6.2 Hydrometeorological Network

The location of rainfall and runoff gauging stations in the vicinity of the Kihansi Project area is shown in Fig. 6-12 and observation periods of each station are in Table 6-3.

6.2.1 Rainfall Data

Since most of rainfall data have missing parts, more or less and there are many errors mainly owing to hand written copies in addition to scarcity of the station's number, it is difficult to select the rainfall pattern to represent the Kihansi Basin. Among these data, however, 983543 (Kibengu), 983547 (Mapanda) and 983550 (Boma la Ngombe) are situated within the Kihansi Basin and 983547 (Mapanda) has relatively long series of data and accuracy. As a result of calculating the correlation between 983547 (Mapanda) and other stations on the basis of monthly rainfall, the rainfall data of 983543 (Kibengu), 983600 (Ifakara Mission) and 983608 (Mchombe Mission) which are all located along the escarpment indicate the high correlation above 0.8. On the contrary, the rainfall data of 983513 (Wasa Mission), 983536 (Irundi Hill) and 983544 (Usakimi) which are all located inside the high land indicate the low correlation below 0.7.

Therefore, the rainfall pattern in the Kihansi Basin is considered to be affected strongly by SE wind during April and May and shows the orographic characteristics rather than the non-orographic ones (refer to Section 6.1.3, Rainfall).

Fig. 6-12 Hydrometric Network

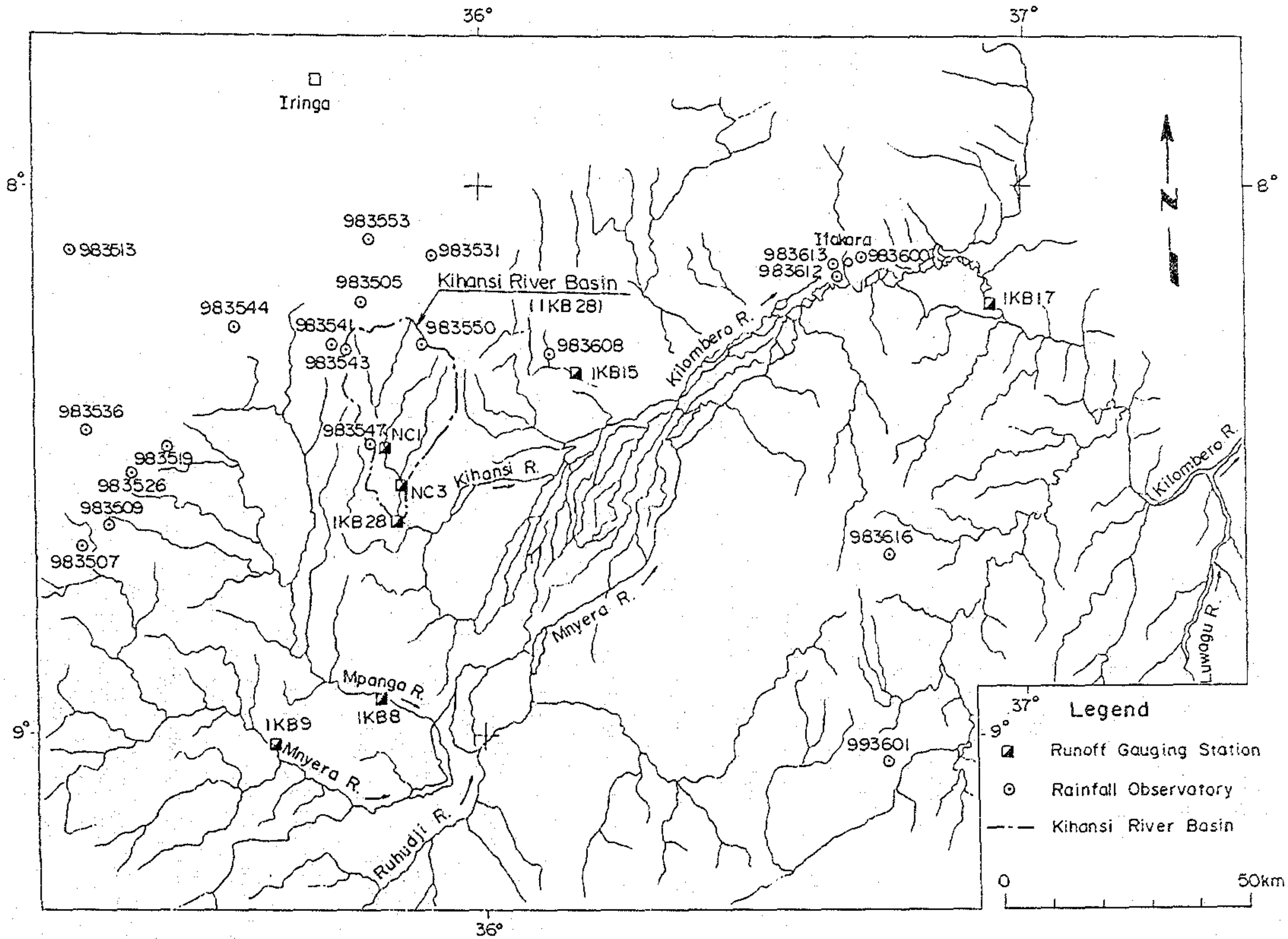


Table 6-3 (1) Hydrological Data List of Rainfall

Name of Rainfall Gauging Station	Station Number	Daily or Monthly
Ifiga	983505	D
Mufindi Forest	983507	D
Kilima	983509	D
Wasa Mission	983513	M
Ifupira Mufindi	983519	D
Echidna Tea Co.	983526	D
Itanga Estate	983531	M
Irundi Hill	983536	D
Luganga Kilolo	983541	D
Kibengu	983543	D
Usakimi	983544	M
Mapanda	983547	D
Boma la Ngombe	983550	D
Ifakara Mission	983600	D
Mchombe Mission	983608	D
Lumemo H./Met.	983612	D
Ifakara KATRIN	983613	D
Kasita Seminary	983616	D
Luhombero H./Met.	993601	D

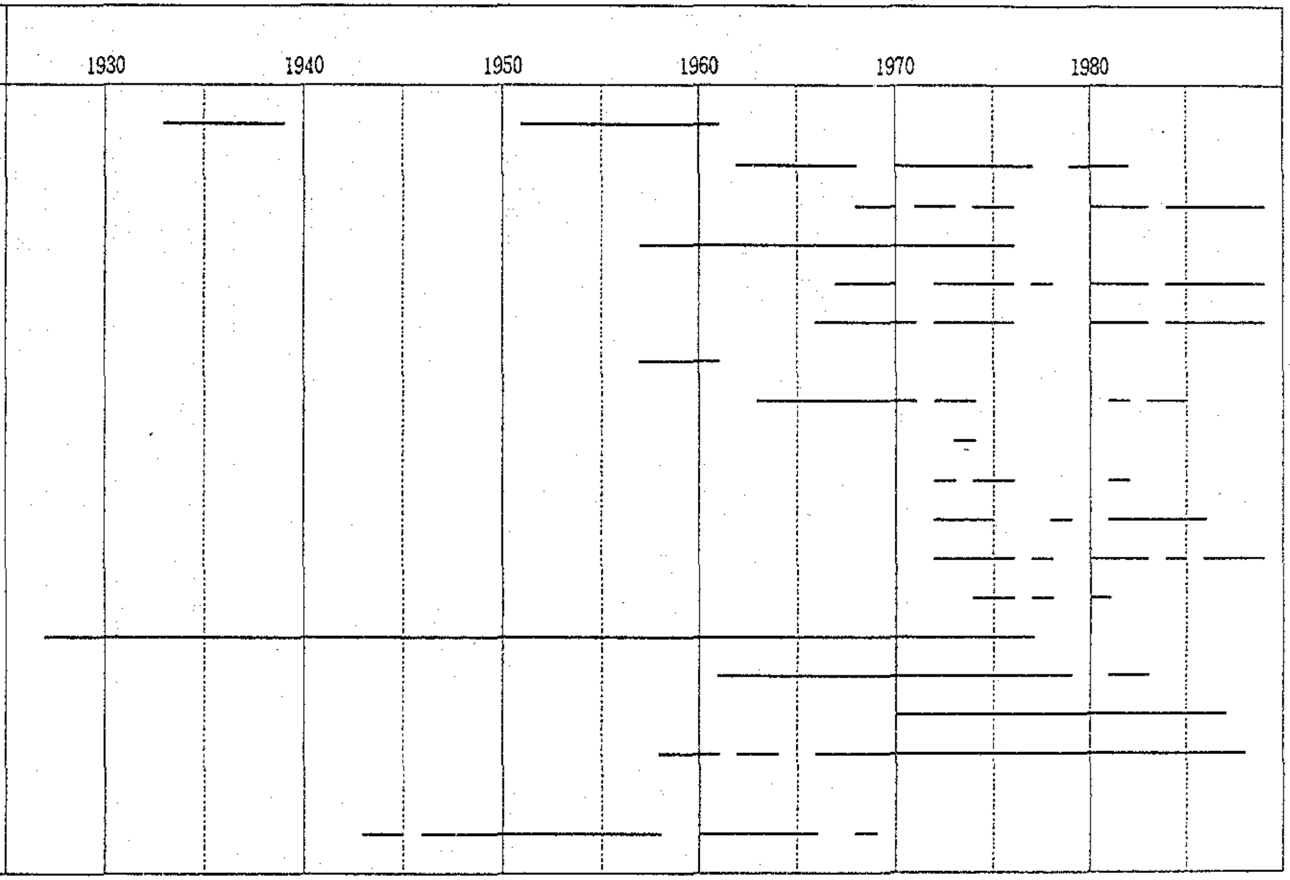
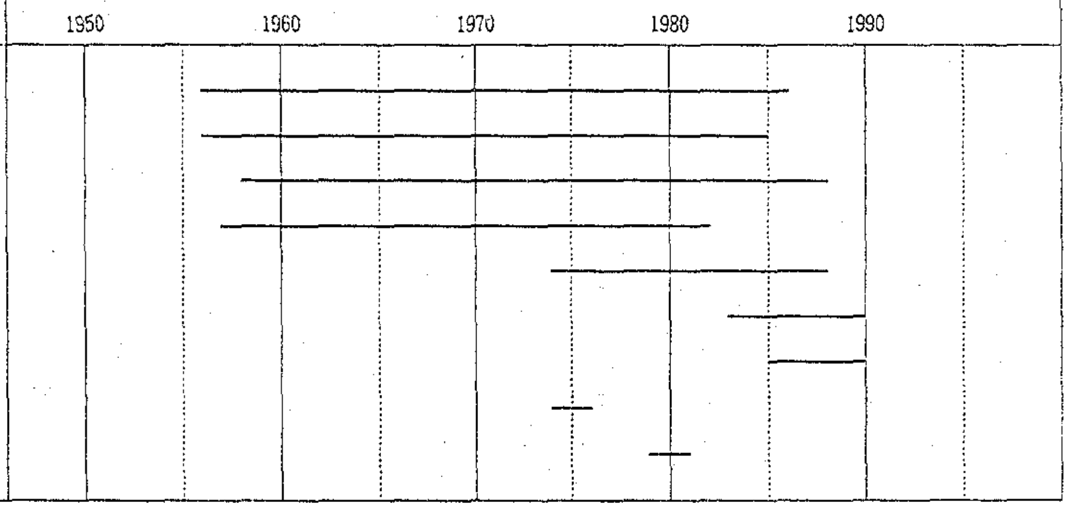


Table 6-3 (2) Hydrological Data List of Runoff

Station Number	Name of River	Location	Catchment Area (km²)
1KB 8	Mpanga	Mpanga	2535
1KB 9	Mnyera	Taveta	4760
1KB15	Mgeta	Mchome	321
1KB17	Kilombero	Ifakara	33400
1KB28	Kihansi		618
NC 1	Kihansi		373
NC 3	Kihansi		580
1KA 3	Great Ruaha	Kidatu	80040
1KA 5	Great Ruaha	Mtera	67884



6.2.2 Outline of Each Runoff Gauging Station

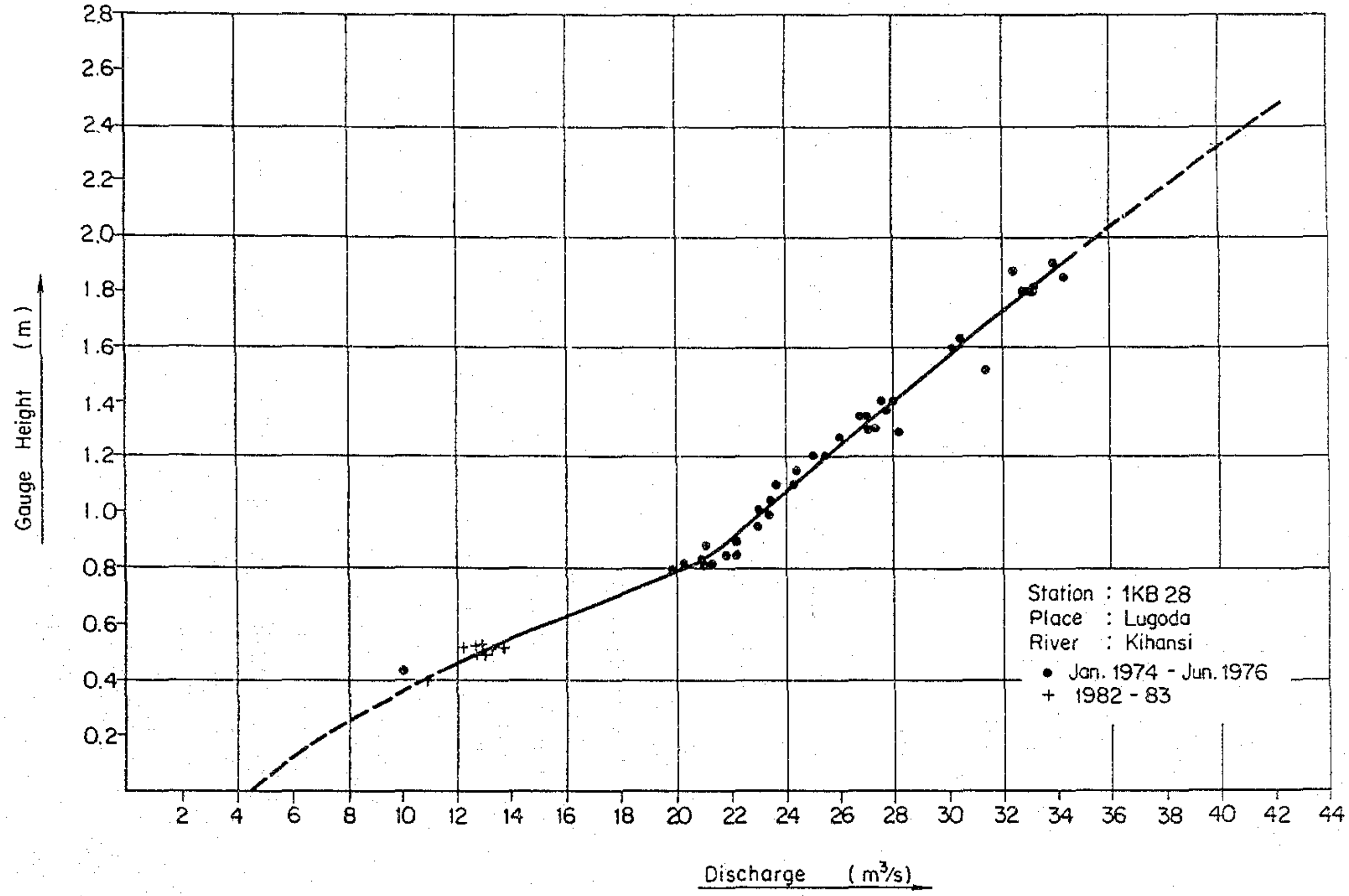
The runoff gauging stations related to the Kihansi Project are to be introduced as follows:

i) 1KB28 (Kihansi River)

The water level records at 1KB28 are very important because they represent the runoff of the Kihansi River, especially inflow to both Upper Kihansi reservoir and Lower Kihansi intake dam. 1KB28 is located near the bridge where the local road along the Kilombero River crosses the Kihansi River and its catchment area is 618 km^2, while that of Upper Kihansi dam is 583 km^2 and that of Lower Kihansi dam is 590 km^2, respectively. The water level has been observed three times a day since 1974 and the total missing days are 146. The rating curve (Fig. 6-13) was prepared by Norconsult considered all past measurements and shows a sharp break at a gauge height of approximately 0.8 m mainly owing to the rapid change of river cross-section at that height. Rufiji Basin Hydropower Master Plan reported that this curve was acceptable within the range between 0.4 m and 3.5 m. Since most records were observed within this range, the same rating curve for converting the water level into discharge is adopted in this report, too.

A new automatic water level recorder of a float type was installed at 1KB28 site on March 14, 1989 in order to investigate the variation of water level by hourly unit.

Fig. 6-13 Rating Curve for 1KB28



ii) NC1 (Kihansi River)

NC1 was established beside the bridge on the road between Mapanda village and Uhafiwa village on October 1982 and covers a drainage area of 373 km^2. The objective of this station was to obtain the inflow discharge into the upper damsite of Norconsult's scheme at that time. Although the upper damsite is now to be moved to lower reach of the Kihansi River, the data of NC1 is still important to understand the runoff characteristics in the upper part of the Kihansi Basin.

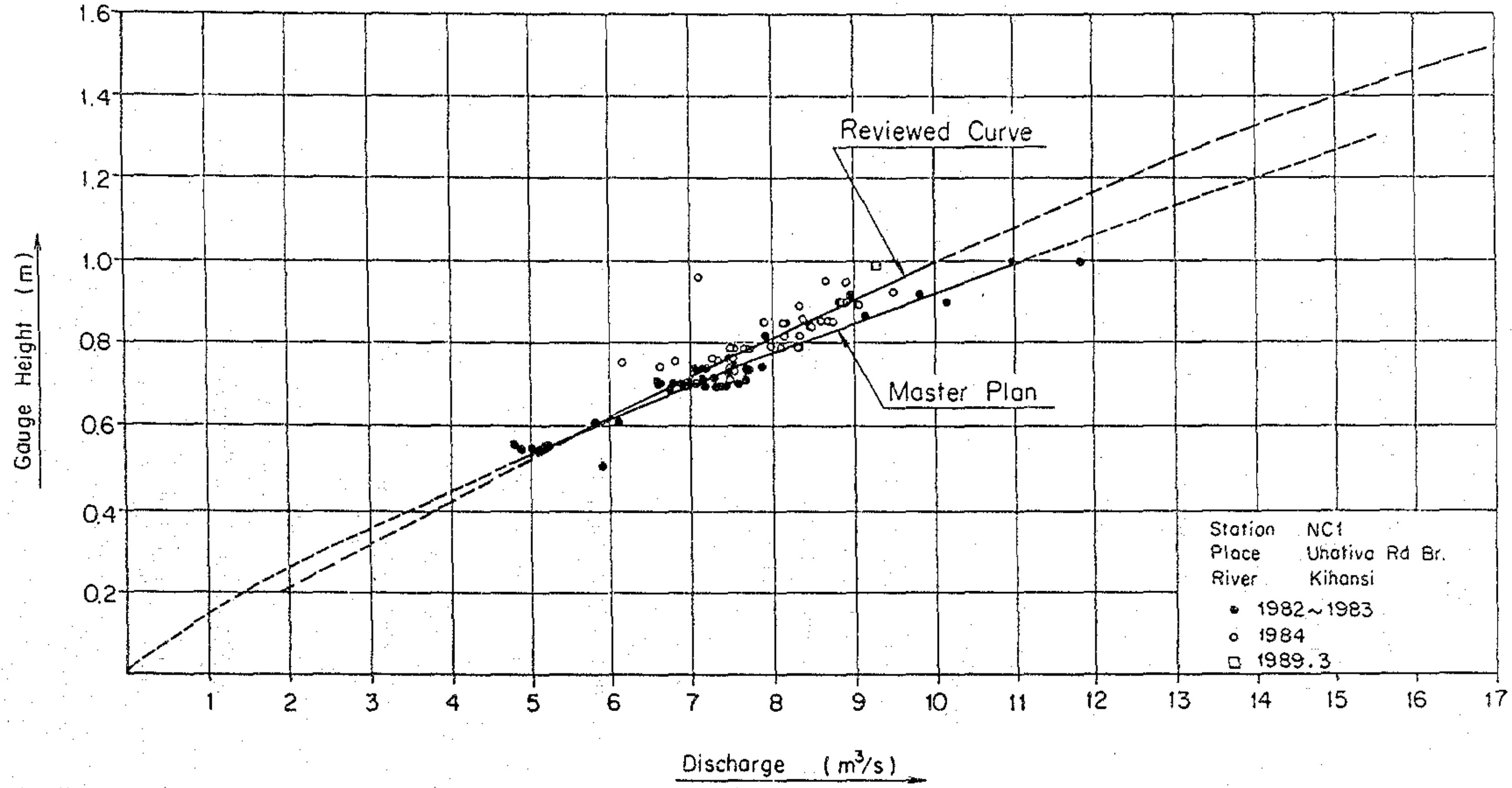
Although the rating curve was once prepared by Norconsult based on the 56 measurements during 1982 to 1983, it is modified slightly this time, considering the results of measurements carried out during 1984. Fig. 6-14 shows both the former curve and modified one. This curve was also checked on 1st, March, 1989 by JICA Study Team.

Since the measurements don't cover the higher level, it cannot be helped to extrapolate in order to estimate the flood discharge.

iii) NC3 (Kihansi River)

NC3 was established near the lower damsite proposed by Norconsult in 1984/1985. Now this site almost corresponds to the Upper Kihansi dam site and the catchment area is estimated to be 582 km^2. The automatic water recorder of a pressure type was installed on February 28, 1989, and besides, a runoff measurement has been executed at least once a week, since the constant observation of the discharge here is considered to be very important to calculate the

Fig. 6-14 Rating Curve for NC1



appropriate energy generation for both Upper and Lower Kihansi Projects.

The rating curve was established by means of a hydraulic model by Norconsult instead of the conventional method such as a series of simultaneous discharge and water level measurements at the site.

The result of this hydraulic modeling method is thought to be quite reasonable, so far as it is compared with the actual measurements carried out since February, 1989. However, since the river channel cannot keep the constant condition and changes the shape of river bed continuously, it is preferable to measure the actual runoff discharge, if possible. The rating curve prepared by Norconsult is indicated in Fig. 6-15.

iv) 1KB8 (Mpanga River)

Daily water level at 1KB8 has been observed since 1955. The catchment area of the Mpanga River at the site of 1KB8 is 2,535 km^2. Although the catchment area of 1KB8 is approximately 4 times as that of 1KB28 of the Kihansi River, the correlation coefficient is relatively high such as 0.845 on the monthly basis and 0.784 on the daily basis as shown in Fig. 6-16. This suggests that rainfall pattern and topographic condition as well as the runoff discharge between two stations are so similar that the data of 1KB8 has reliability enough to compensate the missing data of 1KB28, though there are some missing data of higher water level than 4.0 m.

According to Rufiji Basin Hydropower Master Plan, the rating curve of 1KB8 has been shifted to the present

Fig. 6-15 Rating Curve for NC3

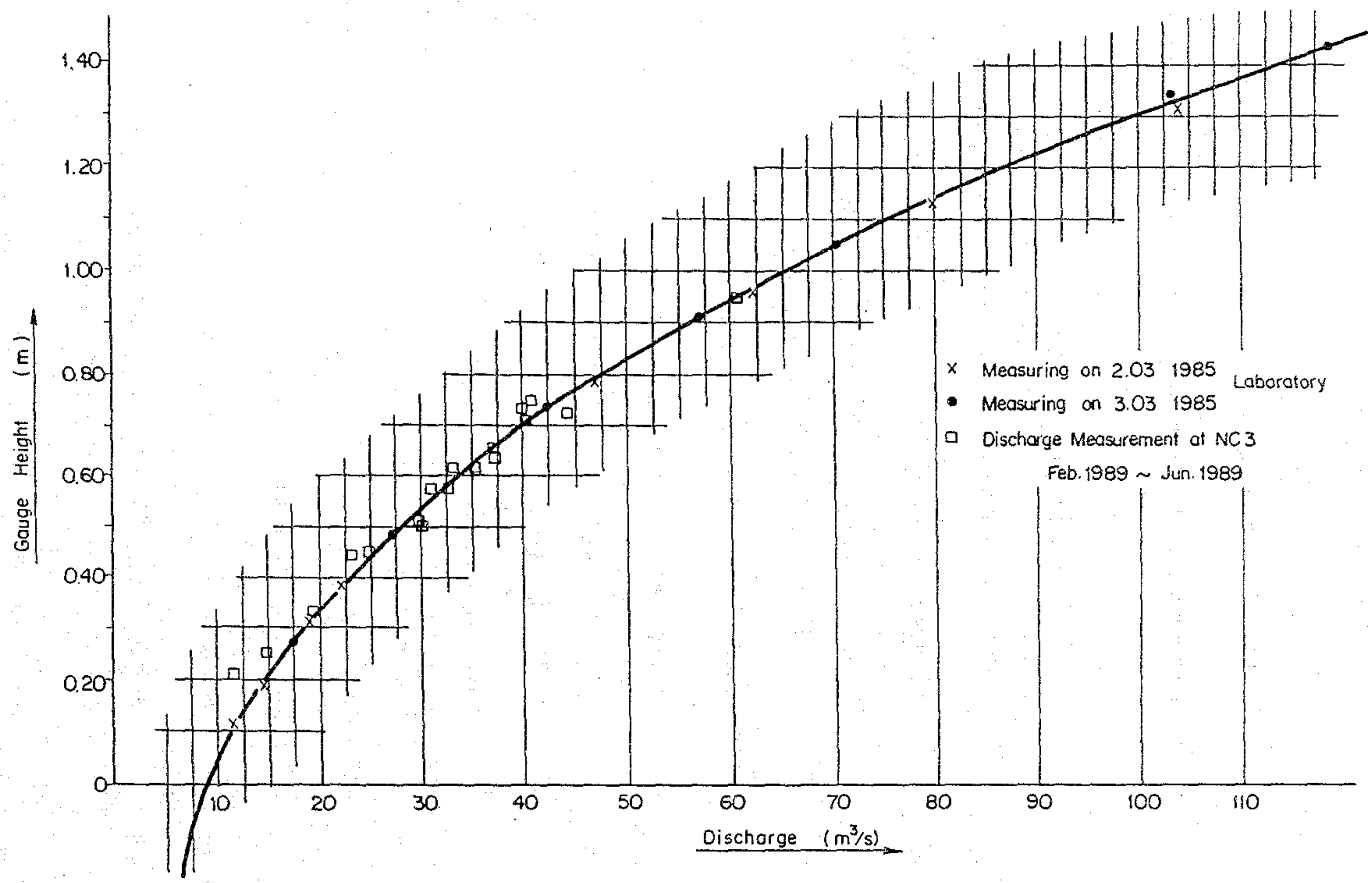
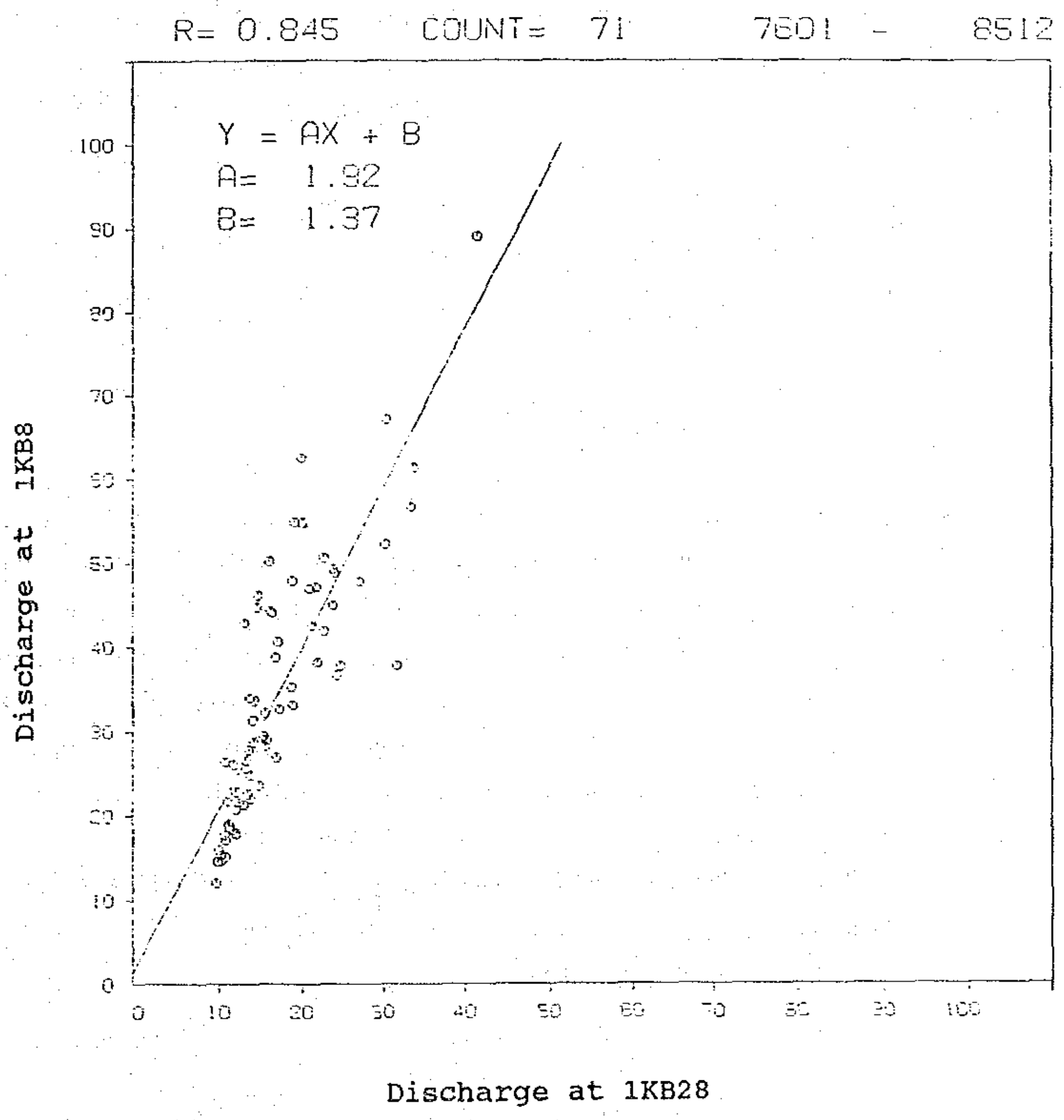


Fig. 6-16 Correlation of Monthly Runoff between 1KB28 and 1KB8



curve on April, 1961 but both of them are thought to be acceptable (Fig. 6-17).

v) 1KB9 (Mnyera River)

Rufiji Basin Hydropower Master Plan reported that there existed various rating curves which happened to cause the conversion errors and the raw data of water level themselves had possibility to include many errors, such as the change of the measurement. Moreover, since the actual hydrograph of 1KB9 indicates the different behavior from that of 1KB28 and the correlation coefficient between these two stations is quite low such as 0.609 on the monthly basis and 0.580 on the daily basis, the data of 1KB9 are not available to compensate the missing data of 1KB28.

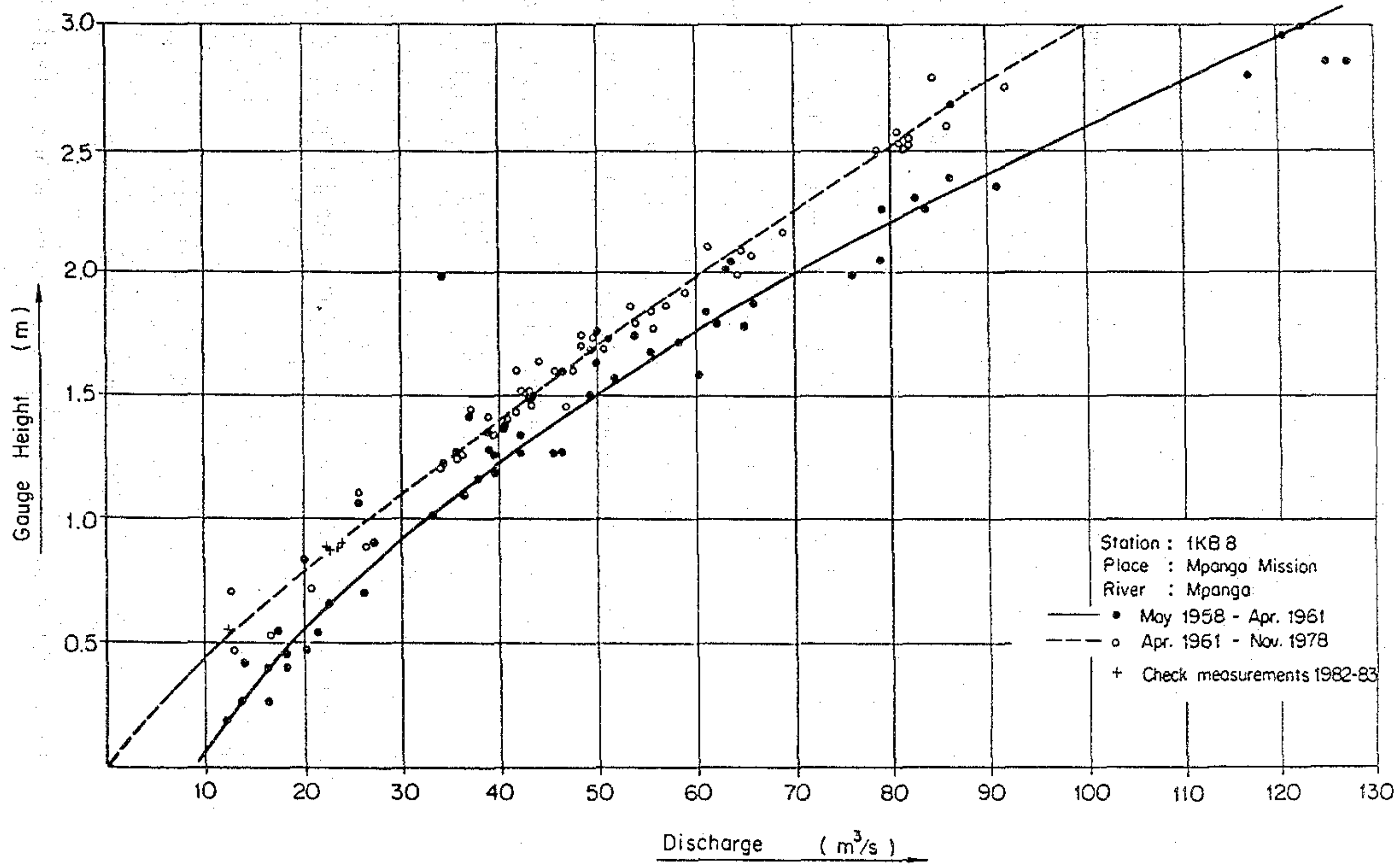
vi) 1KB15 (Mgeta River)

1KB15 was expected to present much useful information to make up for 1KB28 because there are many resemblances; the catchment areas are 321 km^2, 618 km^2 respectively and it is located along the escarpment and belongs to the heavy rain zone. The correlation coefficient, however, between these two stations turned out not to be so high, such as 0.745 on the monthly basis and 0.714 on the daily basis, that 1KB15 is to be available only when the data of 1KB8 are missing. The rating curve of 1KB15 is given as the following equation.

$$Q = 31.1\ H^{2.31} \qquad H \leq 0.76$$

$$Q = 22.2\ H^{1.141} \qquad H > 0.76$$

Fig. 6-17 Rating Curve for 1KB8



6.3 Data Generation

6.3.1 Methodology

The period of river discharge at both Upper and Lower Kihansi dam sites is necessary to extend as long as possible in order to estimate the appropriate energy generation as mentioned in Section 6.1.6, Hydrological Cycle. Basically the data of 1KB28 are considered to represent the discharge at both dam sites adequately and have only to be converted by the ratio of two catchment areas in order to gain the discharge at the dam sites because the difference of catchment areas is very small. The observation period of 1KB28, however, is only 13 years from 1975 to 1987 and the data generation is necessary by means of hydrological analyses. So far, two methods were tried in Rufiji Basin Hydropower Master Plan in 1984 (hereinafter referred to as M/P) and Power Sector Development Plan in 1985 (hereinafter referred to as PSDP). M/P adopted the HEC-4 model developed by U.S. Army Corps based on the monthly correlation between a pair of runoff stations or runoff and rainfall data. The data were expanded to 1955 because the suitable correlation before then could not be found out. Although PSDP also used the recurrence analysis based on the monthly correlation, it expanded the data to 1940 by ranked rainfall and discharge method as for the data before 1957. This report agrees to the idea of PSDP and moreover, tries to adopt the Tank Model Method developed by Mr. Sugawara in Japan as well as the recurrence analysis.

6.3.2 Discharge at 1KB28

(1) Compensation for Missing Data from 1975 to 1987

The missing data were compensated basically according to the following rules.

i) If the corresponding data of NC1 exist, the recurrence equation between 1KB28 and NC1 is adopted.

ii) If there are not the corresponding data of NC1 but the corresponding data of 1KB8 exist, the recurrence equation between 1KB28 and 1KB8 is adopted.

iii) In case of only one day's missing datum during the dry season, the average value of the previous and following values is adopted irrespectively of being the data of NC1 and 1KB8.

iv) Unless both corresponding data of NC1 and 1KB8 to a certain series of missing data exist, the data are simulated by Tank Model method.

(2) Data Generation

The data before 1975 are calculated by two methods; one is a simple conversion method from 1KB8 and 1KB15 using a linear regression formula from 1957 to 1974 and the other is a Tank Model Method from 1927 to 1956.

i) Data Generation from 1957 to 1974

According to Fig. 6-16, the correlation coefficient between 1KB28 and 1KB8 from 1976 to 1985 shows a high value and the runoff data of 1KB28 before 1975 are able to be generated simply by the regression formula. However, the data of 1KB8 have some missing periods whose total is approximately 400 days, so during these periods the data of 1KB15 are used. Although the conversion is basically conducted on the daily basis, the correlation on the daily basis is poorer than that on the monthly basis and so the energy calculation is to be done on the monthly basis.

ii) Data Generation from 1927 to 1956

The runoff data during this period are generated by Tank Model explained below (Fig. 6-18) and the process is as follows:

<u>Determination of each parameter</u> (Fig. 6-19 (1), (2) and (3))

Rainfall data	:	Mapanda and Mchombe
Runoff data	:	1KB28
Evaporation	:	Iringa
Calculating period	:	1975, 1981 and 1982

<u>Verification of accuracy</u>

The correlation coefficient between observed data and the calculated ones is 0.733 on the monthly basis from 1975 to 1985, using the data of Ifakara. This value is much higher than the correlation between monthly rainfall and runoff data tried in the Master Plan and ACRES reports.

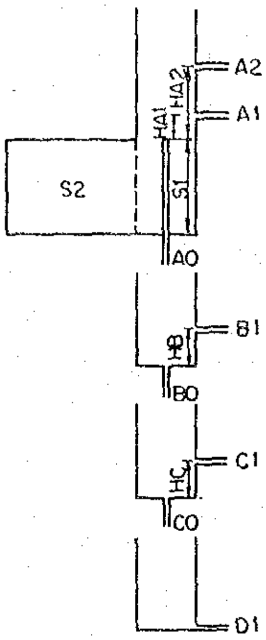
<u>Data generation</u>

The rainfall records at Ifakara are applied because they show a relatively high correlation with those of Mapanda and Mchombe which represent the rainfall within the Kihansi Basin.

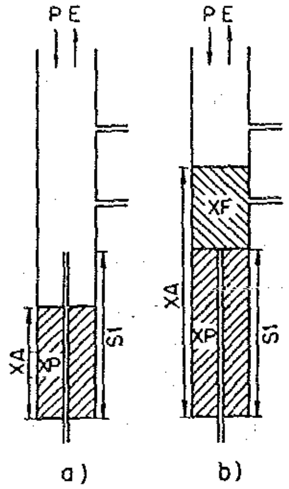
(3) Tank Model

The tank model is shown schematically in Fig. 6-18. Rainfall P is put into the top tank and evaporation E is subtracted from the storage of the top tank. Water in each tank partly infiltrates through the bottom outlet or outlets. The sum of the outputs from side outlets is the calculated discharge. The tank model shown in Fig. 6-18

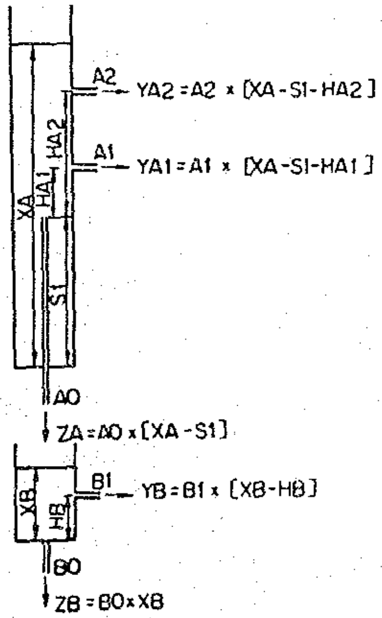
Fig. 6-18 Concept of Tank Model



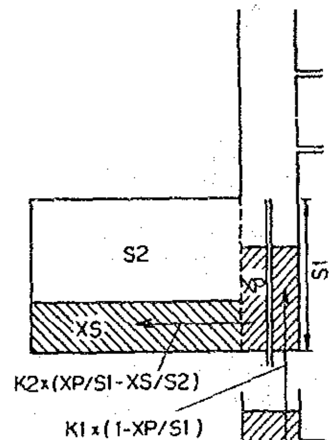
(1) Tank model with soil moisture structure



(2) Water storage in the top tank



(3) Runoff and infiltration



(4) Water transfer of soil moisture

Fig. 6-19 (1) Result of Tank Model in 1975

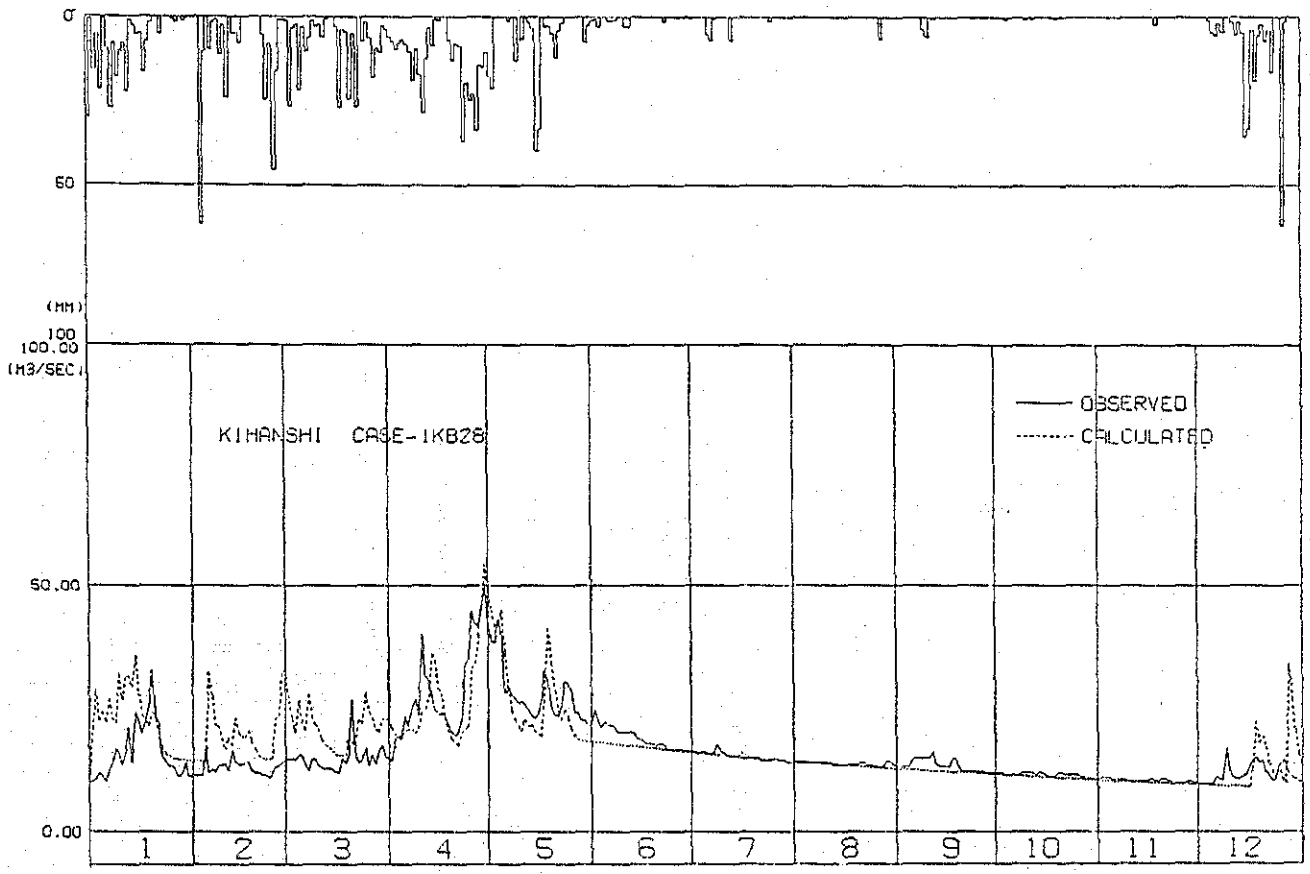


Fig. 6-19 (2) Result of Tank Model in 1981

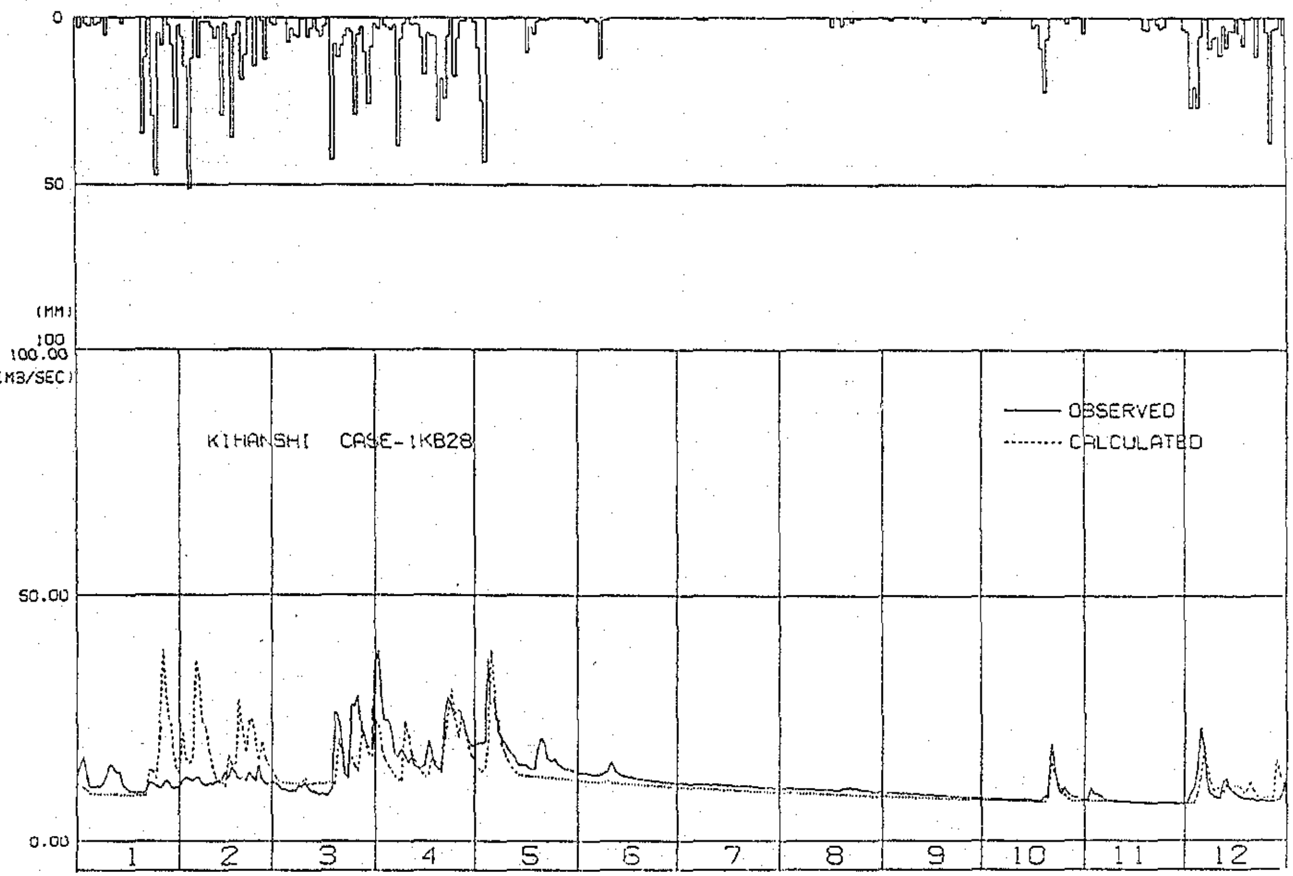
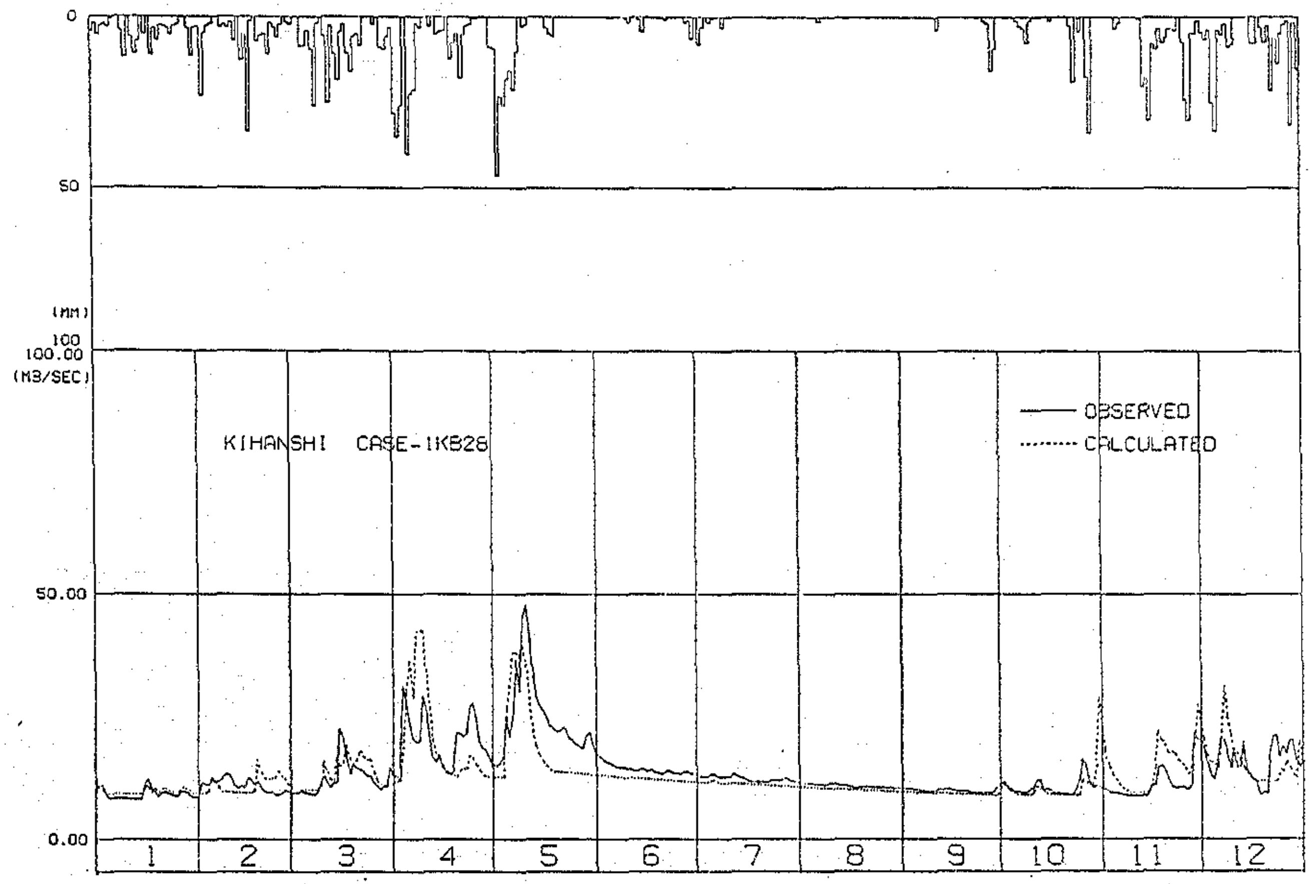


Fig. 6-19 (3) Result of Tank Model in 1982



(1) which is mainly developed for the tropical regions has a soil moisture structure in the top tank. When the storage XA in the top tank is not greater than S1, water can neither infiltrate nor discharge as shown in Fig. 6-18 (2) a).

In such a case XA represents primary soil moisture storage and there is no free water in the top tank, i.e. when XA ≤ S1, XP = XA, XF = 0, where XP is primary soil moisture storage and XF is free water. When XA is greater than S1, the excess part will infiltrate or discharge through the outlets as shown in Fig. 6-18 (2) b).

In such a case the primary soil moisture is saturated as XP = S1 where S1 is the saturation capacity of the primary soil moisture and the free water is given by XF = XA - S1, i.e. when XA > S1, XP = S1, XF = XA -S1. To put it simply, water fills the top tank from the bottom up and the lowest part forms primary soil moisture storage as shown in Fig. 6-18 (2). Soil moisture structure is not necessary to set up the lower tanks since the tanks except the top tank are considered to be always saturated.

Free water in each tank discharges partly through the side outlet or outlets and partly infiltrates through the bottom outlet to the next lower tank. The amount of runoff or infiltration per unit time through an outlet is proportional to the head of water at the outlet. For convenience, the tanks are labelled A, B, C and D from the top, and consequently the runoff coefficients for each tank are called A1, A2, B1, C1 and D1; the infiltration coefficients for each tank are called A0, B0 and C0; and the heights of the side outlets of each tank are called HA1, HA2, HB and HC as shown in Fig. 6-18 (1). Similarly, variables such as water storage in each tank (X), runoff amount from the side outlet (Y) and infiltration amount from the bottom outlet (Z) give the suffix A, B, C or D as shown partly in Fig. 6-18 (3) where the symbol [ ] means that [X] = X when X is not negative, and [X] = 0 when X is negative.

As well as the primary soil moisture storage, there is a secondary soil moisture storage which is situated alongside of the primary soil moisture storage, as shown in Fig. 6-18 (1). Input (rain and snowmelt) fills, at first, the primary soil moisture storage, and then, gradually, penetrates the secondary soil moisture storage (Fig. 6-18 (4)). Evaporation, when it occurs, is subtracted from the storage XA and the primary soil moisture storage becomes dry, then, gradually, water returns from secondary soil moisture storage.

6.3.3 Discharge at the Dam Sites

The generated runoff data are converted to be applied to the Upper Dam site and Lower Dam site respectively by multiplying the area's conversion factors. The results are shown in Table 6-4 and Fig. 6-20 on the monthly basis which are to be used for calculating the power energy, and the duration curves of each dam site are shown in Fig. 6-21 on the daily basis from 1975 to 1987.

Table 6-4 (1) Monthly Discharge at 1KB28

(Unit: m^3/s)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	average
1927	17.11	10.61	13.10	16.40	12.54	11.33	10.36	9.62	9.12	8.65	8.21	11.50	11.56
1928	9.29	9.82	19.69	19.69	15.34	12.02	10.93	9.95	9.60	9.43	9.58	12.43	12.32
1929	9.67	8.72	13.27	28.33	12.34	10.87	9.77	8.96	8.40	7.89	7.52	7.98	11.13
1930	12.20	9.45	25.83	29.13	15.22	13.22	11.56	10.28	9.41	8.76	8.14	7.53	13.41
1931	10.46	15.14	31.08	41.27	23.88	17.33	14.93	13.01	11.53	10.33	9.41	10.33	17.38
1932	15.65	22.03	28.73	43.91	20.15	16.68	14.52	12.85	11.44	10.32	9.88	9.77	17.95
1933	17.96	19.80	23.33	28.02	17.59	14.81	13.00	11.65	10.54	9.63	8.93	8.32	15.26
1934	19.48	13.41	13.88	20.68	18.09	17.16	14.14	12.72	11.55	10.45	9.46	12.44	14.46
1935	14.99	15.95	23.74	14.90	13.61	12.14	11.00	10.01	9.31	9.62	9.59	25.43	14.21
1936	22.87	16.93	14.34	54.85	32.16	19.34	16.98	14.70	12.96	11.56	10.38	11.30	19.83
1937	13.92	11.48	29.19	26.58	22.57	15.91	13.94	12.36	11.51	10.69	9.82	9.07	15.62
1938	8.37	8.83	8.49	16.80	10.86	9.82	9.01	8.47	8.05	8.81	8.56	8.14	9.51
1939	13.79	9.13	13.29	44.73	19.50	14.68	12.83	11.39	10.42	9.49	8.95	8.69	14.73
1940	20.94	15.46	14.91	30.48	16.15	13.44	11.82	10.69	9.75	9.77	8.83	10.86	14.41
1941	10.97	20.82	20.52	15.63	20.31	13.18	11.67	10.43	9.49	8.92	12.08	11.62	13.76
1942	19.75	11.96	26.74	36.33	22.13	16.67	14.44	12.65	11.24	10.09	9.31	12.82	17.04
1943	9.27	12.11	14.16	16.17	24.16	12.27	10.83	9.69	8.96	8.38	7.81	7.34	11.77
1944	9.39	7.72	10.28	33.15	18.16	13.16	11.57	10.29	9.28	8.54	9.83	14.90	13.01
1945	17.47	13.83	15.26	27.35	25.43	14.97	13.18	11.60	10.35	9.33	8.58	11.02	14.87
1946	8.66	7.78	9.93	37.54	15.44	12.55	11.02	9.82	8.90	8.31	8.32	7.97	12.17
1947	17.02	15.08	20.72	23.50	20.31	15.73	13.41	11.79	10.50	9.55	8.69	23.37	15.83
1948	21.67	16.04	24.82	17.35	16.44	13.37	11.81	10.65	9.64	8.90	11.69	8.54	14.25
1949	10.58	21.67	12.72	21.16	13.68	11.66	10.38	9.36	8.61	8.05	7.51	7.07	11.79
1950	7.00	9.17	24.06	20.57	21.04	13.59	11.91	10.58	10.00	9.07	8.42	7.89	12.80
1951	8.26	11.73	11.36	23.31	14.80	11.31	10.37	9.22	8.50	7.90	16.67	11.13	12.02
1952	16.62	19.67	20.65	30.75	37.87	17.47	14.96	12.94	11.38	10.15	13.48	9.56	17.94
1953	8.71	7.80	12.36	13.62	17.05	10.92	9.79	8.86	8.21	7.74	7.26	9.71	10.19
1954	13.47	9.83	10.32	13.19	12.10	9.54	8.57	7.92	7.45	7.15	6.79	6.69	9.42
1955	7.68	17.74	15.56	41.69	23.69	17.59	14.81	12.86	11.28	9.99	9.84	8.77	15.90
1956	20.44	18.17	16.38	41.20	19.77	15.74	13.65	11.95	10.61	9.54	8.68	8.85	16.21
1957	20.13	19.50	17.62	37.96	30.06	15.93	14.09	13.22	12.27	11.47	10.88	12.31	17.93
1958	14.09	15.73	27.56	40.54	25.05	14.98	13.42	12.77	12.11	11.52	10.73	16.05	17.88
1959	14.57	15.99	22.09	22.58	15.94	12.94	12.32	11.80	11.11	10.81	10.69	12.37	14.42
1960	11.13	15.90	31.07	54.53	24.93	15.97	11.89	10.28	9.13	9.21	10.09	10.42	17.84
1961	12.44	15.53	16.31	20.74	22.03	10.39	10.92	11.75	9.38	9.18	11.81	16.82	13.94
1962	37.84	35.61	40.97	42.58	29.55	19.86	17.67	15.82	12.51	13.25	11.81	13.73	24.20
1963	27.48	31.24	41.21	54.33	28.76	18.59	18.36	15.89	14.33	13.06	19.08	10.99	24.36
1964	18.72	23.79	38.69	52.88	30.58	23.48	20.25	18.47	16.04	14.19	13.19	14.83	23.73
1965	17.57	20.19	28.12	43.20	21.55	15.64	14.41	13.68	12.56	12.10	11.62	13.70	18.66
1966	17.17	18.06	32.05	46.16	23.68	17.40	14.43	14.03	12.89	8.38	8.21	8.89	18.42
1967	15.98	17.94	21.14	29.00	29.22	18.92	15.37	14.16	12.70	11.89	13.80	32.62	19.41
1968	27.22	30.65	53.09	61.30	38.92	30.85	24.83	20.89	18.37	15.78	15.81	19.87	29.77
1969	21.62	20.14	24.28	34.47	25.36	15.94	14.30	14.22	12.44	11.21	11.59	12.35	18.14
1970	21.37	32.76	30.99	27.71	17.51	14.16	13.54	12.55	11.64	10.45	9.51	18.14	18.27
1971	15.51	20.37	21.87	39.51	21.24	14.36	14.92	13.10	12.31	14.99	11.57	12.72	17.66
1972	17.89	17.33	34.60	47.50	31.84	19.54	16.72	14.17	14.94	13.41	12.99	23.21	22.02
1973	32.64	23.64	30.76	45.32	34.09	19.60	17.19	15.01	14.19	13.24	13.00	15.12	22.81
1974	20.28	28.44	18.40	45.99	41.78	21.42	17.42	14.37	14.21	13.02	12.43	9.73	21.38
1975	15.81	12.76	14.52	29.04	26.78	18.38	14.79	13.40	13.01	11.17	10.04	11.64	15.95
1976	14.54	16.02	21.09	30.06	27.06	21.82	16.70	14.63	12.85	11.66	10.24	9.83	17.20
1977	13.73	10.74	14.64	26.27	22.67	15.53	13.40	12.00	10.72	9.96	11.17	15.66	14.73
1978	15.68	14.31	19.07	29.00	24.71	16.90	13.72	11.96	10.77	9.68	11.71	14.80	16.03
1979	20.79	19.87	28.89	41.65	42.22	32.33	23.72	18.32	15.49	13.25	13.20	16.19	23.84
1980	17.09	17.22	16.36	21.64	23.95	15.58	13.74	12.36	11.10	10.23	9.92	11.74	15.07
1981	12.18	13.03	16.12	21.43	18.95	13.52	11.74	10.91	9.76	9.89	8.56	10.77	13.07
1982	9.32	11.18	12.64	20.45	25.35	14.55	12.57	11.03	10.12	10.74	11.63	16.43	13.85
1983	25.31	16.75	20.41	33.68	33.32	24.24	18.86	14.89	12.96	11.57	10.60	11.03	19.48
1984	12.75	13.21	20.02	30.22	30.13	21.67	17.15	14.16	12.80	11.85	11.25	18.64	17.83
1985	24.87	18.81	23.82	41.30	31.63	22.58	18.72	15.33	13.63	12.01	14.05	21.15	21.50
1986	25.41	27.41	26.97	44.07	40.20	30.10	23.29	19.41	15.48	13.47	16.11	23.28	25.41
1987	24.58	22.38	24.58	23.98	24.77	18.98	16.09	13.93	12.08	11.57	11.72	14.71	18.26
Ave.	16.55	16.79	21.78	32.25	23.54	16.47	14.16	12.55	11.34	10.51	10.68	12.96	16.62

Table 6-4 (2) Monthly Discharge at Upper Dam

(Unit: m^3/s)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	average
1927	16.14	10.01	12.36	15.47	11.83	10.69	9.77	9.08	8.60	8.16	7.75	10.85	10.91
1928	8.76	9.26	18.57	18.57	14.47	11.34	10.31	9.39	9.06	8.90	9.04	11.73	11.62
1929	9.12	8.23	12.52	26.73	11.64	10.25	9.22	8.45	7.92	7.44	7.09	7.53	10.50
1930	11.51	8.91	24.37	27.48	14.36	12.47	10.91	9.70	8.88	8.26	7.68	7.10	12.65
1931	9.87	14.28	29.32	38.93	22.53	16.35	14.08	12.27	10.88	9.74	8.88	9.74	16.40
1932	14.76	20.78	27.10	41.42	19.01	15.74	13.70	12.12	10.79	9.74	9.32	9.22	16.93
1933	16.94	18.68	22.01	26.43	16.59	13.97	12.26	10.99	9.94	9.08	8.42	7.85	14.40
1934	18.38	12.65	13.09	19.51	17.07	16.19	13.34	12.00	10.90	9.86	8.92	11.74	13.64
1935	14.14	15.05	22.40	14.06	12.84	11.45	10.38	9.44	8.78	9.08	9.05	23.99	13.41
1936	21.57	15.97	13.53	51.74	30.34	18.24	16.02	13.87	12.23	10.91	9.79	10.66	18.71
1937	13.13	10.83	27.54	25.07	21.29	15.01	13.15	11.66	10.86	10.08	9.26	8.56	14.74
1938	7.90	8.33	8.01	15.85	10.24	9.26	8.50	7.99	7.59	8.31	8.08	7.68	8.97
1939	13.01	8.61	12.54	42.20	18.40	13.85	12.10	10.74	9.83	8.95	8.44	8.20	13.90
1940	19.75	14.58	14.07	28.75	15.24	12.68	11.15	10.08	9.20	9.22	8.33	10.24	13.59
1941	10.35	19.64	19.36	14.74	19.16	12.43	11.01	9.84	8.95	8.41	11.40	10.96	12.98
1942	18.63	11.28	25.23	34.27	20.88	15.73	13.62	11.93	10.60	9.52	8.78	12.09	16.07
1943	8.75	11.42	13.36	15.25	22.79	11.58	10.22	9.14	8.45	7.91	7.37	6.92	11.10
1944	8.86	7.28	9.70	31.27	17.13	12.41	10.91	9.71	8.75	8.06	9.27	14.06	12.27
1945	16.48	13.05	14.40	25.80	23.99	14.12	12.43	10.94	9.76	8.80	8.09	10.40	14.03
1946	8.17	7.34	9.37	35.41	14.57	11.84	10.40	9.26	8.40	7.84	7.85	7.52	11.48
1947	16.06	14.23	19.55	22.17	19.16	14.84	12.65	11.12	9.91	9.01	8.20	22.05	14.93
1948	20.44	15.13	23.41	16.37	15.51	12.61	11.14	10.05	9.09	8.40	11.03	8.06	13.44
1949	9.98	20.44	12.00	19.96	12.91	11.00	9.79	8.83	8.12	7.59	7.08	6.67	11.12
1950	6.60	8.65	22.70	19.41	19.85	12.82	11.24	9.98	9.43	8.56	7.94	7.44	12.08
1951	7.79	11.07	10.72	21.99	13.96	10.67	9.78	8.70	8.02	7.45	15.73	10.50	11.34
1952	15.68	18.56	19.48	29.01	35.73	16.48	14.11	12.21	10.74	9.58	12.72	9.02	16.92
1953	8.22	7.36	11.66	12.85	16.08	10.30	9.24	8.36	7.75	7.30	6.85	9.16	9.61
1954	12.71	9.27	9.74	12.44	11.41	9.00	8.08	7.47	7.03	6.75	6.41	6.31	8.89
1955	7.25	16.74	14.68	39.33	22.35	16.59	13.97	12.13	10.64	9.42	9.28	8.27	15.00
1956	19.28	17.14	15.45	38.87	18.65	14.85	12.88	11.27	10.01	9.00	8.19	8.35	15.29
1957	18.99	18.40	16.62	35.81	28.36	15.03	13.29	12.47	11.58	10.82	10.26	11.61	16.91
1958	13.29	14.84	26.00	38.24	23.63	14.13	12.66	12.05	11.42	10.87	10.12	15.14	16.87
1959	13.74	15.08	20.84	21.30	15.04	12.21	11.62	11.13	10.48	10.20	10.08	11.67	13.60
1960	10.50	15.00	29.31	51.44	23.52	15.07	11.22	9.70	8.61	8.69	9.52	9.83	16.83
1961	11.74	14.65	15.39	19.57	20.78	9.80	10.30	11.08	8.85	8.66	11.14	15.87	13.15
1962	35.70	33.59	38.65	40.17	27.88	18.74	16.67	14.92	11.80	12.50	11.14	12.95	22.83
1963	25.92	29.47	38.88	51.25	27.13	17.54	17.32	14.99	13.52	12.32	18.00	10.37	22.98
1964	17.66	22.44	36.50	49.89	28.85	22.15	19.10	17.42	15.13	13.39	12.44	13.99	22.39
1965	16.57	19.05	26.53	40.75	20.33	14.75	13.59	12.91	11.85	11.41	10.96	12.92	17.60
1966	16.20	17.04	30.23	43.55	22.34	16.41	13.61	13.24	12.16	7.91	7.75	8.39	17.38
1967	15.07	16.92	19.94	27.36	27.57	17.85	14.50	13.36	11.98	11.22	13.02	30.77	18.31
1968	25.68	28.91	50.08	57.83	36.72	29.10	23.42	19.71	17.33	14.89	14.91	18.74	28.08
1969	20.40	19.00	22.90	32.52	23.92	15.04	13.49	13.41	11.74	10.58	10.93	11.65	17.11
1970	20.16	30.90	29.23	26.14	16.52	13.36	12.77	11.84	10.98	9.86	8.97	17.11	17.24
1971	14.63	19.22	20.63	37.27	20.04	13.55	14.08	12.36	11.61	14.14	10.91	12.00	16.66
1972	16.88	16.35	32.64	44.81	30.04	18.43	15.77	13.37	14.09	12.65	12.25	21.90	20.77
1973	30.79	22.30	29.02	42.75	32.16	18.49	16.22	14.16	13.39	12.49	12.26	14.26	21.52
1974	19.13	26.83	17.36	43.39	39.41	20.21	16.43	13.56	13.41	12.28	11.73	9.18	20.17
1975	14.91	12.04	13.70	27.40	25.26	17.34	13.95	12.64	12.27	10.54	9.47	10.98	15.05
1976	13.72	15.11	19.90	28.36	25.53	20.58	15.75	13.80	12.12	11.00	9.66	9.27	16.23
1977	12.95	10.13	13.81	24.78	21.39	14.74	12.64	11.32	10.11	9.40	10.54	14.77	13.90
1978	14.79	13.50	17.99	27.36	23.31	15.94	12.94	11.28	10.16	9.13	11.05	13.96	15.12
1979	19.61	18.74	27.25	39.29	39.83	30.50	22.38	17.28	14.61	12.50	12.45	15.27	22.49
1980	16.12	16.24	15.43	20.41	22.59	14.70	12.96	11.66	10.47	9.65	9.36	11.08	14.22
1981	11.49	12.29	15.21	20.22	17.88	12.75	11.08	10.29	9.21	9.33	8.08	10.16	12.33
1982	8.79	10.55	11.92	19.29	23.91	13.73	11.86	10.41	9.55	10.13	10.97	15.50	13.07
1983	23.88	15.80	19.25	31.77	31.43	22.87	17.79	14.05	12.23	10.91	10.00	10.41	18.38
1984	12.03	12.46	18.89	28.51	28.42	20.44	16.18	13.36	12.08	11.18	10.61	17.58	16.82
1985	23.46	17.74	22.47	38.96	29.84	21.30	17.66	14.46	12.86	11.33	13.25	19.95	20.28
1986	23.97	25.86	25.44	41.57	37.92	28.40	21.97	18.31	14.60	12.71	15.20	21.96	23.97
1987	23.19	21.11	23.19	22.62	23.37	17.91	15.18	13.14	11.40	10.91	11.06	13.88	17.23
Ave.	15.61	15.84	20.55	30.43	22.21	15.54	13.36	11.84	10.70	9.92	10.07	12.23	15.68

Table 6-4 (3) Monthly Discharge at Lower Dam

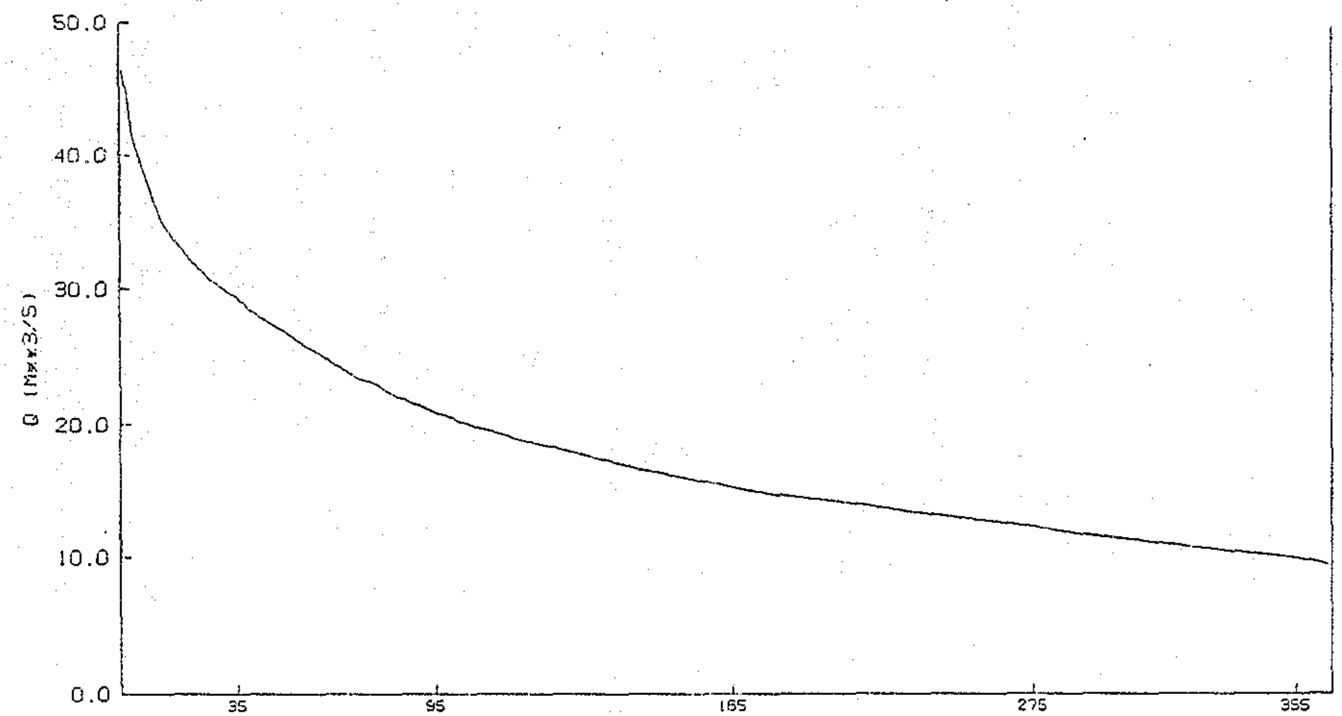
(Unit: m^3/s)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	average
1927	16.33	10.13	12.51	15.66	11.97	10.82	9.89	9.18	8.71	8.26	7.84	10.98	11.04
1928	8.87	9.38	18.80	18.80	14.64	11.48	10.43	9.50	9.17	9.00	9.15	11.87	11.76
1929	9.23	8.32	12.67	27.05	11.78	10.38	9.33	8.55	8.02	7.53	7.18	7.62	10.63
1930	11.65	9.02	24.66	27.81	14.53	12.62	11.04	9.81	8.98	8.36	7.77	7.19	12.80
1931	9.99	14.45	29.67	39.40	22.80	16.54	14.25	12.42	11.01	9.86	8.98	9.86	16.59
1932	14.94	21.03	27.43	41.92	19.24	15.92	13.86	12.27	10.92	9.85	9.43	9.33	17.14
1933	17.15	18.90	22.27	26.75	16.79	14.14	12.41	11.12	10.06	9.19	8.53	7.94	14.57
1934	18.60	12.80	13.25	19.74	17.27	16.38	13.50	12.14	11.03	9.98	9.03	11.88	13.80
1935	14.31	15.23	22.66	14.22	12.99	11.59	10.50	9.56	8.89	9.18	9.16	24.28	13.57
1936	21.83	16.16	13.69	52.36	30.70	18.46	16.21	14.03	12.37	11.04	9.91	10.79	18.93
1937	13.29	10.96	27.87	25.38	21.55	15.19	13.31	11.80	10.99	10.21	9.38	8.66	14.91
1938	7.99	8.43	8.11	16.04	10.37	9.38	8.60	8.09	7.69	8.41	8.17	7.77	9.08
1939	13.17	8.72	12.69	42.70	18.62	14.01	12.25	10.87	9.95	9.06	8.54	8.30	14.06
1940	19.99	14.76	14.23	29.10	15.42	12.83	11.28	10.21	9.31	9.33	8.43	10.37	13.76
1941	10.47	19.88	19.59	14.92	19.39	12.58	11.14	9.96	9.06	8.52	11.53	11.09	13.14
1942	18.86	11.42	25.53	34.68	21.13	15.91	13.79	12.08	10.73	9.63	8.89	12.24	16.27
1943	8.85	11.56	13.52	15.44	23.07	11.71	10.34	9.25	8.55	8.00	7.46	7.01	11.24
1944	8.96	7.37	9.81	31.65	17.34	12.56	11.05	9.82	8.86	8.15	9.38	14.22	12.42
1945	16.68	13.20	14.57	26.11	24.28	14.29	12.58	11.07	9.88	8.91	8.19	10.52	14.20
1946	8.27	7.43	9.48	35.84	14.74	11.98	10.52	9.38	8.50	7.93	7.94	7.61	11.62
1947	16.25	14.40	19.78	22.44	19.39	15.02	12.80	11.26	10.02	9.12	8.30	22.31	15.11
1948	20.69	15.31	23.70	16.56	15.70	12.76	11.27	10.17	9.20	8.50	11.16	8.15	13.60
1949	10.10	20.69	12.14	20.20	13.06	11.13	9.91	8.94	8.22	7.69	7.17	6.75	11.26
1950	6.68	8.75	22.97	19.64	20.09	12.97	11.37	10.10	9.55	8.66	8.04	7.53	12.22
1951	7.89	11.20	10.85	22.25	14.13	10.80	9.90	8.80	8.11	7.54	15.91	10.63	11.48
1952	15.87	18.78	19.71	29.36	36.15	16.68	14.28	12.35	10.86	9.69	12.87	9.13	17.13
1953	8.32	7.45	11.80	13.00	16.28	10.43	9.35	8.46	7.84	7.39	6.93	9.27	9.73
1954	12.86	9.38	9.85	12.59	11.55	9.11	8.18	7.56	7.11	6.83	6.48	6.39	8.99
1955	7.33	16.94	14.86	39.80	22.62	16.79	14.14	12.28	10.77	9.54	9.39	8.37	15.18
1956	19.51	17.35	15.64	39.33	18.87	15.03	13.03	11.41	10.13	9.11	8.29	8.45	15.48
1957	19.22	18.62	16.82	36.24	28.70	15.21	13.45	12.62	11.71	10.95	10.39	11.75	17.12
1958	13.45	15.02	26.31	38.70	23.92	14.30	12.81	12.19	11.56	11.00	10.24	15.32	17.07
1959	13.91	15.27	21.09	21.56	15.22	12.35	11.76	11.27	10.61	10.32	10.21	11.81	13.77
1960	10.63	15.18	29.66	52.06	23.80	15.25	11.35	9.81	8.72	8.79	9.63	9.95	17.03
1961	11.88	14.83	15.57	19.80	21.03	9.92	10.43	11.22	8.96	8.76	11.27	16.06	13.31
1962	36.13	34.00	39.11	40.65	28.21	18.96	16.87	15.10	11.94	12.65	11.27	13.11	23.10
1963	26.23	29.82	39.34	51.87	27.46	17.75	17.53	15.17	13.68	12.47	18.22	10.49	23.26
1964	17.87	22.71	36.94	50.48	29.19	22.42	19.33	17.63	15.31	13.55	12.59	14.16	22.65
1965	16.77	19.28	26.85	41.24	20.57	14.93	13.76	13.06	11.99	11.55	11.09	13.08	17.81
1966	16.39	17.24	30.60	44.07	22.61	16.61	13.78	13.39	12.31	8.00	7.84	8.49	17.59
1967	15.26	17.13	20.18	27.69	27.90	18.06	14.67	13.52	12.12	11.35	13.17	31.14	18.53
1968	25.99	29.26	50.68	58.52	37.16	29.45	23.71	19.94	17.54	15.07	15.09	18.97	28.42
1969	20.64	19.23	23.18	32.91	24.21	15.22	13.65	13.58	11.88	10.70	11.06	11.79	17.32
1970	20.40	31.28	29.59	26.45	16.72	13.52	12.93	11.98	11.11	9.98	9.08	17.32	17.44
1971	14.81	19.45	20.88	37.72	20.28	13.71	14.24	12.51	11.75	14.31	11.05	12.14	16.86
1972	17.08	16.54	33.03	45.35	30.40	18.65	15.96	13.53	14.26	12.80	12.40	22.16	21.02
1973	31.16	22.57	29.37	43.27	32.55	18.71	16.41	14.33	13.55	12.64	12.41	14.43	21.78
1974	19.36	27.15	17.57	43.91	39.89	20.45	16.63	13.72	13.57	12.43	11.87	9.29	20.41
1975	15.09	12.18	13.86	27.72	25.57	17.55	14.12	12.79	12.42	10.66	9.59	11.11	15.23
1976	13.88	15.29	20.13	28.70	25.83	20.83	15.94	13.97	12.27	11.13	9.78	9.38	16.42
1977	13.11	10.25	13.98	25.08	21.64	14.92	12.79	11.46	10.23	9.51	10.66	14.95	14.06
1978	14.97	13.66	18.21	27.69	23.59	16.13	13.10	11.42	10.28	9.24	11.18	14.13	15.30
1979	19.85	18.97	27.58	39.76	40.31	30.87	22.65	17.49	14.79	12.65	12.60	15.46	22.76
1980	16.32	16.44	15.62	20.66	22.86	14.87	13.12	11.80	10.60	9.77	9.47	11.21	14.39
1981	11.63	12.44	15.39	20.46	18.09	12.91	11.21	10.42	9.32	9.44	8.17	10.28	12.48
1982	8.90	10.67	12.07	19.52	24.20	13.89	12.00	10.53	9.66	10.25	11.10	15.69	13.22
1983	24.16	15.99	19.49	32.15	31.81	23.14	18.01	14.22	12.37	11.05	10.12	10.53	18.60
1984	12.17	12.61	19.11	28.85	28.76	20.69	16.37	13.52	12.22	11.31	10.74	17.80	17.02
1985	23.74	17.96	22.74	39.43	30.20	21.56	17.87	14.64	13.01	11.47	13.41	20.19	20.53
1986	24.26	26.17	25.75	42.07	38.38	28.74	22.23	18.53	14.78	12.86	15.38	22.23	24.26
1987	23.47	21.37	23.47	22.89	23.65	18.12	15.36	13.30	11.53	11.05	11.19	14.04	17.43
Ave.	15.80	16.03	20.79	30.79	22.48	15.72	13.52	11.99	10.83	10.04	10.19	12.38	15.87

Fig. 6-20 Hydrograph at 1KB28 from 1927 to 1987

Fig. 6-21   Duration Curve at 1KB28 from 1975 to 1987

1KB28 DISCHRAGE <PAPA-AVERAGE>   C.A = 618.0 KM**2   YEAR = 1975--1987



6.4 Design Flood Discharge

6.4.1 Review of Previous Study

The flood study was reported only by M/P before and it adopted the regional flood frequency curve derived for the Kilombero escarpment. This method, so called BIH method, is developed by the U.K. Institute of Hydrology and is based on the idea that the floods of homogeneous regions have common relation to the mean annual flood and the ratio of the flood of a certain return period to the mean annual flood. This method has such a merit that it can be available for the different catchment areas by means of the parameter of MAF (Mean Annual Flood) at one time. This method, however, has possibility to cause the overestimated or underestimated value if the range of the homogeneous region is not selected appropriately. According to M/P, there are two distinct frequency curves; one is a Kilombero excarpment group whose curve is quite flat and the other is a Upper Ruhudji group whose curve is steeper than the former's. Since the curve gradient of a Kilombero escarpment group is too flat compared with the neighboring regional flood frequency curves as well as the frequency curves of rainfall, the combined curve of Upper Ruhudji and Kilombero Escarpment curves are adopted as the Kilombero Escarpment curve instead of a flat one. The equation is as follows:

$$Q/\overline{Q} = 0.33 + 0.4529289\ e^{0.38683y}$$

where y is the Gumbel reduced variate.

When the return period is 10,000 year, y value corresponds to 9.21029 and $Q/\overline{Q}$ becomes 16.3.

Whereas, the results carried out separately in each station by Gumbel method don't reach the above value at all and all are below 5.8 except 1KB19. This suggests that the flood discharge reported in M/P has possibility to present the overestimated value especially more than the 100 year return period, probably because of the outlier included in the 1KB19 records. Actually, if 5.8 is adopted as $Q/\bar{Q}$ of 1KB28, 10,000 yr flood becomes only 270 m^3/s which is as 0.4 times as the M/P's flood estimates.

6.4.2 Methodology

Since even the longest period of runoff observation is only 30 years, it is considered to be difficult to estimate the long span frequency analysis such as 10,000 year flood. Moreover, it is considered that the Kihansi Project will play a very important role for such economical and social development of Tanzania as the total capacity of both Upper and Lower Kihansi power stations is expected to occupy almost one-third of the national power system. Therefore, it is considered to be appropriate to adopt the PMF method for estimating the design flood. The information necessary to calculate the exact PMF, however, is so limited that a part of analysis is simplified and the data are sometimes substituted for other region's.

PMF is estimated according to the following steps.

i) Examining the hydrological characteristics of the Kihansi Basin

ii) Selection of the storms at Ifakara

iii) Maximization of the storms to estimate the PMP

iv) Determination of rainfall distribution considering the orographic effect

v) Converting PMP to PMF by Tank Model method

The reason for adopting the rainfall data of Ifakara is that the observation period is very long over 60 years and the reliability is high.

PMP and PMF are also to be checked by the result of frequency analysis to confirm their propriety.

6.4.3 PMP in the Kihansi Basin

(1) Hydrological Characteristics

The Kihansi Basin has both non-orographic and orographic characteristics regarding the rainfall pattern. The orographic storms, however, predominate during March and April at the end of the rainy season owing to the moist SE wind and the existence of the steep escarpment normal to the wind. The probability of heavy rain occurrence in the area along the escarpment is much higher than that in the north-western area of the Kihansi Basin during this season. Rainfall data at Ifakara are considered to represent the non-orographic rainfall on the assumption that there is no topographic effect in the Kilombero Basin. Comparison of the rainfall at Ifakara with that in the Kilombero Basin based on the above-mentioned assumption will turn out the actual topographic effect. As mentioned in Section 6.1.1 Topography, the Kihansi Basin is divided into two areas roughly, one is a smoothed land which corresponds to the NC1 catchment area and the other is a steep land which corresponds to the residual area between 1KB28 and NC1. If the representative rainfall observatory of the smoothed area is assumed to be Mapanda (983547) and that of the steep area is assumed to be Mchombe (983608), the results of comparison are shown in Table 6-5. The steep area is obviously so affected by the topographic effect that it exceeds 40% as to the annual rainfall and 30% as to the historical daily maximum rainfall to Ifakara. On the other hand, the rainfall of the smoothed area is reduced

Table 6-5 Topographic Effect on Rainfall

Item	Ifakara Mission (983600) Rainfall (mm)	Mapanda (983547)		Mchombe (983608)	
		Rainfall (mm)	Ratio to Ifakara(%)	Rainfall (mm)	Ratio to Ifakara(%)
Monthly Rainfall					
January	183.5	178.3	97	271.7	148
February	153.9	165.9	108	212.7	138
March	289.2	164.9	57	398.2	138
April	355.7	256.4	72	436.4	123
May	111.5	114.3	103	164.7	148
June	17.8	17.1	96	21.1	119
July	8.8	8.6	98	15.8	180
August	5.4	4.5	83	11.5	213
September	7.9	8.6	109	13.2	167
October	14.7	14.2	97	50.5	344
November	55.4	65.4	118	78.1	141
December	132.0	136.7	104	235.0	178
Annual Rainfall	1,343	1,090	81	1,877	140
Historical Daily Maximum Rainfall	169.0	69.2	41	220.0	130
10000 year Daily Storm(Log Normal)	295.0	178.0	60	339.0	115

owing to the shadow region and especially this tendency is predominant on the heavy storm.

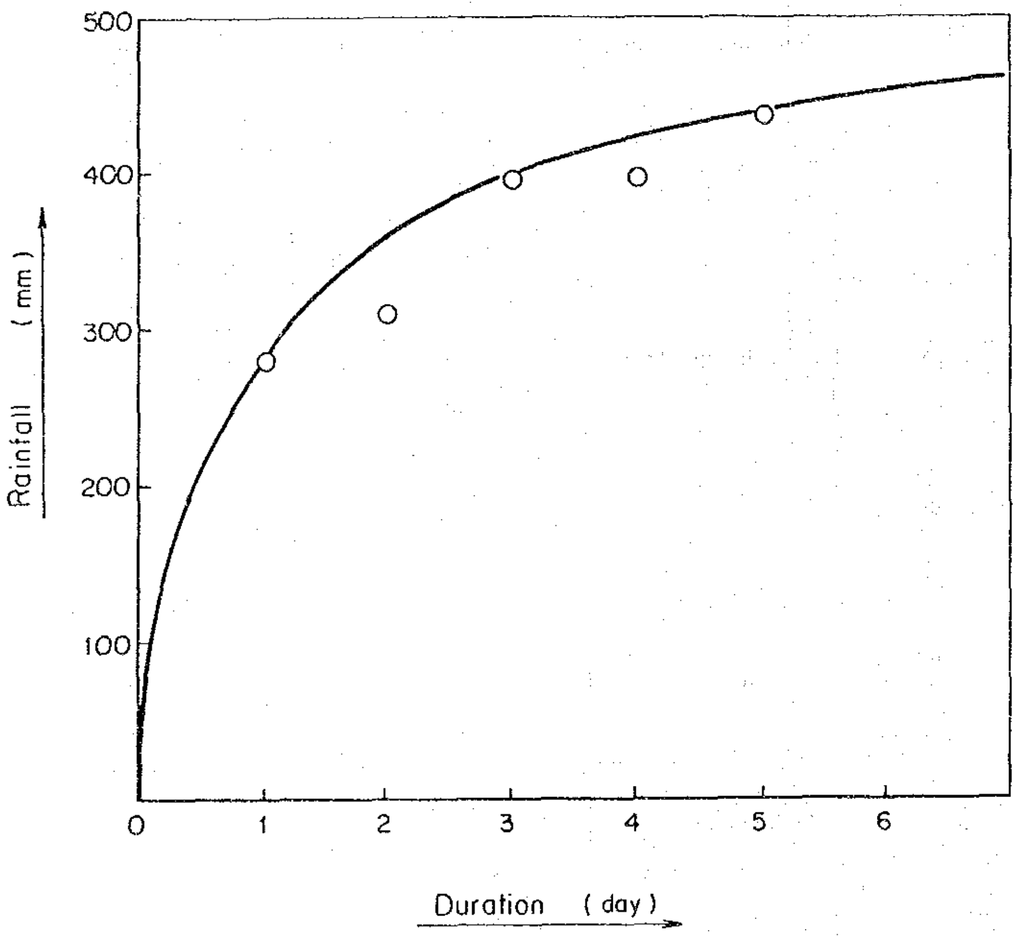
(2) Estimation of PMP (Probable Maximum Precipitation)

PMP is usually derived from the observed heavy storms by multiplying the maximization factor based on the dew point. This factor is defined to be the difference between the actual moisture content during the observed storm and the probable maximum moisture one corresponding to the time when the storm occurs. This probable maximum moisture content is calculated from the maximum persisting 12-hour dew point and usually indicated as an envelope curve. This time, however, only mean monthly data of dew point at Morogoro were collected. Accordingly, the maximization factor is assumed to be the ratio of mean observed dew point at 12:00 to the lowest temperature in each month. This ratio is considered to be the largest value of the expected ratio because the heavy storm is assumed to take place on condition that the humidity is saturated and the representative persisting 12-hr dew point equals to the minimum temperature. After the dew point is converted to the precipitable water, the maximizing factor and maximized storm of each month is calculated according to Table 6-6. As a result, PMP at Ifakara is estimated to be 280 mm in April and almost correspondents to the 10,000 year storm by Log Normal distribution. Similarly 2 day, 3 day, 4 day and 5 day PMP are estimated to be 360 mm, 400 mm, 430 mm and 440 mm respectively as shown in Fig. 6-22. Since the incremental rainfall between 4 day and 5 day is only 10 mm, 5 days sequence is sufficient for analyzing PMF (Probable Maximum Flood).

Table 6-6 Process of PMP Estimation at Ifakara

Contents	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1 Maximum Dew Point (°C)	20.5	20.8	21.4	22.0	20.5	17.6	15.9	15.5	15.9	16.9	18.7	20.1
2 Reduction 1 to 1,000 mb (°C)	22.8	23.1	23.7	24.3	22.8	19.9	18.2	17.8	18.2	19.2	21.0	22.4
3 Precipitable Water (mm)	66 - 5 = 61	67 - 5 = 62	71 - 5 = 66	74 - 5 = 69	66 - 5 = 61	52 - 4 = 48	45 - 3 = 42	43 - 3 = 40	45 - 3 = 42	49 - 3 = 46	57 - 4 = 53	64 - 5 = 59
4 Representative Dew Point (°C)	17.2	17.3	17.3	16.7	13.9	10.6	10.0	9.2	13.2	14.2	16.1	16.2
5 Reduction 4 to 1,000 mb (°C)	19.5	19.6	19.6	19.0	16.2	12.9	12.3	11.5	15.6	16.5	18.4	18.5
6 Precipitable Water (mm)	49 - 4 = 45	49 - 4 = 45	49 - 4 = 45	47 - 3 = 44	37 - 3 = 34	28 - 2 = 26	26 - 2 = 24	24 - 2 = 22	33 - 3 = 30	38 - 3 = 35	46 - 3 = 43	46 - 3 = 43
7 Maximizing Factor 3 / 6	1.36	1.38	1.47	1.57	1.79	1.85	1.75	1.82	1.40	1.31	1.23	1.37
8 Maximum Rainfall (mm) (Year)	171.2 (1986)	168.4 (1959)	138.8 (1937)	178.3 (1978)	85.9 (1977)	30.2 (1936)	36.3 (1967)	56.5 (1976)	44.3 (1972)	51.9 (1982)	136.3 (1935)	159.8 (1967)
9 Maximizing 7 × 8 (mm)	233	232	204	280	154	56	64	103	62	68	167	219

Fig. 6-22 Depth - Duration Envelope of PMP at Ifakara



(3) Aerial Distribution of PMP

As mentioned in (1), the Kihansi Basin is affected by the topography as for the rainfall pattern and its strength. If the storm at Ifakara represents the non-orographic storm without the escarpment, the storms in the Kihansi Basin can be estimated by a certain ratio considering the topographic effect. This ratio is thought to be similar to the ratio of historical maximum rainfalls or statistical results such as 10,000 year rainfall.

According to Table 6-5, the ratio of the smoothed area represented by Mapanda is 41% for historical maximum rainfall and 60% for 10,000 year storm and that of the steep area represented by Mchombe is 130% and 115% respectively. This time the ratio of 10,000 year storm is to be adopted for the PMF analysis since PMP value resemble the 10,000 year storm. As a result, 1 day PMP in the smoothed area is 168 mm and 322 mm in the steep area. Considering the fact that most of the actual observed maximum rainfall records in the whole Tanzania except the islands range at most from 100 mm to 200 mm, this result is considered to be acceptable.

6.4.4 PMF (Probable Maximum Flood)

The base flow plays such an important role in the flood in the Kihansi Basin that it occupies almost a half component of the flood, which differs from the usual flood. Moreover, since the rainfall is localized extremely and the duration is very short, the ordinary approach, i.e. unit hydrograph method, to calculate runoff from rainfall cannot be used. Therefore, this study firstly applies the tank model used for the data generation to estimate the PMF on the daily basis and then the PMF is to be sharpened to obtain the instantaneous flood discharge. According to the hydrograph generated by Tank Model, the maximum discharge is expected to occur in 1929, 1936, 1967, 1968, 1971, 1978 and 1979. When PMP estimated in 6.4.3 (2) takes the place of the rainfall at the corresponding days, the maximum discharge is thought to be maximized to PMF. At that time, the time distribution of PMP is ordered as follows;

	Smoothed Area	Steep Area
1 day	18 mm	35 mm
2 day	48 mm	92 mm
3 day	168 mm	322 mm
4 day	24 mm	46 mm
5 day	6 mm	12 mm

If the original record is over the above value at each day, the original one is adopted. This PMF is multiplied by 1.55 which is the ratio of the instantaneous peak discharge to the mean daily discharge and gained by the mutual comparison of three times observation per day.

From the above calculation, PMF at 1KB28 is estimated to be 380 m^3/s and PMFs at the upper dam site and the lower dam site are to be 360 m^3/s together by multiplying the ratio of the catchment area's difference.

6.4.5 Probable Flood Discharge

Based on the discharge records at 1KB28 for 13 years from 1975 to 1987, the results of probable flood discharge calculated by the Log Normal Distribution, the Log Pearson III and the Gumbel methods are shown in Table 6-7. The result calculated by the Log Pearson III tends to indicate the highest value in this Table.

6.4.6 Flood Discharges Applied to Design

The design floods at the Upper Dam site, Lower Dam site and the Lower Powerhouse site are to be rounded up after multiplying the PMF by each conversion factor for adjusting the catchment area. The design discharge for diversion work of the Upper Dam is to be applied to the 20 year probable flood, because the type of the Upper dam is a rockfill and the dam construction is considered to be a critical path. That of the Lower Dam, however, is to be 5 year probable flood, because the type is a concrete dam and it can be allowable to be overflown to some extent. The results are shown in Table 6-8.

Table 6-7 Probable Flood Discharge at 1KB28

Return Period	Lognormal Distribution		Log Pearson III		Gumbel	
	Daily	Peak	Daily	Peak	Daily	Peak
2	46	71	44	68	46	71
5	51	79	50	78	51	79
10	54	84	55	85	55	85
20	56	87	59	91	59	91
50	59	91	67	104	63	98
100	62	96	73	113	67	104
200	63	98	79	122	70	109
500	66	102	89	138	75	116
1000	68	105	96	149	78	121
10000	72	112	128	198	90	140

(Peaking factor is assumed to be 1.55.)

Table 6-8 Flood Discharge Applied to Design

Objects	Discharge (m^3/s)	Method
Upper Kihansi Dam	400	PMF
Upper Kihansi Powerstation	400	PMF
Lower Kihansi Dam	400	PMF
Lower Kihansi Powerstation	400	PMF
Diversion for Upper Dam	90	20 year probable discharge
Diversion for Lower Dam	80	5 year probable discharge

6.5 Sedimentation

6.5.1 Methodology

After drawing the relationship between discharge and suspended load by means of both the actual suspended load observed in the Kihansi River and those in its surrounding rivers, annual suspended load is to be assumed considering the bed load and the reservoir trap efficiency. Sediment volume in the reservoir is designed in 50 years after completion, which is the same as the life time of the dam.

6.5.2 Data

Discharge:	1KB28 (Kihansi River) 1975 - 1987 Daily observed data		
Suspended load:	1KA3 (Great Ruaha) 1958 - 1959		carried out by FAO
	1KA5 (ditto) 1956 - 1960		carried out by FAO
	1KB17 (Kilombero river) 1958 - 1959		carried out by FAO
	1KB8 (Mpanga river) 1958 - 1959		carried out by FAO
	NC3 (Kihansi river)	1989	by JICA
	NC1 (Kihansi river)	1983	by RUBADA

6.5.3 Results of Calculation

Since the number of suspended load data collected so far in the Kihansi river is only 14 and most records of them, moreover, were observed on condition under mean annual flow, the accurate sediment forecast is impossible. Therefore, at first the equations of suspended load were determined on other rivers according to the relatively ample data executed by FAO, and then the equation whose tendency is most like the actual data of the Kihansi river was adopted as a suspended load equation of it. The distribution of the suspended load of the Kihansi river resembled that of the Mpanga river (1KB8) as shown in Fig. 6-23 and the equation of 1KB8 was adopted.

$$qs = 0.996 \times q^{1.169}$$

where, qs: Suspended load (mg/ℓ)
q: River discharge (m^3/s)

Then, the following formula gave the annual suspended load.

$$Qs = \sum_{i=1}^{365} (Qi \times qsi \times 86{,}400)$$

$$= \sum_{i=1}^{365} (Qi \times 0.996 \times Qi^{1.169} \times 86{,}400)$$

where, Qs : Annual suspended load (g)
Qi : River discharge on the day, i (m^3/s)
qsi: Suspended load on the day, i (mg/ℓ)

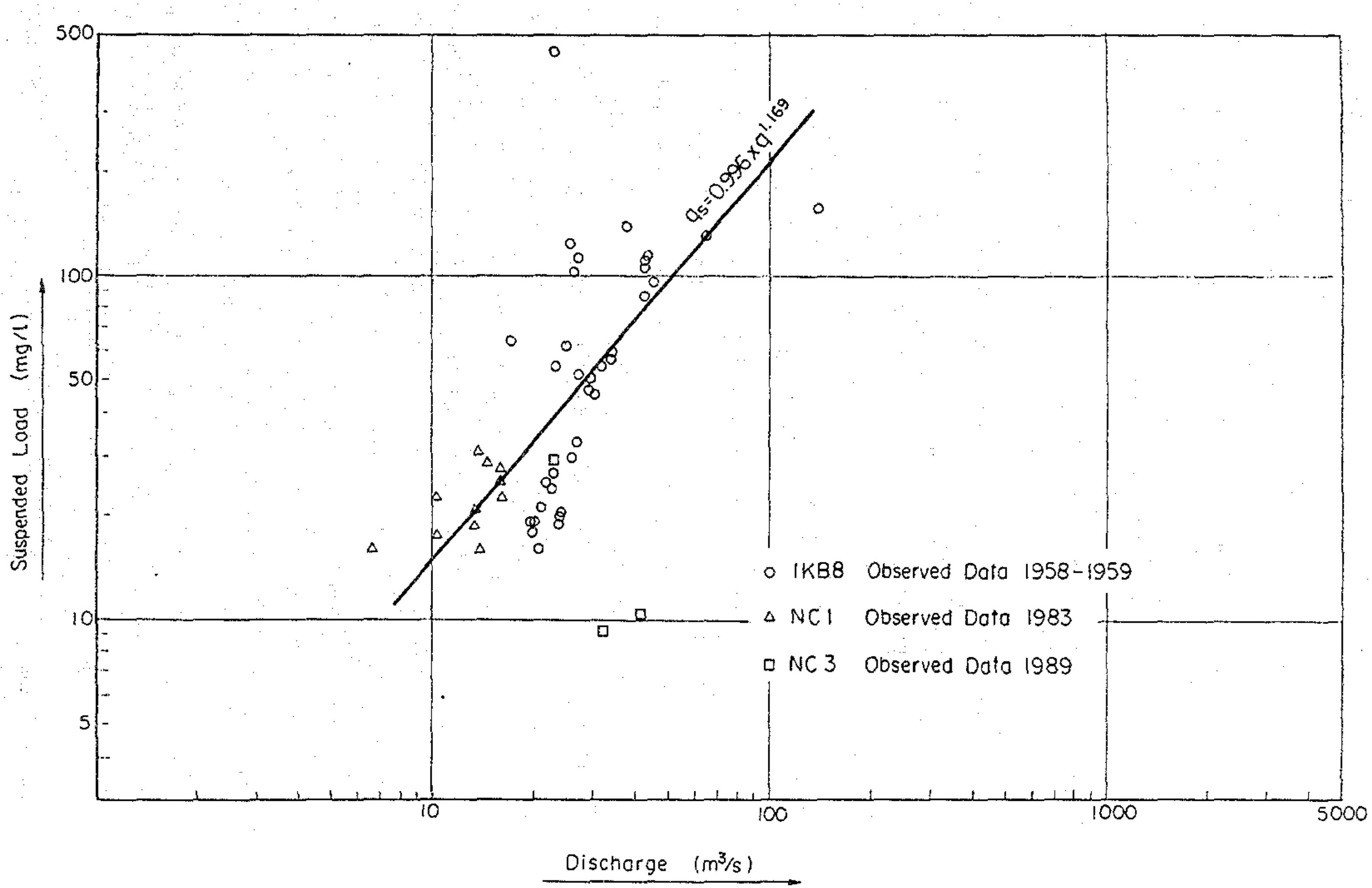
The results of calculation are as shown below.

Upper Kihansi Dam

(Unit: 10^3 ton)

Year	Qs	Year	Qs	Year	Qs
1975	14.0	1980	11.4	1985	26.8
1976	16.4	1981	8.7	1986	37.6
1977	11.7	1982	10.1	1987	17.0
1978	14.1	1983	21.8		
1979	34.4	1984	18.0	Average	18.6

Fig. 6-23 Relation between Suspended Load and Discharge



Lower Kihansi Dam

(Unit: 10^3 ton)

Year	Qs	Year	Qs	Year	Qs
1975	14.4	1980	11.6	1985	27.5
1976	16.9	1981	9.0	1986	38.6
1977	12.1	1982	10.4	1987	17.5
1978	14.4	1983	22.4		
1979	35.3	1984	18.5	Average	19.1

The mean annual suspended load per 1 km^2 is obtained by means of the above average value in the table divided by the catchment area as calculated below.

$$18.6 \times 10^3 \text{ ton}/583 \text{ km}^2 = 32 \text{ ton/km}^2/\text{Yr}$$

It is necessary to assume the ratio of the bed load to estimate the sedimentation in the reservoir and 20% is adopted in this study. With regard to the reservoir trap efficiency, Brune's method is generally applied. According to this method, the capacity-inflow ratio for Upper Kihansi dam with the gross reservoir capacity of 125×10^6 m^3 versus annual inflow of 494×10^6 m^3 becomes 0.25 and the trap efficiency is 94%. On the other hand, the capacity-inflow ratio for Lower Kihansi dam with the gross reservoir capacity of 0.73×10^6 m^3 versus annual inflow of 500×10^6 m^3 becomes 0.0015 and the trap efficiency is almost 0. This study, however, adopts 15% as a trap efficiency tentatively.

Thus, the annual sedimentation in each reservoir is given as calculated below, assuming that specific gravity of the sediment load is 1.4.

Upper Kihansi Dam:

$$\begin{aligned} Vs &= 18.6 \times 10^3 \times (1 + 0.2) \times 0.94/1.4 \\ &= 15.0 \times 10^3 \text{ m}^3 \end{aligned}$$

The sediment volume and the sediment level after 50 years will be

$Vs50 = 15.0 \times 10^3 \times 50 = 750 \times 10^3 \ m^3$

The sediment level is approximately 1,300 m

Lower Kihansi Dam (without Upper Kihansi dam):

$Vs = 19.1 \times 10^3 \times (1 + 0.2) \times 0.15/1.4 = 2.5 \times 10^3 \ m^3$

The sediment volume and the sediment level after 50 years will be

$Vs50 = 2.5 \times 10^3 \times 50 = 125 \times 10^3 \ m^3$

The sediment level is approximately 1,125 m

Chapter 7 GEOLOGY, MATERIALS AND SEISMICITY

Chapter 7

GEOLOGY, MATERIALS AND SEISMICITY

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Chapter 7 GEOLOGY, MATERIALS AND SEISMICITY

7.1 Outline of Investigation

7.1.1 Field Investigations

Of the field investigations made by the JICA Study Team, the geological investigation was carried out divided into the two periods below.

June 1 ~ June 30, 1989	- Site reconnaissance - Planning and contracting of geological investigation works - Collection of geological information
August 1 ~ December 15, 1989	- Management of geological investigation works execution - Seismic prospecting (not using explosives) - Surface geological mapping - Study and evaluation of geological investigation works - Collection of geological information

This chapter describes the geological, hydrogeological, and engineering geological conditions of the principal structures and construction materials collection sites planned based on the geological data obtained during these periods.

Since it is the prefeasibility stage with regard to the Upper Kihansi Project and the feasibility stage with regard to the Lower Kihansi Project, geological studies were made using topographic maps of 1/5,000-scale for the

Upper Kihansi Project and 1/1,000-scale for the Lower Kihansi Project.

7.1.2 Geological Investigation Works

The geological investigation works performed by the JICA Study Team and TANESCO at the various sites of the Upper Kihansi Project and the Lower Kihansi Project are as follows:

Site	Investigation Item	Quantity
Upper Kihansi	Boring (incl. permeability tests)	3 holes, total 130 m
	Seismic prospecting (not using explosives)	2 lines, total 105 m
Lower Kihansi	Boring (incl. permeability tests)	5 holes, total 100 m
Materials investigation site	Boring	2 holes, total 40 m
	Test pit	4 pits, total 6.8 m
Laboratory tests	Boring core tests Materials tests	Total 17 samples 6 places, total 10 samples

The location map of these investigation works is shown in Fig. 7-1 and a detailed list in Table 7-1.

7.1.3 Existing Data

The existing geological and seismic data including the areas of the Upper Kihansi Project and the Lower Kihansi Project are as given in Table 7-2. In preparation of this Report, these existing geological and seismic data were referred to together with the results of investigations by this Study Team.

Table 7-1 List of Geological Investigations

[DRILLING WORK AND PERMEABILITY TEST]

Hole No.	Site	Coordinate N	Coordinate E	Elevation (m)	Length (m)	Permeability T F (Times)	Permeability T P (Times)
KU-1	Upper	9,053,964	813,957	1,373.61	50.0	4	0
KU-2	"	9,054,175	814,175	1,356.66	30.0	4	0
KU-3	"	9,054,093	814,405	1,361.23	50.0	3	2
KL-1	Lower	9,050,962	813,883	1,135.25	20.0	2	3
KL-2	"	9,050,996	813,974	1,132.17	20.0	2	2
KL-3	"	9,050,558	814,150	1,139.99	20.0	3	0
KL-4	"	9,047,352	813,488	325.04	20.0	2	0
KL-5	"	9,047,258	813,468	315.66	20.0	2	3
KM-1	Material	9,052,992	814,005	1,153.72	20.0	-	-
KM-2	"	9,046,281	814,320	281	20.0	-	-
Total 10 holes					270.0	22	10

Note: F; Falling head (Permeability test in unconsolidated deposit).
P; Packer test (Permeability test in hard rock).

[TEST PITTING]

Pit No.	Site and Geology	Coordinate N	Coordinate E	Elevation (m)	Length (m)
P-1	Upper; Residual soil	9,054,855	814,636	1,355	2.0
P-2	Upper; River deposit	9,054,190	813,324	1,295	2.0
P-3	Upper; River deposit	9,053,010	814,128	1,150	1.2
P-4	Lower; River deposit	9,046,310	814,340	281	1.6
Total 4 pits					6.8

[SEISMIC PROSPECTING]

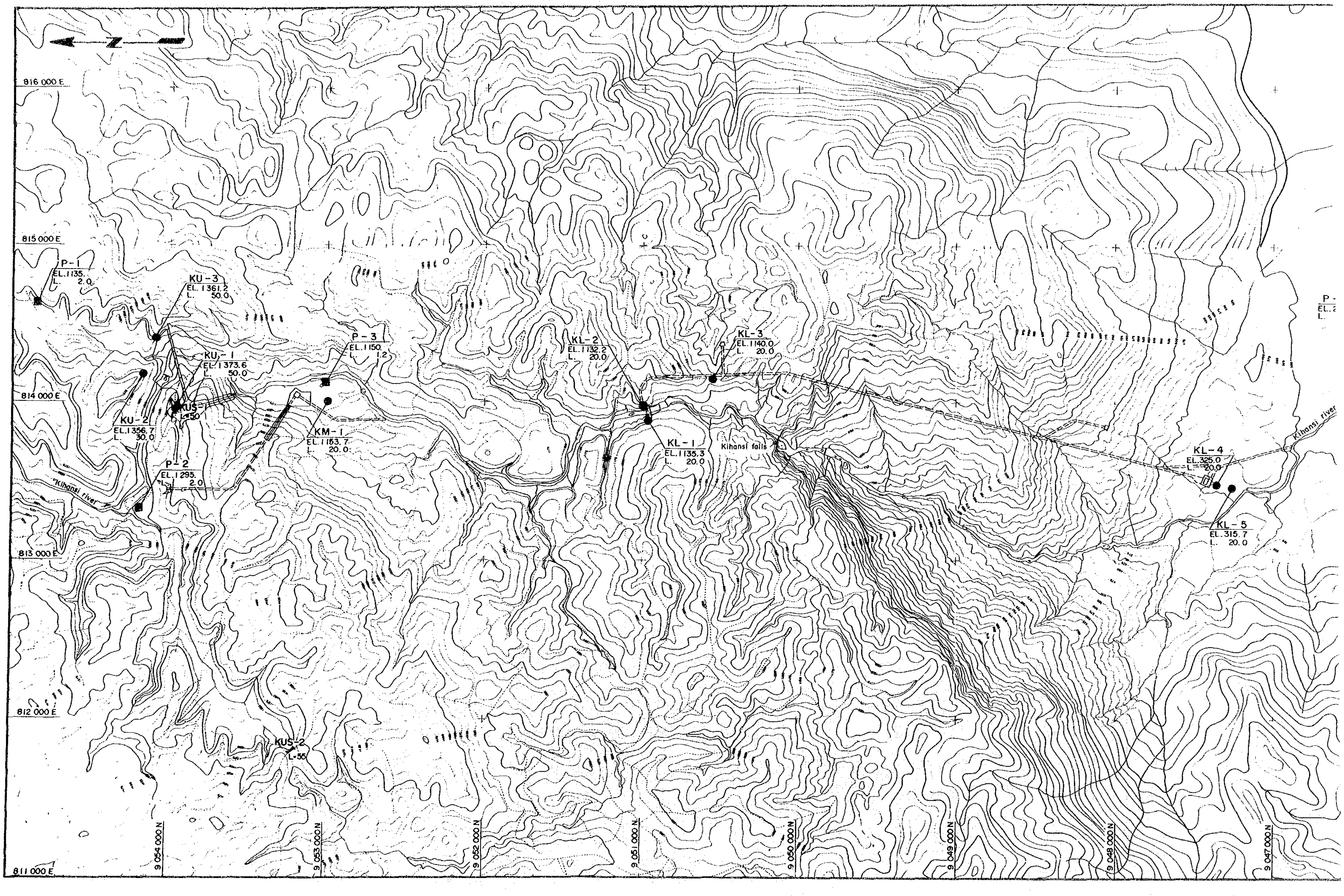
Line No.	Site	Coordinate N	Coordinate E	Elevation (m)	Length (m)	Note
KUS-1	Upper	9,053,962 9,053,958	813,984 813,934	1,370 ~1,380	50	KU-1 is on this line.
KUS-2	Upper	9,053,225 9,053,180	811,785 811,810	1,364 ~1,370	55	West rim of reservoir.

[LABORATORY TEST]

Test	Quantity	Test Item
Core material test	5 Samples	Specific gravity, Compaction, etc.
Concrete aggregate test	5 Samples	Alkali-aggregate reaction, etc.
Drilled core test	17 Samples	Unconfined compression, etc.

Table 7-2 List of Reference Data

Title	Note
1. Rufiji Basin Hydropower Master Plan Report	Norconsult Nov.1984
2. The Geology of the Rufiji Basin with reference to proposed dam sites	Geological Survey of Tanganyika 1962
3. Summary of the Geology of Tanzania	Mineral Resources Division,Tanzania 1970
4. Geological Map "Utengulu,Sheet249" Scale 1/125000	German Geological Mission in Tanzania 1970
5. Geological Map "Dabaga,Sheet233" Scale 1/125000	German Geological Mission in Tanzania 1971
6. The Geochronology of the Tanzanian Shield	K.BellandM.H.Dodson 1981 J.of Geo.Vol.89
7. The Earthquake Data File	NOAA (National Oceanic and Atmospheric Administration)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L. 2.0
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EL.1361.2
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L. 50.0
KU-2
EL.1356.7
L. 30.0
KUS-1
L.50
P-2
EL.1295.
L. 2.0
Kihansi river
P-3
EL.1150.
L. 1.2
KM-1
EL.1153.7
L. 20.0
KL-2
EL.1132.2
L. 20.0
KL-3
EL.1140.0
L. 20.0
KL-1
EL.1135.3
L. 20.0
Kihansi falls
KL-4
EL.325.0
L. 20.0
KL-5
EL.315.7
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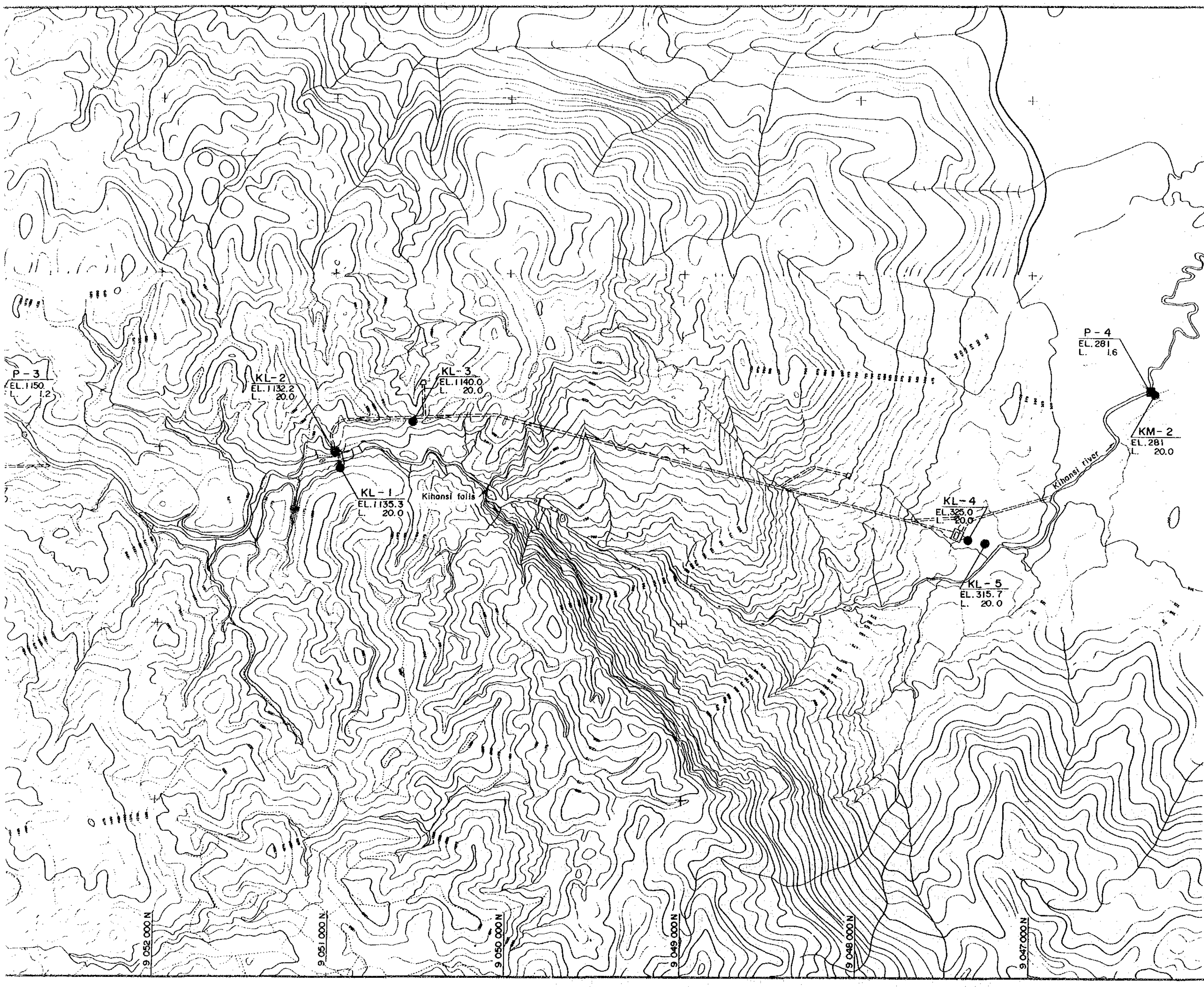


KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

LOCATION MAP OF INVESTIGATION WORKS

Fig. 7 - 1	DATE;

7.2 Regional Geology

7.2.1 Topography

As shown in Fig. 7-2, the site of the Kihansi Project, as seen from the whole of Tanzania, corresponds to the boundary area between the interior highlands of elevation 1,000 m and higher and lowlands of elevation under 500 m extending inland from the Indian Ocean coast.

The Kihansi River on which this Project is planned, rises from the gently-sloped mountainland of elevation 2,000 m approximately 50 km south of Iringa, flows south, and on passing the project site and reaching lowland of EL. 300 m (Kilombero Valley), changes course to the northeast, passes east of Chita, and merges with the Kilombero River. Further, the Kilombero River passes Ifakara, merges with the Great Ruaha River, and flowing eastward empties into the Indian Ocean approximately 140 km south of Dar Es Salaam.

The region of the Kihansi River fountainhead of elevation from 2,000 to 1,500 m is a gently-sloped mountainland, and the gradient of the Kihansi River, which has tributaries highly developed in network form, is 1/50 to 1/130. In the downstream area of elevation from 1,500 to 1,100 m, although the mountain tops are gently sloped, there are many steep slopes along the river due to erosion caused by the river. The gradient of the Kihansi River in this area is approximately 1/30, and the dam and powerhouse of the Upper Kihansi Project is planned in this area.

Further downstream, from EL. 1,100 m to EL. 300 m, there is a steep cliff dropping as much as 800 m, and the gradient of the Kihansi River here is approximately 1/5. The Lower Kihansi Project takes advantage of this head. This steep cliff extends northeast along the Kilombero Valley and is called the Uzungwa Scarp.

The Kihansi River, on coming down to the lowland of EL. 300 m and under, changes its course to the northeast, and meandering through a vast marshland called the Kilombero Valley which is practically flat, merges with the Kilombero River between Chita and Ifakara.

7.2.2 Geology

(1) Geological Outline of Tanzania

Precambrian basement rocks are widely distributed on the African continent. Tanzania, situated at the central part of eastern Africa facing on the Indian Ocean, has the Precambrian Tanzanian Shield and surrounding orogenic belts widely making up its basement as shown in Fig. 7-3.

The Tanzanian Shield, existing widely from the central part of Tanzania to the west comprises a part of the Congo Craton which spreads out over Central Africa immediately on the equator, and is made up of granites, gneisses, and greenstone belts. According to radiometric dating done so far, the Tanzanian Shield is indicated to be 2,500±100 Ma (Mega-annum).

As if to surround this Tanzanian Shield, there are the Usagaran Orogenic Belt to the east and the Ubendian Orogenic Belt to the southwest, and the ages of these orogenic movements are estimated to be 2,000±200 Ma. Furthermore, there is the Karagwe-Ankolean Orogenic Belt said to be 1,100±200 Ma spread out to the northwest near the west bank of Lake Victoria. Overlying the Ubendian and Karagwe-Ankolean bounding the west side of the Tanzanian Shield there is the thick Bukoban Group consisting of sandstone, shale, basaltic lava, and siliceous limestone which were deposited from late Precambrian to Paleozoic time.

On the other hand, in the eastern part of Tanzania, there is the Mozambique Orogenic Belt (or Pan-African Orogenic Belt) which runs from the Arabian Peninsula to Ethiopia to Kenya in the north and Malawi to Mozambique in the south, and the age of this belt is 600±200 Ma.

In the southern part of Tanzania and along the Indian Ocean coast is seen the Karroo System with intercalations of coal beds said to have been deposited from late Paleozoic to early Mesozoic time.

What should be especially noted as disturbances in Cenozoic time are the formation of East African Rift Valleys and the volcanic activities. The East African Rift Valleys begin with the Afar Depression of Ethiopia and continue through Kenya, Tanzania, Malawi down to the mouth of the Zambezi River. In Tanzania, these rift valleys are divided into the Eastern Rift and Western Rift sandwiching Lake Victoria. The Eastern Rift is distinct in the northern part of Tanzania in the vicinity of Arusha, but becomes indistinct in the central part near Dodoma. On the other hand, the Western Rift is continuous from Lake Tanganyika to Lake Malawi. It is said that the East African Rift Valleys were formed after the Palaeogene.

Preceding the formation of the rift valleys there was large-scale basaltic volcanic activity along the areas of the rift valleys. The volcanic rocks produced in this activity are widely distributed in the northern part of Tanzania centered at Arusha. Mt. Kilimanjaro was formed as part of this volcanic activity.

(2) Geology of the Kihansi River Basin

As shown in Fig. 7-3, the Kihansi River Basin where the Kihansi Project is planned is located in the Usagaran Orogenic Belt which bounds the southeast part of the Tanzanian Shield spread widely to the west from the central part of Tanzania.

The basement rocks making up the basin are Precambrian gneisses and granites. The gneisses which can be subdivided into migmatic gneiss, biotite gneiss, and quartzo-feldspathic gneiss are widely distributed in the greater part of the Kihansi River Basin. The most predominant of these gneisses, the quartzo-feldspathic gneiss, can be seen in a wide range from the vicinity of the Kihansi River head down to the Uzungwa Scarp. The migmatic gneiss is limited to the vicinity of the Kihansi River fountainhead only, while biotite gneiss has outcroppings at the southwestern part of the Kihansi River, and their distribution areas are both smaller than the quartzo-feldspathic gneiss. Quartzites and amphibolites in the forms of small-scale lenses are included in the gneisses. On the other hand, the granites which consist mostly of biotite granite have their main distribution ranges in the other basin areas to the west of the Kihansi River, and are seen in the Kihansi River Basin only on a small scale at the fountainhead area.

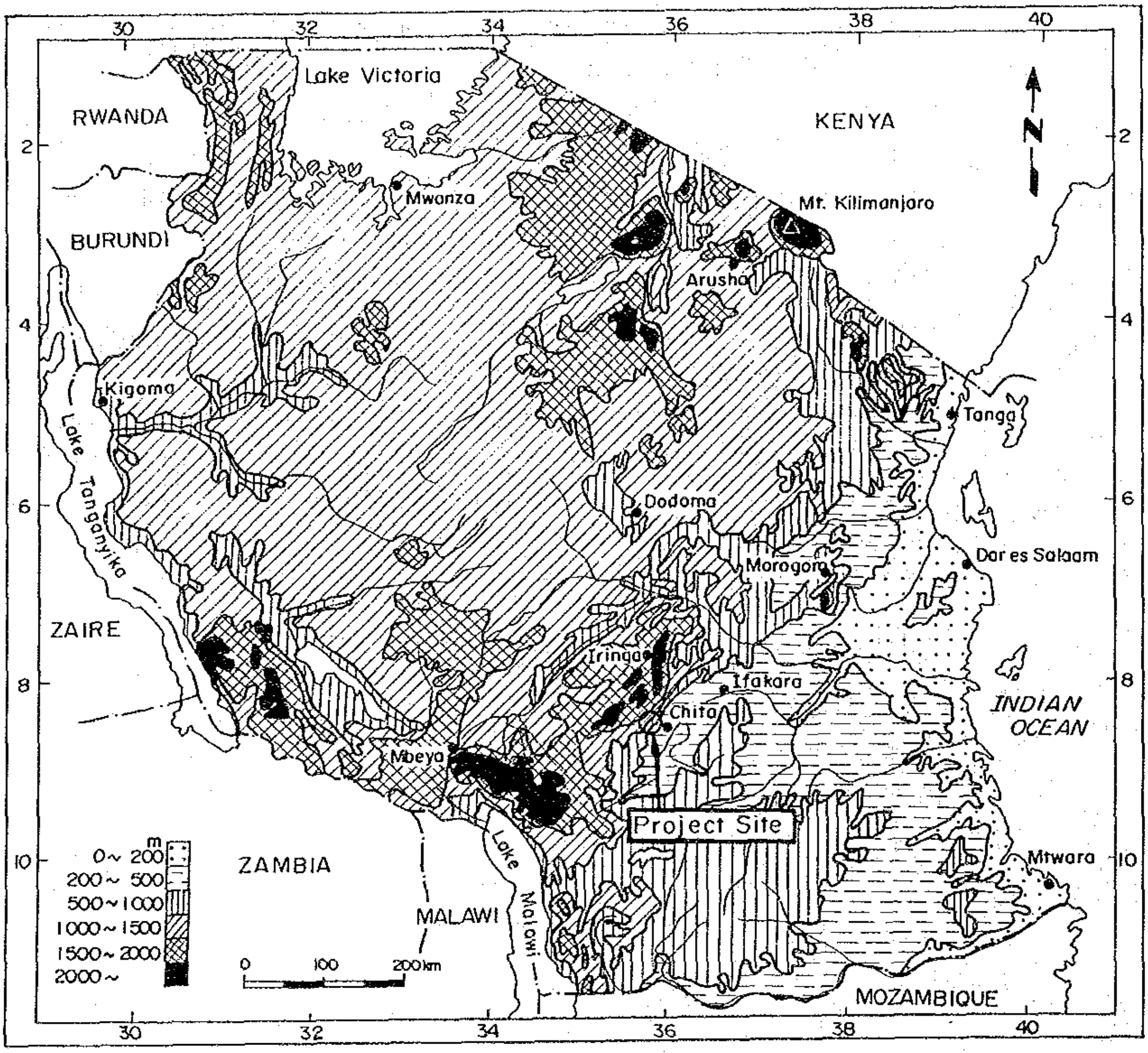
As dykes that can be seen in these rocks, there are quartz dykes, pegmatite dykes, and dolerite dykes. All of these dykes are of very small distribution areas, but dolerite dykes are predominant inside the river basin.

Surface deposits are distributed widely in the Kilombero Valley which comprises a vast marshland below EL. 300 m. At the parts of elevation higher than the Uzungwa Scarp (1,100 to 2,000 m), river deposits are distributed only at scattered places along the river. Furthermore, as seen in Fig. 7.3, at the high-elevation part above the Uzungwa Scarp, the basement rocks are covered by rainforest soils and lateritic soils.

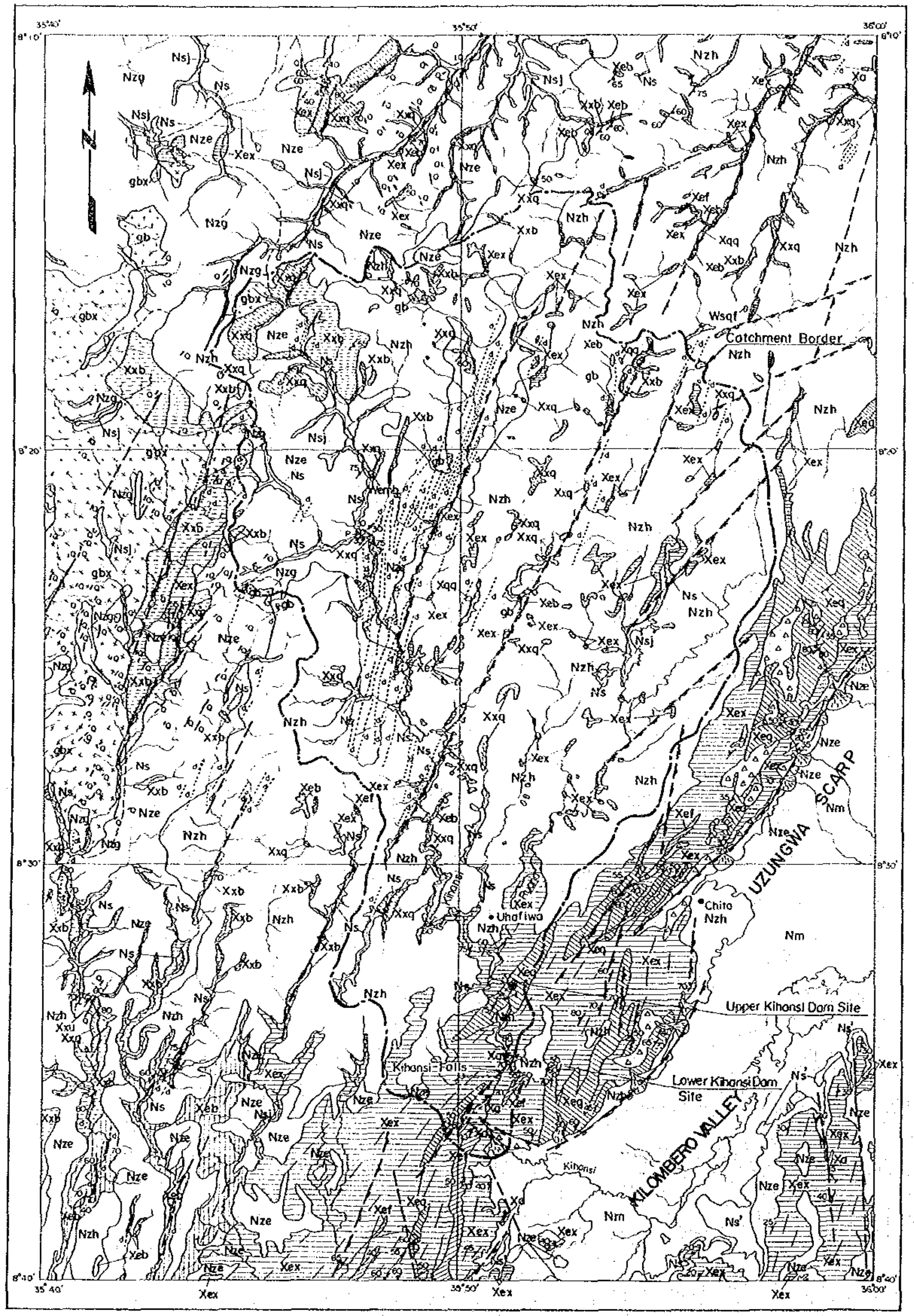
The geologic structure of this river basin is featured by faults oriented NE-SW and NNE-SSW. The Uzungwa Scarp of height difference as much as 800 m was formed by these fault groups, and the dislocation is considered to have occurred after the time (late Paleozoic to early Mesozoic) of deposition of the Karroo System distributed in the southern part of Tanzania. Geologic structures such as foliation of gneiss or arrangement of dykes at places other than the faults predominate in the NE-SW or NNE-SSW directions.

It is considered that other than clay used for brick, there are no exploitable mineral resources to be found in this river basin.

Fig. 7-2 Topographic Map of Tanzania



REGIONAL GEOLOGICAL MAP



Note : This map is compiled from "Geological Map of Utengule (Sheet No. 249), scale 1 : 125,000, 1970" and "Geological Map of Dabaga (Sheet No. 233), scale 1 : 125,000, 1971" by Geological Survey of the Federal Republic of Germany.

0 10km

LEGEND

QUATERNARY AND NEOGENE

- Nm — Sands, grits, and clays of Kilombero Valley
- Nsj — River deposits, swampy, humic, clayey sand
- Ns — River deposits (silt, sand, gravel)
- Ns' — Yellow, pink and greyish sands, probably river deposits
- Talus fan
- Debris on Uzungwa Scarp
- Nzh — Humus-rich soils of rainforest
- Nze — Brownish red to chocolate brown soils, overlying gneisses and amphibolites
- Nzg — Pink to light red soils, overlying granites

PRECAMBRIAN

GRANITES

- gb — Biotite granite
- gbx — Contaminated biotite granite

ROCKS OF MAGALILWA

- Wsqf — Quartz phyllites and layers of sericite phyllite with magnetite
- Wemb — Muscovite-biotite gneiss : Conglomerates

USAGARAN

Migmatitic gneisses

- Xxb — Migmatitic biotite gneiss, medium-to coarse-grained
- Xxq — Migmatitic quartzo-feldspathic gneiss, medium-to coarse-grained
- Xxu — Migmatitic biotite augengneiss, occasionally with hornblende, medium-to coarse-grained

Gneisses

- Xeb — Biotite-gneiss, fine-grained
- Xqq — Quartzites
- Xa — Amphibolite
- Xex — Quartzo-feldspathic gneiss, fine-to medium-grained
- Xef — Quartzo feldspathic gneiss with high amounts of microcline, medium-to coarse-grained
- Xeq — Quartzo-feldspathic gneiss with thick layers of quartzitic gneisses, fine-grained

Dykes

- Quartz dyke
- Pegmatite dyke
- Dolerite dyke

Geological boundaries

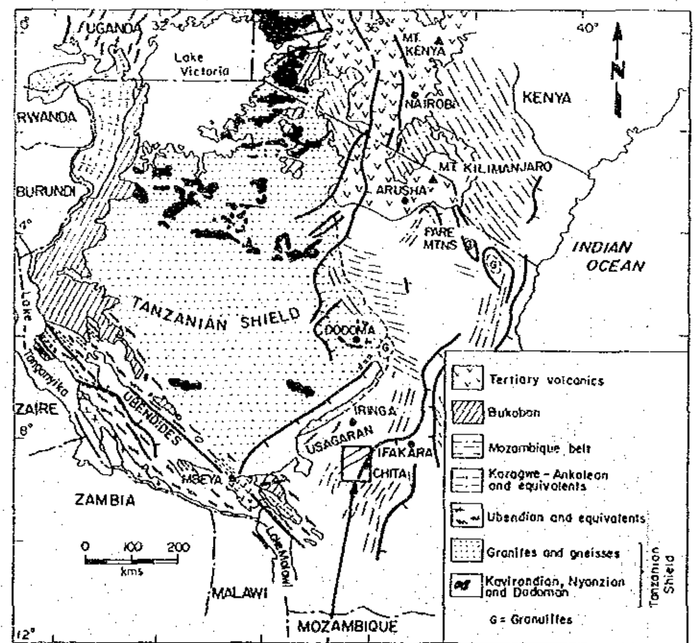
- Observed
- Gradational

Geological structures

- Foliation, inclined, vertical
- Planar elements in granites indicated by crystals and xenoliths
- Fold axis
- b - lineation
- Major fault, mark on downthrown side
- Minor fault
- Trend of foliation

GEOLOGICAL MAP OF THE TANZANIAN SHIELD

(After BELL and DODSON, 1981)



REGIONAL GEOLOGICAL MAP AREA

KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT	
REGIONAL GEOLOGICAL MAP	
Fig. 7-3	DATE

7.3 Geological Outline of Survey Area

7.3.1 Topography

The Upper Kihansi and Lower Kihansi Project sites may be broadly divided, topographically, into the three areas below. These are ① a mountainland of comparatively gentle features from EL. 1,500 to 1,100 m, ② a steep cliff portion of head as much as 800 m from EL. 1,100 to 300 m, and ③ a more or less flat lowland of elevation approximately 300 m.

In ①, mountain peaks are lined up roughly at a given height, between which the Kihansi River and the Ruaha River flow down at river gradients of approximately 1/30. The Kihansi and the Ruaha merge at an elevation of approximately 1,300 m after which the flow is to the south. Tributaries which merge with the two rivers are developed in net-like form and the watersheds of these tributaries are interwoven in a complex manner bounded by the gently-sloped mountain peak area. The mountain forms are gentle as a whole, but there are many places where steep slopes of approximately 30 deg can be seen along streams due to erosion by water flows. The dam, powerhouse, etc. of the Upper Kihansi Project are planned inside the area of ① above.

The area of ② comprises a part of the large-scale cliff extending in the NE-SW direction called the Uzungwa Scarp. The gradient of the Kihansi River becomes approximately 1/5 here and numerous waterfalls can be seen along the way. The largest of these is called Kihansi Falls and the drop is as much as approximately 200 m. The dam and powerhouse of the Lower Kihansi Project are respectively planned upstream and downstream of Uzungwa Scarp.

The area of ③ is a more or less flat marshland called Kilombero Valley. The gradient of the Kihansi River here