.0	615877.4	102748.7	513128.6	
		774.19	771.14	0	0				0.0	361.1	376781.6	0.0	376781.6	
		771.14	769.62	0	0				0.0	337.1	67569.3	0.0	67569.3	
											1944875.0	857020.5	1087854.0	55.93
<b>K3-K4</b>														
		780.29	777.24	1209	382				2092.0	330.7	814616.2	691771.4	122844.8	
		777.24	774.19	371	107				476.1	304.3	635628.4	145736.4	489892.0	
		774.19	771.14	14	0				14.6	267.0	37881.6	3907.2	374974.4	
		771.14	768.10	0	0				0.0	220.6	103078.1	0.0	103078.1	
											1937203.0	841414.9	1095788.0	56.57
<b>K4-K5</b>														
		780.29	777.24	1435	1209				2644.5	201.6	587291.7	533089.1	54202.7	
		777.24	774.19	501	371				872.5	202.7	474137.7	176895.5	297242.2	
		774.19	771.14	7	14				22.5	266.6	303329.3	5995.0	297334.3	
		771.14	768.40	0	0				0.0	211.2	83926.2	0.0	83926.2	
											1443084.0	715979.6	732704.4	50.58
<b>K5-K6</b>														
		780.29	777.24	1112	1435				2547.7	265.2	705334.4	754601.9	11232.6	
		777.24	774.19	747	501				1249.5	290.4	576637.4	362800.1	213837.3	
		774.19	771.14	195	7				203.6	362.7	375914.4	80004.4	295910.0	
		771.14	769.01	0	0				0.0	329.7	94875.5	0.0	94875.5	
											1613360.0	1197400.0	615954.0	38.96

85

K6-K7

780.29	777.24	1139	1112	2252.0	465.2	1044842.3	1047650.2	-2807.9
777.24	774.19	768	747	1516.7	443.4	765077.0	672587.1	92489.9
774.19	771.14	408	195	604.3	430.1	503017.6	259903.5	243114.1
771.14	768.10	29	0	29.4	480.4	299519.3	14113.4	285405.9
768.10	765.18	0	0	0.0	407.1	34073.6	0.0	34073.6
						2646528.0	1994253.0	652275.0
								24.65

K7-K8

780.29	777.24	2752	1139	3892.8	152.6	599538.6	594085.6	5453.0
777.24	774.19	2076	768	2845.8	147.1	463675.5	418664.2	45011.2
774.19	771.14	1007	408	1416.2	153.3	322391.6	217180.1	105211.5
771.14	768.10	68	29	97.6	163.5	242177.3	15931.1	226226.2
768.10	766.27	0	0	0.0	165.3	65909.2	0.0	65909.2
						1693691.0	1245880.0	447811.0
								26.44

K8-K9

780.29	777.24	1597	2752	4350.4	235.4	1029151.2	1024131.2	5020.0
777.24	774.19	1321	2076	3398.2	247.7	908345.2	841568.9	66776.3
774.19	771.14	1113	1007	2121.5	286.9	785282.2	608690.1	176592.1
771.14	768.10	263	68	331.3	311.2	659782.3	103113.7	556668.6
768.10	765.96	0	0	0.0	432.4	211483.4	0.0	211483.4
						3594043.0	2577503.0	1016340.0
								28.28

K9-DAM

780.29	777.24	1597	1597	3195.0	148.0	469134.4	472933.2	-3798.7
777.24	774.19	1321	1321	2642.7	143.0	390130.3	378007.5	12122.8
774.19	771.14	1113	1113	2227.6	140.9	328440.3	313854.2	14586.1
771.14	768.10	263	263	526.3	134.8	262688.8	70924.2	191764.6
768.10	765.96	0	0	0.0	235.7	80222.2	0.0	80222.2
						1530615.0	1235718.0	294897.0
								19.27

TOTAL RESERVOIR 18331952.0 11217490.0 7114475.0 38.81

1965 VOLUME BELOW 768.10 =	391688. CU.M
1965 VOLUME BELOW 771.14 =	2269105. CU.M
1965 VOLUME BELOW 774.19 =	6015487. CU.M
1965 VOLUME BELOW 777.24 =	11399549. CU.M
1965 VOLUME BELOW 780.29 =	18331968. CU.M
1983 VOLUME BELOW 768.10 =	0. CU.M
1983 VOLUME BELOW 771.14 =	264102. CU.M
1983 VOLUME BELOW 774.19 =	1692636. CU.M
1983 VOLUME BELOW 777.24 =	4254311. CU.M
1983 VOLUME BELOW 780.29 =	11217491. CU.M

TABLE 4 - Kamburu reservoir - areas and volumes

SECTIONS U/S D/S	UPPER CONTOUR	LOWER CONTOUR	END D/S	END AREAS U/S	SUM OF END AREAS	CONSTANT FACTOR	DESIGN CAPACITY	1983		% LOSS OF CAPACITY
								[SQ.M]	[SQ.M]	
TN3-TN4	1005.84	1002.79	234	199	433.3	267.4	419779.7	115850.6	393929.1	
	1002.79	999.74	16	31	47.8	316.9	263755.6	15163.7	248591.9	
	999.74	998.00	0	0	0.0	531.5	63794.5	0.0	63794.5	
TN4-TN5	1005.84	1002.79	316	234	550.9	565.3	623410.5	311432.7	311977.8	
	1002.79	999.74	69	16	85.5	602.0	358470.8	51467.4	307009.4	
	999.74	996.70	0	0	0.0	629.8	136443.7	0.0	136443.7	
	996.70	995.55	0	0	0.0	561.1	8676.7	0.0	8676.7	
TN5-TN6	1005.84	1002.79	294	316	611.1	530.3	536385.6	324090.1	212295.5	
	1002.79	999.74	100	69	169.4	486.2	365918.5	82342.1	283576.4	
	999.74	996.70	0	0	0.0	515.8	238144.8	0.0	238144.8	
	996.70	995.55	0	0	0.0	938.8	36753.4	0.0	36753.4	
							1127007.0	362900.1	764106.9	67.80
TN6-TN7	1005.84	1002.79	485	294	780.2	554.9	721167.5	432879.2	288288.2	
	1002.79	999.74	291	100	392.1	525.8	536152.4	206145.9	330006.5	
	999.74	996.70	18	0	18.1	490.7	368769.9	8892.6	359877.2	
	996.70	995.65	0	0	0.0	685.0	253656.3	0.0	258656.3	
	993.65	991.70	0	0	0.0	702.9	71973.5	0.0	71973.5	
							1177201.0	406432.1	770768.9	65.47
TN7-TN8	1005.84	1002.79	754	485	1239.9	653.4	1151209.0	810153.4	341055.6	
	1002.79	999.74	117	291	409.1	614.4	872991.4	251367.2	621624.2	
	999.74	996.70	59	18	77.6	560.1	603057.5	43471.2	559586.2	
	996.70	995.65	0	0	0.4	444.2	351413.1	161.3	351251.7	
	993.65	991.00	0	0	0.0	431.8	108842.1	0.0	108842.1	
TN8-TN10/10A	1005.84	1002.79	1795	754	2549.7	505.6	1380450.0	1289150.0	91300.0	
	1002.79	999.74	1281	117	1398.3	519.7	1203387.0	726632.8	476754.2	
	999.74	996.70	538	59	598.3	498.9	972153.6	298499.4	673654.2	
	996.70	995.65	236	0	237.0	428.6	676026.6	101598.4	574428.2	
	993.65	990.60	28	0	28.3	395.2	11186.8	11186.8	416561.9	
	990.60	988.80	0	0	0.0	359.7	99567.9	0.0	99567.9	
							4759331.0	2427065.0	2332266.0	49.00

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TN10/10A-TN11		TN11-TN12		TN12-TN13		TN13/TB12-TN14		SECTIONS	U/S	D/S	UPPER	LOWER	END	SUM	CONSTANT	DESIGN	CAPACITY	1983	CHANGE	%	LOSS	
U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	U/S	D/S	U/S	U/S	U/S	U/S	U/S	U/S	U/S	U/S	U/S	
1005.84	1002.79	1911	1795	3707.2	581.2	2011448.0	2154468.0	-143020.0														
1002.79	999.74	1685	1281	2966.7	593.5	1756910.0	1760626.0	-3716.0														
999.74	996.70	1427	538	1966.2	571.9	1494227.0	1124557.0	369670.0														
996.70	993.65	988	236	1224.7	536.8	1234202.0	657452.2	576749.7														
993.65	990.60	187	28	215.5	522.5	961878.7	112575.9	849302.8														
990.60	987.55	0	0	0.0	911.5	733205.6	0.0	733205.6														
987.55	984.50	0	0	0.0	1246.1	400955.2	0.0	400955.2														
984.50	983.30	0	0	0.0	449.0	30252.6	0.0	30252.6														
						8623077.0	5809678.0	2813399.0													32.63	
1005.84	1002.79	1752	1911	3664.1	843.4	2936606.0	3090369.0	-153763.0														
1002.79	999.74	1511	1685	3197.1	764.3	2317678.0	2443658.0	-125980.0														
999.74	996.70	1271	1427	2699.3	689.5	1800880.0	1861200.0	-60320.0														
996.70	993.65	994	988	1982.7	610.0	1374346.0	1209362.0	164984.0														
993.65	990.60	778	187	965.4	547.4	986942.5	528434.5	458508.0														
990.60	987.55	464	0	464.1	535.0	633200.7	248294.9	384905.8														
987.55	984.50	188	0	188.4	462.7	371461.3	87197.2	284264.1														
984.50	981.46	0	0	0.0	371.9	166471.1	0.0	166471.1														
981.46	979.15	0	0	0.0	152.1	18994.0	0.0	18994.0														
						10606577.0	9468514.0	1138063.0													10.73	
1005.84	1002.79	2586	1752	4339.1	388.1	1699174.0	1683928.0	15246.0														
1002.79	999.74	1937	1511	3449.3	391.5	1402269.0	1350310.0	51959.0														
999.74	996.70	1290	1271	2562.6	391.3	1138970.0	1002613.4	136356.6														
996.70	993.65	997	994	1992.1	409.1	914464.1	815020.6	99443.5														
993.65	990.60	763	778	1541.4	390.9	711488.6	602546.4	108942.1														
990.60	987.55	544	464	1008.7	390.2	526813.3	393642.4	133170.9														
987.55	984.50	303	188	491.5	374.1	368481.9	183859.4	184622.5														
984.50	981.46	51	0	51.0	217.6	163784.2	11099.7	152684.6														
981.46	978.55	0	0	0.0	57.1	15447.7	0.0	15447.7														
						6940890.0	6043017.0	897873.0													12.94	
1005.84	1002.79	4170	6614	10784.3	192.7	2043228.0	2078471.0	-35243.0														
1002.79	999.74	3857	5519	9376.4	214.9	2009628.0	2014691.0	-5063.0														
999.74	996.70	3552	4260	7813.3	234.3	1899573.0	1830705.0	68668.0														
996.70	993.65	3244	3608	6852.8	235.9	1660622.0	1616635.0	43987.0														
993.65	990.60	2922	3059	5981.7	221.6	1410597.0	1325715.0	84882.0														
990.60	987.55	2350	2089	4440.6	237.1	1184152.0	1052928.0	131224.0														
987.55	984.50	1509	1118	2628.3	244.0	952979.1	641239.4	291739.7														
984.50	981.46	491	390	882.6	221.3	671439.4	195285.3	476154.1														
981.46	978.41	62	15	78.2	303.9	388987.3	23755.0	365232.3														
978.41	977.15	0	0	0.0	252.8	50531.0	0.0	50531.0														
						12251736.0	10779424.0	1472312.0														12.02

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TN14-TN15/15A

1005.84	1002.79	2681	4170	6851.6	292.8	1916282.0	2005994.0	-89712.0
1002.79	999.74	2397	3857	6254.7	277.1	1647752.0	1733228.0	-85476.0
999.74	996.70	2157	3552	5710.0	261.5	1408241.0	1493415.0	-85174.0
996.70	993.65	1897	3244	5142.5	237.2	1152960.0	1219985.0	-67025.0
993.65	990.60	1599	2932	4522.4	206.4	882956.9	933409.2	-50452.3
990.60	987.55	1103	2350	3454.0	212.2	664848.1	733018.0	-63169.9
987.55	984.50	461	1509	1971.5	194.5	482855.1	363380.2	99474.9
984.50	981.46	249	491	741.6	157.1	314052.2	116467.4	197584.8
981.46	978.41	133	62	195.5	288.4	192273.9	56399.3	135874.6
978.41	976.70	0	0	0.2	368.4	42781.6	71.6	42710.0
						870500.0	8675366.0	29634.0
								U.34

TN15/15A-TN16

1005.84	1002.79	2462	2681	5143.4	658.0	3246614.0	3384187.0	-137573.0
1002.79	999.74	2191	2397	4589.5	658.6	2916808.0	3022585.0	-105777.0
999.74	996.70	1921	2157	4079.1	680.2	2593854.0	2774698.0	-180844.0
996.70	993.65	1638	1897	3536.7	695.4	2258580.0	2459296.0	-200710.0
993.65	990.60	1348	1599	2948.0	734.3	1914220.0	2164852.0	-250632.0
990.60	987.55	1073	1103	2176.5	854.7	1549295.0	1860218.0	-310923.0
987.55	984.50	461	461	1333.3	952.0	1176412.0	1269260.0	-92848.0
984.50	981.46	249	249	959.8	927.2	842366.7	88954.3	-47587.6
981.46	978.41	133	133	564.9	862.0	585575.7	486907.2	98668.4
978.41	975.36	46	46	46.6	800.1	385422.7	37305.5	348117.2
975.36	973.85	0	0	0.0	825.4	71657.8	0.0	71657.8
						17540768.0	18349232.0	-808464.0
								-4.61

TN16-TN17

1005.84	1002.79	2876	2462	5338.2	520.5	2744137.0	2778431.0	-34294.0
1002.79	999.74	2582	2191	4774.3	502.3	2375664.0	2398032.0	-22368.0
999.74	996.70	2332	1921	4254.3	482.7	2015673.0	2035576.0	-37903.0
996.70	993.65	2096	1638	3735.3	458.4	1674277.0	1712122.0	-37845.0
993.65	990.60	1874	1348	3222.8	439.0	1367067.0	1414682.0	-47615.0
990.60	987.55	1679	1073	2752.6	416.4	1111980.0	1146214.0	-34234.0
987.55	984.50	1467	871	2338.9	380.7	877805.7	890402.7	-12597.0
984.50	981.46	1292	710	2003.1	347.8	665075.2	696714.2	-31639.0
981.46	978.41	975	431	1407.1	350.0	513100.4	492460.1	20640.3
978.41	975.36	389	46	436.0	342.7	397328.1	149412.1	247916.0
975.36	968.55	23	0	23.7	623.4	373954.1	14797.2	359156.9
						14116060.0	13746842.0	369218.0
								2.62

TN17-DAM

1005.84	1002.79	2876	2876	5752.2	403.7	2255672.0	2322043.0	-66371.0
1002.79	999.74	2582	2582	5164.7	404.1	1996897.0	2087282.0	-90385.0
999.74	996.70	2332	2332	4665.6	395.5	1758848.0	1845390.0	-86542.0
996.70	993.65	2096	2096	4192.8	381.8	1530248.0	1600664.0	-70416.0
993.65	990.60	1874	1874	3749.3	363.7	1307896.0	1363478.0	-5582.0
990.60	987.55	1679	1679	3358.6	358.1	1096365.0	1135465.0	-39100.0
987.55	984.50	1467	1467	2934.5	305.9	894892.9	897582.4	-2689.6
984.50	981.46	1292	1292	2585.9	277.9	699973.2	718514.0	-18540.7
981.46	978.41	975	975	1951.1	273.1	517093.2	532796.3	-15703.1
978.41	975.36	389	389	779.1	252.1	357378.0	196444.8	160933.2
975.36	972.31	23	23	47.5	234.5	240639.6	11133.1	229506.5
972.31	969.26	0	0	0.0	223.5	120833.2	U.0	120853.2
969.26	968.60	0	0	0.0	243.7	4356.0	U.0	4356.0

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SECTIONS U/S D/S	UPPER CONTOUR	LOWER CONTOUR	END AREAS		SUM OF END AREAS	CONSTANT FACTOR	DESIGN CAPACITY	12781110.0 [CU.M]	12710701.0 1983 CAPACITY [CU.M]	70319.0 CHANGE IN VOLUME [CU.M]	0.55 % LOSS OF CAPACITY
			[SQ.M]	D/S							
<b>U/S-TN9</b>											
	1005.84	1002.79	717	0	717.1	596.3	460613.7	426166.1	34447.7		
	1002.79	999.74	113	0	113.1	470.0	265320.7	471146.7	218174.0		
	999.74	996.70	0	0	0.0	249.1	105678.7	0.0	195678.7		
	996.70	993.65	0	0	0.0	188.6	34442.4	0.0	34442.4		
	993.65	992.60	0	0	0.0	148.1	2519.5	0.0	2519.5		
<b>SECTIONS</b>											
U/S D/S	UPPER CONTOUR	LOWER CONTOUR	END AREAS D/S	END AREAS U/S	SUM OF END AREAS	CONSTANT FACTOR	DESIGN CAPACITY	12781110.0 [CU.M]	12710701.0 1983 CAPACITY [CU.M]	70319.0 CHANGE IN VOLUME [CU.M]	0.55 % LOSS OF CAPACITY
<b>TB1-TB2</b>											
	1005.84	1002.79	821	667	1488.9	635.3	663868.2	945979.8	-282111.6		
	1002.79	999.74	413	170	584.2	608.9	412071.3	355678.7	56392.6		
	999.74	996.70	4	0	4.4	400.9	157133.5	1775.0	155358.5		
	996.70	995.85	0	0	0.0	106.8	5936.0	0.0	5936.0		
							1239007.0	1303432.0	-64425.0		-5.20
<b>TB2-TB3</b>											
	1005.84	1002.79	1352	821	2174.6	589.1	840452.6	1281147.0	-440694.4		
	1002.79	999.74	1018	413	1431.6	686.3	605018.9	982477.2	-377458.4		
	999.74	996.70	88	4	92.9	665.4	335920.1	61819.7	295799.1		
	996.70	994.20	0	0	0.0	765.4	91480.2	0.0	91480.2		
							1894575.0	2325443.0	-430868.0		-22.74
<b>TB3-TB4</b>											
	1005.84	1002.79	917	1352	2270.4	444.4	797792.7	1008968.4	-211175.6		
	1002.79	999.74	627	1018	1645.9	484.5	583535.1	797415.8	-213880.7		
	999.74	996.70	206	88	294.7	460.3	335920.1	135667.3	203252.7		
	996.70	993.65	0	0	0.0	494.1	146360.4	0.0	146360.4		
	993.65	991.75	0	0	0.0	630.0	32072.9	0.0	32072.9		
							1895679.0	1942051.0	-46372.0		-2.45
<b>TB4-TB6</b>											
	1005.84	1002.79	1059	917	1976.7	919.5	1955418.0	1817631.0	137787.0		
	1002.79	999.74	836	627	1464.5	837.2	1409735.0	1226069.0	183666.0		
	999.74	996.70	594	206	800.3	782.1	894578.9	625945.5	268633.4		
	996.70	993.65	12	0	12.9	705.9	422148.0	9103.8	413044.2		
	993.65	992.70	0	0	0.0	387.4	32476.7	0.0	32476.7		
							4714355.0	3678748.0	1035607.0		21.97

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TB11-TB12

1005.84	1002.79	4025	3074	7100.2	150.6	1032251.0	1069147.0	-23596.0
1002.79	999.74	3581	2759	6340.9	150.6	228157.2	954775.9	-26618.7
999.74	996.70	2970	2430	5401.1	150.2	834589.7	843521.5	-6931.0
996.70	993.65	2610	2105	4716.4	155.8	733152.5	734694.4	3458.1
993.65	990.60	2295	1775	4070.5	147.7	629790.0	601110.0	28680.0
990.60	987.55	1544	1391	2936.4	147.8	516262.6	433997.7	82354.9
987.55	984.50	815	618	1433.8	160.2	397000.5	229680.1	167320.4
984.50	981.46	337	111	449.1	171.4	286080.7	76990.3	209090.4
981.46	978.41	15	0	16.0	204.2	192309.0	3259.0	189049.9
978.41	977.00	0	0	0.0	231.3	34222.8	0.0	34222.8

5588812.0 4947083.0 641729.0 11.48

TOTAL RESERVOIR 14601374.0 128981120.0 17032672.0 11.67

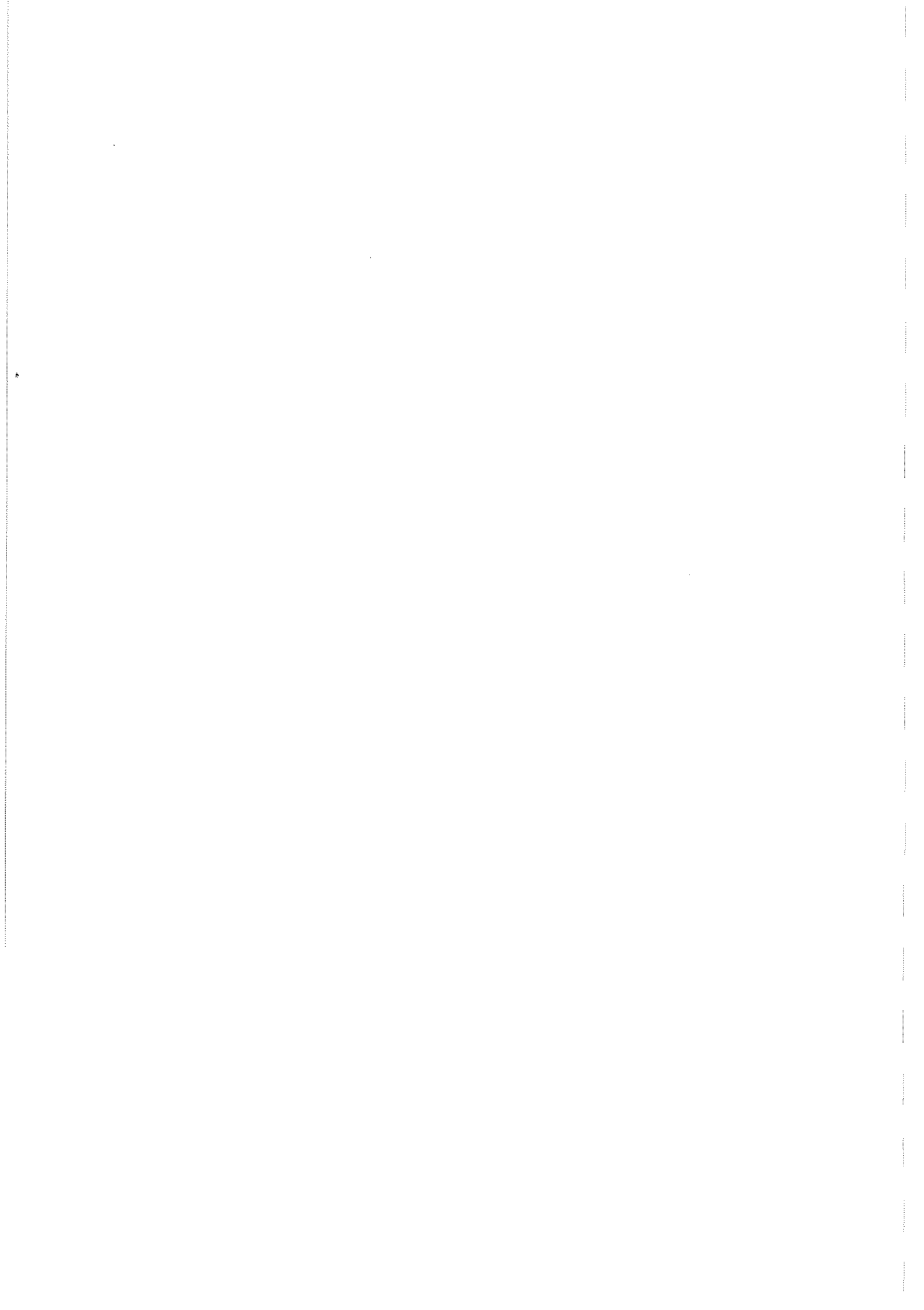
1965 VOLUME BELOW	969.26 =	4356. CU.M
1965 VOLUME BELOW	972.31 =	125209. CU.M
1965 VOLUME BELOW	975.36 =	811461. CU.M
1965 VOLUME BELOW	978.41 =	2093549. CU.M
1965 VOLUME BELOW	981.46 =	4640279. CU.M
1965 VOLUME BELOW	984.50 =	8762659. CU.M
1965 VOLUME BELOW	987.55 =	15289257. CU.M
1965 VOLUME BELOW	990.60 =	24889920. CU.M
1965 VOLUME BELOW	993.65 =	38241424. CU.M
1965 VOLUME BELOW	996.70 =	56376384. CU.M
1965 VOLUME BELOW	999.74 =	80159008. CU.M
1965 VOLUME BELOW	1002.79 =	109993968. CU.M
1965 VOLUME BELOW	1005.84 =	146013648. CU.M
1983 VOLUME BELOW	969.26 =	0. CU.M
1983 VOLUME BELOW	972.31 =	0. CU.M
1983 VOLUME BELOW	975.36 =	25930. CU.M
1983 VOLUME BELOW	978.41 =	409164. CU.M
1983 VOLUME BELOW	981.46 =	2004740. CU.M
1983 VOLUME BELOW	984.50 =	4742837. CU.M
1983 VOLUME BELOW	987.55 =	9669168. CU.M
1983 VOLUME BELOW	990.60 =	17627728. CU.M
1983 VOLUME BELOW	993.65 =	28765424. CU.M
1983 VOLUME BELOW	996.70 =	44314192. CU.M

TABLE 5 - Kamburu Reservoir - unconsolidated sediment volume, 1981

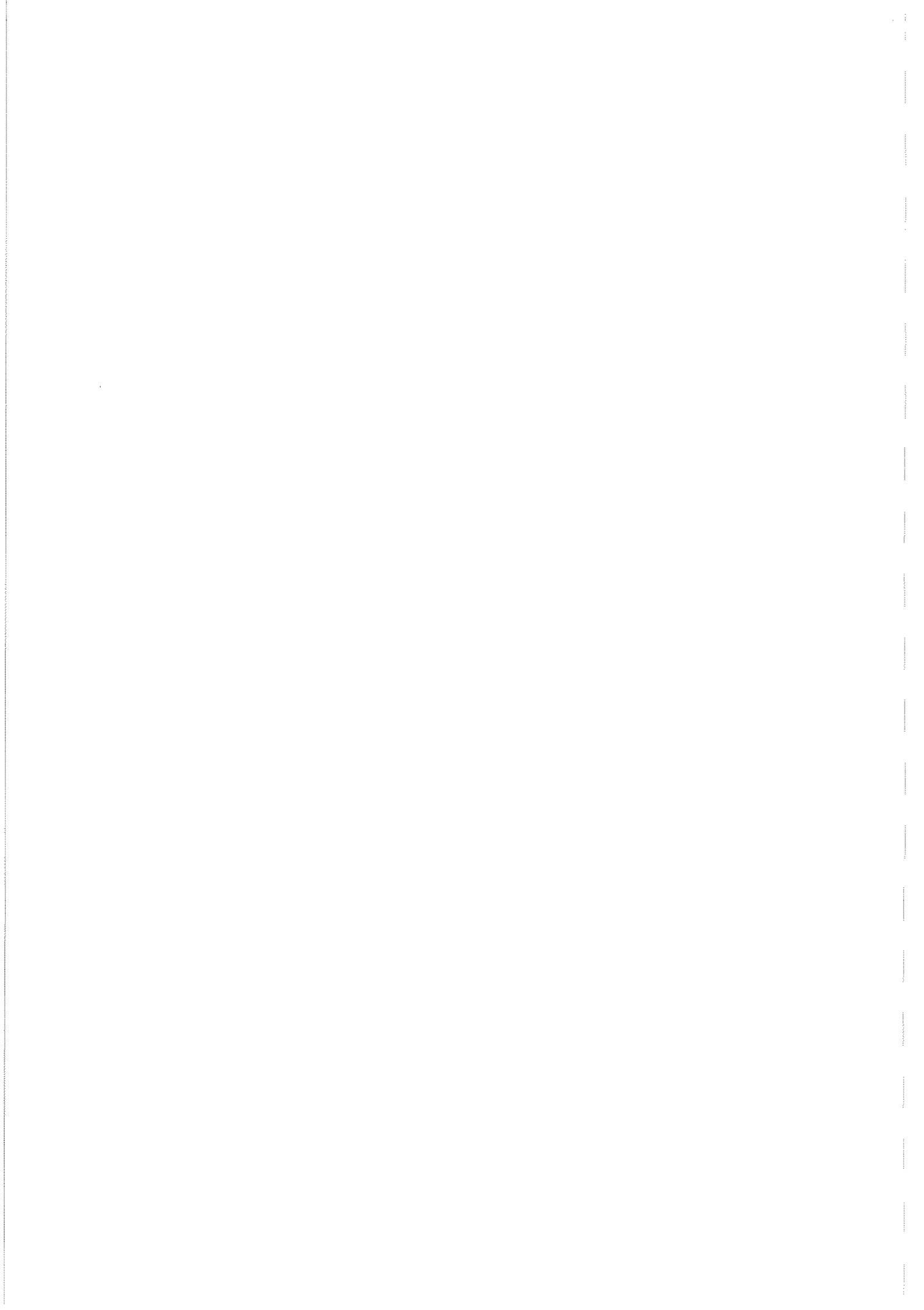
Section	Sediment Volume (m <sup>3</sup> )	Av Contour Area (m <sup>2</sup> )	Av Sediment Depth (m)	Sediment Density (x10 <sup>3</sup> kg/m <sup>3</sup> )	$\frac{V_o}{V_{act}}$	Unconsolidated Volume (m <sup>3</sup> )
TN 3-TN 4	660081	116258	5.7	1236	1.13	745892
TN 4-TN 5	845972	124648	6.8	1258	1.14	964408
TN 5-TN 6	870612	127056	6.9	1260	1.14	992498
TN 6-TN 7	1514036	157800	9.6	1308	1.17	1771422
TN 7-TN 8	2189847	246648	8.9	1296	1.16	2540223
TN 8-TN10/10A	2305985	304063	7.6	1274	1.15	2651883
U/S -TN 9	363495	75276	4.8	1215	1.12	407114
TN10/10A-TN11	2374207	399320	5.9	1240	1.13	2682854
TN11-TN12	770957	446264	1.7	1134	1.08	832634
TN12-TN13	723185	286840	2.5	1156	1.09	788272
TN13/TB12-TN14	1454770	438016	3.3	1178	1.10	1600247
TN14-TN15/15A	-35521	320381	-0.1	-	-	(-35521)
TN15/15A-TN16	-831808	576314	-0.4	-	-	(-831808)
TN16-TN17	485301	458432	1.1	1110	1.07	519272
TN17-Dam	138449	381400	0.4	1067	1.05	145371
Total for Tana River limb						15774761
TB 1-TB 2	232717	134679	1.7	1134	1.08	251334
TB 2-TB 3	-536772	196534	-2.7	-	-	(-536772)
TB 3-TB 4	-221108	155533	-1.4	-	-	(-221108)
TB 4-TB 6	1001828	387690	2.6	1160	1.09	1091993
TB 6-TB 7	346597	157166	2.2	1150	1.09	377791
TB 7-TB 8	223082	176637	1.3	1119	1.07	238698
TB 8-TB 9	403261	458165	0.9	1100	1.06	427457
TB 9-TB10	128885	205504	0.6	1082	1.05	135329
TB10-TB11	190587	228842	0.8	1094	1.06	202022
TB11-TB12	570779	202490	2.8	1166	1.10	627857
Total for Thiba River limb						2594601

TABLE 6 - Kamburu Reservoir - unconsolidated sediment volumes, 1983

Section	Sediment Volume (m <sup>3</sup> )	Av Contour Area (m <sup>2</sup> )	Av Sediment Depth (m)	Sediment Density (x10 <sup>3</sup> kg/m <sup>3</sup> )	Vo Vact	Unconsolidated Volume (m <sup>3</sup> )
TN 3-TN 4	616316	116258	5.3	1225	1.13	696437
TN 4-TN 5	764107	124648	6.2	1245	1.14	871082
TN 5-TN 6	770769	127056	6.1	1245	1.14	878677
TN 6-TN 7	1308799	157800	8.3	1286	1.16	1518207
TN 7-TN 8	1982360	246648	8.0	1324	1.18	2339185
TN 8-TN10/10A	2332266	304063	7.7	1275	1.16	2705429
U/S -TN 9	395262	75276	5.3	1226	1.13	446646
TN10/10A-TN11	2813399	399320	7.0	1262	1.15	3235409
TN11-TN12	1138063	446264	2.6	1160	1.10	1251869
TN12-TN13	897873	286840	3.1	1174	1.11	996639
TN13/TB12-TN14	1472312	438016	3.4	1181	1.11	1634266
TN14-TN15/15A	29634	320381	0.1	1020	1.03	30523
TN15/15A-TN16	808464	576314	-1.4	-	-	(-808464)
TN16-TN17	369218	458432	0.8	1094	1.07	395063
TN17-Dam	70319	381400	0.2	1050	1.04	73132
Total for Tana River limb						16264100
TB 1-TB 2	-64425	134679	-0.5	-	-	(-64425)
TB 2-TB 3	-430868	196534	-2.2	-	-	(-430868)
TB 3-TB 4	-46372	155533	-0.3	-	-	(-46372)
TB 4-TB 6	1035607	387690	2.7	1160	1.10	1139168
TB 6-TB 7	386463	157166	2.5	1156	1.10	425109
TB 7-TB 8	320138	176637	1.8	1136	1.09	348950
TB 8-TB 9	485825	458165	1.1	1110	1.07	519833
TB 9-TB10	162692	205504	0.8	1094	1.07	174080
TB10-TB11	389661	228842	1.7	1134	1.09	424730
TB11-TB12	641729	202490	3.2	1176	1.11	712319
Total for Thiba River limb						3202524



## Figures



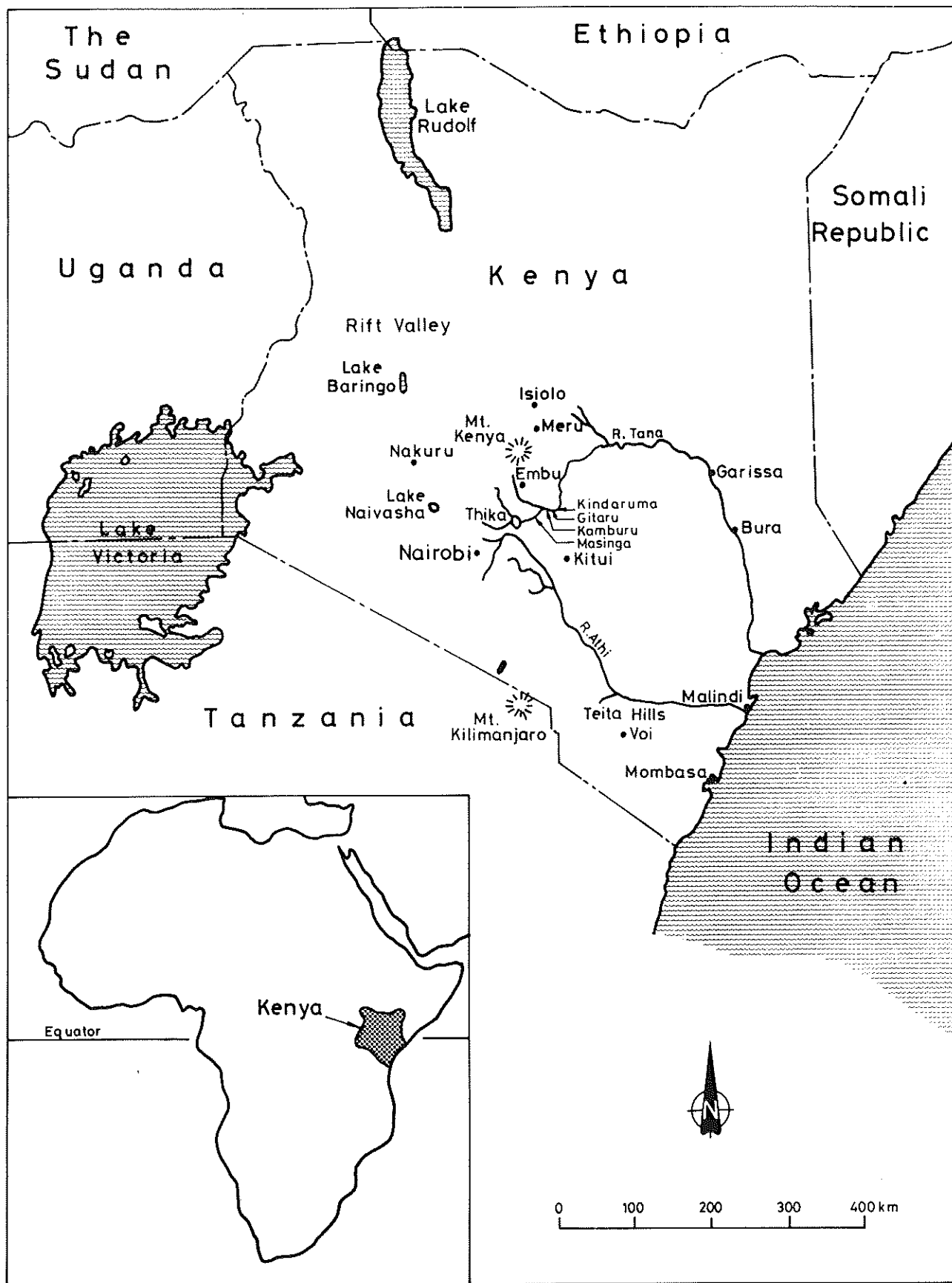


Fig 1 Location map

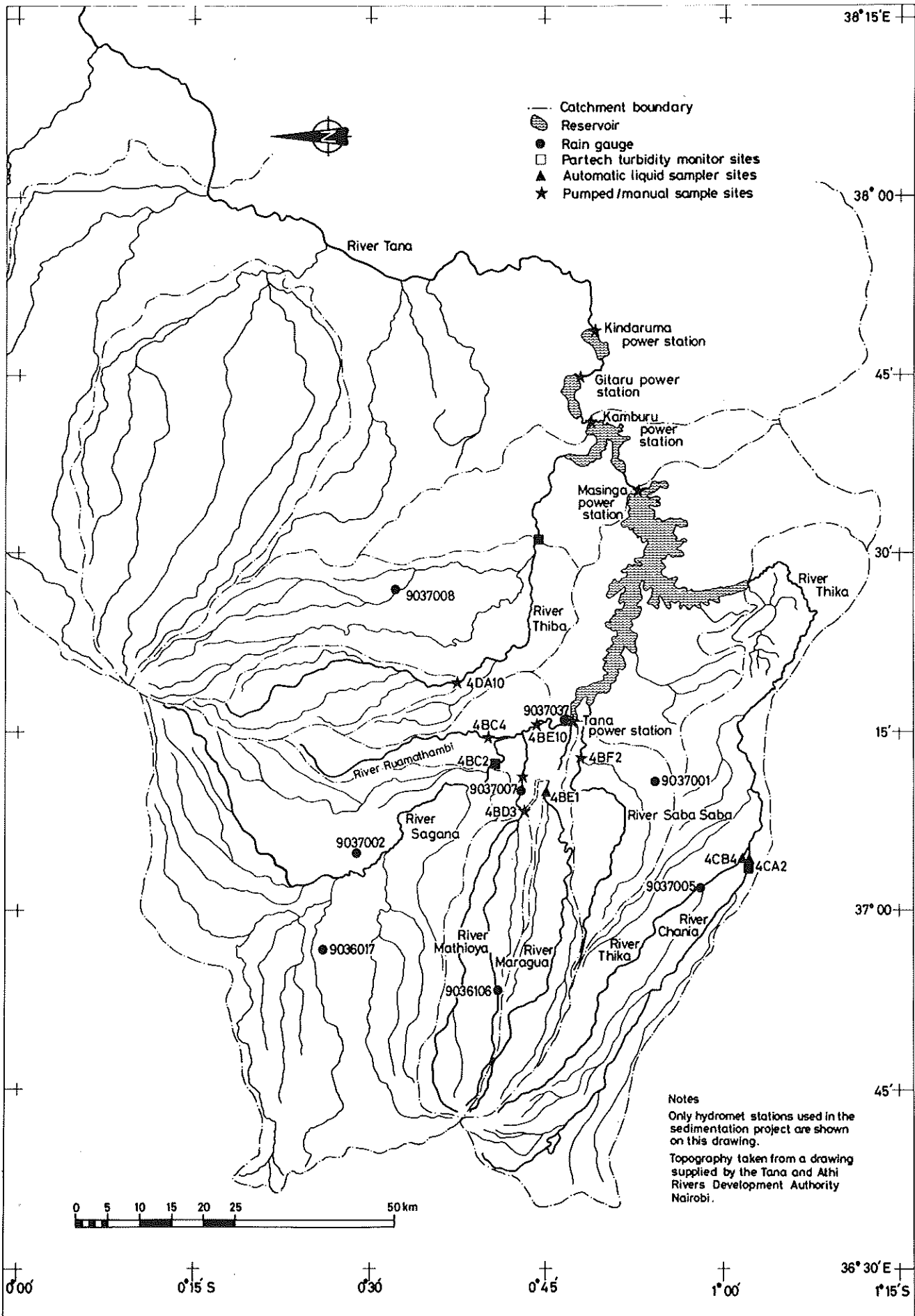


Fig 2 Tana River basin

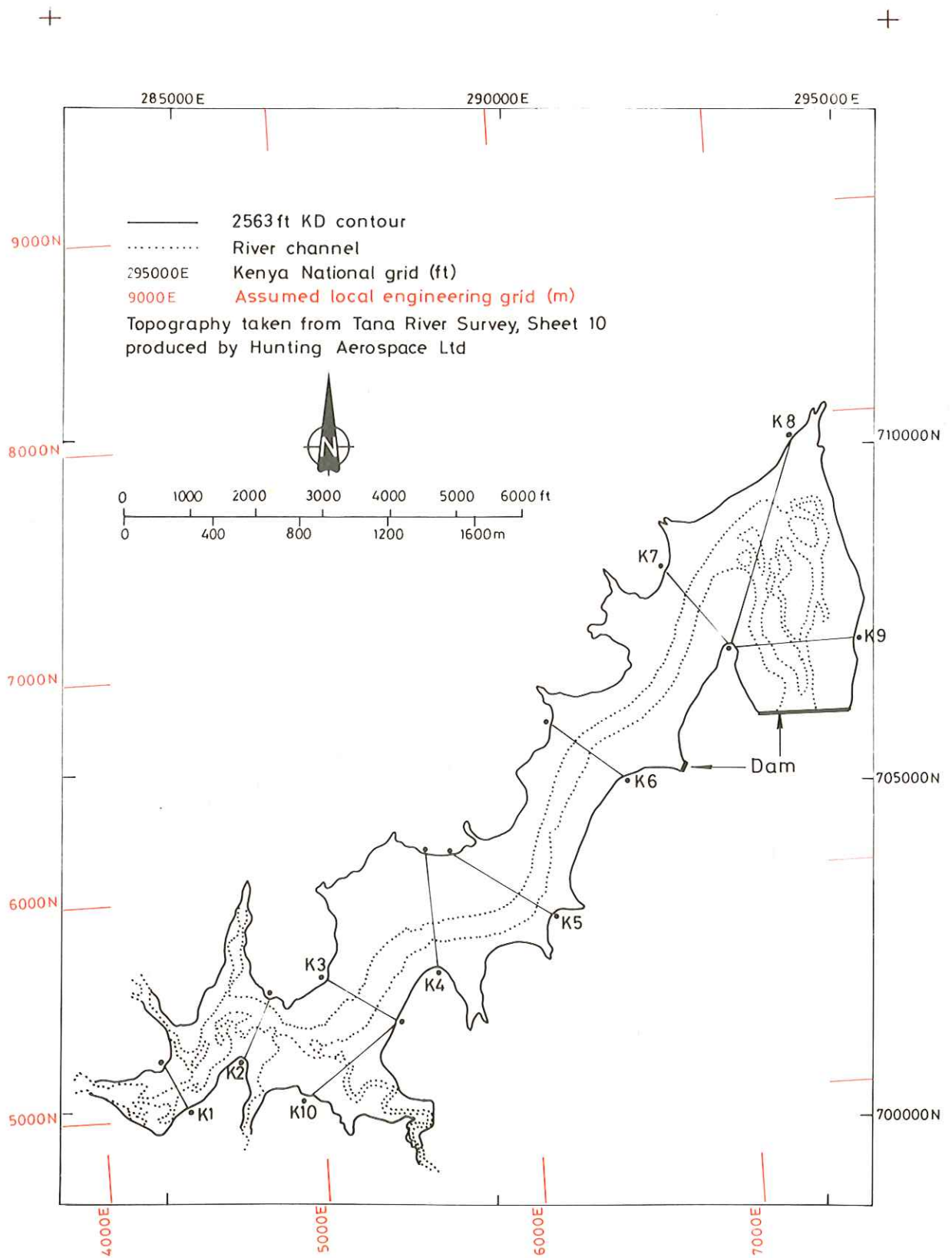


Fig 3 Kindaruma Reservoir

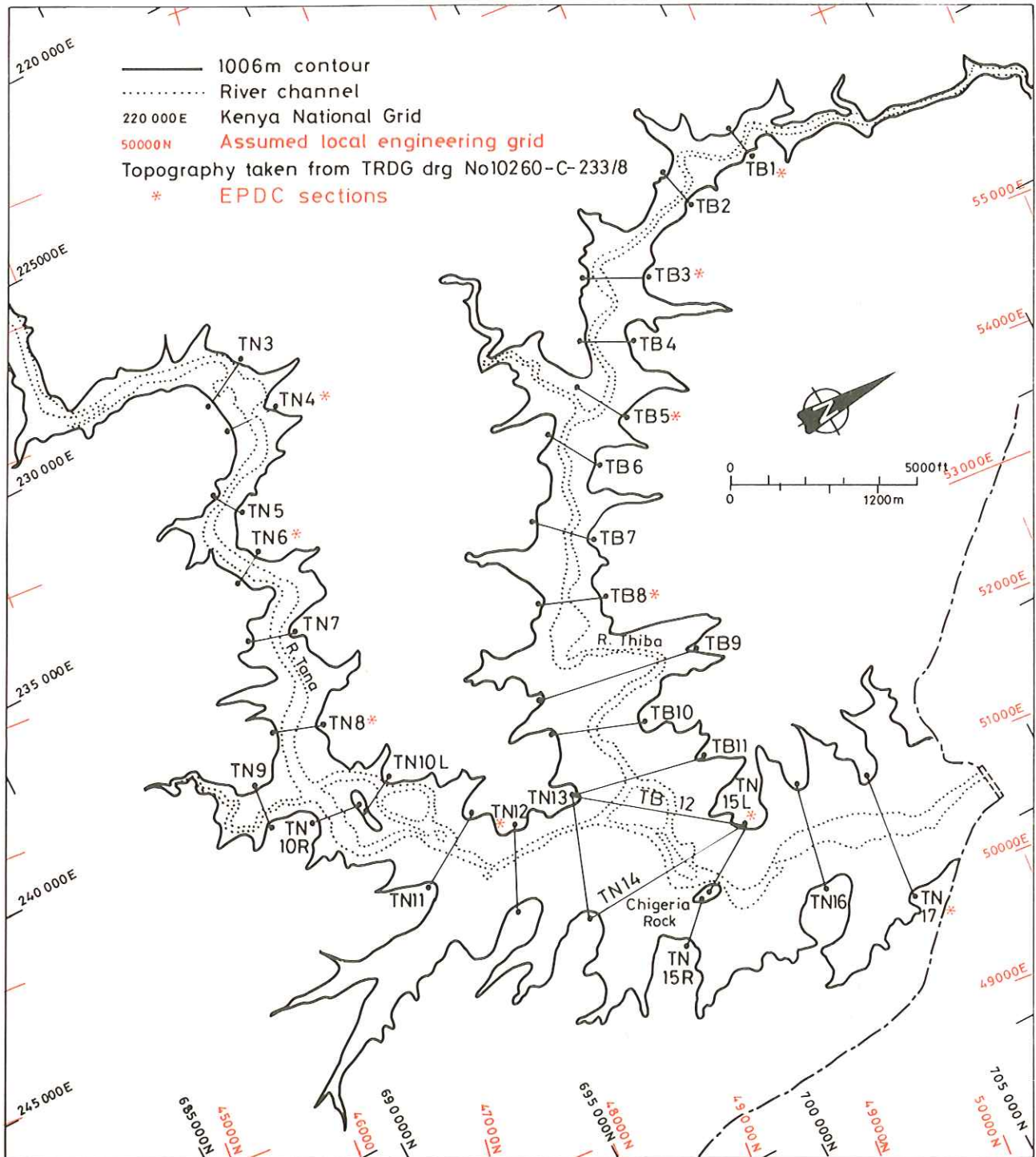


Fig 4 Kamburu Reservoir

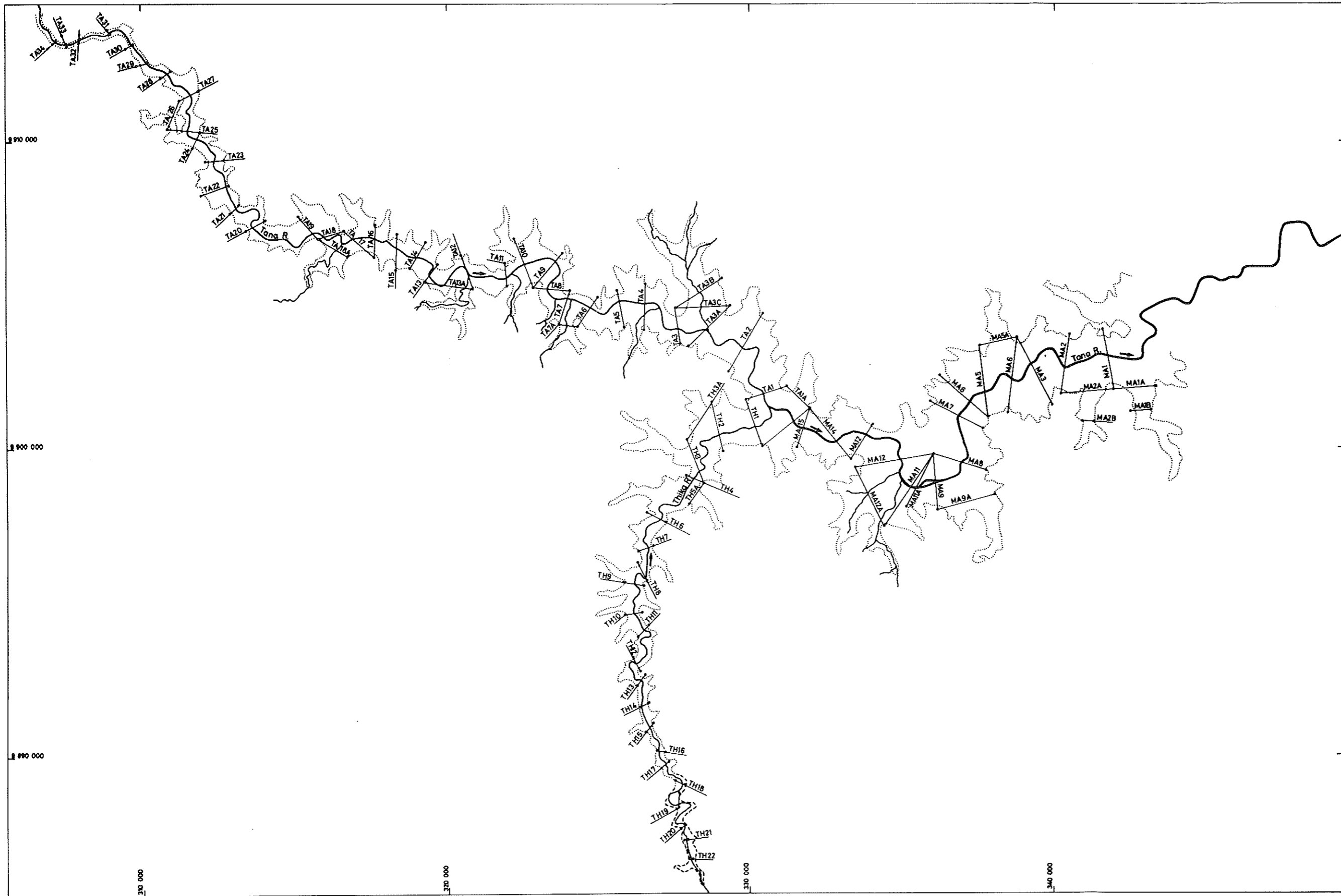


Fig 5 Masinga Reservoir

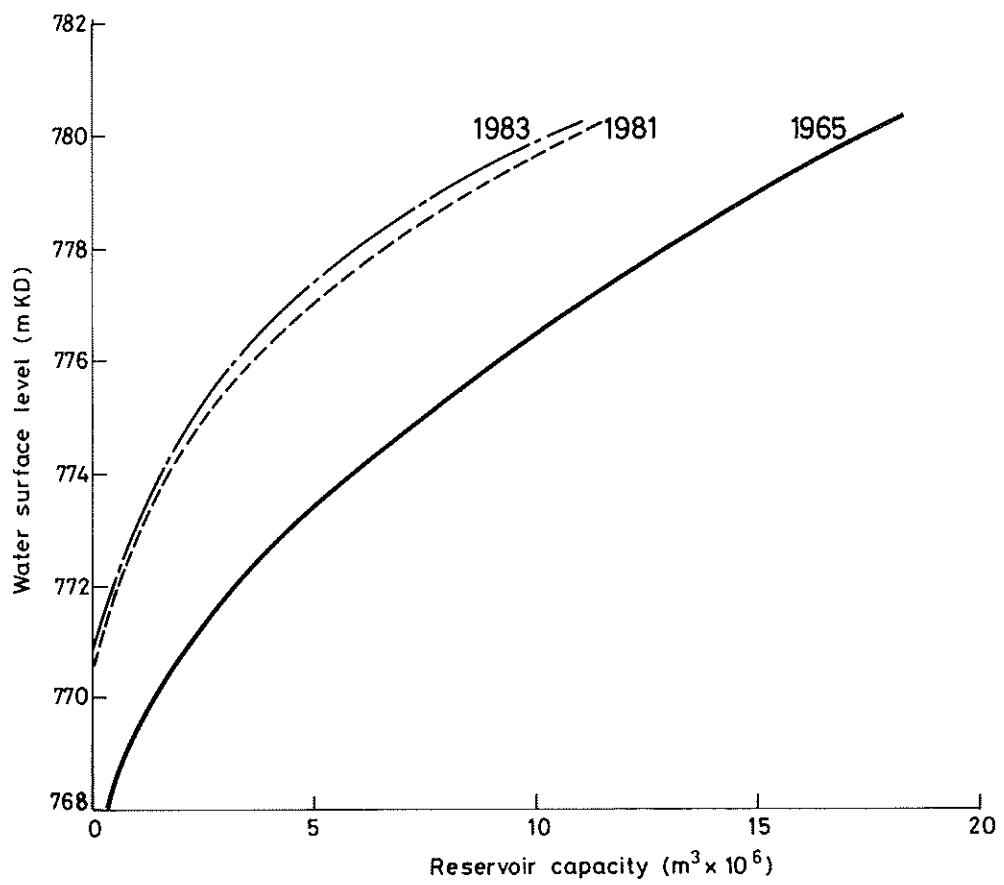


Fig 6 Kindaruma Reservoir - stage/capacity curve

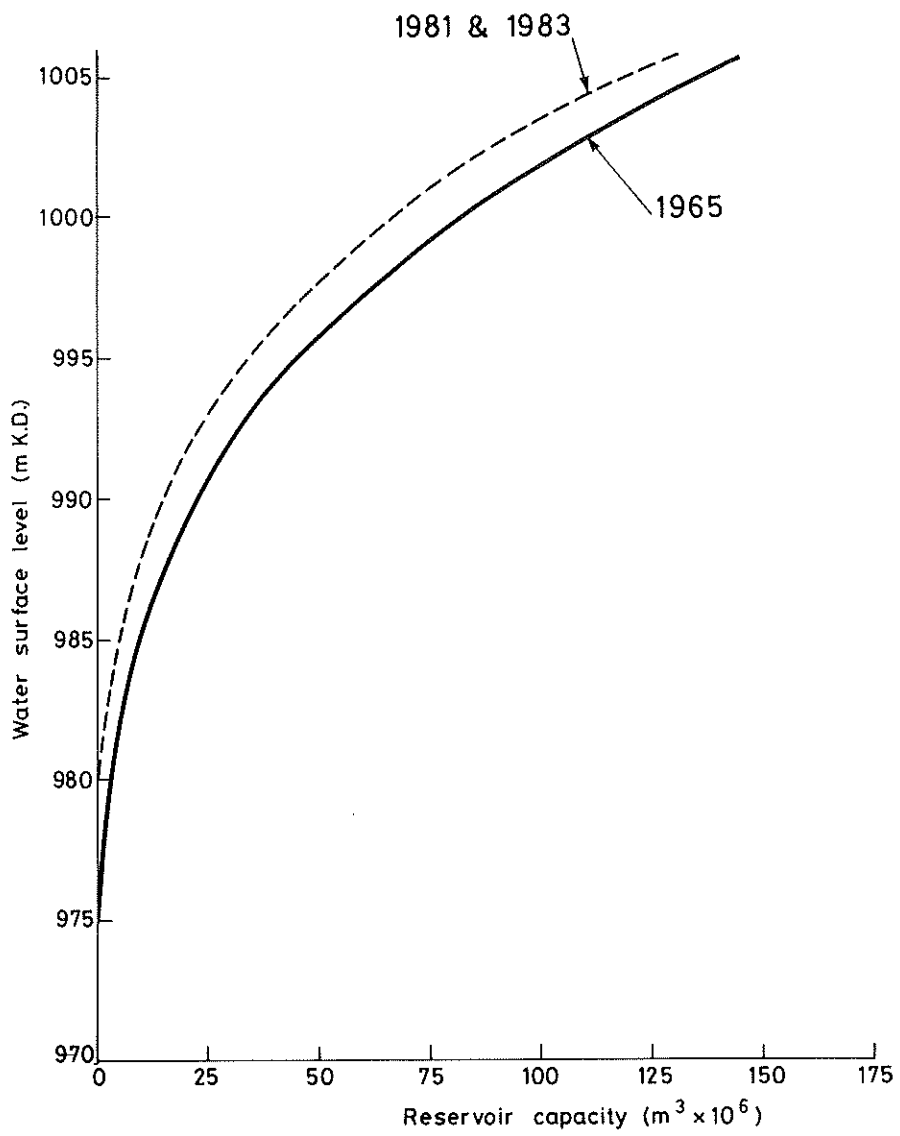


Fig 7 Kamburu Reservoir - stage/capacity curve

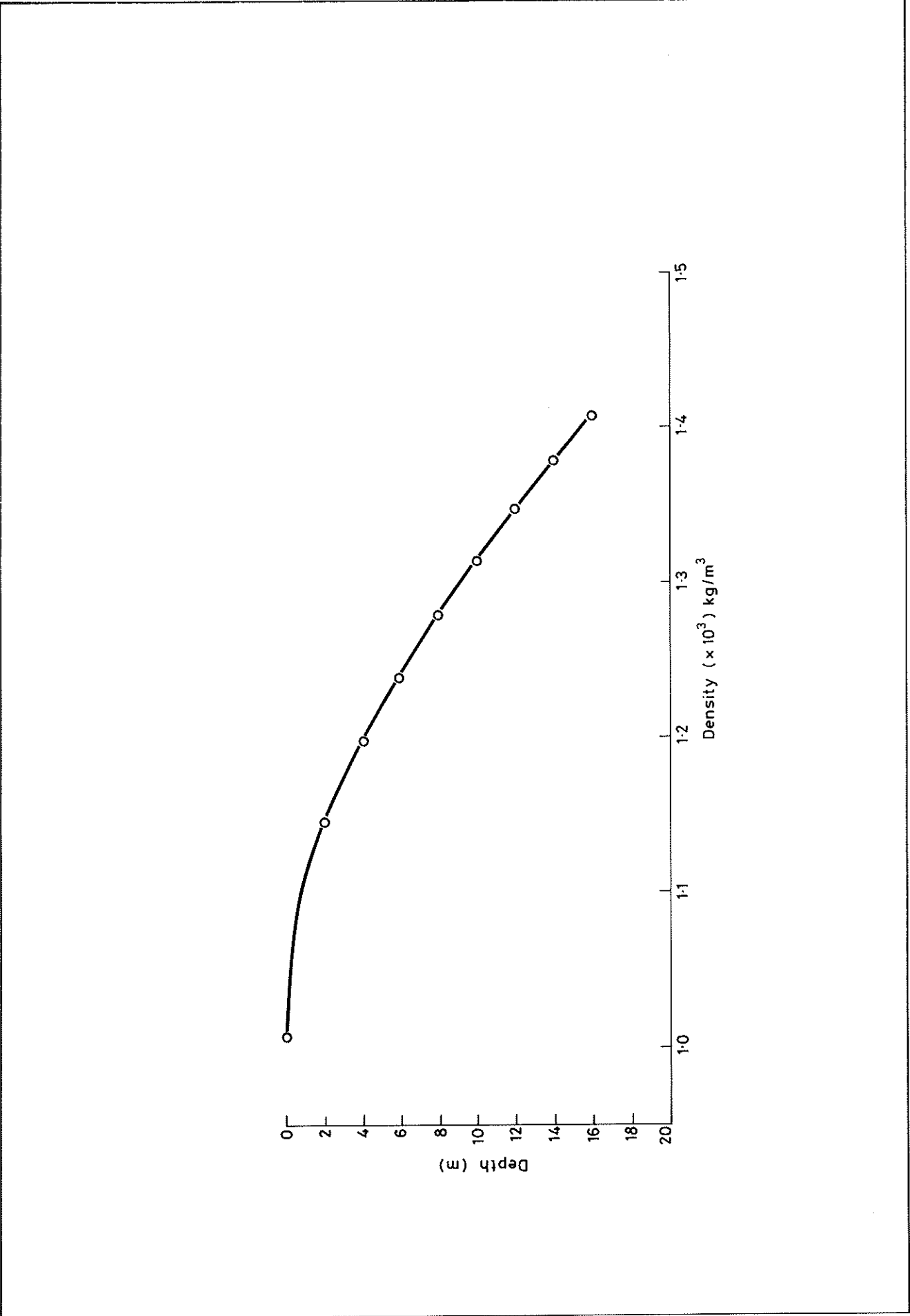
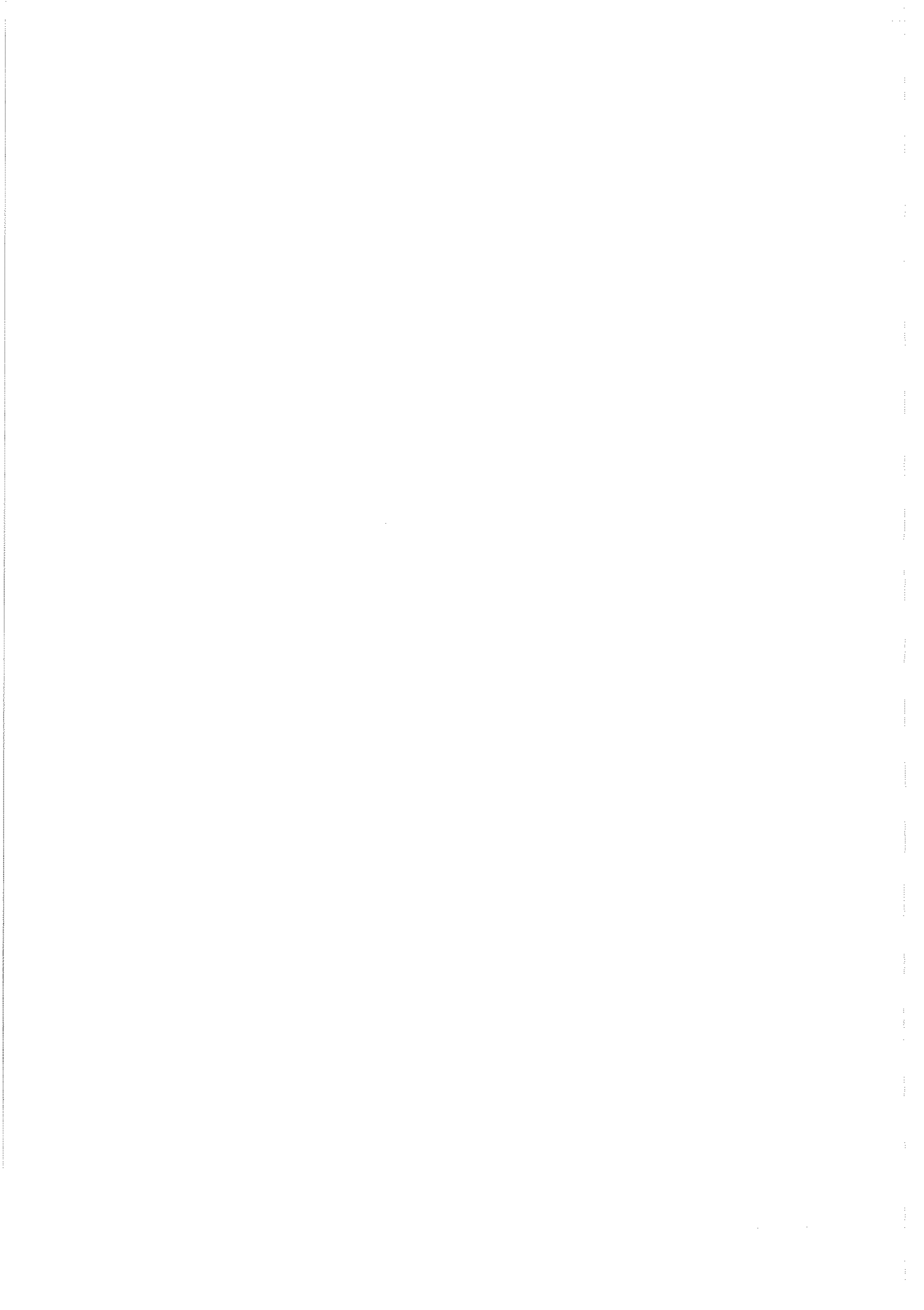


Fig 8 Variation of sediment density with depth



## Plates

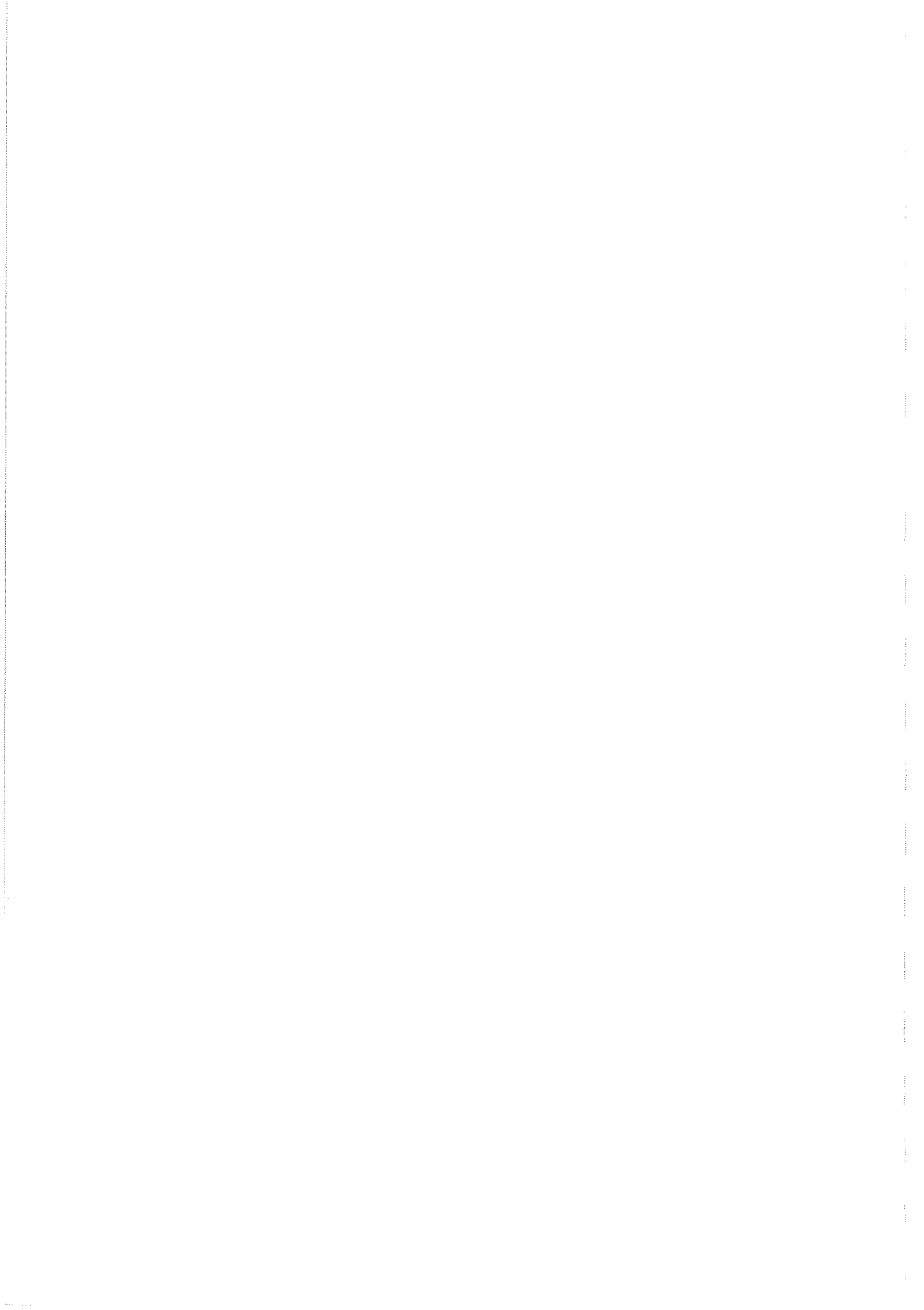




PLATE 1. Partech installation at Sagana Bridge



PLATE 2. Kamburu reservoir, survey marker TN 8 (right)

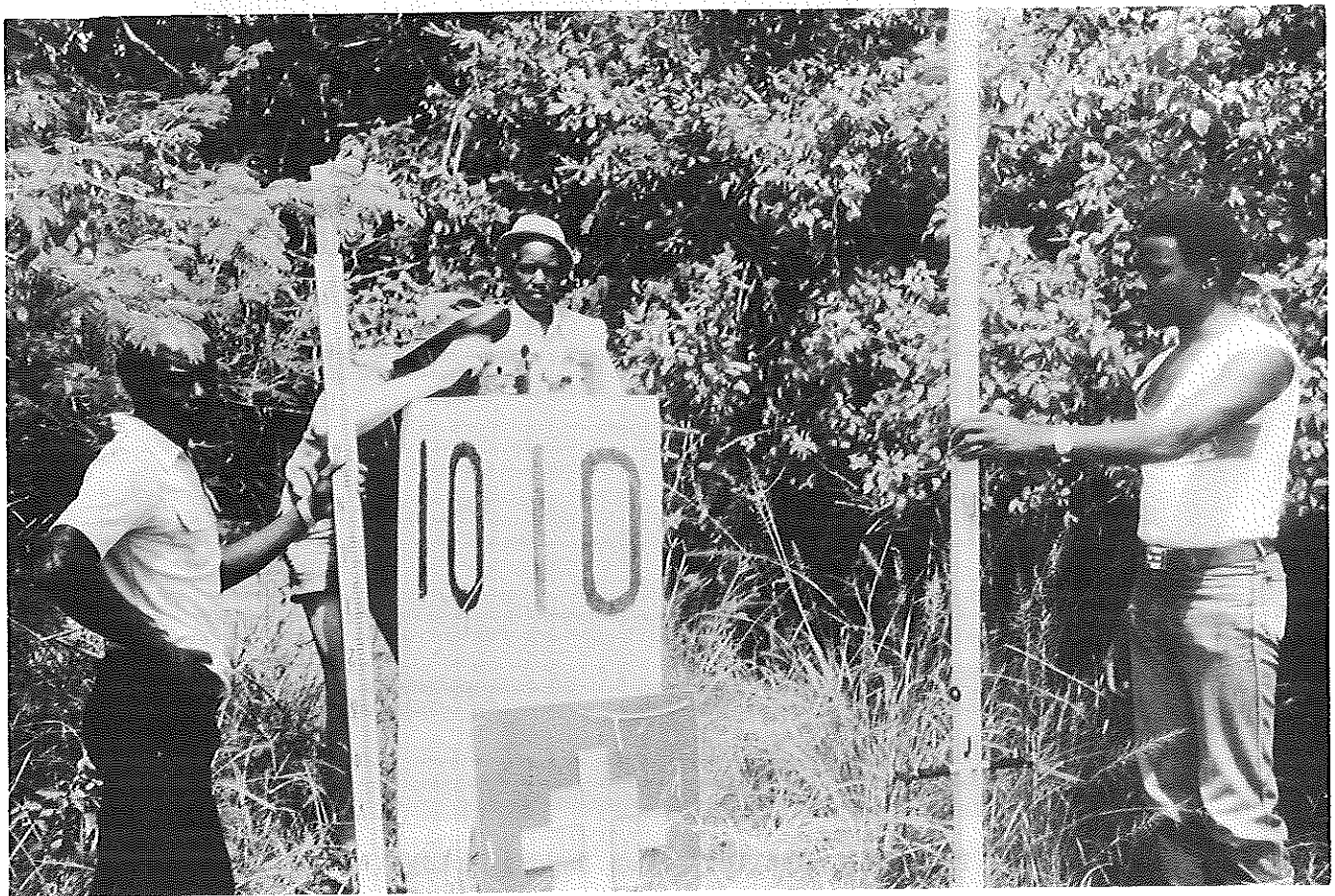


PLATE 3. Kamburu reservoir, survey marker TN 10 (right)



PLATE 4. Kamburu reservoir, survey marker TB 8 (right)



PLATE 5. Masinga reservoir, typical survey marker



PLATE 6. Upstream limit of Kindaruma reservoir



PLATE 7. Survey equipment by Kamburu dam

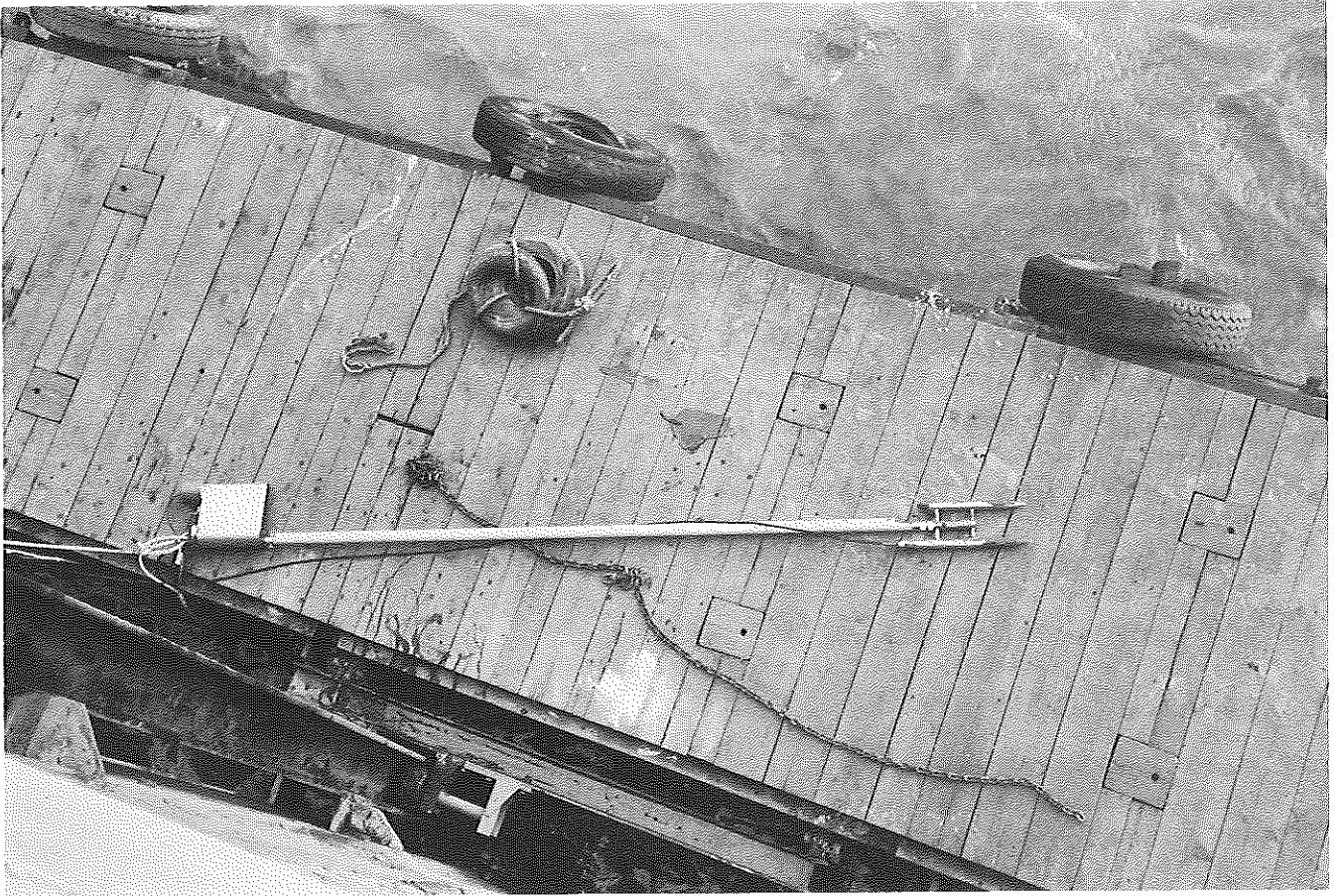
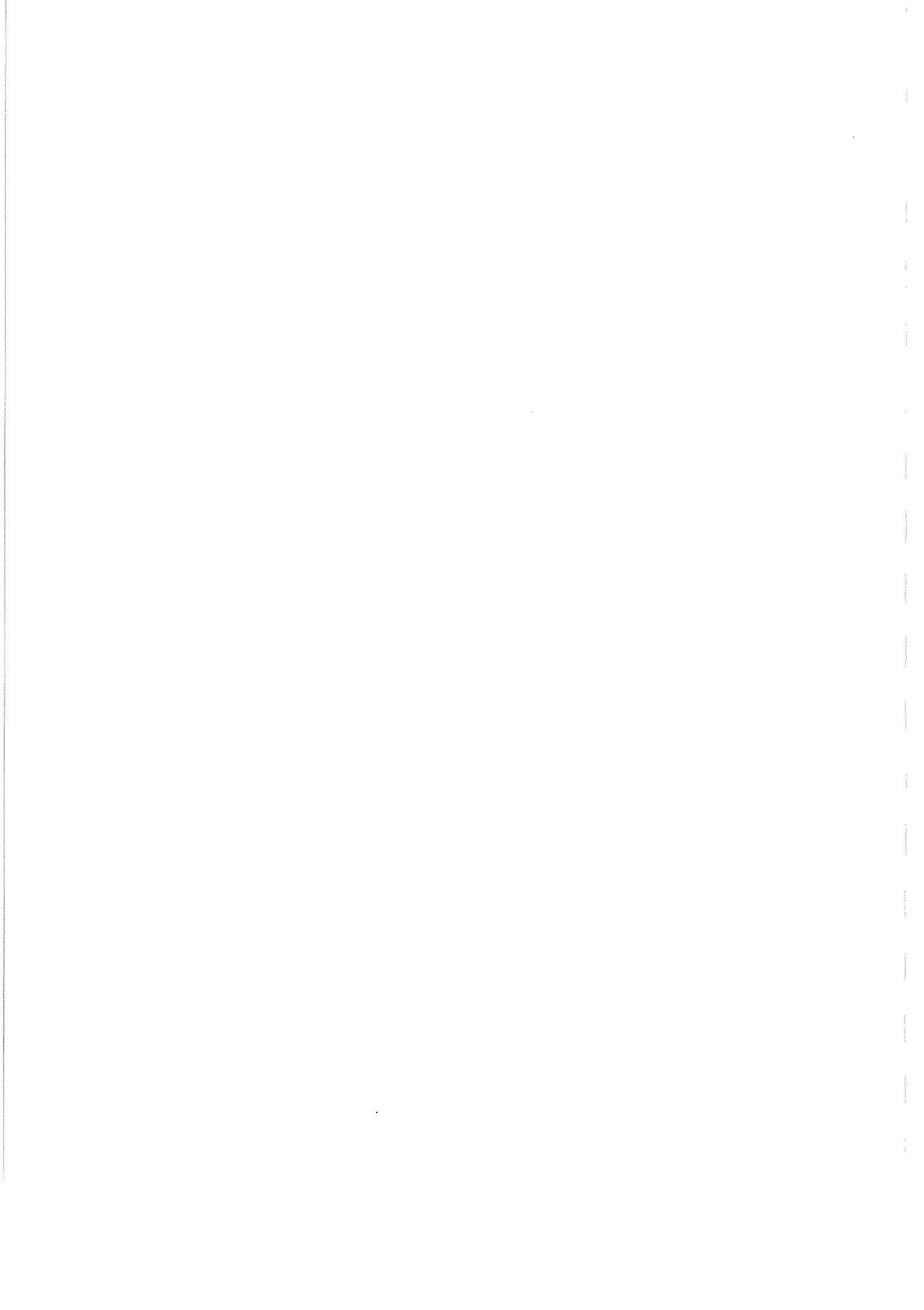


PLATE 8. Gamma transmission probe



PLATE 9. Collecting a bed sample using a Van Essen grab



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