PD-AAX-058

Democratic Socialist Republic of Sri Lanka

Ministry of Mahaweli Development

Maduru Oya Project

Feasibility Report

Annex C
Hydrology and Water Balance

Acres International Limited, Niagara Falls, Canada

August 1980

FOREWORD

The Feasibility Report on the Maduru Oya Project, of which this Annex forms a part, is made up as follows:

Main Report

Annex A - The Project Area

Annex B - Soils and Land Classification

Annex C - Hydrology and Water Balance

Annex D - Engineering Works

Annex E - Agronomic Studies

Annex F - Livestock

Annex G - Agroeconomic Studies

Annex H - Forestry

Annex I - Settlement Planning

Annex J - Environmental Aspects

Annex K - Implementation, Organization and Management

Annex L - Economic and Financial Analysis

TABLE OF CONTENTS

LIST OF TABLES
LIST OF FIGURES

SUMMARY

	Page
1 - INTRODUCTION	1
2 - CLIMATE AND HYDROLOGY	3
2.1 - Climate	3
2.2 - Hydrometeorological Data	3
3 - IRRIGATION WATER REQUIREMENTS	21
3.1 - Field Water Requirements	22
3.2 - Effective Rainfall	27
3.3 - System Water Requirements	30
3.4 - Comparison with Other Calculations	36
3.5 - The Influence of Water Requirements on System Operation	38
4 - THE WATER BALANCE	41
4.1 - Simulation Input	42
4.2 - Simulation Results	44
4.3 - Interaction Between the Reservoir and the Link Tunnel	48
4.4 - Operational Features of the Project	53
5 - WATER QUALITY	55
6 - FLOOD HYDROLOGY	57
6.1 - Rainfall	57
6.2 - Observed Flood Frequency	58
6.3 - Unit Hydrograph Analysis	61
6.4 - Implications For Floodplain Cropping	68
6.5 - Flood Behavior	69

REFERENCES

FIGURES

N

LIST OF TABLES

Number	Title
C-2.1	Rainfall Stations Located Near System B
C-2.2	Summary of Regression Relationships
C-2.3	Welikanda Rainfall
C-2.4	Polonnaruwa Rainfall
C-2.5	Vakaneri Rainfall
C-2.6	Batticaloa Rainfall
C-2.7	Trincomalee Rainfall
C-2.8	Ekiriyankumbura Rainfall
C-2.9	Horaborawewa Rainfall
C-2.10	Summary of Characteristics of Maduru Oya Streamflow Gauging Stations
C-2.11	Maduru Oya at Welikanda
C-2.12	Maduru Oya at Damsite
C-3.1	Crop Water Requirements for the Lowlands and Floodplains
C-3.2	Crop Water Requirements for the Uplands
C-3.3	Infiltration Test Results
C-3.4	Weighted Rainfall for System B
C-3.5	Effective Rainfall for Lowland Paddy
C-3.6	Effective Rainfall for Upland Crops
C-3.7	Summary of Key Assumptions Used in Computing Water Requirements
C-3.8	Sample Calculation of 1950 Irrigation Water Requirements
C-3.9	System B - Irrigation Water Requirements - Full Development

Number	Title
C-3.10	Comparison of Computed and Observed Irrigation Water Requirements
C-4.1	Water Requirements for System C
C-4.2	Summary of Simulation Results
C-4.3	Potential Tunnel Inflows
C-5.1	Summary of Water Quality Data
C-6.1	Observed Floods at Welikanda
C-6.2	Derivation of 5-year Design Storm for 3-hour Intervals
C-6.3	Summary of Design Storms
C-6.4	Influence of Maduru Oya Dam on Flood Peaks at Welikanda

C

LIST OF FIGURES

Number	Title
C-1	Rainfall and Streamflow Stations
C-2	Flow Measurements at Welikanda
C-3	Cross Section of Maduru Oya at Welikanda
C-4	Crop Calendar
C-5	Major System Components
C-6	Operational Features
C-7	Reservoir Characteristics
C-8	Rainfall Intensity - Duration - Frequency Curves for System B
C-9	Flood Frequency Curves for Welikanda
C-10	3 Hour, 10-mm Unit Hydrographs

SUMMARY

Studies related to water in the Maduru Oya project area were conducted under five major headings.

1 - Assessment of precipitation and streamflow data reliability.

2 - Calculation of irrigation water requirements.

3 - Examination of the balance between irrigation water demands and the available supply.

4 - Comparison of available water quality data and recognized standards for irrigation water quality.

5 - Assessment of the flood regime in the Maduru Oya floodplain both before and after the construction of the Maduru Oya dam.

Data Reliability

Seven reliable rainfall stations with records spanning most of the 1950 to 1977 period are located in and near the project area. Their locations permit the calculation of weighted monthly rainfall over the watershed area or the irrigation area, as required.

Streamflow data are available for the Maduru Oya for most of the 1950 to 1977 period from observations at Welikanda. Streamflow measurements made in 1978 to 1979 confirmed that the rating curve established in the 1950's has not altered to a significant degree. Hydraulic analyses indicate that extrapolation of the rating curve to flood conditions, while limited in reliability, should be adequate for the floodplain assessments required for this study.

Irrigation Water Requirements

Irrigation water requirements were calculated for each month of the 1950 to 1977 period, based on the following assumptions

- cropped areas derived from land classification studies, as documented in Annex B, with allowances for irrigation infrastructure and other losses, as documented in Annex D

- average monthly crop water requirements computed as documented in Annex E, for a cropping pattern which is dominated by double cropped paddy

- deep percolation rates of 3 mm and 6 mm/d, for the least porous and most porous paddy soils respectively

- effective rainfall computed for each month using recognized formulae for paddy and upland crops, with weighted project-wide monthly rainfall as basic data

- irrigation efficiencies which imply lined main and branch canals (main canal efficiency = .90) and good project and farm water management (distribution and field efficiency = .70 in paddy areas, .50 in upland areas).

Computed Yala (dry season) water requirements were compared against other theoretical calculations, locally used design "rules of thumb" and observed water usage in the Pimburettewa Tank Scheme, which is located within the project area. Satisfactory agreement was obtained.

Water Balance

Water balance studies were directed at verifying that the combination of dam height, link tunnel capacity and upstream

diversion capacity identified in previous studies by CECB and NEDECO and now contractually committed, would be adequate to satisfy the newly computed irrigation water requirements for Systems B and C. The computer simulation program developed by NEDECO was used, with Mahaweli diversion flows as computed in NEDECO's studies of the operation of mainstem reservoirs. The studies showed that the headworks, as now committed, can provide a reliable water supply with minor shortages for about 92 percent of the land identified in land classification studies (Annex B) as being both irrigable and commandable. The elimination of a portion of the Left Bank branch canal system is recommended to achieve a satisfactory water balance. If actual water usage rates prove to be lower than assumed herein, this area can be developed at a later date.

Water Quality

The sparse water quality data which are available indicate that the combination of Mahaweli and Maduru Oya water which will supply the project with irrigation water will fall into the "no problem" irrigation water quality category, as defined by the United States Department of Agriculture (USDA) and the Food and Agriculture Organization of the United Nations (FAO).

Flood Studies

Analysis of flood records using the Dimensionless Unit Hydrograph approach indicates that the Maduru Oya dam can be expected to reduce flood peaks to about 75 percent of their pre-dam levels for a given probability of exceedence. The resulting flood stages would still cause substantial flood

problems. However, if transplanting of the paddy crop is delayed until after January 15, the combination of this delay and the flood control effect of the dam will reduce the risk of flood damage to a much lower level. The following flood peaks are indicated.

Return Period	Probability of Exceedence	Flood Peaks (m^3/s) Pre-Dam All Year	Pre-Dam Post Jan 15	Post-Dam All Year	Post-Dam Post Jan 15
5 yr	.20	907	400	677	300
10 yr	.10	1 190	540	875	470
25 yr	.04	1 590	950	1 130	680

1 - INTRODUCTION

This annex presents the hydrological data base for the Maduru Oya project, followed by analysis of the data to calculate the monthly water balance for the project and to assess the present and future flood regime in the Maduru Oya floodplain.

Section 2 presents the monthly rainfall and runoff data, and includes a commentary on the reliability of the data. Section 3 documents the calculation procedures, key assumptions and comparisons with other calculations and observations which are associated with monthly irrigation water requirements. Section 4 presents the results of computer simulation studies which assess the project water balance. Section 5 presents water quality data available for the anticipated water sources, and compares them to internationally recognized irrigation water quality standards. Finally, Section 6 presents the results of analyses of the flood regime in the Maduru Oya floodplain, including an assessment of the influence of the Maduru Oya dam on flood peaks and an assessment of the effect of flood timing on agricultural development in the floodplain.

2 - CLIMATE AND HYDROLOGY

2.1 - Climate

The Maduru Oya basin experiences a tropical climate, falling under the influence of the northeast (December to February) and southwest (May to September) monsoons. The northeast monsoon (Maha) brings most of the annual rainfall, and therefore runoff, in the catchment area. The southwest monsoon (Yala) is typically dry due to the orographic effect of the Central Highlands of Sri Lanka. Rainfall in the intermonsoon periods can be caused by either convective or cyclonic storms. Relatively minor temperature fluctuations are normally experienced, compared with wider fluctuations in precipitation and streamflow. The latter fluctuations have important implications for the development of rainfed and irrigated agriculture.

2.2 - Hydrometeorological Data

The quality of basic rainfall and streamflow data in and near the project area is generally adequate. The one important deficiency is the lack of a representative climatic station, the impact of which is discussed in Annex E (Agronomic Studies).

This section emphasizes the monthly rainfall and streamflow data base. Daily and shorter duration rainfall data are discussed in Section 6, and flood peak data are also presented and analyzed in Section 6.

2.2.1 - Rainfall

There are seven rainfall stations which have periods of record which span the 1950 to 1977 simulation period used in the NEDECO studies[1] and which has been adopted for use here. The locations of these stations (see Figure C-1) are such that they can be used to determine average rainfall over the catchment area or the irrigation area, as required.

Table C-2.1 summarizes the periods of record of the seven stations, and documents the periods of missing data. The records from these stations, when subjected to double mass curve analysis to check for consistency, show that no important "breaks" in interstation relationships have occurred. This indicates that the records can be used for analytical purposes with reasonable confidence.

The data from those stations which have gaps in their records were subjected to regression analysis to develop equations for the estimation of missing data. Best results were obtained by developing different equations for the maha and yala seasons. Table C-2.2 summarizes the derived relationships, and the observed and estimated data are presented in Tables C-2.3 to C-2.9. Estimated data are indicated by asterisks (*).

2.2.2 - Streamflow

As Table C-2.10 shows, streamflow data have been collected in the Maduru Oya basin since 1946. The station at Welikanda, because of its greater accessibility over the years, has been operating more or less continuously since that time. A station was operated for over 6 years at the Maduru Oya damsite, but observations were discontinued in 1957.

TABLE C-2.1

RAINFALL STATIONS
LOCATED NEAR SYSTEM B

Station Name	Period of Record		Missing Data	
	Begin	End	Total Months	Major Periods Missing
Batticaloa	Jan 1869	-	0	-
Ekiriyankumbura	Jan 1943	July 1977	14	Aug 1959 to Dec 1959
Horaborawewa	Nov 1909	-	18	Feb 1971 to Feb 1972
Polonnaruwa	Jan 1940	-	5	-
Trincomalee	Jun 1869	-	0	-
Vakaneri	Oct 1900	Nov 1972	18	Jan 1968 to Dec 1968
Welikanda	Jan 1942	June 1973	21	Feb 1967 to Jan 1968

TABLE C-2.2

SUMMARY OF
REGRESSION RELATIONSHIPS

Dependent Variable (Y)	Independent Variable (X)	Period Used	Regression Equation (a)	Regression Equation (m)	R
Welikanda	Polonnaruwa	Oct-Apr	-0.3	0.95	0.85
	Polonnaruwa	May-Sep	31.7	0.41	0.46
Polonnaruwa	Trincomalee	Oct-Apr	59.9	0.86	0.80
	Trincomalee	May-Sep	33.9	0.39	0.30
Vakaneri	Polonnaruwa	Oct-Apr	14.5	0.96	0.81
	Polonnaruwa	May-Sep	33.2	0.59	0.48
Ekiriyankumbura	Horaborawewa	Oct-Apr	4.5	0.93	0.88
	Horaborawewa	May-Sep	48.2	0.72	0.51
Horaborawewa	Ekiriyankumbura	Oct-Apr	55.1	0.84	0.84
	Ekiriyankumbura	May-Sep	18.2	0.38	0.52

Notes: Regression equation of the form $Y = a + mX$, where

Y = dependent variable (monthly rainfall, in mm)
X = independent variable (monthly rainfall, in mm)
a = constant, estimated by regression analysis
m = slope of fitted line, estimated by regression analysis
R = correlation coefficient

TABLE C-2.3

WELIKANDA RAINFALL (MM)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1950	214.9	70.9	196.6	19.6	70.4	0.0	0.0	110.7	183.4	157.2	163.6*	204.5	1 391.7*
1951	714.2	112.5	45.2	154.4	106.4	0.0	0.0	43.7	57.9	127.5	467.1	262.1	2 091.2
1952	524.8	58.4	36.3	93.0	63.2	0.0	64.0	0.0	4.6	113.5	268.2	247.9	1 474.0
1953	296.4	17.0	0.0	57.1	0.0	55.4	165.4	150.1	110.0	263.4	344.9	504.2	1 963.9
1954	496.6	127.8	107.9	93.2	51.1	0.0	20.6	42.9	0.0	230.9	146.3	407.4	1 724.7
1955	341.9	182.6	7.9	191.8	21.6	0.0	0.0	64.8	213.1	73.2	82.3	253.5	1 432.6
1956	243.8	60.7*	0.0	0.0	0.0	116.1	55.9	84.1	44.4	256.0	605.3	328.2	1 794.5*
1957	152.4	402.3	0.0	0.0	101.9	0.0	28.4	7.4	37.6	172.5	578.6	1 465.1	2 946.1
1958	175.5	86.9*	95.8	150.6	194.1	0.0	119.4	97.3*	39.9	108.5	109.5	440.2	1 617.5*
1959	323.1	0.0	0.0	31.5	35.6	0.0	5.1	78.2	45.5	220.2	281.7	270.8	1 291.6
1960	372.9	641.6	25.4	119.4	55.9	2.5	176.3	0.0	50.8	96.3	466.6	160.5	2 168.1
1961	407.7	326.9	118.9	0.0	78.7	0.0	116.8	0.0	109.2	149.9	436.9	564.1	2 309.1
1962	102.1	7.6	55.9	22.9	69.1	0.0	129.5	7.6	86.4	325.4	263.7	355.6	1 425.7
1963	438.4	441.5	109.0	102.1	0.0	0.0	0.0	16.5	146.0	273.3	466.6	573.0	2 566.4
1964	201.9	205.7	107.9	1.3	127.0	0.0	165.1	141.0	0.0	209.5	41.9	112.0	1 313.4
1965	97.5	444.5	13.2	98.0	7.6	0.0	0.0	116.8	0.0	73.7	439.4	274.3	1 565.1
1966	230.6*	16.5*	121.9	26.4	45.5	32.8*	34.0*	303.5	108.2	537.2	491.5	184.4	2 132.6*
1967	80.5	201.9*	50.3*	83.3*	36.3*	31.7*	31.7*	32.0*	37.8*	247.9*	445.3*	482.3*	1 761.2*
1968	127.8*	0.0	116.1*	0.0	0.0	0.0	0.0	0.0	17.8	26.2	268.7	314.5	871.0*
1969	71.1	98.0	6.1	300.7	38.1	0.0	19.3	128.8	74.2	318.3	128.8	768.3	1 951.7
1970	147.8	232.9	51.3	84.8	129.0	40.6	0.0	37.8	86.9	89.4	270.5	258.3	1 429.5
1971	285.5	21.8	35.1	125.0	33.8	0.0	75.2	47.2	55.6	157.5	154.4	444.0	1 435.1
1972	54.3	22.1	40.4	21.1	89.9	54.6	32.3	0.0	102.1	368.3	197.9	280.4	1 243.3
1973	11.2	52.3	117.6	114.0	119.9	121.2	174.5*	50.0*	188.5*	175.3*	131.1*	1199.4*	2 454.9*
1974	0.0*	52.8*	31.2*	137.9*	58.7*	31.7*	31.7*	34.8*	93.7*	24.1*	183.4*	225.8*	905.8*
1975	141.2*	165.9*	194.6*	180.5*	78.0*	31.7*	240.0*	71.4*	31.7*	200.4*	272.3*	364.5*	1 972.1*
1976	219.5*	14.2*	3.3*	55.9*	31.7*	50.0*	38.9*	64.0*	74.9*	120.4*	578.9*	654.6*	1 906.3*
1977	146.8*	47.0*	138.2*	181.9*	81.5*	33.8*	99.8*	66.0*	95.2*	249.4*	639.6*	492.3*	2 271.5
AVG	235.7*	146.9*	65.2*	87.4*	61.6*	21.5*	65.1*	64.2*	74.8*	191.6*	318.7	431.9*	1 764.7*

*Estimated

TABLE C-2.4

POLONNARUWA RAINFALL (MM)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1950	134.4	150.6*	168.9	14.0	61.7	0.0	0.0	82.3	18.0	117.6	171.7	178.6	1 097.8
1951	500.4	108.7	75.4	134.9	13.7	0.0	55.4	41.4	147.8	62.2	384.0	265.2	1 789.2
1952	463.8	127.5	46.5	133.3	97.0	0.0	52.8	0.0	105.4	179.1	185.7	227.1	1 618.2
1953	224.0	89.4	73.2	214.6	0.0	51.1	171.4	36.1	133.1	265.7	244.9	436.9	1 940.3
1954	296.9	97.5	211.6	112.5	0.0	0.0	90.9	64.8	0.0	199.6	184.4	578.1	1 836.4
1955	260.9	105.7	31.0	127.8	44.4	0.0	0.0	134.1	174.2	164.6	102.6	147.3	1 292.6
1956	125.5	63.8	69.7	104.9	0.5	111.0	12.2	55.1	4.3	224.0	311.9	300.7	1 373.6
1957	112.8	315.5	0.0	71.1	127.3	2.3	51.8	18.0	14.7	178.3	612.6	1218.7	2 753.1
1958	192.0	91.2	103.6	81.3	60.2	0.0	0.0	159.8	31.2	212.1	226.8	397.5	1 555.7
1959	268.0	15.2	9.1	96.5	29.2	21.6	0.0	30.0	118.9	371.3	338.6	269.5	1 567.9
1960	274.8	409.2	84.8	306.6	164.3	0.0	140.2	23.9	37.6	101.1	264.7	129.0	1 936.2
1961	422.9	259.8	103.6	115.6	140.7	6.9	0.0	0.0	9.1	144.5	348.7	513.3	2 065.3
1962	207.5	65.5	71.9	95.8	76.2	0.0	4.8	27.2	127.0	168.9	205.5	222.3	1 272.5
1963	488.7	257.3	101.6	216.9	39.4	1.8	47.8	5.1	134.1	186.2	490.5	432.1	2 403.3
1964	162.6	220.7	255.5	79.2	36.6*	0.0	103.6	46.5	72.9	87.1	147.1	155.2	1 367.9*
1965	105.4	412.2	2.3	181.9	158.7	21.6	0.0	151.9	0.5	241.3	595.4	574.0	2 445.3
1966	241.8	17.5	161.5	239.8	2.5	2.5	5.3	119.6	52.1	421.9	295.7*	397.3*	1 957.6*
1967	65.5	180.1*	52.8	87.6	10.9	0.0	0.0	0.8	15.0	259.8	466.6	505.5	1 644.6*
1968	134.1	0.0	121.9	98.6	1.3	0.0	0.0	15.5	32.5	189.5	313.9	213.1	1 120.4
1969	111.0	42.2	28.2	271.0	0.0	0.0	96.5	87.4	34.3	269.7	109.2	709.4	1 759.0
1970	179.8	302.8	18.8	196.8	137.7	95.2	0.0	103.4	35.6	219.7	488.7	326.9	2 105.4
1971	176.3	101.6	160.5	168.1	30.2	0.0	148.8	282.7	2.5	200.2	180.1	798.1	2 249.2
1972	40.1	0.0	0.0	138.2	132.3	0.0	11.7	0.5	407.2	617.5	579.4	435.4	2 362.2
1973	20.3	116.8	44.4	36.8	88.9	66.0	348.0	44.7	382.3	183.9	391.4	1256.5	2 980.2
1974	0.0	55.4	33.0	144.8	65.5	0.0	0.0	7.6	151.1	25.4	192.3	236.7	911.9
1975	148.1	174.0	204.0	191.5	112.8	0.0	508.0	96.8	0.0	210.1	285.5	382.0	2 312.7
1976	230.1	15.2	3.8	58.9	0.0	44.7	17.3	78.7	105.4	126.2	606.6	685.8	1 972.8
1977	153.9	49.5	145.0	190.8	121.4	4.8	165.9	83.6	154.7	261.4	670.1	515.9	2 516.9
AVG	205.1	137.3*	84.7	139.6	62.6*	15.3	73.7	64.2	89.3	210.4	335.5*	446.7*	1 864.6*

*Estimated

TABLE C-2.5

VAKANERI RAINFALL (MM)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1950	207.0	70.6	244.3	15.7	39.6	0.0	1.0	158.5	75.7	131.3	194.3	300.7	1438.9
1951	890.5	133.9	43.4	118.1	38.6	0.0	38.6	9.7	40.6	97.3	452.9	206.2	2069.8
1952	385.3	107.2	50.8	78.5	23.6	0.0	44.2	29.0	20.8	79.2	330.7	281.4	1430.8
1953	234.7	52.6	77.2	85.1	0.0	28.2	298.7	91.4	128.8	248.2	251.5	560.3	2056.6
1954	367.0	59.2	128.3	148.8	61.2	0.5	23.6	24.6	17.5	80.0	219.2	417.6	1547.6
1955	305.3	252.5	2.8	89.4	59.4	0.0	3.6	105.4	55.1	330.7	180.6	305.8	1690.6
1956	266.7	142.7	31.5	40.1	0.0	52.6	121.2	150.1	59.9	233.4	493.8	296.9	1889.0
1957	214.4	483.6	0.5	1.8	139.4	0.0	82.3	4.6	8.4	188.0	479.6	1245.9	2848.4
1958	128.0	58.4	124.5	101.6	103.4	0.0	70.4	251.0	29.0	153.9	87.4	414.5	1522.0
1959	398.3	33.3	36.1	69.3	155.7	121.4	0.0	36.8	116.8	270.5	399.0	498.9	2136.1
1960	645.2	548.6	52.6	66.8	141.5	12.4	174.8	12.2	18.0	58.2	288.3	243.8	2262.4
1961	331.7	345.7	140.5	70.1	109.7	3.6	46.0	29.2	118.6	76.7	460.2	506.0	2238.0
1962	303.3	45.0	48.3	29.2	97.5	0.0	74.4	32.5	68.3	408.7	396.0	384.0	1887.2
1963	490.7	244.6	145.5	93.0	56.1*	33.5	61.2*	109.2	111.8*	155.2	638.8	594.6	2734.3*
1964	289.1	259.8	193.5	21.3	128.3	21.6	214.9	13.2	10.4	127.0	89.9	217.2	1586.2
1965	88.1	399.5	3.0	48.3	46.2	0.0	0.0	208.8	0.0	179.8	740.4	670.3	2384.6
1966	319.5	29.0	232.4	22.6	22.1	29.2	14.0	175.8	142.0	502.7	572.0	450.1	2511.3
1967	159.0	105.7	118.4	41.4	38.6	4.8	0.0	57.4	53.6	225.0	613.4	581.7	1999.0
1968	142.7*	14.5*	131.1*	108.7*	34.0*	33.3*	33.3*	42.2*	52.3*	195.6*	314.7*	218.2*	1320.5*
1969	160.8	132.6	0.0	209.0	7.9	0.0	4.6	110.7	34.0*	272.3*	118.9*	692.9*	1743.7*
1970	201.9	311.1	46.0	13.5	21.6	0.0	0.0	81.3	96.5	27.9	312.9	229.1	1341.8
1971	340.6	38.1	1.0	42.4	66.0	0.0	5.8	10.7	12.2	11.9	80.8	715.0	1324.6
1972	11.4	0.5	2.8	0.0	208.0	167.6	0.0	147.6	184.9	112.3	107.2	430.8	1373.1*
1973	33.8*	126.2*	56.9*	49.8*	85.3*	71.9*	237.0*	59.2*	257.0*	190.2*	388.9*	1216.2*	2772.4*
1974	14.5*	67.3*	46.0*	152.9*	71.6*	33.3*	33.3*	37.6*	121.7*	38.6*	198.4*	240.8*	1055.9*
1975	156.2*	180.8*	209.5*	197.6*	99.3*	33.3*	330.7*	89.9*	33.3*	215.4*	287.5*	379.7*	2213.4*
1976	234.4*	29.0*	18.0*	70.9*	33.3*	59.4*	43.4*	79.2*	95.0*	135.4*	594.6*	670.3*	2063.0*
1977	161.8*	61.7*	153.2*	196.8*	104.4*	36.1*	130.3*	82.0*	123.7*	264.4*	655.3*	507.7*	2477.5*
AVG.	267.2*	154.8*	83.5*	78.0*	71.2*	26.5*	74.5*	80.0*	74.5*	178.9*	355.3*	481.3*	1925.7*

*Estimated

TABLE C-2.6

BATTICALOA RAINFALL (MM)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1950	240.8	149.6	192.8	66.3	20.8	1.8	6.1	211.1	3.8	78.5	112.5	250.7	1334.8
1951	572.3	207.8	130.3	71.6	18.3	24.9	27.7	4.3	18.3	45.0	281.4	357.9	1759.7
1952	539.7	136.7	28.2	26.2	20.1	13.5	56.9	2.5	6.6	83.6	274.1	224.8	1412.7
1953	424.9	87.9	45.7	29.5	0.0	9.1	81.8	64.5	61.0	199.9	234.4	471.2	1709.9
1954	306.8	125.5	135.4	129.0	28.4	14.5	33.0	24.6	1.8	189.7	362.2	365.8	1716.8
1955	195.3	308.6	20.8	68.8	62.0	20.3	74.4	179.6	34.8	286.8	163.8	161.8	1577.1
1956	208.0	120.9	28.7	16.3	2.5	84.1	129.3	92.7	136.4	267.2	338.6	233.9	1658.6
1957	256.3	300.5	0.3	21.1	57.7	9.9	37.8	18.3	14.7	176.0	515.1	1180.3	2588.0
1958	226.8	103.1	71.6	41.9	36.3	0.3	23.6	129.8	18.8	148.1	304.3	435.4	1540.0
1959	110.5	34.0	9.1	192.3	27.2	44.4	0.0	14.2	25.1	256.8	342.1	386.3	1442.2
1960	432.6	661.2	113.0	104.4	29.0	45.0	199.6	23.6	91.4	84.3	344.2	172.2	2300.5
1961	381.5	378.7	0.0	0.0	118.1	12.2	50.5	43.7	86.1	42.9	591.3	702.8	2407.9
1962	585.7	90.4	75.2	113.0	97.0	0.0	7.1	103.6	60.7	226.8	415.0	261.1	2035.8
1963	515.4	191.5	224.5	67.1	12.4	9.1	19.1	62.7	13.7	197.4	836.2	748.3	2897.4
1964	411.5	99.3	178.3	23.1	136.7	0.0	223.0	42.4	0.5	103.9	114.8	313.7	1647.2
1965	69.1	226.3	16.0	45.5	60.5	0.0	49.0	116.6	17.5	160.3	587.5	663.7	2011.9
1966	237.5	170.2	134.6	28.7	7.1	56.6	13.7	91.4	113.3	563.6	380.0	409.4	2206.2
1967	165.6	176.8	106.7	81.0	4.1	24.6	46.0	68.1	95.2	135.9	544.1	672.3	2120.4
1968	132.8	0.0	189.2	21.8	31.2	2.8	41.7	59.2	46.5	50.5	151.9	135.9	863.6
1969	155.7	56.6	0.3	97.5	22.6	7.6	3.0	91.2	67.6	342.1	159.5	817.1	1820.9
1970	459.0	323.8	93.7	54.6	33.5	0.8	74.2	113.0	164.1	58.9	263.9	299.5	1939.0
1971	387.6	64.5	36.1	27.9	2.5	4.1	64.8	38.9	22.6	181.6	249.4	501.4	1581.4
1972	66.3	61.0	37.3	17.5	80.3	62.7	50.3	8.9	130.3	430.8	340.1	328.2	1613.7
1973	2.3	44.2	109.2	29.5	12.7	89.7	9.9	58.7	70.4	235.5	269.2	550.4	1481.6
1974	3.8	47.5	17.5	79.5	25.1	14.7	26.2	44.2	75.7	53.6	196.1	525.8	1109.7
1975	112.3	114.6	114.0	46.2	6.9	0.3	16.5	112.0	34.3	162.8	498.9	256.5	1475.2
1976	452.1	38.1	26.7	5.8	22.6	0.8	4.6	19.8	12.4	150.6	11.2	590.0	1334.8
1977	48.5	113.0	96.0	48.5	92.2	25.4	36.6	17.5	36.6	221.5	276.6	605.3	1617.7
AVG.	275.0	158.3	79.7	55.5	38.1	20.7	50.2	66.3	52.2	183.4	327.1	450.8	1757.3

TABLE C-2.7

TRINCOMALEE RAINFALL (MM)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1950	59.9	105.7	15.7	26.7	176.8	0.0	16.3	153.2	57.1	136.4	442.7	219.2	1409.7
1951	314.7	94.5	51.3	99.3	61.7	1.0	36.6	50.0	62.0	206.0	417.6	179.8	1574.5
1952	471.2	45.7	3.3	63.8	59.9	0.0	141.0	23.6	21.8	182.1	207.8	124.2	1344.4
1953	282.4	67.6	20.8	106.2	1.3	58.4	138.2	150.4	87.6	205.7	205.0	215.6	1539.2
1954	197.1	22.6	38.4	99.1	57.7	15.5	34.3	137.9	72.4	137.9	229.4	570.7	1612.9
1955	325.4	160.8	0.8	222.3	105.9	0.0	51.3	125.0	79.0	57.9	133.1	283.5	1545.3
1956	91.2	34.8	8.4	21.3	0.0	43.2	96.0	183.1	151.1	252.5	324.1	231.6	1437.4
1957	160.8	98.6	0.0	0.0	53.3	0.5	53.1	49.8	63.0	332.7	953.5	757.2	2522.5
1958	132.3	50.8	37.3	90.4	85.1	0.0	31.0	153.9	208.8	385.6	263.4	273.1	1711.7
1959	150.1	4.1	1.5	67.1	68.3	98.0	10.9	56.9	80.8	305.1	484.6	143.5	1470.9
1960	461.5	307.1	59.4	66.0	56.6	3.3	168.9	7.1	141.2	81.0	243.8	114.6	1710.7
1961	276.4	84.8	38.6	71.9	94.2	2.5	109.5	58.4	66.3	124.7	563.6	549.7	2040.6
1962	318.0	89.9	44.7	14.7	73.7	0.0	10.7	91.7	51.3	347.5	277.6	139.2	1459.0
1963	659.1	188.7	159.5	50.5	60.2	59.9	120.6	125.0	138.9	162.8	523.7	329.2	2578.4
1964	71.9	37.6	82.8	23.9	7.1	0.0	155.2	125.5	15.0	148.8	150.6	216.9	1035.3
1965	33.8	351.4	95.5	77.0	59.2	0.0	2.3	328.4	109.7	301.0	404.9	444.0	2407.2
1966	126.0	32.5	189.7	54.6	10.7	0.0	4.1	50.3	47.5	404.1	274.3	392.4	1586.2
1967	52.3	140.0	25.7	28.2	0.8	31.2	70.1	48.5	78.0	304.0	403.6	435.9	1618.2
1968	81.0	0.3	177.0	73.9	4.1	2.3	0.0	26.4	73.4	173.7	304.8	165.1	1082.0
1969	80.3	106.7	0.0	33.8	16.8	0.0	6.1	85.1	25.9	418.3	348.5	638.6	1760.0
1970	159.3	78.2	49.3	85.6	66.5	29.5	1.0	279.1	31.2	255.8	551.7	278.1	1865.4
1971	276.1	71.4	14.0	13.2	18.5	4.6	219.2	136.9	272.8	145.3	134.6	796.8	2103.4
1972	30.2	15.6	2.8	5.3	119.1	94.5	147.1	26.4	165.9	565.7	477.5	259.8	1909.8
1973	0.8	11.2	30.0	9.9	110.7	181.1	13.2	108.7	54.4	435.4	54.6	683.8	1693.7
1974	11.7	64.0	6.3	87.1	96.5	0.0	51.1	51.8	210.3	26.2	113.3	395.2	1113.5
1975	96.5	61.7	46.5	18.3	36.8	28.4	37.8	73.4	31.0	115.6	412.5	317.0	1275.6
1976	17.5	9.4	9.7	34.5	28.4	25.4	50.0	99.1	96.3	175.0	264.7	400.6	1210.6
1977	48.0	157.7	57.4	44.4	66.8	54.6	17.5	12.7	157.0	209.8	376.2	342.9	1545.1
AVG.	178.1	96.2	45.2	56.8	57.0	26.2	64.0	100.7	94.6	235.6	340.8	353.5	1648.7

TABLE C-2.8

EKIRIYANKUMBURA RAINFALL (MM)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1950	277.1	224.5	211.8	56.6	117.9	0.0	0.8	198.4	83.3	207.8	121.9	102.1	1602.2
1951	1034.0	179.8	130.6	89.9	69.6	0.0	2.3	5.3	92.7	261.6	412.8	387.6	2666.2
1952	436.1	53.1	69.3	166.9	65.3	0.0	137.7	0.0	18.8	126.2	373.6	181.6	1628.6
1953	265.2	136.1	42.4	192.0	12.4	21.6	170.7	24.9	11.2	251.7	209.3	509.8*	1847.3*
1954	364.0	338.3	71.1	179.8	104.1	10.9	18.0	64.8	123.7	234.4	217.4	514.4	2241.0
1955	830.6	455.4	147.6	195.3	218.7	0.0	0.0	386.3	353.3	0.0	225.0	181.1	2993.4
1956	230.1	61.6	88.1	47.8	25.9	158.7	52.6	115.6	46.2	211.8	341.1	358.6	1738.1
1957	307.1	311.9	1.5	41.4	108.2	0.0	36.8	55.1	34.3	280.9	704.1	1356.1	3237.5
1958	217.2	64.5	185.2	187.2	163.3	0.0	52.8	131.3	77.7	147.1	230.1	867.9	2324.4
1959	201.7	158.0	0.5	343.7	153.4	112.5	31.7	99.1*	117.6*	388.6*	419.6*	638.6*	2665.0*
1960	536.2	1006.6	37.8	268.2	85.1	18.0	218.4	29.5	68.6	131.1	182.4	249.7	2831.6
1961	315.5	263.4	127.3	185.2	56.9	21.8	62.2	0.0	215.6	145.0	691.1	524.8	2608.8
1962	323.6	132.6	92.2	174.0	151.9	25.1	24.1	266.7	96.8	219.7	258.8	276.6	2042.2
1963	591.1	222.8	48.8	180.8	65.0	22.6	68.6	139.4	248.7	270.0	590.5	586.2	3034.5
1964	484.6	435.1	120.1	108.5	94.2	38.4	185.9	31.5	26.9	325.4	95.0	327.2	2272.8
1965	170.4	434.3	107.4	306.1	210.1	0.0	11.9	266.2	63.2	344.9	461.8	462.0	2838.4
1966	279.7	98.6	241.3*	195.6	24.9	35.8	68.1	123.4	88.9	295.7	244.6	306.1	2002.5*
1967	282.4	352.6	140.5	44.4	41.1	76.7	0.0	31.0	195.8	252.2	648.2	361.9	2427.0
1968	208.5	12.2	193.0	63.0	73.4	94.0	5.6	131.1	96.8	180.3	336.5	302.5	1697.0
1969	448.6	217.2	62.2	249.4	25.4	0.0	50.5	215.4	100.1	243.3	266.2	846.6	2724.9
1970	380.7	320.8	63.0	181.1	244.3	0.0	78.7	117.1	112.0	216.2	272.0*	274.3*	2260.3*
1971	551.2	114.8	95.8	88.9	45.0*	0.0	0.0	191.3	190.8	243.6	143.0	528.1	2191.5*
1972	278.6	270.5	9.7	107.7	103.4	14.0	23.4	23.4	147.3	484.1	402.6	789.2	2553.8
1973	74.7	83.8	69.6	1.8	174.8	137.9	43.7	6.6	161.8	174.8*	345.4	859.3	2134.1*
1974	76.2	354.1	39.6*	168.4*	126.5*	28.7	3.0	35.6	101.3	2.3	84.1*	227.8	1247.6*
1975	163.8	91.7	168.4	13.5	27.9	31.7	78.0	117.9	198.1	71.1	246.4	134.1	1342.6
1976	233.4	26.7	60.2	175.0	42.4	81.3	196.3	0.0	74.7	133.3	318.5	220.5	1562.4
1977	10.9	109.7	65.8	71.4	92.5	202.9	218.7	69.6*	172.0*	240.5*	264.9*	274.1*	1793.0*
AVG.	341.9	233.2	96.1*	145.8*	97.3*	40.5	65.7	102.7*	118.5*	217.3*	325.3*	451.7*	2236.0*

*Estimated

TABLE C-2.9

HORABORAWEWA RAINFALL (MM)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1950	234.9	110.5	92.7	37.6	90.7	0.0	7.6	26.7	38.1	141.0	207.8	253.5	1241.0
1951	1051.1	109.2	66.5	75.4	30.5	0.0	32.0	129.5	108.2	193.5	514.4	581.4	2891.8
1952	666.0	87.6	34.0	268.5	130.8	0.0	76.7	19.1	164.1	126.2	321.1	246.4	2140.5
1953	423.4	241.3	124.5	191.0	0.0	33.5	57.1	47.0	63.2	200.7	264.2	544.6	2190.5
1954	346.7	374.6	177.8	147.3	50.8	0.0	10.2	41.1	0.0	342.6	262.9	603.3	2357.4
1955	870.7	344.9	209.3	176.3	12.7	0.0	0.0	60.2	110.2	69.8	172.5	284.0	2313.7
1956	288.5	81.0	106.9	121.9	0.0	82.8	0.0	19.3	0.0	190.2	651.5	456.4	1998.7
1957	376.2	281.2	16.5	33.5	33.0	6.3	32.8	8.6	88.6	301.8	636.5	1304.5	3119.6
1958	415.5	152.4	210.6	199.9	43.2	5.8	8.4	45.2	45.5	55.6	345.2	503.4	2030.7
1959	244.9	84.1	55.6	205.5	220.7	24.9	3.3	71.1	97.0	414.0	447.3	683.3	2551.7
1960	569.0	843.0	22.6	261.9	143.8	0.0	151.4	25.4	13.7	247.4	362.5	173.5	2814.1
1961	515.9	195.1	144.3	343.2	54.6	6.3	14.2	5.3	52.8	197.9	603.8	560.8	2694.2
1962	394.0	169.7	177.8	244.3	174.5	4.3	10.9	339.1	46.5	163.3	275.3	338.3	2338.1
1963	455.4	319.8	113.5	158.7	61.2	0.0	42.4	2.3	184.4	238.5	494.8	641.3	2712.5
1964	514.4	419.4	159.0	70.4	79.2	3.8	112.8	104.4	37.3	110.2	185.2	411.5	2207.5
1965	208.5	513.8	103.4	231.4	65.0	10.2	1.5	229.9	0.0	305.8	454.9	412.2	2536.7
1966	358.1	96.5	255.3	81.0	44.2	12.2	3.3	84.1	111.5	323.6	356.9	307.6	2034.3
1967	275.6	299.2	130.0	54.6	11.2	49.8	2.8	4.1	54.6	251.5	749.0	379.0	2261.4
1968	287.5	18.0	290.3	88.1	8.6	6.1	10.9	0.0	26.7	222.5	200.2	342.6	1501.8
1969	362.7	189.2	35.8	253.2	43.9	0.0	4.6	182.1	120.6	365.5	119.4	704.6	2381.8
1970	354.6	532.1	105.2	143.0	85.1	4.3	2.5	21.1	64.3	40.1	288.3	290.8	1931.4
1971	357.6	151.6*	135.9*	130.3*	31.0*	18.3*	18.3*	89.9*	89.7*	260.0*	175.8*	500.9*	1959.9*
1972	290.3*	283.5*	72.6	146.0*	56.9*	16.5	38.1	26.9*	73.4*	463.8*	427.7*	507.5	2403.3*
1973	134.1	448.8	75.2	69.1	38.6	58.4	59.9	10.7	95.2	183.4	530.4	621.5	2325.4
1974	3.0	139.4	37.8	176.5	109.5	6.1	38.6	26.9	46.2	52.3	85.9	522.2	1244.6
1975	225.0	161.0	135.1	104.6	130.0	11.9	147.6	49.5	116.1	67.1	194.8	317.0	1659.9
1976	326.9	53.3	57.7	117.1	39.9	54.6	56.4	75.4	30.5	78.5	310.4	224.5	1425.2
1977	60.5	66.3	181.6	67.3	84.1	4.1	107.9	29.7	173.0	254.3	280.7	290.6	1599.9
AVG.	379.0*	241.7*	118.8*	150.0*	66.9*	15.0*	37.6*	63.4*	73.3*	209.4*	354.2*	464.5*	2173.8*

*Estimated

TABLE C-2.10

SUMMARY OF CHARACTERISTICS OF
MADURU OYA STREAMFLOW GAUGING STATIONS

Location	Drainage Area (km^2)[1]	Stage Observations Begin	Stage Observations End	Stage Observations Missing	Maximum Est'd Flow (m^3/s)[2]	Flow Measurements Begin	Flow Measurements End	Flow Measurements Max Stage (ft)	Flow Measurements Max Flow (m^3/s)
Maduru Oya at Damsite	452	Feb 1951	Sept 1957	2 mo	416	Nov 1951	Mar 1957	9.50	156
Maduru Oya below Damsite	459	Jan 1978	present	-	27	Oct 1978	present	N.A.[3]	N.A.[3]
Maduru Oya at Welikanda	966	Feb 1946	present	15 mo	1800	Nov 1953	June 1960	11.0	202
						Dec 1978	present	8.30	77

Notes: 1 - Measured from 1 in. = 1 mi. maps

2 - Estimated by extending rating curve beyond measured range and using the observed stage

3 - Not available

Streamflow data are needed for three main purposes for the Maduru Oya project studies

1 - estimation of monthly reservoir inflows over the 1950 to 1977 simulation period, for use in water balance studies

2 - estimation of reservoir inflow hydrographs for use in spillway design calculations

3 - assessment of the probable impact of the reservoir on floods in the Maduru Oya floodplain.

Item (2) above was the responsibility of the Central Engineering Consultancy Bureau (CECB), as that agency was responsible for all aspects of dam design. The hydrological studies reported here concentrate on items (1) and (3).

Because of the short period of record at the damsite, some means of estimating the monthly flows over the balance of the simulation period at the damsite must be found. NEDECO(1), in their 1978 studies, performed regression analyses which showed that a very good correlation (R>.90) exists between monthly flows at the damsite and at Welikanda. This is to be expected, since the two stations are only some 30 km apart on the same river. NEDECO estimated the missing monthly flows at the damsite using the derived regression equation and observed Welikanda flows.

The flows for Welikanda are summarized in Table C-2.11, while those observed and estimated for the damsite are found in Table C-2.12.

The NEDECO studies established statistically valid relationships on which to base estimates of missing data. However, at the time of report preparation in 1978, concern was

TABLE C-2.11

MADURU OYA AT WELIKANDA CATCHMENT
AREA: 966 KM^2 FLOW IN MILLION M^3

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tota
1950	106	38	99	12	16	1	0	0	0	14	12	28	326
51	554	2	17	15	6	10	6	5	5	5	89	94	808
52	265	62	129	16	16	7	6	0	0	7	18	38	564
53	145	25	69	83	10	0	16	0	0	44	30	107	529
54	173	111	22	18	12	1	0	1	0	6	6	159	509
1955	255	157	15	33	23	2	1	11	18	12	9	30	566
56	62	12	4	1	0	1	0	0	0	14	63	112	269
57	72	179	14	1	4	1	0	0	0	0	131	1016	1418
58	154	60	16	27	16	1	0	1	0	2	17	86	380
59	48	12	2	12	6	1	0	0	0	10	44	136	271
1960	168	456	44	41	33	2	1	0	0	15	63	28	946
61	165	94	21	22	36	6	1	0	0	2	289	234	870
62	70	33	30	25	21	16	11	10	7	31	81	116	451
63	184	99	33	31	59	10	7	2	0	6	190	210	831
64	164	109	36	31	25	18	14	9	6	54	12	68	546
1965	39	48	25	42	25	7	5	20	6	30	118	75	435
66	111	64	59	27	23	6	1	22	11	78	157	70	629
67	105	75	52	20	11	5	1	1	7	23	208	237	745
68	137	26	37	21	11	7	1	0	11	17	58	74	400
69	115	80	16	37	15	4	1	9	5	48	7	386	723
1970	233	164	42	1	49	15	0	0	17	28	30	141	720
71	142	37	39	42	35	22	25	25	27	48	25	102	569
72	5	10	7	11	15	2	1	1	1	106	280	529	968
73	64	31	9	4	5	14	11	4	11	59	145	407	764
74	143	35	18	17	75	7	4	2	26	11	6	138	482
1975	123	51	121	21	6	1	6	31	1	1	35	174	571
76	582	48	6	16	9	1	1	2	1	1	46	118	831
77	37	6	7	2	4	4	4	1	2	23	69	228	387
MEAN	158	76	35	22	20	6	4	6	6	25	80	184	622
STDEV	132	89	34	17	18	6	6	9	8	26	81	202	248
CVAR	0.84	1.18	0.96	0.76	0.89	0.98	1.35	1.61	1.38	1.05	1.01	1.10	0.40

Notes: STDEV - Standard Deviation
CVAR - Coefficient of Variation (STDEV/MEAN)

Source: NEDECO[1]

TABLE C-2.12

MADURU OYA AT DAMSITE CATCHMENT
AREA: 452 KM^2 FLOW IN MILLION M^3

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1950	66	24	61	7	10	1	0	0	0	9	7	17	202
51	343	1	21	16	4	12	4	2	2	0	57	59	521
52	120	49	15	6	2	0	1	0	0	1	22	10	226
53	72	12	27	49	7	1	12	4	7	26	22	59	298
54	99	104	25	14	11	2	0	2	0	2	6	85	350
1955	134	76	18	17	15	2	1	11	12	6	6	12	310
56	3[illegible]	9	6	14	0	1	0	1	0	9	25	53	154
57	59	107	14	2	4	0	0	0	0	0	81	630	897
58	95	37	10	17	10	1	0	1	0	1	11	53	236
59	30	7	1	7	4	1	0	0	0	6	27	84	167
1960	101	283	27	25	20	1	1	0	0	9	39	17	523
61	102	58	13	14	22	4	1	0	0	1	179	145	539
62	43	20	19	16	13	10	7	6	4	19	50	72	279
63	114	61	20	19	37	6	4	1	0	4	110	130	514
64	102	68	22	19	16	11	9	6	4	33	7	42	339
1965	24	27	16	26	16	4	3	12	4	19	73	47	271
66	69	40	37	17	14	4	1	14	7	48	97	43	391
67	65	47	32	12	7	3	1	1	4	14	129	147	462
68	85	16	23	13	7	4	1	0	7	11	36	46	249
69	71	50	10	23	9	2	1	6	3	30	4	239	448
1970	144	102	26	1	30	9	0	0	11	17	19	87	446
71	88	23	24	26	22	14	16	16	17	30	16	63	355
72	3	6	4	7	9	1	1	1	1	66	174	328	601
73	40	19	6	2	3	9	7	2	7	37	90	252	474
74	89	22	11	11	47	4	2	1	16	7	4	86	300
1975	76	32	75	13	4	1	4	19	1	1	22	108	356
76	361	30	4	10	6	1	1	1	1	1	29	73	518
77	23	4	4	1	2	2	2	1	1	14	43	141	238
MEAN	95	48	20	14	13	4	3	4	4	15	50	112	381
STDV	80	55	16	10	11	4	4	5	5	16	50	126	161
CVAR	0.84	1.15	0.78	0.69	0.88	1.01	1.40	1.30	1.28	1.06	1.01	1.13	0.42

Notes: STDV - Standard Deviation
CVAR - Coefficient of Variation (STDV/MEAN)

Source: NEDECO[1]

expressed regarding the reliability of the rating curve at Welikanda. Table C-2.10 indicates that flow measurements were discontinued in 1960; all estimates of flows since that time have been based on the rating curve established from these flow measurements. In addition, the table shows that the largest flow measured at Welikanda was 202 m^3/s (see also Figure C-2), which is substantially lower than the maximum flow which is estimated to have occurred during the period of stage observations (1,800 m^3/s). This deficiency would be difficult to remedy--there is no bridge from which measurements could be taken during flood periods, and the section is about 2 km wide at this point (see Figure C-3), making construction of an instrument cableway a difficult proposition.

Flow measurements were recommenced at Welikanda in late 1978 by the Irrigation Department to check for shifts in the riverbed or displacement of the staff gauge from its datum. The newly measured flows, which are indicated in Figure C-2, fall close to the rating curve which was established in the mid-1950's. It can be inferred that any movement in the rating curve, either due to shifting of the section or movement of the staff gauge, is no more than .15 m (0.5 ft). Since it is not known when the shift occurred and since the effect on estimated flows is minor (about 10 percent), no adjustments to the flows estimated since 1960 are proposed.

The validity of the extrapolation of the rating curve beyond the range of measured flows is difficult to assess. When flow begins in the flood plain, the shrubs and trees growing there substantially alter the hydraulic roughness of the section, and make measurement of all parts of the flow impossible from a boat. Hydraulic calculations were performed, however, to assess the characteristics of the river both within and outside the range of measured flows. These

calculations, though of limited value due to the lack of calibration data, do indicate that the extrapolation is reasonable. For the study of relatively minor floods in the floodplain, where flows are reconverted to stage and the consequences of an underestimate of the flood peak are not serious, the extrapolated rating curve should be adequate. Derivation of floods for spillway design at the dam may need a more conservative approach however.

3 - IRRIGATION WATER REQUIREMENTS

The calculation of monthly irrigation water requirements for the 1950 to 1977 simulation period adopted by NEDECO is based on the following general equation.

$$\text{Water requirements (mm)} = \frac{ET_c + LP + P - ER}{e} \quad \text{----------(C1)}$$

Where - ET_c = Crop evapotranspiration (mm)
LP = Land preparation requirement (mm)
P = Deep percolation losses (mm)
ER = Effective rainfall (mm)
e = Overall efficiency factor.

This equation is solved for four different land class/crop calendar combinations - one "upland", two "lowland" and one "floodplain". Effective rainfall is calculated using appropriate formulae for each month of the simulation period. Water requirements in mm are converted to $10^6 m^3$/month by multiplication by the appropriate cropped areas.

Water requirements are computed for flooded paddy for the "lowland" and "floodplain" classes and for an index upland rotation of groundnuts (Maha) and cotton (Yala). The latter Yala crop was assumed in order to give conservatively high upland water requirements. Since it can be assumed that some farmers will broadcast their paddy, water requirements were calculated for 100 percent broadcasting to give paddy water requirements on the conservative side.

3.1 - Field Water Requirements

The development of cropping patterns and of corresponding field water requirements is presented in Annex E. The following paragraphs present this information in summary form.

3.1.1 - Crop Evapotranspiration

Crop evapotranspiration is a function of the stage of growth of the given crop, and can be computed by using "crop coefficients" which are developed for each crop at various growth stages, combined with computed potential evapotranspiration for a reference crop. Potential evapotranspiration is computed here using the Penman equation to estimate average values for each of the 12 months. Crop coefficients based on water-use studies performed in Sri Lanka and on published data from elsewhere are used to reflect the proposed crop calendar (Figure C-4). The resulting monthly crop evapotranspiration values for paddy and upland crops are shown in Table C-3.1 and C-3.2 respectively.

3.1.2 - Land Preparation

Land preparation requirements are considered separately, and are based on water use studies carried out in Sri Lanka.[2] Requirements of 180 mm for paddy and 75 mm for upland crops are assumed.

TABLE C-3.1

CROP WATER REQUIREMENTS FOR THE LOWLANDS AND FLOOD PLAINS (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
				Lowlands; Paddy (135 d)/Paddy (105 d)								
ET paddy - Maha	149	109	23	-	-	-	-	-	-	81	135	127
ET paddy - Yala	-	-	-	84	211	228	165	31	-	-	-	-
Land Preparation	-	-	60	120	-	-	-	-	60	120	-	-
Percolation Loss 1R	90	75	30	75	90	90	75	15	15	75	90	90
2R	180	150	60	150	180	180	150	30	30	150	180	180
Field Water Requirements 1R	239	184	113	279	301	318	240	46	75	276	225	217
2R	329	259	143	354	391	408	315	61	90	351	315	307
				Flood Plains; Paddy (105 d)/Paddy (105 d)								
ET paddy - Meda	-	72	182	162	66	-	-	-	-	-	-	-
ET paddy - Yala	-	-	-	-	-	89	217	222	94	-	-	-
Land Preparation	60	120	-	-	40	120	20	-	-	-	-	-
Percolation Loss 1R	15	75	90	85	25	65	90	90	45	-	-	-
2R	30	150	180	170	50	130	180	180	90	-	-	-
Field Water Requirements 1R	75	267	272	247	131	274	327	312	139	-	-	-
2R	90	342	362	332	156	339	417	402	184	-	-	-

TABLE C-3.2

CROP WATER REQUIREMENTS
FOR THE UPLANDS (mm)

	Cropping Pattern for Uplands: Groundnuts (110 d)/Cotton (150 d)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET Groundnuts	107	34	-	-	-	-	-	-	-	35	61	102
ET Cotton	-	-	34	116	110	207	182	75	-	-	-	-
Land Preparation	-	-	75	-	-	-	-	-	-	75	-	-
Gross Field Water Requirements	107	34	109	116	110	207	182	75	-	110	61	102

Note: Cotton was used as an index Yala crop to arrive at conservatively high crop water requirements. The index Yala crop used in the economic analysis is Soybeans.

3.1.3 - Deep Percolation Losses

In Equation (C1) above, deep percolation losses in flooded paddy fields* are considered to be unavoidable and are therefore explicitly accounted for in the equation, rather than including them in the efficiency factor. The latter should represent losses which are difficult to model explicitly, and should generally fall into the category of management or "avoidable" losses. Research and practical experience in Sri Lanka(2;3,4,5) have indicated that deep percolation losses under flooded paddy cultivation in soils in Sri Lanka can range between a low of under 2 mm/d** in the least porous of soils, up to 10 mm/d or more in the well drained upland soils.

In the land classification system described in Annex B, the least porous paddy soils with the poorest drainage are generally included in the "1R" land class group, while the more porous paddy soils are found in the "2R" land class group. Exceptions to this are found (for example, in the "$2R_t$" soils which are "1R" soils, downgraded due to their slope falling into the 2 to 4 percent range), but they are relatively unimportant since the areas involved are not large.

Infiltration tests performed in 1979 in the project area on representative soil series are presented in Table C-3.3. While infiltration test results are not directly applicable

---

* For upland crops, percolation losses are incorporated into the efficiency factor, since the anticipated irrigation method will involve standing water in the field over a relatively minor proportion of the time. The direct estimation of percolation losses under these conditions is not practical.

**An average of 1.4 mm/day was computed by water balance methods during the Kaudulla Scheme experiments in Yala 1978.

TABLE C-3.3

INFILTRATION TEST RESULTS

Great Soil Group[1]	Drainage Type	Soil Series	Basic Land Class	Infiltration Rate[2] (cm/h) Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Mean	Month Performed	Remark
RBE	Mod well drained	Wilayaya	1U	10.0	10.7	10.3	10.4	17.4	11.8	Jun/79	
	Mod well drained	Wilayaya	1U	3.4	1.3	4.4	2.3	-	3.0	Apr/79	
	Mod well drained	Wilayaya	1U	4.5	2.5	8.0	5.0	6.0	5.2		
	Mod well drained	Wilayaya	1U	12.0	15.0	11.0	11.0	11.0	12.0		
	Mod well drained	Wilayaya	1U	7.0	3.0	18.0	3.0	3.0	6.8		
RBE	Well drained	Manampitiya	1U	10.1	11.2	8.0	9.9	11.3	10.1	Jun/79	Not typical
	Well drained	Manampitiya	1U	2.0	3.0	10.0	6.0	7.0	5.6		
RBE	Imp drained	Alawakumbura	1R	2 0	2.4	2.8	2.3	-	2.4	Apr/79	
NCB	Well drained	Maduru	6U	6.6	22.4	15.4	9.8	20.1	14.9	Jun/79	
	Well drained	Maduru	6U	14.1	19.9	19.9	20.1	-	18.5	Jun/79	
	Mod well drained	Maduru	6U	23.0	22.0	19.0	16.0	13.0	18.6		
NCB	Mod well drained	Welikanda	2Us	3.0	1.0	3.2	2.1	19.2	5.7	Jun/79	
	Mod well drained	Welikanda	2Us	2.7	1.4	-	2.5	2.3	2.2	Jun/79	
	Mod well drained	Welikanda	2Us	1.3	2.3	1.4	0.6	-	1.4	May/79	
	Mod well drained	Welikanda	2Us	5.0	-	1.3	5.5	-	3.9	Jun/79	
	Mod well drained	Welikanda	2Us	1.2	0.5	1.5	2.8	1.8	1.6		
	Mod well drained	Welikanda	2Us	1.5	1.1	0.9	2.0	1.1	1.3		
	Mod well drained	Welikanda	2Us	14.0	18.0	15.0	25.0	7.0	15.8		
	Mod well drained	Welikanda	2Us	10.0	8.0	5.0	20.0	-	10.8		
NCB	Im drained	Galwewa	6Rs	4.5	11.1	11.3	10.1	-	9.3	Jan/79	
	Im drained	Galwewa	6Rs	18.1	10.2	11.3	11.1	-	12.7	Jun/79	
	Im drained	Galwewa	6Rs	5.0	2.5	2.0	2.0	-	2.9	Apr/79	
	Im drained	Galwewa	6Rs	12.0	10.0	11.0	-	-	11.0		
	Im drained	Boattewewa	2Rs	3.5	3.2	5.7	4.0	3.5	4.0	Jun/79	
NCB	Im drained	Boattewewa	2Rs	1.9	2.1	2.2	5.1	-	2.8	May/79	
	Im drained	Boattewewa	2Rs	2.0	3.0	1.5	3.0	2.0	2.3		
OAL	Im drained	Ulpothawewa	2Rs	3.8	2.8	-	2.5	2.6	2.9	Jun/79	Paddy field
	Im drained	Ulpothawewa	2Rs	2.1	2.3	2.1	3.0	-	2.4	Jun/79	
	Im drained	Ulpothawewa	2Rs	10.0	4.0	3.0	2.0	12.0	6.2		
OAL	Poorly drained	Moogamana Ela	1R	2.1	2.1	0.7	1.6	2.0	1.7	Jun/79	Paddy field
SS	Im drained	Pochchakadu	2Rs	1.6	0.9	1.4	1.3	-	1.3	Apr/79	

Notes: [1]Great Soil Group - RBE = Reddish Brown Earth
NCB = Noncalcic Brown Soils
OAL = Old Alluvial Soils
SS = Solodized Solonetz Soils

[2]Infiltration rate in fourth hour of test.

Source: Field measurements made by Irrigation Department (LUD) crews.

to estimate deep percolation rates, these tests do indicate that the infiltration rates in the Class "2R" soils can be expected to be about twice as high as in the Class "1R" soils. This is consistent with the physical characteristics of the soils, and with subjective field observations made by Irrigation Department staff in the Pimburettewa Tank Scheme.

Since a deep percolation rate of about 3 mm/d has been found[5] to be suitable for soils elsewhere in the country which are comparable to the project's Class "1R" soils, the following percolation rates* are used in the water requirement calculations

- Class "1R" soils - 3 mm/d = 90 mm/month
- Class "2R" soils - 6 mm/d = 180 mm/month.

3.2 - Effective Rainfall

Monthly rainfall for the project area is calculated for the 1950 to 1977 simulation period using data from three reliable stations in the area--Polonnaruwa, Welikanda and Vakaneri (see Section 2.1). The Thiessen polygon method allows the calculation of weighting factors for use with the data from the three stations to estimate weighted monthly rainfall over the irrigation area. The following Thiessen weighting factors apply

- Polonnaruwa	- 0.14
- Welikanda	- 0.73
- Vakaneri	- 0.13
Total	1.00

*These assumptions are checked further in Section 3.4.

Table C-3.4 presents the monthly rainfall calculated over the simulation period using these weighting factors.

The amount of rainfall that is effective in reducing irrigation demands is called the "effective rainfall", and is rarely as great as the total monthly rainfall. Reduction in rainfall effectiveness can result from uneven distribution of rainfall and wasteful on-farm water management. Uneven distribution can lead to nonconsumptive evaporation losses in the case of light rainfall, or runoff of water which exceeds field storage capacity in the case of heavy rainfall.

Wasteful on-farm water management can lead to low effective rainfall if fields are always at or near capacity due to excessive irrigation water applications, leading to rapid runoff and loss of rainwater.

Two approaches to the estimation of effective rainfall are used here--one for flooded paddy and another for upland crops. The first approach uses an equation advocated by the Land Use Division (LUD) of the Irrigation Department.(5)

$$ER(mm) = 0.67\ (MR - 25) \qquad \text{(C2)}$$

Where MR = total monthly rainfall (mm), and
maximum ER = 225 mm.

This equation recognizes that the first inch (25 mm) of rainfall is unlikely to be effective in reducing demands, and recognizes that an upper limit to effective rainfall exists which is somewhat lower than the peak evapotranspiration level. The latter reflects the need to keep the irrigation system "primed" to a minimum level, especially during peak demand periods. The relationship is in a form which closely

TABLE C-3.4

WEIGHTED RAINFALL FOR SYSTEM B

YRS = 28	WELIKANDA	TFAC = 0.730
YRS = 28	POLONNARUWA	TFAC = 0.140
YRS = 28	VAKANERI	TFAC = 0.130

Rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1950	202.6	82.0	198.9	18.3	65.2	0.0	0.1	113.0	146.2	148.3	168.7	213.4	1356.7
1951	707.2	114.8	49.2	147.0	84.6	0.0	12.8	38.9	68.3	114.4	453.6	255.3	2046.1
1952	498.1	74.4	39.6	96.7	62.8	0.0	59.9	3.8	20.8	118.3	264.8	249.3	1488.5
1953	278.3	31.8	20.3	82.8	0.0	51.2	183.5	126.5	115.7	261.7	318.8	502.1	1972.7
1954	451.8	114.6	125.1	103.2	45.2	0.1	30.8	43.6	2.3	206.9	161.1	432.6	1717.3
1955	325.8	180.9	10.4	169.5	29.7	0.0	0.5	79.8	187.1	119.4	97.9	245.4	1446.4
1956	230.2	71.8	12.5	19.9	0.1	107.1	58.2	88.6	40.8	246.6	549.7	320.3	1747.8
1957	154.9	400.7	0.1	10.2	110.3	0.3	42.9	8.5	30.6	175.3	570.5	1402.1	2906.4
1958	171.7	83.8	100.6	134.5	163.5	0.0	96.3	126.0	37.2	128.9	123.0	430.9	1596.4
1959	325.1	6.5	6.0	45.5	50.3	18.8	3.7	66.1	65.0	247.9	304.9	300.2	1440.0
1960	394.5	597.0	37.3	138.8	82.2	3.5	171.0	4.9	44.7	92.0	415.1	166.9	2147.9
1961	399.9	320.0	119.5	25.3	91.4	1.4	91.3	3.8	96.4	139.6	427.6	549.5	2265.7
1962	143.0	20.6	57.1	33.9	73.8	0.0	104.9	13.6	89.7	314.3	272.7	340.6	1464.2
1963	452.2	390.1	112.7	117.0	12.8	4.6	14.6	27.0	139.9	246.0	492.3	556.1	2565.3
1964	207.7	214.9	139.7	14.8	114.5	2.8	163.0	111.1	11.6	181.7	62.9	131.7	1356.4
1965	97.4	434.1	10.4	103.3	33.8	3.0	0.0	133.7	0.1	110.9	500.4	367.8	1794.9
1966	243.8	18.3	141.8	55.8	36.4	28.1	27.4	261.2	104.7	516.6	474.5	248.7	2157.3
1967	88.6	186.4	59.5	78.5	33.1	23.8	23.2	30.9	36.7	246.6	470.1	498.5	1775.9
1968	130.6	1.9	118.8	27.9	4.6	4.3	4.3	7.7	24.3	71.1	281.0	287.7	964.2
1969	88.4	94.7	8.4	284.7	28.8	0.0	28.2	120.6	63.4	305.5	124.8	750.3	1897.8
1970	159.3	252.9	46.1	91.2	116.3	43.0	0.0	52.7	80.9	99.7	306.6	264.1	1512.8
1971	277.4	35.1	48.2	120.3	37.5	0.0	76.5	75.5	42.5	144.5	148.4	528.8	1534.7
1972	32.1	16.2	29.8	34.7	111.2	61.7	25.2	19.3	155.6	369.9	239.5	321.7	1416.9
1973	15.4	71.0	99.5	94.9	111.1	107.0	206.9	50.5	224.5	178.4	201.0	1209.6	2569.8
1974	1.9	54.9	33.4	140.8	61.3	27.5	27.5	31.4	105.4	26.2	186.6	229.3	926.2
1975	144.1	168.9	197.8	184.1	85.6	27.5	289.3	77.3	27.5	203.7	276.1	368.9	2050.8
1976	222.9	16.3	5.3	58.3	27.5	50.5	36.4	68.1	81.8	123.2	584.8	661.0	1936.1
1977	149.8	49.3	141.1	185.1	90.1	30.0	113.0	70.6	107.3	253.0	645.9	497.6	2332.8
AVG	235.5	146.6	70.3	93.5	63.0	21.3	67.6	66.2	76.8	192.6	325.8	440.4	1799.6

agrees with that derived in recent field and computer studies in Thailand.(6,7)

In the absence of significant field data on effective rainfall for irrigated upland crops in Sri Lanka, the relationship presented in FAO Paper 25 for upland crops(8) is used. This relationship also has a logical form, and recognizes the influence of monthly crop water requirements on rainfall effectiveness.

Tables C-3.5 and C-3.6 present computed monthly effective rainfall values for the paddy areas [Equation (C2)] and upland areas (FAO Paper 25), respectively. These effective rainfall figures are used in the solution of Equation (C1), as explained in Section 3.3.

3.3 - System Water Requirements

Equation (C1) is solved using the data developed in Sections 3.1 and 3.2 for each month of the 1950 to 1977 simulation period, and for each of the four land class groups which have different crop water requirements. The assumptions used in the calculations are summarized in Table C-3.7, and sample calculations for 1950 are presented in Table C-3.8. Total "full development"* monthly water requirements for the simulation period are summarized in Table C-3.9.

*The water requirements calculated here are for the "full development" case. Section 4.1 shows that demands representing about 92 percent of this level of development can actually be satisfied by the headworks now committed for the project.

TABLE C-3.5

EFFECTIVE RAINFALL FOR LOWLAND PADDY (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1950	119	38	117	0	27	0	0	59	81	82	96	126
51	225	60	16	82	40	0	0	9	29	60	225	154
52	225	33	10	48	25	0	23	0	0	62	161	150
53	170	5	0	39	0	17	107	68	61	159	197	225
54	225	60	67	52	13	0	4	13	0	122	91	225
55	202	105	0	97	3	0	0	37	109	63	49	147
56	137	31	0	0	0	55	22	43	11	150	225	198
57	87	225	0	0	57	0	12	0	4	101	225	225
58	98	40	51	74	93	0	48	68	8	70	66	225
59	201	0	0	14	17	0	0	27	27	149	188	184
1960	225	225	8	76	38	0	98	0	13	45	225	95
61	225	198	64	0	44	0	44	0	48	77	225	225
62	79	0	21	6	33	0	54	0	44	194	166	212
63	225	225	59	62	0	0	0	1	77	148	225	225
64	123	127	77	0	60	0	92	58	0	105	25	72
65	48	225	0	52	6	0	0	73	0	58	225	225
66	147	0	78	21	7	2	1	158	54	225	225	150
67	43	108	23	36	5	0	0	4	8	149	225	225
68	71	0	63	2	0	0	0	0	0	31	172	176
69	42	47	0	174	3	0	2	64	25	188	67	225
1970	90	153	14	44	61	12	0	19	38	50	189	160
71	169	7	16	64	9	0	35	34	12	80	82	225
72	4	0	3	7	58	25	0	0	88	225	144	199
73	0	31	50	47	58	55	122	17	134	103	118	225
74	0	20	5	78	24	2	2	4	54	1	109	137
75	80	96	116	107	41	2	177	35	2	120	168	225
76	133	0	0	22	2	17	7	29	38	66	225	225
77	84	16	78	107	44	3	59	31	55	153	225	225
AVG	124	74	33	47	27	8	32	30	36	108	163	190

Note: Calculated using formula ER (mm) = 0.67 (MR - 25) where MR = total monthly rainfall. Maximum effective rainfall = 225 (mm).

TABLE C-3.6

EFFECTIVE RAINFALL
FOR UPLAND CROPS (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1950	107	34	109	12	47	0	0	71	93	97	61	102
51	107	34	35	98	58	0	11	28	48	78	61	102
52	107	34	30	68	45	0	50	3	15	80	61	102
53	107	22	15	59	0	51	135	75	77	110	61	102
54	107	34	84	72	33	0	25	30	1	110	61	102
55	107	34	8	110	22	0	0	52	100	81	59	102
56	107	34	9	17	0	102	48	58	31	110	61	102
57	97	34	0	8	75	0	36	7	22	110	61	102
58	107	34	69	91	103	0	76	75	28	86	61	102
59	107	04	4	32	14	19	3	45	46	110	61	102
1960	107	34	28	93	58	3	127	4	32	63	61	102
61	107	34	79	18	64	1	73	3	64	92	61	102
62	91	13	42	26	52	0	83	9	62	110	61	102
63	107	34	77	81	9	5	11	20	90	110	61	102
64	107	34	92	12	79	3	123	69	9	110	42	84
65	65	34	7	72	24	3	0	75	0	75	61	102
66	107	13	94	40	27	28	23	75	71	110	61	102
67	64	34	42	56	24	24	19	21	27	110	61	102
68	86	1	80	21	3	4	3	6	17	50	61	102
69	61	34	5	116	21	0	23	72	44	110	61	102
1970	107	34	32	6[illegible]	78	43	0	36	56	69	61	102
71	107	22	35	82	28	0	63	50	31	93	61	102
72	23	10	22	26	75	62	21	14	98	110	61	102
73	12	34	69	67	75	104	148	36	100	110	61	102
74	01	30	17	96	44	28	23	21	71	19	61	102
75	92	34	109	114	60	28	177	52	19	110	61	102
76	107	10	02	41	20	51	30	45	55	82	61	102
77	95	32	94	114	63	30	88	46	72	110	61	102
AVG	90	27	46	61	43	21	51	39	49	93	60	101

Note: Calculated using procedure outlined in FAO Paper 25 on Effective Rainfall[8]

TABLE C-3.7

SUMMARY OF KEY ASSUMPTIONS USED IN COMPUTING WATER REQUIREMENTS

	Land Class Grouping			
	Lowlands		Flood Plain	Uplands
	1R	2R	1R	1U + 2U
Areas (ha)	14 400	20 350	2 430	2 580
Land preparation (mm)	180	180	180	75
Percolation rate (mm/d)	3	6	3	-
Calculation of effective rainfall	LUD Formula*	LUD Formula*	LUD Formula*	FAO Paper 25 (8)
Farm/distribution efficiency	0.70	0.70	0.70	0.50
Main canal efficiency	0.90	0.90	0.90	0.90
Overall efficiency	0.63	0.63	0.63	0.45

Note: *LUD Formula:[5] ER (mm) = 0.67 (MR-25) Max ER = 225 mm*

TABLE C-3.8

SAMPLE CALCULATION OF 1950 IRRIGATION WATER REQUIREMENTS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1R - Lowlands - 14 400 ha													
FWR (mm)[1]	239	184	113	279	301	318	240	46	75	276	225	217	
ER (mm)[2]	119	38	117	0	27	0	0	59	81	82	96	126	
Net FWR (mm)	120	146	-	279	274	318	240	-	-	194	129	91	
Project WR (mm)[3]	190	232	-	443	435	505	381	-	-	308	205	144	
Project WR (10^6 m^3)[4]	27	33	-	64	63	73	55	-	-	44	30	21	328
2R - Lowlands - 20 350 ha													
FWR (mm)[1]	329	259	143	354	391	408	315	61	90	351	315	307	
ER (mm)[2]	119	38	117	0	27	0	0	59	81	82	96	126	
Net FWR (mm)	210	221	26	354	364	408	315	2	9	269	219	181	
Project WR (mm)[3]	333	351	41	562	578	648	500	3	14	427	348	287	
Project WR (10^6 m^3)[4]	68	72	8	114	118	132	102	1	3	87	70	58	647
1R - Floodplains - 2430 ha													
FWR (mm)[1]	75	267	272	247	131	274	327	312	139	-	-	-	
ER (mm)[2]	119	38	117	0	27	0	0	59	81	82	96	126	
Net FWR (mm)	-	229	155	247	104	274	327	253	58	-	-	-	
Project WR (mm)[3]	-	363	246	392	165	435	519	402	92	-	-	-	
Project WR (10^6 m^3)[4]	-	9	6	10	4	11	13	10	2	-	-	-	59
Uplands - 2580 ha													
FWR (mm)[1]	107	34	109	116	110	207	182	75	-	110	61	102	
ER (mm)[2]	107	34	109	12	47	0	0	71	93	97	61	102	
Net FWR (mm)	-	-	-	104	63	207	182	4	-	13	-	-	
Project WR (mm)[3]	-	-	-	231	140	460	404	9	-	29	-	-	
Project WR (10^6 m^3)[4]	-	-	-	6	3	11	10	-	-	1	-	-	70
Total project WR (10^6 m^3)[5]	95	114	14	194	188	227	180	11	5	132	100	79	1339

Notes:
[1] Source - Tables C-3.4 and C-3.5
[2] Source - Tables C-3.2 and C-3.3
[3] Obtained by dividing Net FWR by appropriate efficiency factor.
[4] Obtained by multiplying depth by area to obtain volume.
[5] Obtained by adding the 4 water demands together.

TABLE C-3.9

SYSTEM B - IRRIGATION WATER REQUIREMENTS - FULL DEVELOPMENT
(10^6 m^3/month)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1950	95	114	14	194	188	227	180	11	5	132	100	79	1339
1	37	101	77	140	180	227	179	40	34	145	29	64	1253
2	37	117	81	162	189	227	163	46	52	144	64	66	1348
3	67	134	88	168	206	214	109	9	16	89	45	26	1171
4	37	101	44	159	197	227	178	37	52	109	103	26	1270
5	49	74	88	131	203	227	178	22	1	143	126	68	1310
6	85	118	88	193	206	189	164	18	45	94	29	40	1269
7	113	13	89	194	169	227	171	46	49	121	29	26	1247
8	10[illegible]	112	55	145	146	227	147	9	47	139	117	26	1277
9	50	138	88	184	196	226	179	28	36	94	49	47	1315
1960	37	13	82	144	181	227	115	46	4[illegible]	154	29	96	1168
1	37	23	46	193	177	227	150	46	23	135	29	26	1112
2	118	137	74	189	184	227	143	46	26	69	62	32	1307
3	37	13	50	153	206	227	179	45	7	95	29	26	1067
4	93	61	38	194	167	227	118	11	52	119	140	110	1330
5	138	13	88	159	202	227	180	9	52	146	29	26	1269
6	80	137	37	180	201	224	178	6	20	52	29	66	1210
7	141	72	73	170	202	226	179	43	47	94	29	26	1292
8	123	138	47	192	206	227	179	46	52	163	58	52	1483
9	142	108	88	85	203	227	177	10	37	73	116	26	1347
1970	111	46	79	165	166	217	180	33	29	151	49	61	1287
1	68	133	77	152	200	227	155	24	44	133	108	26	1347
2	166	137	86	189	168	209	178	46	3	52	74	39	1347
3	169	118	55	163	168	188	99	34	1	120	88	26	1229
4	170	124	85	143	190	224	177	43	20	181	93	73	1523
5	118	79	15	125	179	224	65	23	50	110	61	26	1075
6	88	137	89	179	204	214	174	27	29	142	29	26	1338
7	115	127	37	125	177	223	140	26	19	92	29	26	1136
AVG	94	94	66	163	188	222	158	30	32	118	63	45	1273

Note: These water demands are computed for the "full development" case. Section 4.1 shows that demands representing about 92 percent of this level of development can actually be satisfied by the headworks as now committed for the project.

3.4 - Comparison with Other Calculations

Average water requirements for flooded paddy in Maha (October to March) and Yala (April to September) seasons as computed according to the method outlined above are compared with water requirements computed from a variety of other sources in Table C-3.10. Comparing the computed water requirements for System B with the Irrigation Department's design "rules-of-thumb" is open to criticism, since these rules are based on experience with systems having unlined canals. Unless the important factor of conveyance losses is taken into account, the comparison is of questionable validity. It is therefore not surprising that a gross comparison between the computed water requirements for the "1R" group against the Irrigation Department's design rules-of-thumb indicates that, general water use in both the Maha and Yala seasons is higher than that predicted for System B. Significantly better water use in the project area is expected to be realized from the lining of main and branch canals, and the improvement of water management on a projectwide and individual farm basis. In fact, lining of the main and branch canals should result in an improvement of canal efficiency from 0.70 to 0.90, accounting for a 22 percent reduction in water use by itself.

Since the more porous soils which dominate the "2R" group are not found in large areas elsewhere in the country, it is of particular interest to examine the recorded water use in the Pimburettewa Tank Scheme. This scheme, which is located within the project area, consists of about two thirds "1R" soils and one third "2R" soils.* Although it was recently

*The overall project area is estimated to consist of 45 percent "1R" soils and 55 percent "2R" soils.

TABLE C-3.10

COMPARISON OF COMPUTED AND OBSERVED IRRIGATION WATER REQUIREMENTS

Source	Main Canal Lining	Land Class Type	Season[1]	Total Water Requirement For Season (mm)	(ac-ft/acre)	Remarks
Acres report - lowlands	Lined	1R	Maha	890	2.9	Using average effective rainfall.
			Yala	1 710	5.6	Using average effective rainfall.
		2R	Maha	1 610	5.3	Using average effective rainfall.
			Yala	2 280	7.5	Using average effective rainfall.
Hunting's report[9]		1R[4]	Maha	858	2.8	
- System C			Yala	1 591=	5.2	
Irrigation Dept.	Unlined	1R[2]	Maha	1 500	5.0	
"Rule of Thumb"			Yala	2 100	7.0	
Kaudulla Scheme (1978)	Unlined	1R	Yala	1 320	4.3	Intensive water management input.
Pimburettewa	Unlined	1R + 2R	Yala	2 400	7.9	Serious attempt made to conserve water, although lack of tertiary control structures and unlined canals imposed limitations.
Pimburettewa calculated[3]	Lined	1R + 2R	Yala	1 890	6.2	Using average effective rainfall.

Notes:

[1] Maha taken as October - March
Yala taken as April - September

[2] Experience in Sri Lanka is mainly with soils of the "1R" type.

[3] Assuming 2/3 - 1R soils, 1/3 - 2R soils and assuming lined canals and full tertiary controls.

[4] Average of water use calculated for LHG<1.5 percent slope and imperfectly drained RBE<1.5 percent slope, Hunting Annex D, Table 2.12a.

constructed (cultivation began in 1974), the canals are unlined, and only limited control of water distribution is possible due to a lack of tertiary control structures. In the 1979 Yala season, the newly appointed Irrigation Engineer at Manampitiya introduced new water conservation measures. In spite of the limitations imposed by the unlined canal system and the lack of tertiary control structures, total Yala water use was 2,400 mm. Computing average Yala water use for the same area, assuming the lined canals and better tertiary system control which would be expected under project conditions, gives a total Yala water requirement of 1,900 mm. All of the reduction from 2,400 to 1,900 mm should be achievable by lining the main and branch canals, as discussed previously.

The above comparisons demonstrate that the computed water requirements are commensurate with, or slightly higher than, water usage rates now being observed in the project area when canal efficiency and distribution system limitations are considered. They are also comparable to the rates estimated by Hunting Technical Services(9) for "1R" type soils in System C. While they are lower than the rates used as rules-of-thumb by the Irrigation Department, the latter are based on unlined canals and less intensive water management than that expected with the project. The computed rates should therefore be realistically achievable for the assumed cropping pattern.

3.5 - The Influence of Water Requirements on System Operation

Cropping patterns assumed for the project area in previous studies have typically aimed at minimizing irrigation water requirements by assuming that field crops (often soybeans or groundnuts) are grown in the more porous soils in the Yala

season. Financial returns from these crops are much lower than those to be expected from paddy, however, as discussed in the Main Report. It is considered unlikely that a farmer whose fields are bunded and produce a Maha paddy crop will plant anything but paddy in the Yala season.

The upland areas (2,580 ha) are assumed to be cropped in a groundnut (Maha)-soybean (Yala) rotation for purposes of calculating economic benefits. This assumption is used because the more lucrative Yala crop of cotton may not, in fact, be practical for small farmers. However, cotton, with its longer duration, requires more water than other potential upland crops. It has therefore been used as an index crop for the calculation of irrigation water requirements.

Water requirements as computed for this report use cropping assumptions which tend to maximize Yala water requirements. This is done to ensure that the Minipe Right Bank Canal, the link tunnel and the Maduru Oya reservoir will be large enough to provide for maximum probable water demands. Irrigation water demands could still be reduced in the project area to permit development of that part of System B which cannot be reliably served by the headworks as they are now committed. This is discussed further in Section 4.1.

4 - THE WATER BALANCE

Figure C-5 illustrates the position of the Maduru Oya project within the Accelerated Mahaweli Scheme. Not shown are certain of the upstream projects, both existing and potential.

This diagram illustrates the dependence of the project on operational decisions made at three key points--Victoria Reservoir, Minipe Anicut and at Ratkinda Oya Reservoir. Over 70 percent of the irrigation water used in System B originates in the Mahaweli, the balance being natural reservoir inflows.

In their system studies, NEDECO used two computer simulation programs. The first, and largest, simulates the operation of the major reservoirs and diversion points in the system; the second, which is run on a Hewlett Packard "desk top" computer, uses as input data monthly flows at Minipe Anicut (diversion) which are computed by the first program. It simulates the operation of the system downstream from Minipe. Sizing of the major elements of the project and the setting of diversion and reservoir operating policies were carried out as part of the NEDECO studies.

The water requirements which are presented in Table C-3.9 are greater than those computed by NEDECO, due to changed unit water requirements, cropping patterns and estimated irrigable areas. They are also greater than those computed for the Initial Issue of this report. The limited number of computer runs reported herein are intended to assess the performance of the delivery system (the Minipe Right Bank Canal, link tunnel and Maduru Oya reservoir) which was sized by NEDECO in cooperation with the Irrigation Department and CECB. No changes to the headworks design parameters are assumed to be

possible, but tests of the effects of increasing the size of each of them individually are shown for illustrative purposes.

4.1 - Simulation Input

The input data for the smaller NEDECO simulation program are as follows.

1 - Flows at Minipe, as modified by Victoria and Kotmale Reservoirs and Polgolla Diversion.

2 - Natural inflows between Minipe and Ratkinda Oya.

3 - Operating characteristics of the small Ulhitiya Oya and Ratkinda Oya reservoirs.

4 - Irrigation demands for System C, which are satisfied first by the program (see Table C-4.1).

5 - Design capacities for major conveyance works

- Minipe Right Bank Transbasin Canal - 62 m^3/s
- Ratkinda Oya - Maduru Oya Link Tunnel - 34 m^3/s*.

6 - Natural inflows to Maduru Oya reservoir.

7 - Storage-elevation curve and operating limits for Maduru Oya reservoir (see Figure C-7).

8 - Monthly average net reservoir evaporation.

9 - Irrigation demands for System B (see Table C-3.9).

*The capacity of the tunnel is assumed to remain constant at 34 m^3/s, although it can operate for several months of the year with excess capacity by raising the Ratkinda Oya reservoir level above the minimum operating level of 104.42 m. Tunnel capacity with a Ratkinda Oya reservoir level of 106.68 m (maximum operating level) is about 39 m^3/s.

TABLE C-4.1

WATER REQUIREMENTS FOR SYSTEM C
(10^6 m^3/month)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1950	71.8	66.3	29.3	26.0	83.5	118.4	91.0	33.8	-	76.4	98.5	65.8	760.8
1	29.1	78.2	29.9	25.3	88.3	118.4	89.8	31.6	-	73.7	73.4	43.4	681.1
2	46.6	67.6	30.6	22.0	80.6	118.4	87.6	33.6	-	77.1	90.8	66.4	721.3
3	61.3	62.6	29.1	23.4	99.6	127.4	86.1	34.1	-	73.6	101.4	63.9	762.5
4	61.5	52.0	24.9	23.3	83.7	119.6	85.3	31.4	-	66.4	96.4	37.5	682.0
5	29.5	51.1	26.0	23.0	86.2	111.8	89.6	29.6	-	77.8	104.0	65.6	694.2
6	67.3	67.9	28.6	25.2	99.2	106.6	93.4	33.5	-	73.5	60.0	46.3	701.5
7	64.1	55.6	31.5	26.3	83.2	109.7	88.0	35.2	-	68.2	71.9	0.0	633.7
8	61.7	63.8	26.1	22.7	84.3	115.8	93.0	31.6	-	80.7	88.5	51.9	720.1
9	72.5	67.7	31.8	23.0	79.0	106.2	90.0	34.6	-	63.5	82.8	32.6	683.7
1960	50.7	24.8	30.4	21.8	110.8	102.5	82.1	34.1	-	73.5	84.7	71.3	686.7
1	54.7	57.1	27.5	20.7	84.0	112.1	84.4	34.5	-	75.4	64.0	44.0	658.4
2	57.4	63.4	27.3	22.2	73.8	114.3	91.0	28.1	-	73.0	96.0	60.1	706.6
3	57.1	53.2	27.8	23.7	83.8	124.2	86.8	34.6	-	72.4	71.2	38.4	673.2
4	55.6	51.6	27.4	25.7	87.8	121.0	82.7	32.2	-	78.0	103.4	57.0	722.4
5	74.0	44.4	29.6	22.4	83.0	120.2	96.3	26.0	-	66.8	79.2	51.1	693.0
6	64.0	68.0	24.5	25.0	90.5	122.3	92.5	31.7	-	79.5	88.5	60.7	747.2
7	68.7	55.2	28.5	25.9	90.0	115.4	93.3	36.0	-	72.7	53.9	60.0	699.6
8	70.5	74.8	24.5	25.3	93.2	120.0	94.8	37.5	-	72.6	103.1	61.6	777.9
9	64.3	63.1	31.9	22.2	85.2	123.5	93.2	29.3	-	63.7	110.5	32.3	719.2
1970	65.3	44.4	29.3	24.2	83.8	119.4	91.3	35.9	-	82.2	91.8	57.4	725.0
1	62.3	63.3	28.3	20.9	86.7	118.4	95.3	33.1	-	75.0	75.0	51.3	709.6
2	73.0	70.0	31.7	24.0	89.3	116.8	92.1	36.5	-	82.3	82.3	52.2	750.2
3	82.7	53.9	31.0	25.8	92.2	117.0	91.6	34.7	-	75.0	73.5	40.6	718.0
4	88.6	67.3	31.6	23.4	81.4	123.8	95.1	35.7	-	85.3	117.3	50.5	800.0
5	74.1	66.3	29.1	25.0	87.1	118.7	82.1	32.9	-	81.9	100.3	63.0	760.5
6	67.5	72.2	30.8	24.6	96.0	123.2	93.0	32.8	-	78.7	89.5	67.9	776.2
7	85.7	67.9	28.7	23.6	73.2	109.8	80.7	33.6	-	53.8	79.4	56.5	692.9
AVG	63.6	60.5	28.8	23.8	87.1	117.0	89.7	33.2	-	74.0	86.8	51.8	716.3

Source: Hunting Technical Services Ltd. - 1980

4.2 - Simulation Results

The simulation runs presented here provide a basis for the assessment of system performance under various levels of System B irrigation demand, and for increased headworks capacities with full System B irrigation demand. Shortage frequency and total shortage volume over the 28 year simulation period are shown in the table as indicators of system performance. Since it is not normally practical to design for a "zero shortage" condition for an irrigation project, a frequency of serious shortage of about one in ten years (two to three occurrences in 28 years) is regarded as acceptable; this was the condition reached for full irrigation demands in the studies leading to the Initial Issue of the Feasibility Report(10).

4.2.1 - Fully Regulated Condition

Table C-4.2 summarizes the results of six computer simulation runs, which were executed by MDB in June 1979. The first set of runs (Runs 1-3) show how the system performs under 100, 95 and 90 percent of full irrigation demands respectively. Run No. 1 indicates an unacceptably high frequency and volume of shortages for full irrigation demands; almost 50 percent of the simulated years had some shortage, most of them serious. Run No. 2 shows a reduction in shortages, and Run No. 3 showed an almost complete elimination of shortages. Interpolating between the results of Runs 2 and 3 indicates that about 92 percent of full demand could be supplied with the acceptable volume and frequency of shortage described earlier in this section.

A further set of runs (Runs 4, 5 and 6) was also executed to assess the effects on System B's shortages of individually increasing the capacity of the three major headworks elements which affect the project. The results in Table C-4.2

TABLE C-4.2

SUMMARY OF SIMULATION RESULTS

Run No.	Input[1] Headworks Sizing: Capacity of Minipe RB Canal (m^3/s)	Capacity of Link Tunnel (m^3/s)	FSL of Reservoir (m)	Irrigation Demands Percent of Table C-3.9	Output: Total Shortage Volume[2]	No. of Shortages[3] <50	>50	Total
1	62	34	95.5	100	1,596	4	9	13
2	62	34	95.5	95	752	3	7	10
3	62	34	95.5	90	123	2	1	3
4	62	100	95.5	100	1,004	4	9	13
5	68	34	95.5	100	1,122	2	8	10
6	62	34	97.5	100	733	0	7	7

Notes:

[1]All runs were performed for full System C demands (Table C-4.1), with upstream regulation provided by Victoria and Kotmale dams.

[2]Total shortage volume - Total volume of water not delivered to the irrigated area in the 28-year simulation period. An index of system performance.

[3]Number of shortages - Number of years of the 28-year simulation period in which shortages were simulated.

<50 - Total shortage volume in the simulated year less than $50 \times 10^6 m^3$ (a minor shortage)

>50 - Total shortage volume in the simulated year more than $50 \times 10^6 m^3$ (a major shortage)

indicate that increasing by a modest amount the capacity of any one of the headworks elements would be insufficient to satisfy 100 percent of irrigation demands. A combination of increased dam height, link tunnel capacity and Minipe Right Bank Canal capacity would be required.

4.2.2 - Unregulated Condition

In preparing the Initial Issue of this report, a computer run was executed which assessed the ability of the Maduru Oya reservoir to satisfy irrigation water demands before the completion of Victoria dam, with partial development of Systems B and C. This run indicated that over 50 percent of the full demands (as computed at that time) could be met with no shortages. It can be inferred from this run that the Yala 1985 cropped area (for Scenario A) of 20 300 ha of paddy land can be irrigated with a low probability of shortage. This will be the last Yala crop grown before the Victoria dam provides regulated flows to the Minipe Anicut.

4.2.3 - Influence of System C Demands

It should be noted that the water demands of System C during the peak usage months of May, June and July have a significant influence on the behavior of the Maduru Oya reservoir. During these months, the quantity of water available for diversion through the link tunnel is reduced to a level below its hydraulic capacity. Since these are months of low natural reservoir inflows and high System B irrigation demands, the quantity of water diverted through the tunnel will directly affect the minimum reservoir level, which is normally reached at the end of July. A 20 percent increase in May to July water demand in System C would, therefore, deprive System B of the same amount of water--an average of 59 million m^3/yr. The frequency and magnitude of shortages in System B would increase as a result.

4.2.4 - Implications for Project Development

It is clear from the simulation studies reported herein that the combination of headworks committed for System B is not capable of delivering the water requirements now estimated for the full potential development area. It is estimated that about 92 percent of these demands can be reliably met, however. Since the irrigation water requirements are theoretical values which will undoubtedly prove inaccurate under actual project conditions, it is recommended that the following project development sequence be followed.

(a) Develop about 92 percent (i.e. eliminate some 3,200 ha of paddy land and 200 ha of uplands) of the total project area, postponing development of a relatively expensive* "tail-end" area of the project to achieve a water balance. Allow for the later development of the area by providing adequate upstream canal capacities, turnout structures, etc.

(b) Implement a water use monitoring program as the project is developed, so that projections of ultimate water demand levels can be revised to reflect actual project conditions. This program should be combined with a concerted effort to deliver water efficiently and equitably.

*Annex L contains a discussion of the economics of choosing among three potential "drop off" areas
1 - The area commanded by Branch Canals LBL7 and LBR8
2 - The area commanded by Branch Canals LBL10 and LBR8
3 - The area commanded by Branch Canal RBR1.

(c) Using new information on the operating policies to be followed at Polgolla diversion, Victoria dam and Minipe Anicut, along with revised estimates of System C demands, perform new simulation studies to assess the level of water demand which can be met within System B.

(d) If the simulation studies indicate that it is feasible, proceed with the development of the postponed area. This would involve the construction of the necessary lined branch canals and the construction of the tertiary irrigation and drainage systems, social infrastructure, etc. No modifications to the headworks or main canals would be involved.

4.3 - Interaction Between the Reservoir and the Link Tunnel

The functions of the Maduru Oya reservoir are

1 - The regulation of the natural inflows originating from the Maduru Oya catchment. Flows drop to zero during the Yala season, when irrigation demands are at their peak.

2 - The regulation of flows diverted through the link tunnel. Typically, these flows are at the tunnel capacity of 90 x $10^6 m^3$ through the Maha season, but drop to 30 to 40 x $10^6 m^3$ in June, the peak irrigation demand month. This is because upstream run-of-river projects (Systems E and C) have peak demands in these months as well.

3 - The establishment of gravity command over the Left and Right Bank Canal systems in the project area.

4.3.1 - The Project Without the Reservoir

The reservoir is clearly necessary to permit full development of the project, which is desired at the earliest possible date by the Government of Sri Lanka. However, a limited area on the Left Bank could be irrigated directly from an extension of one of the System C main canals.* This canal could later be extended further to the postponed Maduru Oya reservoir, at which time it would serve the same purpose as the link tunnel. This possibility has attracted some attention during the course of the study, in the hope that some improvement in the project's economic viability could be achieved by the postponement of the investment in the dam which would be made possible by the choice of this "link canal" approach. As pointed out in Annex D, however, the link canal approach presents problems in the areas of design and construction scheduling, as well as being a less desirable diversion mode from an operational point of view. This section of the report examines the potential of the link canal alone to serve as a reliable source of irrigation water for a part of the project area. The potential for staged construction of the headworks can then be assessed.

Table C-4.3 presents the monthly flows over the 28-yr simulation period which are available for diversion into the link tunnel or link canal after the capacity of the Minipe Right Bank Canal and full System C water requirements are accounted for. The minimum flows which are observed in the May to August period are due to a combination of low flows at Minipe

*The engineering aspects of this proposal, referred to as the "link canal", are discussed in Annex D.

TABLE C-4.3 POTENTIAL TUNNEL INFLOWS

DIVERSION THROUGH LINK TUNNEL
IRRIGATION AREA: 39760 HA.
FLOW IN MILLION CUBIC METRES

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tota
1950	90	90	90	90	80	44	70	90	90	90	72	90	98
1	90	87	90	90	76	50	73	82	90	90	90	90	99
2	90	90	90	90	83	43	75	90	90	89	88	90	1,00
3	90	90	90	90	54	34	87	90	90	90	78	90	97
4	90	90	90	90	84	42	69	90	90	90	73	90	98
1955	90	90	90	90	86	51	72	90	90	89	65	90	99
6	90	89	90	90	57	57	68	90	90	90	90	90	991
7	90	90	90	90	66	52	74	90	90	90	90	90	1,00
8	90	90	90	90	85	46	68	90	90	84	84	90	997
9	90	90	90	90	87	58	71	90	90	90	90	90	1,026
1960	90	90	90	90	66	59	84	90	90	90	90	90	1,019
1	90	90	90	90	90	52	79	90	90	90	90	90	1,031
2	90	90	90	90	90	53	74	90	90	90	90	90	1,027
3	90	90	90	90	90	40	62	90	90	90	90	90	1,002
4	90	90	90	90	84	46	85	90	90	90	66	90	1,001
1965	90	90	90	90	90	43	67	90	90	90	90	90	1,010
6	90	90	90	90	78	41	69	90	90	90	90	90	998
7	90	90	90	90	76	48	69	90	90	90	90	90	1,003
8	90	72	90	90	72	43	67	90	90	90	85	90	969
9	90	90	90	90	82	38	71	90	90	90	59	90	970
1970	90	90	90	90	90	48	70	90	90	90	88	90	1,016
1	90	90	90	90	90	51	75	90	90	90	90	90	1,026
2	90	90	76	90	80	45	70	90	90	90	90	90	991
3	90	90	90	90	72	50	77	90	90	90	90	90	1,009
4	90	88	90	90	90	39	66	90	90	80	49	90	952
1975	90	90	90	90	78	43	85	90	90	82	81	90	999
6	90	90	86	90	67	38	69	90	90	59	90	90	949
7	72	85	90	90	90	29	83	82	90	90	90	90	981
MEAN	89	89	89	90	80	46	73	89	90	88	83	90	997

Notes: 1. Assumes a link tunnel diversion capacity of 90×10^6 m^3 (34 m^3/s). Where an inflow of 90×10^6 m^3 is indicated, surplus flow is available.

2. Source - Computer output from NEDECO simulation program, "post-Victoria" conditions.

and high System C demands. In other words, an increase in the capacity of the Minipe Right Bank Canal would not increase the amount of water available in these months in a dry year. Taking June as the month in which peak demands must be met, the data in the table show that the average flow available in this month is 46 x $10^6 m^3$, while that available 1 year in 5 is about 40 x $10^6 m^3$. The latter figure can be compared with the full development June demand of 204 x $10^6 m^3$,* indicating that about 20 percent of the full project demand could be satisfied by the link canal alone. This might translate into 8,000 ha (20 percent) of irrigation area if ultimate irrigation efficiencies are assumed, or less in the early years of the project, when lower irrigation efficiencies can be expected.

4.3.2 - The Project Without the Link Tunnel

NEDECO conducted simulation studies to determine the ability of the Maduru Oya reservoir to meet irrigation demands without supplementary inflows from the Mahaweli basin. These studies indicated that an average annual water demand of 289 x $10^6 m^3$, consisting of 97 x $10^6 m^3$ Maha and 192 x $10^6 m^3$ Yala deliveries, can be met with acceptable shortage frequencies in the long run. This water delivery translates into about 24 percent of the water demands in Table C-3.9, or some 9,500 ha of the total irrigable area.

*92 percent of 222 x $10^6 m^3$, from Table C-3.9.

4.3.3 - The Early Years of the Project

The Link Canal Alone

In Yala 1984 and 1985, serious shortages could be experienced in Systems B and C, since no regulation will be available from the Victoria dam. These shortages would be more severe and would have a greater chance of occurring than those indicated in Table C-4.3.

The Reservoir Alone

As discussed in Section 4.2.2, the reservoir is capable of regulating the natural inflows to supply irrigation water to some 9,500 ha of land, in the long run. However, if a 1-in-10 dry year* (which has a 10 percent chance of occurrence in any year) occurs in the year of reservoir filling, there will probably be insufficient water for the first Yala crop. Since it is now planned to complete the dam by August 1983, there would be no water available in any case for the Maha 1983/84 crop, due to reservoir filling requirements.

The Dam and Diversion Combined

It is now planned to complete the construction of Maduru Oya dam by August 1983. Provided that upstream diversion works (the Minipe Right Bank Canal, Ulhitiya and Ratkinda Oya Reservoirs and the link tunnel) are also operational by that time, there should be no problem in delivering sufficient water via the tunnel to fill the dead storage zone and supply water for the 1983/84 Maha crop in Sector 1. As noted above,

*The 1-in-10-dry yr volume of 190 x $10^6 m^3$ would leave only 90 x $10^6 m^3$ available for the Yala crop, after water requirements for filling the dead storage volume and satisfying reservoir evaporation requirements are subtracted. This would irrigate less than 5,000 ha of paddy land.

if the dams were constructed without the tunnel, it would not be possible to fill the dead storage zone in time to provide water before Yala 1984. The "canal alone" option would be highly vulnerable to low flow events and upstream construction delays.

4.3.4 - Implications for Project Implementation

The interaction between the Maduru Oya reservoir and the diversion from the Mahaweli is clearly important to the project, particularly in the crucial early years. The areas which can be irrigated with either the dam or link canal alone are not large when compared with the Government's objectives for even the earliest years of the development. It is therefore recommended that both the dam and diversion be scheduled for simultaneous completion.

4.4 - Operational Features of the Project

Apart from the interactions with other projects in the Mahaweli Scheme which are discussed in Section 4.1, certain other features of the project which will influence its operation are worthy of discussion. These features, which are outlined in schematic form in Figure C-6, are

- Irrigation bypasses are available at both the Left Bank and Right Bank powerhouses, to allow delivery of irrigation water in the event of power plant shutdowns.

- The first level crossing on the Right Bank main canal will require a gate to permit water to be discharged into the Maduru Oya. This will augment (if necessary) return flows which will be reused in the Vakaneri and Punanai Schemes.

- The return flows which are being reused in the Vakaneri and Punanai Schemes should be tested periodically for dissolved salts to ensure that concentrations do not reach harmful levels. If the observed levels are undesirably high, it should be possible to lower them by dilution with reservoir releases.

- Measures to reuse return flows in the numerous existing small tanks in the project area should be taken. Operational procedures should ensure that the tanks are capable of storing and redistributing return flows to maximum effect. No water should be supplied from the canal system until tank levels are low, and the deliveries should be limited to maximize available storage for later inflows from natural or return flow sources.

- Provision for supplementing inflows to Pimburettewa Tank will be needed at the Kuda Oya level crossing. Pimburettewa Tract 9 (the northern-most tract, at present undeveloped) may well be supplied via a branch canal (Branch Canal RB-R2), which will take off directly from the Left Bank Main Canal.

- Any shortages which are unusually severe will occur in the Yala season. Warning of an impending shortage will be available by assessing reservoir storage at the beginning of the season, along with probable Yala demands in System C. This will allow measures to be taken to deal with the shortage well ahead of time, in contrast to a "run-of-river" type project which can experience shortages with little warning.

5 - WATER QUALITY

The limited water quality data which are available for the Maduru Oya and Mahaweli basins are summarized in Table C-5.1. Additional testing of water samples is being carried out as part of the USAID-sponsored environmental study of the Mahaweli Scheme. Initial results from the latter program and the potential water supply is of good quality. Electrical conductivity levels are below 170 mhos/cm in the Mahaweli and below 300 mhos/cm in the Maduru Oya. The maximum computed Sodium Adsorption Ration (SAR) is 2.25. According to the standards published by the U.S. Department of Agriculture(11) and the Food and Agriculture Organization of the United Nations (FAO)(12), the combination of Mahaweli and Maduru Oya water which will irrigate the project area should fall into the "no problem"* category for both salinity and sodium hazards. This, combined with the heavy Maha rainfall and basic drainage provisions to be incorporated into the project design, will render water quality problems unlikely.

*The USDA category of "C1 - S1" is indicated by the SAR and conductivity data. The FAO "no problem" category is indicated by conductivity, SAR, and alkalinity data.

TABLE C-5.1

SUMMARY OF
WATER QUALITY DATA

Sample Location	Date	PH	Conductivity (µmhos/cm)	Total Dissolved Solids	CO_3+ HCO_3 (meq/l)	Ca+Mg (meq/l)	Na (meq/l)	SAR[3]	SAR[4]
MADURU OYA									
Vakaneri Tank	5/11/79	8.4	425	270[2]	NM[1]	NM	NM	NC[1]	NC
Maha Oya	7/11/79	7.2	82	52[2]	NM	NM	NM	NC	NC
Welikanda	5/11/79	7.4	300	160[2]	NM	NM	NM	NC	NC
Damsite	22/ 5/79	7.2	250[2]	159	1.70	1.05	1.42	1.96	2.25
Damsite	3/ 5/79	7.8	150[2]	95	0.84	0.46	0.87	1.81	1.09
Pimburettewa Tank	No date	7.0	215[2]	136	2.07	1.13	1.06	1.00	1.27
MAHAWELI GANGA									
Mahiyangana	7/11/79	7.0	95	59*	NM	NM	NM	NM	NM
Polgolla	11/60	NM	35	50*	NM	0.146	0.14	0.52	NC
	7/61	NM	40	50*	NM	0.250	0.11	0.31	NC
	11/60	NM	75	50*	NM	0.208	0.17	0.51	NC
	7/61	NM	170	108*	NM	1.752	0.200	0.21	NC
Manampitiya	No date	8.0	200	127	1.30	1.01	0.65	0.91	0.91

Notes:

[1] NM = Not Measured NC - Not Calculated

[2] Using USDA Conductivity - TDS graph

[3] SAR = Sodium Adsorption Ratio

$$= \frac{[NA]}{\frac{[CA] + [Mg]}{2}}$$

Where [NA] = concentration of sodium ions, in meq/l

[4] Adjusted SAR - SAR computed as in Note 3, adjusted using procedure outlined in FAO Paper 29 ...

6 - FLOOD HYDROLOGY

Flood hydrology studies in the project area concentrated on the Maduru Oya due to the agricultural potential of its floodplain. As discussed in the Main Report, the flood regime of the Mahaweli Ganga was not given detailed attention due partly to the uncertainty surrounding future structural modifications to the flood regime, and partly to the desirability of preserving the floodplain for wildlife and cattle grazing.

This section presents rainfall frequency curves which can be used for flood analysis calculations, followed by unit hydrographs for the Maduru Oya and an analysis of flood frequency under the conditions which will prevail after the project is completed.

6.1 - Rainfall

The 1978 paper on rainfall intensity-duration-frequency studies for Sri Lanka(13) provides several sets of rainfall frequency curves which can be used in different climatic regions of Sri Lanka. The curves derived in the paper for Region I, which covers the eastern portion of the Dry Zone, are presented in Figure C-8.

Before accepting these curves for use in the project area, frequency analysis was carried out on maximum annual 1- and 2-day precipitation at all seven of the reliable rainfall stations in or near the project area which were listed in Section 2.2.1. The mean annual maximum daily rainfalls for the seven stations were tested against the mean of all seven, and the differences were not found to be statistically

significant. Hence the area within which these stations fall appears to be homogeneous, and the use of a regional curve is valid. The daily maximum rainfall figures analyzed in the exercise were about 5 percent lower than the 24-h maxima recommended in the 1978 paper, but this difference can be explained by the fact that the former figures are based on a "floating" 24-h period which can include parts of two calendar days. Since the analysis outlined above substantiated the regional curves proposed in the 1978 paper, the curves in Figure C-8 were judged to be usable for hydrological analysis in the project area.

6.2 - Observed Flood Frequency

Flood stages at Welikanda have been recorded since 1947, as discussed in Section 2.2.2. However, no flow measurements have been made during large floods, since no bridge or cableway is available at the gauging site. The rating curve used to estimate flood flows has been extrapolated from that derived for lower flows and presented in Figure C-2. Flood frequency data derived from the extrapolated rating curve must, therefore, be checked against regional data and unit hydrograph-derived flows before they can be used with confidence.

Pertinent data regarding the observed occurrence of floods at Welikanda since 1948 are summarized in Table C-6.1. Peak flows observed at any time during the flood season are tabulated, as are peak flows which occurred after January 15 in each year. The latter data can be used to assess the flood risk in the floodplain late in the flood season, if the crop calendar for the floodplain can be modified to provide for late planting of the paddy crop.

TABLE C-6.1

OBSERVED FLOODS
AT WELIKANDA

Water Year	Peak Flow (m^3/s)	Date of Peak	Peak Flow Frequency: Order (m)	Peak Flow Frequency: Plotting Position (m/n+1)[1]	Post January 15 Peak Flows: Peak (m^3/s)	Post January 15 Peak Flows: Order (m)	Post January 15 Peak Flows: Plotting Position (m/n+1)[2]
1947	839	Jan 13	7	0.26	171	11	0.39
1948	317	Jan 4	20	0.74	151	14	0.50
1949	232	Jan 2	22	0.81	36	26	0.93
1950	501	Dec 7	13	0.48	169	12	0.43
1951	864	Jan 20	6	0.22	864	2	0.07
1952	598	Jan 7	11	0.41	137	16	0.57
1953	212	Jan 23	25	0.93	212	10	0.36
1954	283	Feb 12	21	0.78	283	9	0.32
1955	496	Feb 9	15	0.56	496	5	0.18
1956	225	Jan 11	23	0.85	46	24	0.86
1957	613	Feb 18	10	0.37	613	4	0.14
1958	1800	Dec 25	1	0.04	139	15	0.54
1959	213	Dec 26	24	0.89	65	21	0.75
1960	1120	Feb 22	3	0.11	1120	1	0.04
1961	819	Jan 16	8	0.30	819	3	0.11
1962	NM	NM	-	-	-	-	-
1963	416	Feb 6	17	0.63	416	6	0.21
1964	NM	NM	-	-	NM	-	-
1965	NM	NM	-	-	NM	-	-
1966	NM	NM	-	-	NM	-	-
1967	507	Nov 9	12	0.44	77	19	0.68
1968	448	Nov 21	16	0.59	109	17	0.61
1969	337	Jan 21	19	0.70	337	8	0.29
1970	909	Dec 28	5	0.19	162	13	0.46
1971	499	Jan 5	14	0.52	63	23	0.82
1972	NM	NM	-	-	21	27	0.96
1973	932	Dec 20	4	0.15	71	20	0.71
1974	649	Dec 31	9	0.33	78	18	0.64
1975	391	Dec 30	18	0.67	65	22	0.79
1976	1560	Jan 13	2	0.07	351	7	0.25
1977	190	Dec 24	26	0.96	41	25	0.89

Notes: - 1 N = 26
2 N = 27

Figure C-9 presents frequency curves plotted from these data. The post-January 15 curve illustrates the significantly reduced risk of flooding after this date.

To ensure that the flow data at Welikanda are consistent with data elsewhere in the country, flood peaks can be compared with those computed using a regional flood frequency curve developed as part of the recent studies of the Victoria Dam.(14)

The basic equation is

$$\overline{Q}_P = 3.846\ A_d^{0.688} R^{1.837} \times 10^{-6} \text{----------(C3)}$$

Where $\overline{Q}_P$ = Mean annual flood peak, m^3/s

A_d = Drainage area, km^2

R = Mean annual basin rainfall, mm.

Floods of various return periods are computed using the following ratios

$$\frac{Q_5}{\overline{Q}_P} = 1.25 \text{ ----------(C4)}$$

$$\frac{Q10}{\overline{Q}_P} = 1.75 \text{ ----------(C5)}$$

$$\frac{Q25}{\overline{Q}_P} = 2.50 \text{ ----------(C6)}$$

Solving these equations for the Welikanda station yields the following flows

$$\overline{Q}_P = 427 \text{ m}^3/\text{s}$$
$$Q_5 = 535 \text{ m}^3/\text{s}$$
$$Q_{10} = 747 \text{ m}^3/\text{s}$$
$$Q_{25} = 1{,}070 \text{ m}^3/\text{s}$$

Comparison of these flows with those indicated in Figure C-9, which are derived directly from the flow data, indicates that the flows obtained from the regional formula are substantially lower (33 to 41 percent) than those estimated from the observed data. The latter flows are therefore proposed for design use, with the possibility that they may err somewhat on the high side.

6.3 - Unit Hydrograph Analysis

The dimensionless unit hydrograph method(15,16) allows the calculation of flood hydrographs at gauged or ungauged locations, using a design rainstorm combined with a unit hydrograph which is derived from the physical characteristics of the river basin. It is particularly useful when a structural alteration (such as the construction of a major dam) is proposed for a basin, in that the influence of the dam on the flood peak can be examined, based on the combination of the modified flows at the damsite and the flow originating from the uncontrolled portion of the drainage basin. The method has been applied previously in Sri Lanka, and a paper reporting derivation of Snyder's coefficients for representative catchments in Sri Lanka is available.(17)

The following sections describe the derivation of design storms for use with the unit hydrographs, the derivation of

the unit hydrographs for the Maduru Oya, and the calculation of flood peaks. Finally, derived flood frequency curves at Welikanda are presented.

6.3.1 - Derivation of Design Storms

Design storms for various return periods can be constructed from intensity-duration-frequency curves. First, since the curves represent rainfall at a single point, a reduction factor to allow for the effect of a storm on a large basin can be chosen by interpolating between the following points.

Factor	A_D (mi^2)
0.928	25
0.890	50
0.855	100
0.840	200
0.830	300

The reduced ordinates of the intensity-duration curve for the given return period are then interpreted to allow tabulation of the 3-h, 6-h, 9-h, etc storms. The ordinates are then subtracted and the resulting rainfall values arranged to give a reasonable storm pattern. Thus a 10-yr design storm contains the maximum 3-h, 6-h, 9-h, etc storms for that return period. Table C-6.2 illustrates the procedure for the 5-yr storm, while Table C-6.3 summarizes the 5-, 10-, 25- and 50-yr design storms for use in the unit hydrograph analysis described in the following sections.

6.3.2 - Unit Hydrographs

The unit hydrograph is defined as the "hydrograph of direct runoff resulting from (1 unit) of effective rainfall gener-

TABLE C-6.2

DERIVATION OF 5-YEAR DESIGN STORM FOR 3-HOUR INTERVALS (MM)

	Duration (h)							
	3	6	9	12	15	18	21	24
Rainfall	105	126	140	150	160	170	178	184

	Storm Interval (h)							
	0-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24
Increm rainfall	105	21	14	10	10	10	8	6
Rain x 0.84[1]	88	18	12	8	8	8	7	5
Losses[2]	4	4	4	4	4	4	4	4
Net rainfall	84	14	8	4	4	4	3	1
Rearranged	4	4	14	84	8	4	3	1

Notes: - [1]0.84 = reduction factor for A_d = 175 miles^2

- [2]0.05 in/h - 4mm/3 h.

Source: MDB Study[17]

TABLE C-6.3

SUMMARY OF DESIGN STORMS

Return Period (yrs)	Storm Interval (h) 0-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	27-30
5	4	4	14	84	8	4	3	1	-	-
10	4	4	6	17	98	10	6	4	2	-
25	4	6	8	20	117	17	8	6	4	2
50	4	6	8	11	25	130	20	9	7	5

ated uniformly over the basin area at a uniform rate during a specified period of time".[15] In the Imperial system of measurement, the unit of rainfall is usually defined as 1 in.; in the metric system, it is usually defined as 10 mm.

Snyder, in his paper on dimensionless unit hydrographs,[16] proposed that the key elements of the unit hydrograph for a basin--the peak flow, the time to the peak, and the width of the hydrograph at certain percentages of peak flow--could be related to the physical characteristics of the basin. His relationships have been modified somewhat over time, and the equations which have been fitted to conditions in Sri Lanka[17] are

$$tp = C_t(L.L_c)^{0.30} \qquad \text{(C7)}$$

$$q_p = \frac{640.C_p.A_D}{tp} \qquad \text{(C8)}$$

Where tp = the time required to reach peak flow (h)

C_t = a coefficient which varies according to the physical characteristics of the catchment

L = the length of the longest river course (mi)

L_c = the length along the river channel from the point of observation to the basin centroid (mi)

q_p = peak flow (ft^3/s)

C_p = a coefficient that varies according to the physical characteristics of the catchment

A_D - drainage area (mi^2)

The studies which were performed for Sri Lanka included the analysis of the Maduru Oya catchment, and values of C_t and Cp were derived for it and other similar catchments. Based on these analyses, values of C_t = 3.0 to 3.9 and C_p = 1.0 to 1.2 were used in this study. The characteristics of the 10-mm, 3-h unit hydrographs for Maduru Oya at the damsite, below the damsite, and at Welikanda before dam construction are as follows

Location	tp (h)	$q_p (m^3/s)$
Damsite	27.0	51.8
Below damsite	16.6	74.4
Welikanda	36.0	91.5

6.3.3 - Derived Flood Flows

Combining the design storms and unit hydrographs presented in the preceding sections allows the calculation of flood hydrographs representing each of the return periods considered. The influence of the flood regulation expected* from the Maduru Oya dam can then be assessed.

Table C-6.4 summarizes the computed flood peaks and shows that the dam can be expected to reduce flood peaks for a

*The dam is expected to regulate fully (i.e. to delay the release of significant flood flows well past the time of downstream peak occurrence) the flows originating upstream from the dam. Flood peaks for the "post-dam" condition have therefore been calculated assuming no contribution from the dam. This assumption is reasonable for the relatively minor (5- or 10-yr recurrence interval) floods used in agricultural planning, when the magnitude of potential flood volumes is compared with the storage available in the Maduru Oya reservoir.

TABLE C-6.4

INFLUENCE OF MADURU OYA DAM ON FLOOD PEAKS AT WELIKANDA

Return Period (yrs)	Peak Flow Before Dam (m^3/s)	Peak Flow After Dam (m^3/s)	Ratio After/Before
5	1021	762	0.75
10	1245	915	0.73
25	1576	1130	0.72

Note: The flows shown were calculated using the unit hydrograph method, and differ slightly from those estimated from observed data for the pre-dam situation.

given return period by 25 to 28 percent, in spite of the fact that it controls about 50 percent of the drainage area at Welikanda. This is to be expected, however, as the flood peak per unit area from the smaller area downstream from the dam will be greater than that observed for the larger unmodified catchment.

If the peak flows of various probabilities of exceedence which were derived from observed data (Figure C-9) are adjusted by the same ratios as shown in Table C-6.4, the following flood flows can be estimated.

	Flood Peaks (m^3/s)			
	Pre-Dam		Post-Dam	
Return Period	All Year	Post Jan 15	All Year	Post Jan 15
5 yr	907	400	677	300
10 yr	1,190	640	875	470
25 yr	1,590	950	1,130	680

6.4 - Implications For Floodplain Cropping

The figures in the preceding section show that, by delaying transplanting of the Maha paddy crop in flood-prone areas to after January 15, a substantially reduced risk of flood damage will result. Whereas before dam construction the 1-in-5-yr flood (20 percent chance of exceedence in any one year) is 907 m^3/s, the post-dam, late season "5-yr" flood is 300 m^3/s. The rating curve at Welikanda and hydraulic analyses in the vicinity indicate that the former flow involves substantial overbank flow especially upstream from Welikanda, while the latter flow should be substantially confined to the main channel downstream from Welikanda.

6.5 - Flood Behavior

The preceding sections have described the flood regime in terms of probability of exceedence of different peak flows, both before and after dam construction and over the entire flood season and in the later part of the flood season. From an agricultural point of view, it is equally important to understand the flood depth, velocity, timing and duration to be expected at a given point. Insight into these aspects was gained in two ways--firstly by recording the high water-mark from the 1978 to 1979 flood peak and secondly by performing water surface profile calculations in the reach of the Maduru Oya immediately upstream from Welikanda.

The cyclone of November 23 and 24, 1978, passed through the project area, causing considerable damage. Much of the damage resulted from high winds, which were estimated to have exceeded 90 mi/h at Batticaloa. The area of greatest rainfall appears to have followed a relatively narrow track-- the bunds of Tharavai Kulam and Meeyankolla Kulam in the lower right bank area were breached, indicating a rare flood event, while the available evidence indicates that the flood peak on the Maduru Oya was less than 1,000 m^3/s. A flood peak of this magnitude would have a probability of exceedence in any year of about 20 percent, certainly not an extremely rare event.

No rainfall or streamflow records are available in or near the project area for this flood event. The meteorological station at Batticaloa ceased functioning early in the storm, and the gauge reader for the Welikanda station was away from his post. However, the high water marks from the flood were marked with paint a few days after the flood receded on bridges and culverts along the main road, and subsequently leveled by survey crews. These points provide useful references to judge the suitability of lands for permanent

settlement, and will assist in future analyses for flood levels. Figure 6 of the Main Report shows the limit of the estimated flooded area in 1978. The levels obtained indicate that flood depths of 1 m or more were experienced over much of the area which would be classed as "floodplain", using soil type as the criterion. Hence the area for which the delayed "floodplain" cropping pattern has been adopted in Section 3 consists of soils which are classed as floodplain soils, with allowances for losses from permanently flooded land, irrigation infrastructure, etc.

Water surface profile calculations performed for the reach of the Maduru Oya upstream from Welikanda indicated that an area over 5 km in length along the river will continue to be prone to serious flooding after dam construction and would probably be better used for grazing and/or wildlife. Flood depths of 1 to 1.5 m and velocities of about 0.25 m/s are anticipated for the 10-yr flood. Smaller velocities and depths are to be expected in the wider floodplain downstream from Welikanda, a conclusion which should be verified during the detail design stage by observations of flood levels in the proposed development areas. For the purposes of this feasibility study it can be assumed that much of this portion of the floodplain can be made productive under irrigation. Much of the area is now used for rainfed paddy cultivation, in spite of the present high risk of flood damage, and the need to plant early so that plants are mature enough to withstand minor floods. Greatly improved agricultural returns should be attainable through a combination of the flood control provided by the dam and the possibility of irrigating late in the Maha season.

REFERENCES

LIST OF REFERENCES

1 NEDECO. "Revised Mahaweli Ganga Development Program Implementation Strategy Study", Colombo, July 1979
Annex A - Hydrology
Annex O - Preliminary Water Balance Studies

2 Joshua, W.D. "Irrigation Requirements and Water Management for Rice at the Farm Level", Irrigation Department, Colombo, 1977

3 Institute of Hydrology, U.K. Report on 1979 Studies in the Kaudulla Irrigation Project, Colombo, 1979

4 CECB/SOGREAH. "Maduru Oya Reservoir, Revised Project Report", Colombo, February 1979

5 Irrigation Department. "Mahaweli Ganga Development - Water Requirements for System C", Irrigation Department Memorandum, Colombo, 1978

6 Acres International Limited, "Chao Phraya - Meklong Basin Study - Phase I", Main Report and Appendix C - Agricultural Water Use, Niagara Falls, 1979

7 Committee for the Coordination of Investigations of the Lower Meklong Basin, "Summary of Monthly and Yearly Hydro-Meteorological Data in the Thai Part of the Lower Mekong Basin", Mekong Secretariat, Bangkok, 1975

8 Food and Agriculture Organization of the United Nations. "Effective Rainfall in Irrigated Agriculture", FAO Irrigation and Drainage Paper No. 25, Rome 1974

9 Hunting Technical Services Ltd. "System C - Mahaweli Development Project - Feasibility Study 1979. Annex D - Agronomy", Colombo, December 1979

[10]Acres International Ltd. "Maduru Oya Feasibility Study - Feasibility Report Initial Issue - Annex C - Hydrology and Water Balance", Niagara Falls, November, 1979

[11]United States Government Department of Agriculture. "Quality of Irrigation Water", Agriculture Handbook No. 60, Washington, 1954

[12]Food and Agriculture Organization of the United Nations. "Water Quality for Agriculture" FAO Irrigation and Drainage Paper No. 29, Rome, 1976

[13]Baghirathan Vanniasingham, R. and Shaw, E.M. "Rainfall Depth - Duration - Frequency Studies for Sri Lanka", Journal of Hydrology, Volume 37, Amsterdam, 1978

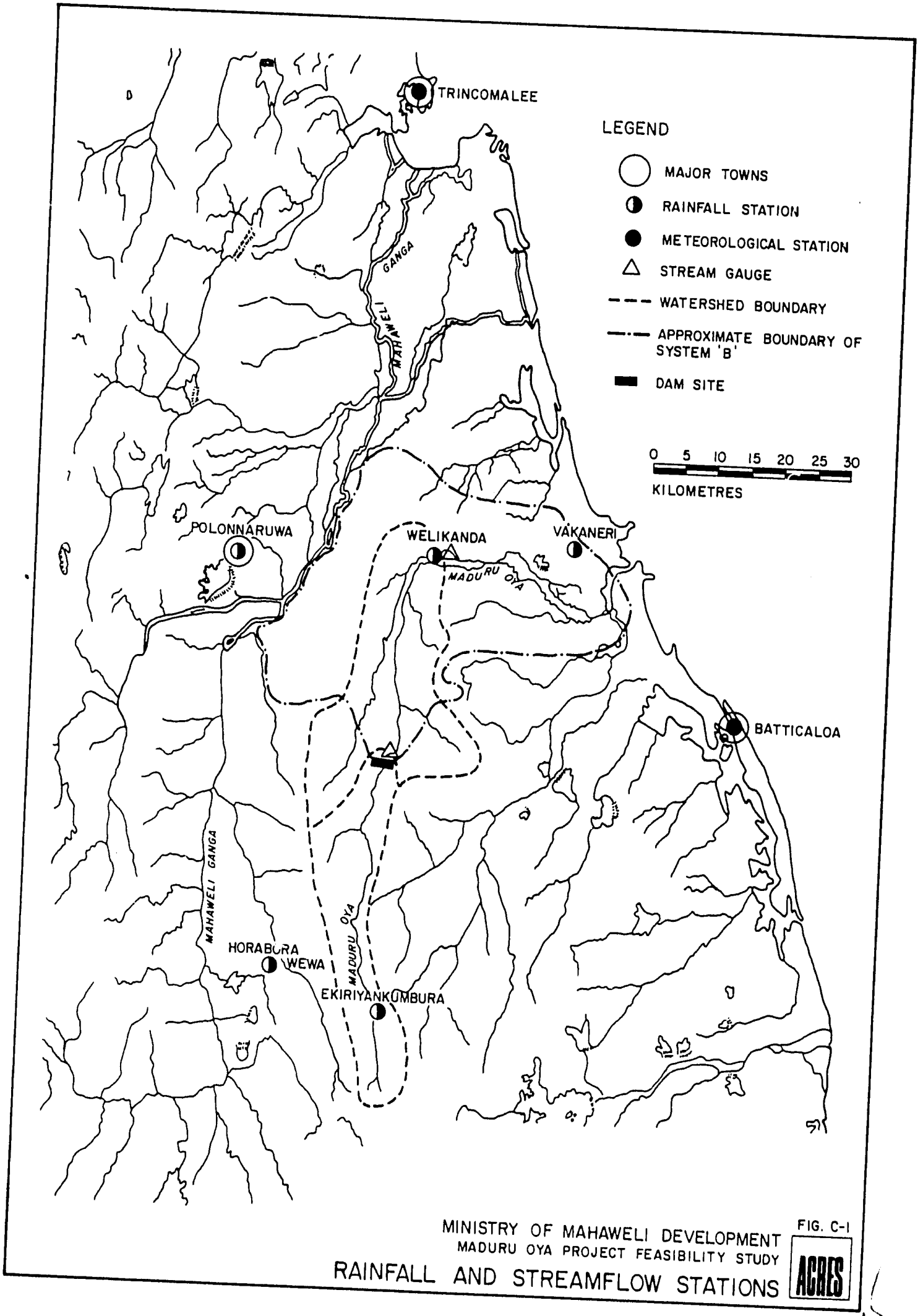
[14]Hunting Technical Services Ltd, Sir Alexander Gibb and Partners Ltd and Preece, Kardew and Rider. "Victoria Scheme - Mahaweli Development Project - Phase I - Preliminary Feasibility Report", Borehamwood, 1978

[15]Chow, V.T. ed. "Handbook of Applied Hydrology", McGraw Hill, New York, 1964

[16]Snyder, F.F. "Synthetic Unit-Graphs", Transactions of the American Geophysical Union, Vol 19, 1938

[17]Mahaweli Development Board. "Development of Design Flood Hydrographs for Ungauged Catchments Using Snyder's Techniques as Adopted to Catchments of Sri Lanka", Colombo, 1976.

FIGURES



MINISTRY OF MAHAWELI DEVELOPMENT
MADURU OYA PROJECT FEASIBILITY STUDY

RAINFALL AND STREAMFLOW STATIONS

FIG. C-1

ACRES

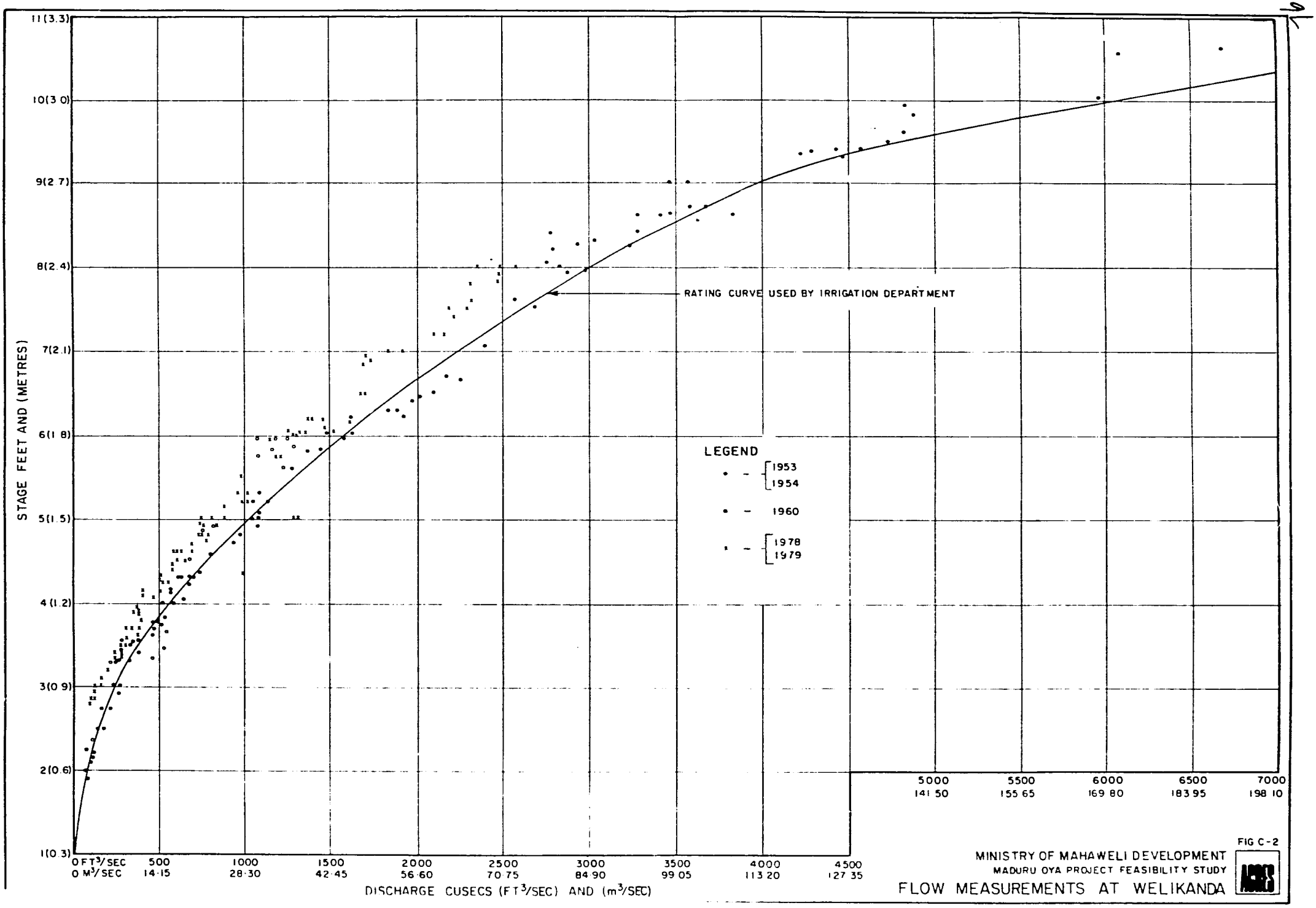
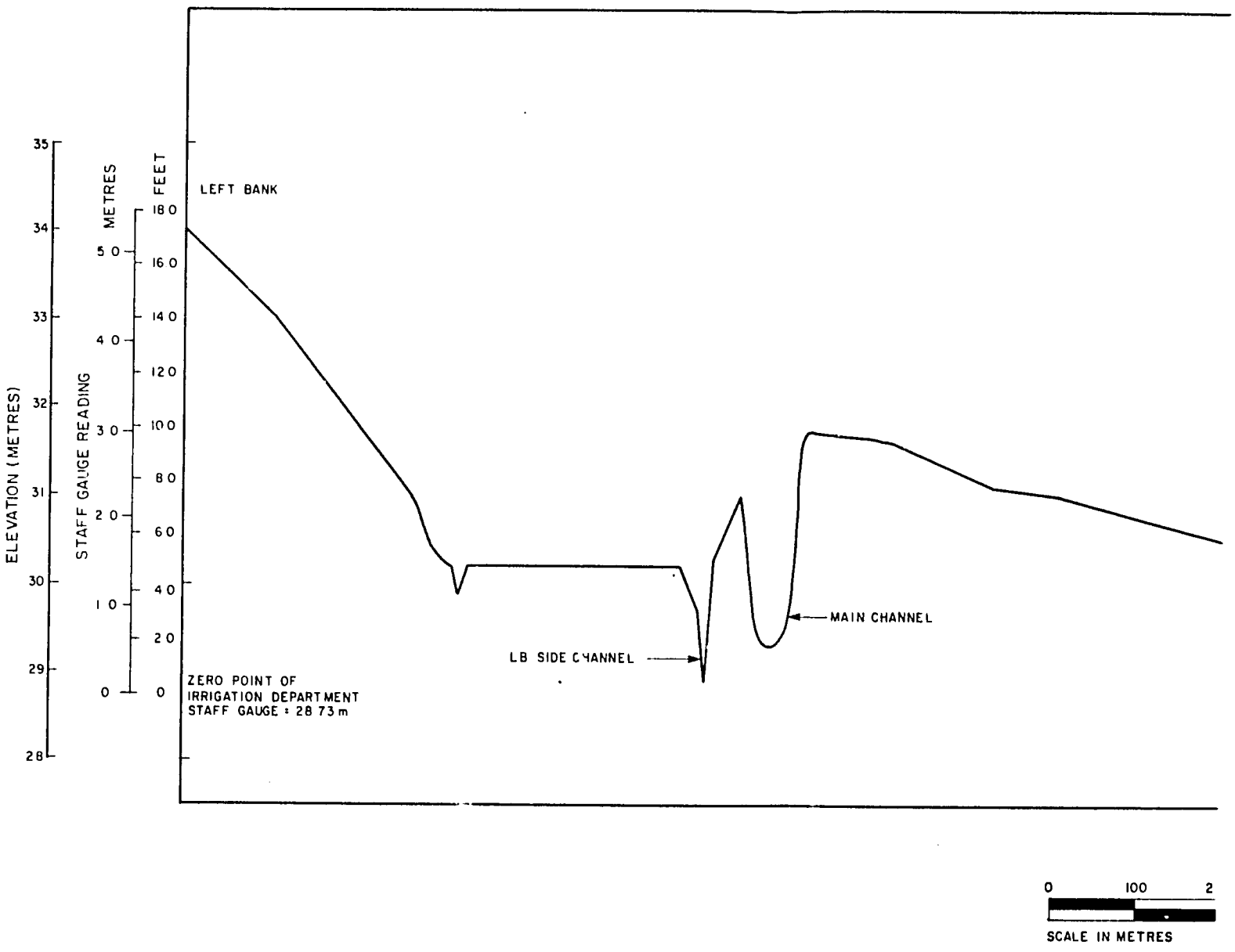


FIG C-2

MINISTRY OF MAHAWELI DEVELOPMENT

MADURU OYA PROJECT FEASIBILITY STUDY

FLOW MEASUREMENTS AT WELIKANDA


ELEVATION (METRES)
35
34
33
32
31
30
29
28
STAFF GAUGE READING
METRES
5 0
4 0
3 0
2 0
1 0
0
FEET
18 0
16 0
14 0
12 0
10 0
8 0
6 0
4 0
2 0
0
LEFT BANK
MAIN CHANNEL
LB SIDE CHANNEL
ZERO POINT OF
IRRIGATION DEPARTMENT
STAFF GAUGE = 28 73 m
0
100
2
SCALE IN METRES

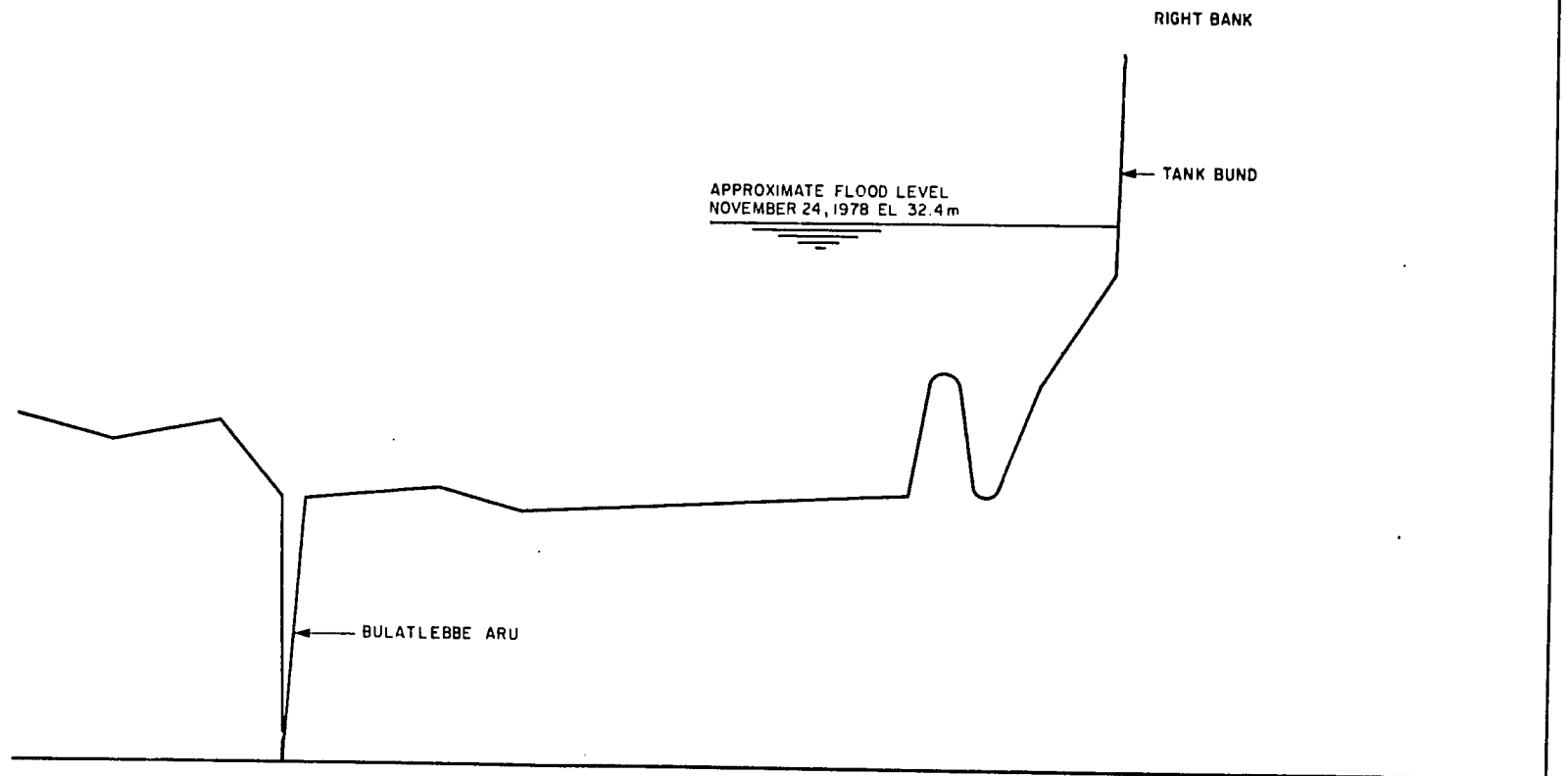
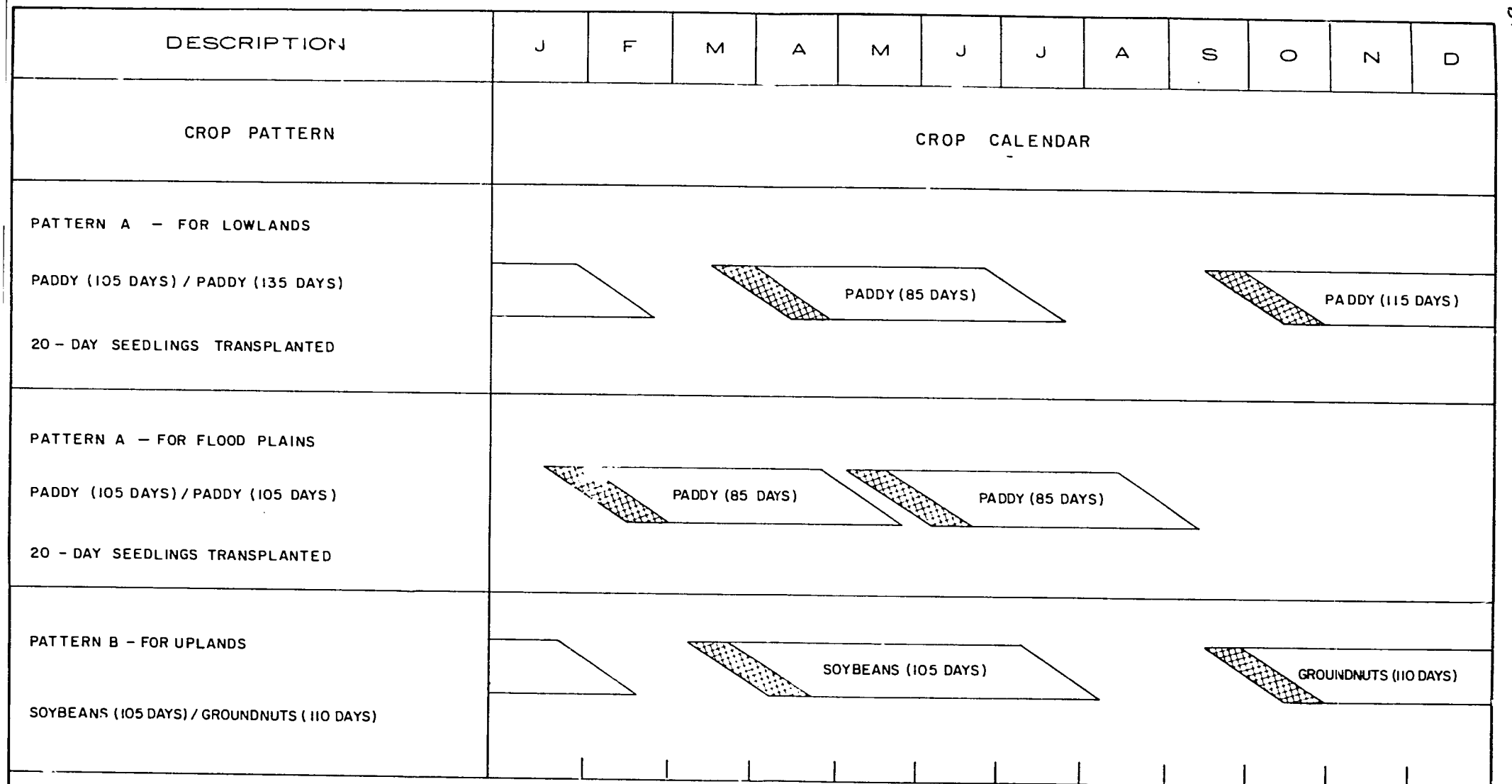


FIG.C-3

MINISTRY OF MAHAWELI DEVELOPMENT
MADURU OYA PROJECT FEASIBILITY STUDY

CROSS SECTION OF MADURU OYA AT WELIKANDA



NOTE

LAND PREPARATION

FIG C-4

MINISTRY OF MAHAWELI DEVELOPMENT
MADURU OYA PROJECT FEASIBILITY STUDY
CROP CALENDAR

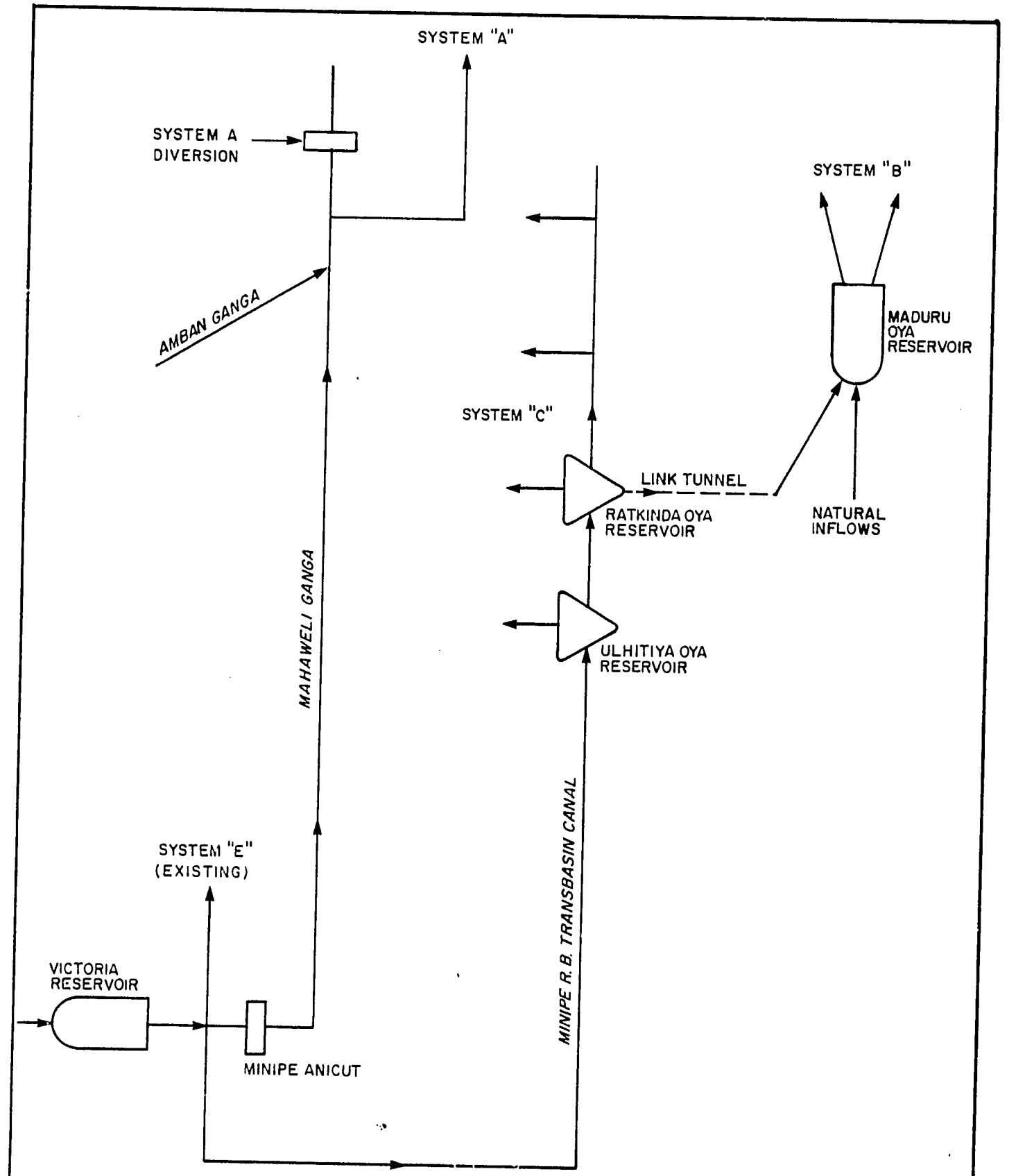
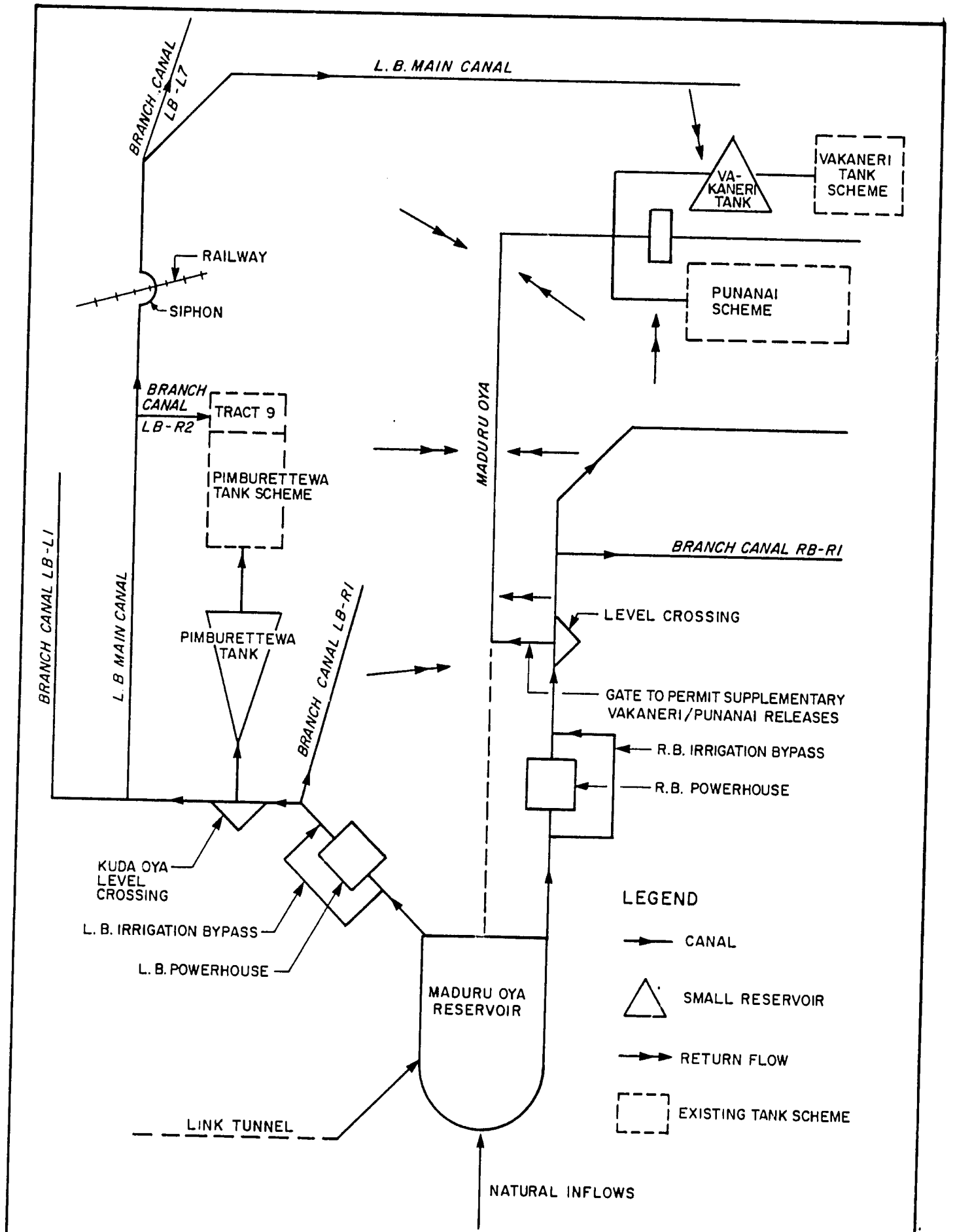


FIG. C-5

MINISTRY OF MAHAWELI DEVELOPMENT
MADURU OYA PROJECT FEASIBILITY STUDY

MAJOR SYSTEM COMPONENTS

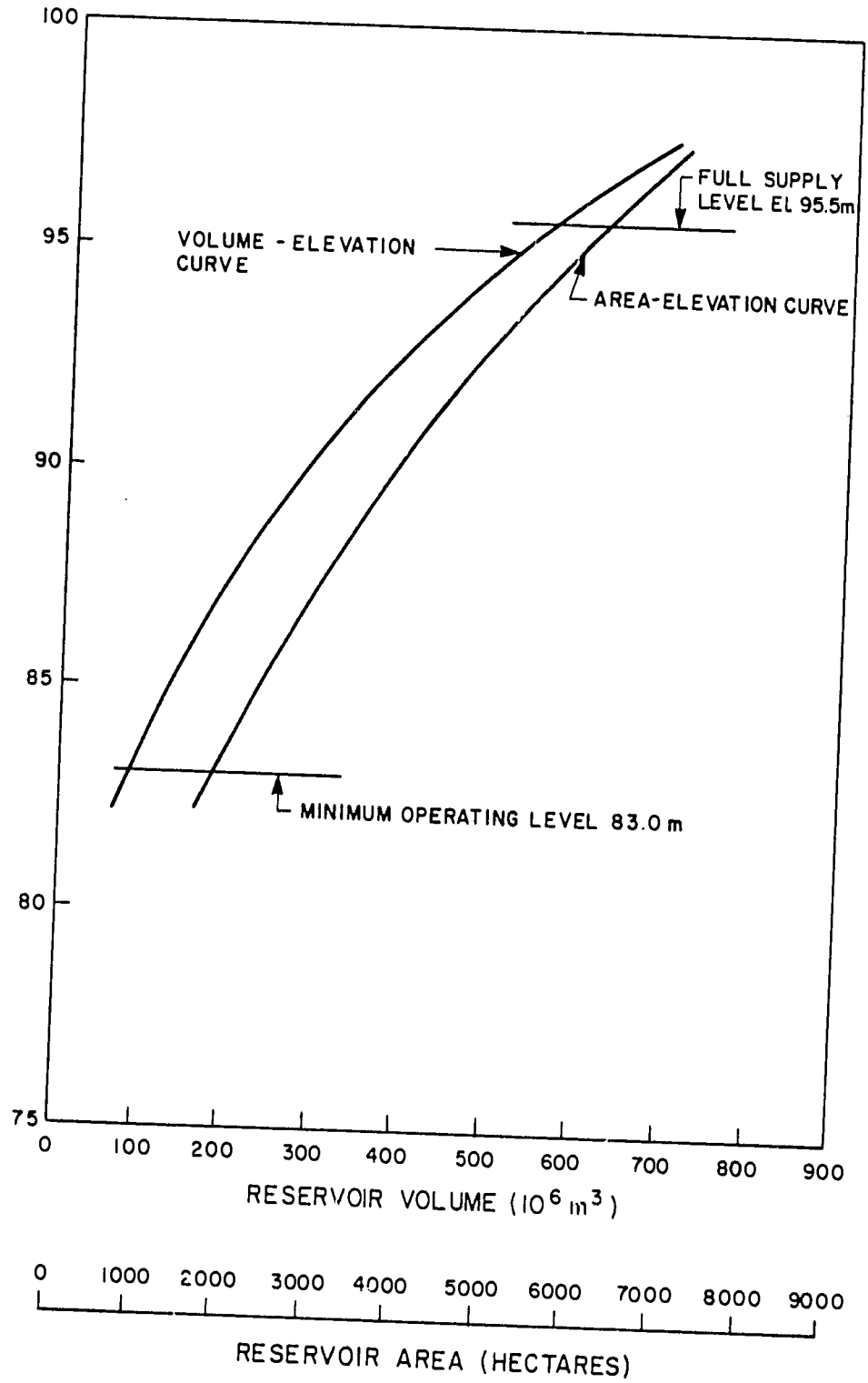
ACRES



MINISTRY OF MAHAWELI DEVELOPMENT
MADURU OYA PROJECT FEASIBILITY STUDY
OPERATIONAL FEATURES

FIG. C-6

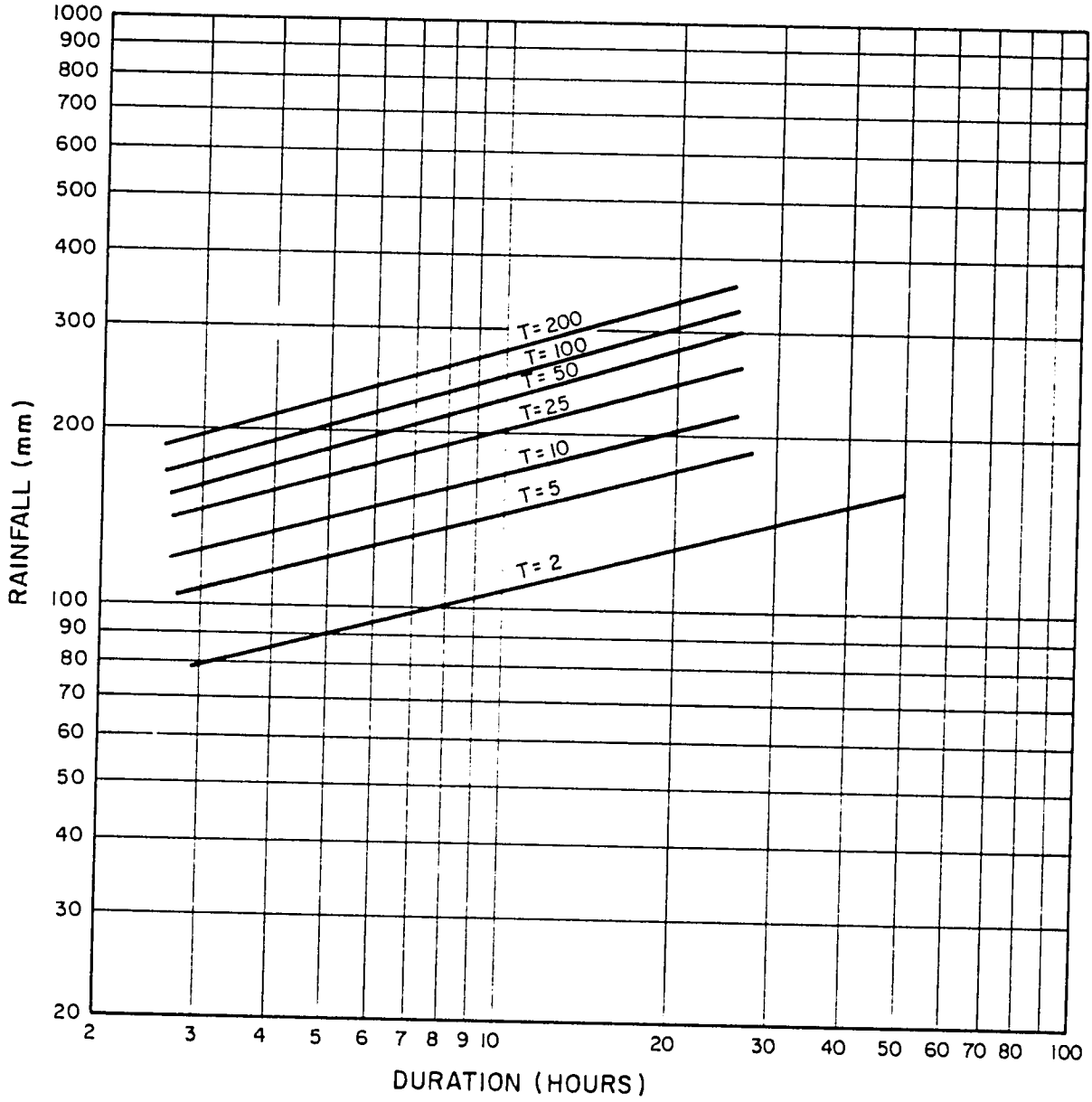
ACRES



MINISTRY OF MAHAWELI DEVELOPMENT
MADURU OYA PROJECT FEASIBILITY STUDY
RESERVOIR CHARACTERISTICS

FIG. C-7

ACHES



SOURCE: VANNIASINGAM R. BAGHIRATHAN AND E M. SHAW
"RAINFALL DEPTH - DURATION FREQUENCY STUDIES FOR SRI LANKA" JOURNAL OF HYDROLOGY, AMSTERDAM VOL 37, 1978.

FIG. C-8

MINISTRY OF MAHAWELI DEVELOPMENT
MADURU OYA PROJECT FEASIBILITY STUDY

ACRES

RAINFALL INTENSITY-DURATION FREQUENCY CURVES FOR SYSTEM B

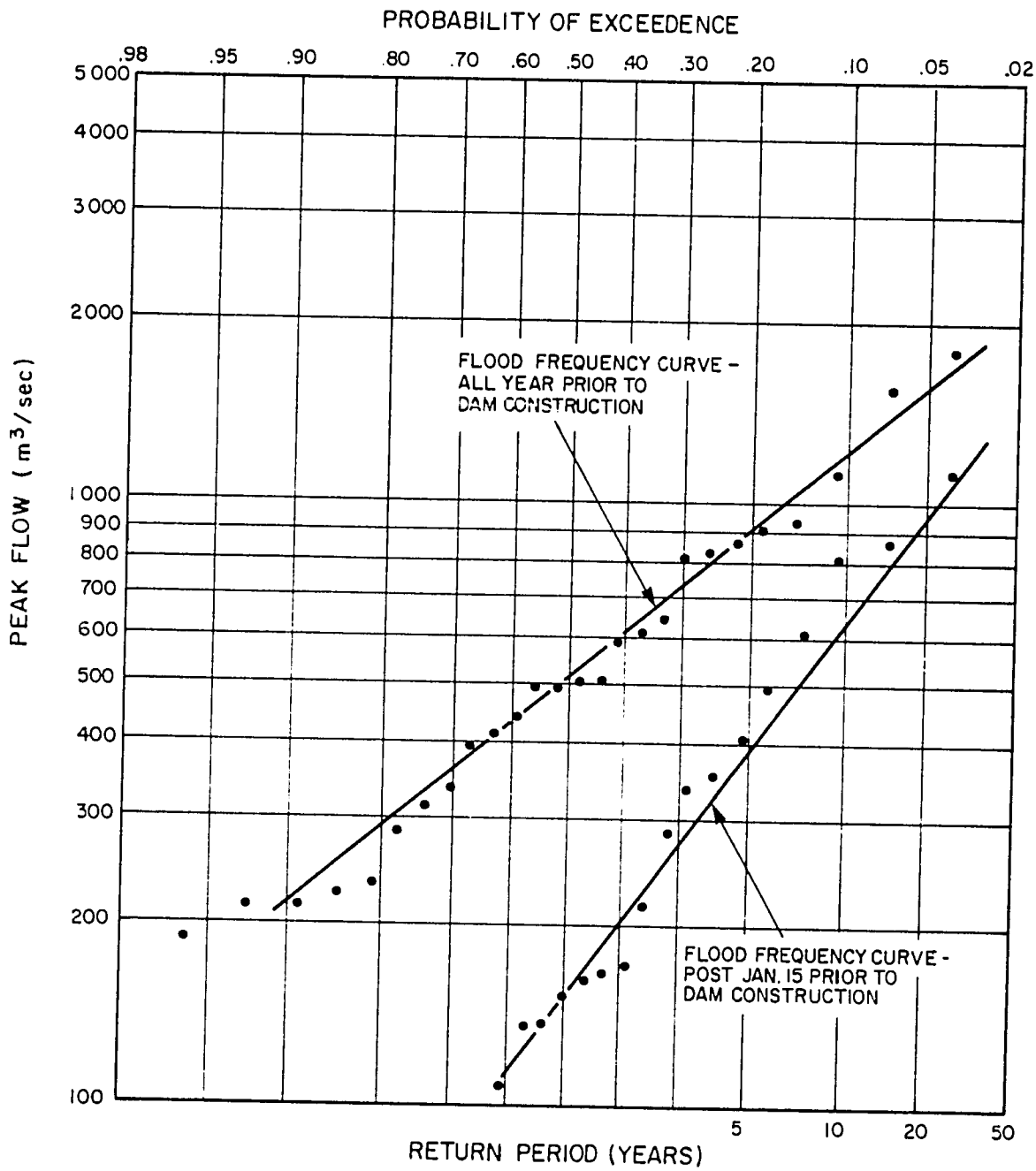


FIG.C-9

MINISTRY OF MAHAWELI DEVELOPMENT

MADURU OYA PROJECT FEASIBILITY STUDY

FLOOD FREQUENCY CURVES FOR WELIKANDA

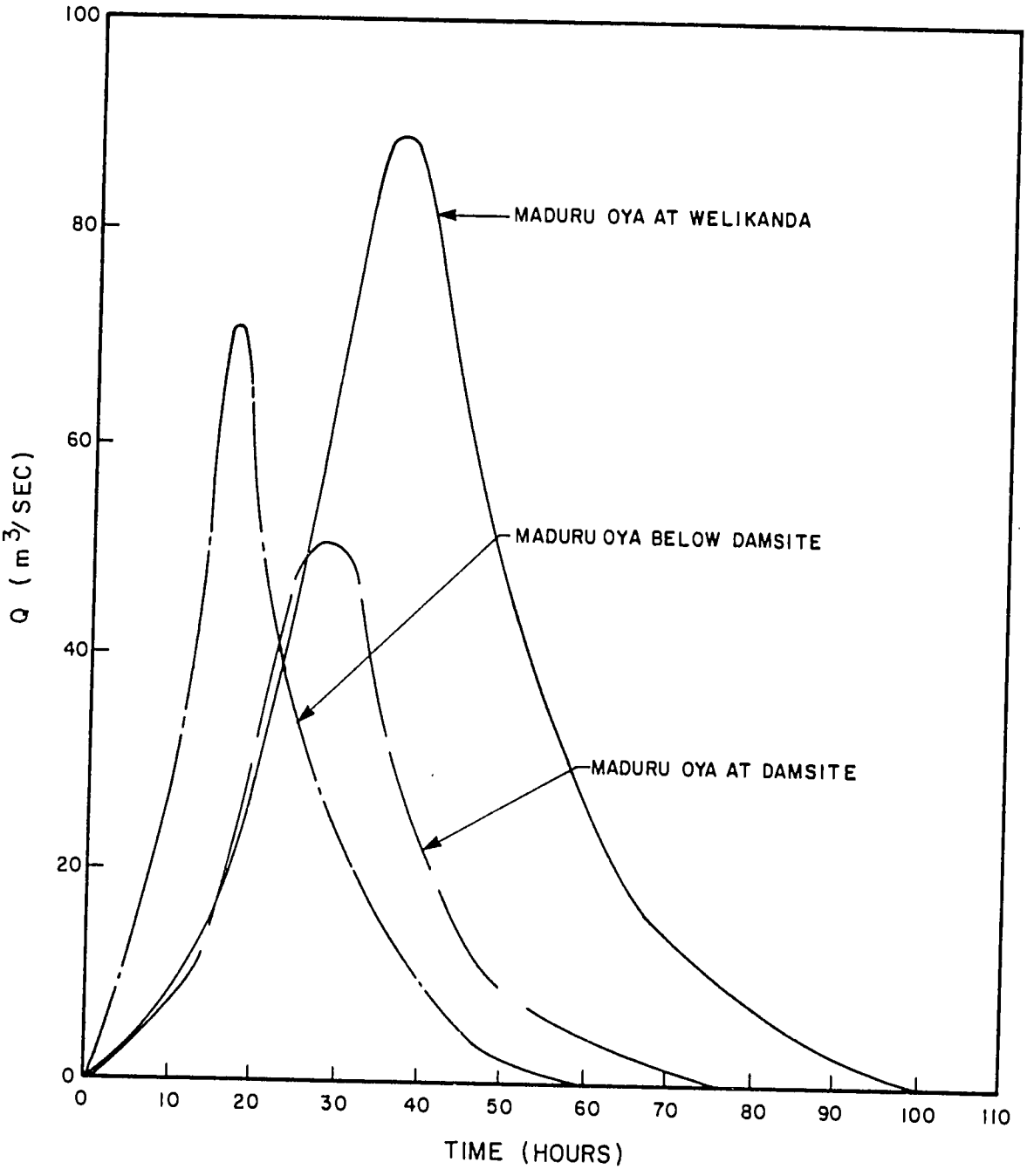


FIG. C - 10

MINISTRY OF MAHAWELI DEVELOPMENT
MADURU OYA PROJECT FEASIBILITY STUDY

3 HR, 10 - MM UNIT HYDROGRAPHS

ACRES