OPTIMIZATION AND STAGING MODELS IN RIVER BASIN PLANNING

A DISSERTATION
submitted in partial fulfilment of
the requirements for the award of the Degree
of
MASTER OF ENGINEERING
in
HYDROLOGY

by
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CERTIFICATE

Certified that the dissertation entitled 'OPTIMIZATION AND STAGING MODELS IN RIVER BASIN PLANNING', which is being submitted by Sri P.Sathyanath, in partial fulfilment for the award of the degree of MASTER OF ENGINEERING IN HYDROLOGY of the University of Roorkee, is a record of bonafide work, carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

It is further certified that he has worked from October 1,1976 to March 31, 1977 for preparing this dissertation for Master of Engineering Degree at the University of Roorkee, Roorkee.

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A C K N O W L E D G E M E N T S

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Sathyanath
4/4/77
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S Y N O P S I S

The goal of river basin planning is to prepare long range development plans to serve as a base for selection of basin configuration and timing of construction of the component units that is optimal. The questions that arise and need to be solved are: What and how big projects should be constructed, where they should be located, when and in what sequence they should be constructed based on budget, need and other constraints. Several mathematical models have been developed to answer these questions.

The object of this study is to indicate, the methodology of application of mathematical models - co-ordination and staging models - to a typical river basin in India viz. Upper Cauvery Basin (Cauvery basin upto Mettur Reservoir) in answering these questions. An attempt to solve these questions has been made by the use of IBM's Mathematical programming System for the 360/44 and IPE package program.

CONTENTS

UNITS AND CONVERSION FACTORS

1 inch = 2.54 centimetres	10 millimetres = 1 centimetre
1 foot = 0.305 metre	1 metre = 3.281 feet
1 acre = 0.40 hectare	1 hectare = 100 metres X 100 metres = 2.471 acres
1 square mile = 2.59 square kilometres = 259 hectares	1 square kilometre = 100 hectares = = 0.386 square mile
1 million cubic feet = 11.574 cusec days = 22.957 acre feet = 28,316.8 cubic metres	1 cubic metre = 35.315 cubic feet
1 thousand million cubic feet = 31.71 cusec for one year = 28.317 million cubic metres = 2.832 thousand hectare metres	1 million cubic metres = 100 hectare metres = 35.31 million cubit feet.

ABBREVIATIONS

MMs	=	Milimeters
TMC	=	Thousand million cubic feet
RS	=	Rupees
Sq. Kms.	=	Square Kilometres
C.A.	=	Catchment Area
t.h.m.	=	Thousand Hectare metres
R.F.	=	Rain Fall
R.G.	=	Rain gauge
O and M	=	Operation and Maintenance
Mcft.	=	Million cubic feet
K.R.S	=	Krishnaraja Sagar
C.R.S.	=	Chamaraja Sagar
P.V.	=	Present Value

CHAPTER I

INTRODUCTION

Problem:

How to carry out an optimal expansion of an existing water resources system is of continuing importance because of the rising demand for and limited supply of water. Governmental agencies have made large investments in the field of water resources in the past and will continue to do so in the future. Whenever investment in a water resource project is under consideration, important questions such as what is the economical value of the projects, what is the optimal scale of development of the projects and when should the projects be constructed need to be asnwered.

It is here attempted to describe a methodology for optimal expansion of a realistic water resource system to meet the increasing demand for irrigation and power over a planning horizon of say 15 years.

In formulating the model, it is assumed that a number of possible dam sites are available for further diversion for irrigation and power. The model has been limited to systems that have (1) deterministic inputs

(2) a net work configuration (3) linear constraints and (4) capital investment and operating decisions made on a yearly basis. The model of the system did not include (1) stochastic effects (2) intangible benefits. Emphasis in the preparation of the model has been placed on the diversity of applicability rather than a specific river basin.

Approach:

System analysis has been attempted to solve the problem of optimal expansion. A system is an arbitrarily isolated combinations of elements of the real world. For a river basin these components are rivers, dams, sources of water and users of water. The mathematical representation of the system is termed as 'the model' of the system. Systems approach represents an attempt to find answers to questions that are posed regarding complex assemblies of physical systems with interaction between the sub-systems. Normally systems analysis is undertaken in order to make rational decisions in so far as possible as to the optimal design, selection or operation of a physical system.

The first phase of systems analysis consists of understanding the objectives and performance requirements.

The next phase is to formulate the structure and boundary of the system. Then a mathematical model is prepared to include all the possible inter-relations between the variables that can be qualified. Then the coefficients in the model are estimated and the desired input relations specified.

Finally, the model is used to get the required answers.

In our case, the staging model has been attempted with a view to optimally expand the existing water resources system. A typical river basin similar to Upper Cauvery Basin is taken for our study. The data and all the required particulars are taken from the 'Master Plan for an Equitable Use of the Waters of the Cauvery Basin in Karnataka' published by Water Resources Development Organization, Govt. of Karnataka. Suitable assumptions have been made wherever necessary.

The Upper Cauvery basin, its hydrological features, the net work of existing and proposed projects, their costs and benefits have been discussed in Chapter II. A water resources system model is developed for scheduling and optimizing the available resources and explained in Chapter III. Chapter IV indicates a method of solving the problem. Conclusions have been drawnup in Chapter V.

CHAPTER II

THE RIVER SYSTEM

The Upper Cauvery Basin:

The river system considered for our problem is the river having configuration typical to Cauvery from its source upto Mettur reservoir, together with all its tributaries which fall into the Cauvery in the reach. This sub basin of the river Cauvery is termed as the Upper Cauvery basin. This upper Cauvery basin has 12 principal tributaries. They are Harangi, Hemavathy, Lakshmanathirtha, Lokapavani, Kabini, Suvarnavathi, Shimsha, Arkavathi, Uduthorchalla, Chinnar, Palar and Thoppaiar. In terms of catchment area, the two largest are the Shimsha and the Kabini and the longest one is the Hemavathy. An index map showing the Upper Cauvery basin is appended (Map I).

Sub-Basins:

The upper Cauvery basin has been divided into the following sub basins for study purposes.

C_1	The catchment of Cauvery and its tributaries upto Krishnarajasagara Sagar Dam.
C_2	Kabini river sub basin
C_3	Suvarnavathy sub basin

C_4 Shimsha Sub basin

C_5 Arkavathy sub basin

C_6 The balance catchment of Cauver y upto Mettur Dam excluding C_7 and C_8

C_7 Palar sub basin

C_8 Chinnar sub basin

The above sub-basins are shown in the Map-I.

Rainfall:

Like most other parts of India, the Upper Cauvery basin receives its maximum rainfall during the South-west monsoon. There are 78 raingauges in and around the Upper Cauvery basin. The normal annual rainfall at these stations are available. The annual normal rainfall of the stations, that are used for our study have been given (table A). Also the basin map showing the locations of the raingauge stations is appended (Map I).

River Flow:

There are 15 discharge sites on the Cauvery river and its distributaries, in this basin. Of them 4 are on the main river and the rest are on its tributaries. Map I gives the location of these sites and table B gives the relevant particulars of these sites.

Irrigation and Power Projects:

There are 9 existing major and medium irrigation projects and 1 hydel scheme. Eight major and medium irrigation projects are under construction. Forty five major and medium schemes are proposed in this basin.

Of the above projects, we could consider only those schemes for which we could get the estimated cost and other required particulars. Table C gives the required particulars of these schemes. These schemes have been shown in a scheamatic diagram on plate 1.

Benefit and Cost:

The increased utilization of water resources for irrigation promotes a sharp rise in productivity of agriculture and the introduction of more valuable and profitable ~~costs~~ crops. Crop yields are not only significantly increased but are far less variable since they are no longer dependent exclusively upon the rainfall. The direct benefits of new or supplemental irrigation are the difference between the annual net income from farm produce 'with' irrigation and that 'without' irrigation.

Based on the above principle, benefits from all the proposed schemes have been worked out vide

Table D. Also annual costs of all these schemes are also worked out and presented in table E.

Critical Period Analysis:

When a long-term historical hydrologic record is used to analyse the firm output levels of water and energy, the optimum policy will be controlled by a sequence of sub normal flows over a consecutive portion of the record. This time period, always begins with the reservoir full and always ends with the reservoir at its lowest permissible value. This period is termed as 'Critical Period'.

The critical period, for our study, is considered from Nov.64 to May 67 (i.e. 31 months). It is assumed that all the projects are designed for this critical period.

Hydrology:

Discharge data is available at Krishnarajasagar. It is not available at other project sites. The inflow data at these sites is estimated from the discharge data available on the stream for sites upstream or downstream of the project sites. vide table F

Regeneration:

The entire water divarted for irrigation is not utilized by crops in meeting its evapotranspirational needs. Some portions of it seeps into the ground and finds its way into the parent river or downstream after some period. This flow back into the river is known as 'return flow' or 'regeneration'. It has been observed that this is about 57 percent of the withdrawals (vide supplement to Annexture VI - Part II, Master Plan of the Cauvery basin). However, it is assumed as 55 percent for our problem.

MAP 1

INDEX MAP OF UPPER CAUVERY BASIN

SCALE 10 0 10 20 30 40 KM

Basin	
Sub basin	
River & tributary	
Discharge site	
Raingauge station	
Project site	
Hemavathy	H.M.T.
Lakshmanatirtha	L.T.
Votehole	VOT
Yagachi	YGH

Refer TABLES		
	A	FOR RAINGAUGE STATIONS
	B	FOR DISCHARGE SITES
	H	FOR PROJECT SITES

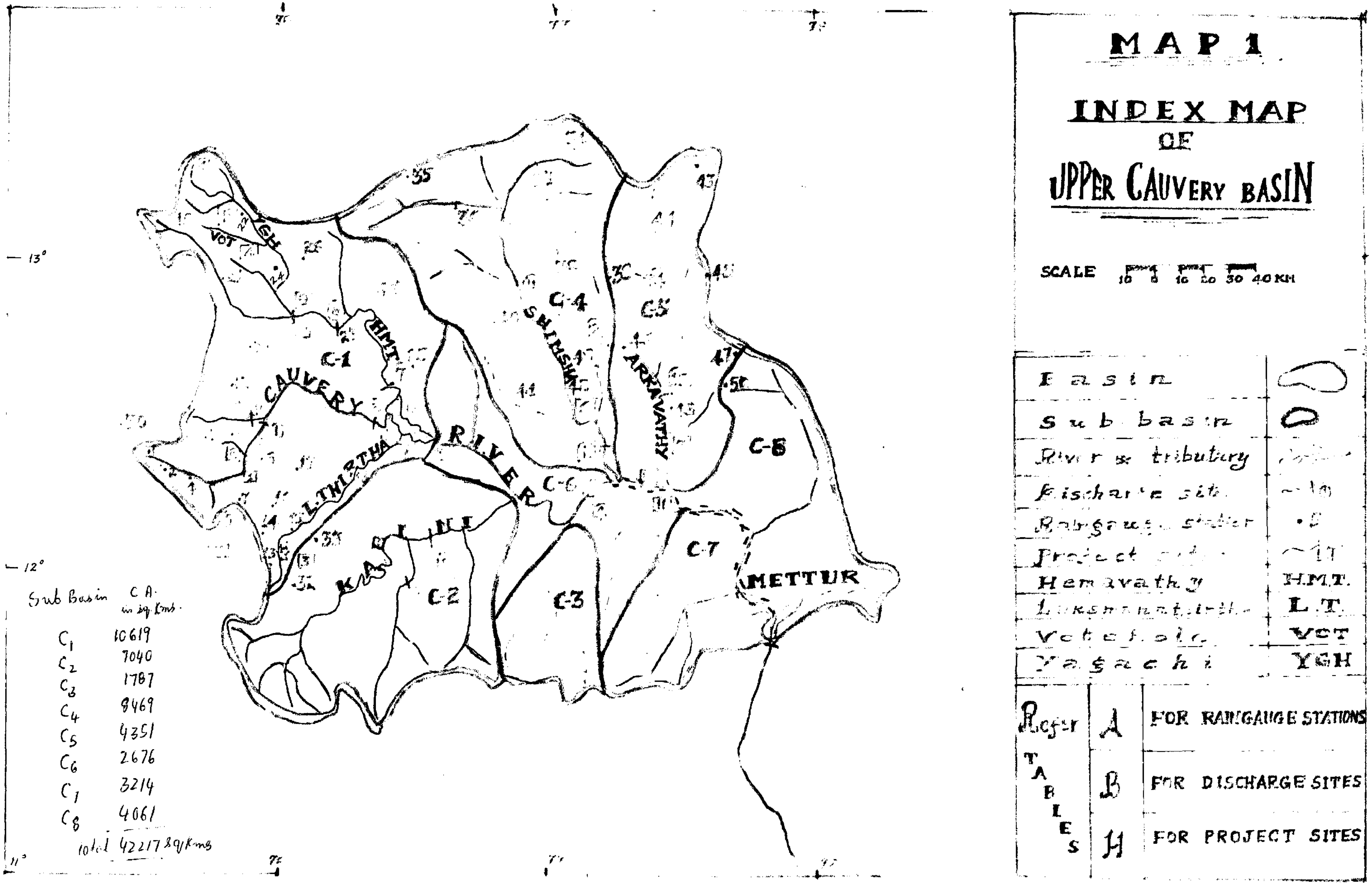
13°

12°

Sub

11°

Sourc



Sub Basin	C.A. in sq. Kms.
C_1	10619
C_2	7040
C_3	1787
C_4	8469
C_5	4351
C_6	2676
C_7	3214
C_8	4061
Total	42217 Sq Kms

Source: Map [illegible] Rain[illegible] Basin
P.9 of Statement V of part III of the Master plan

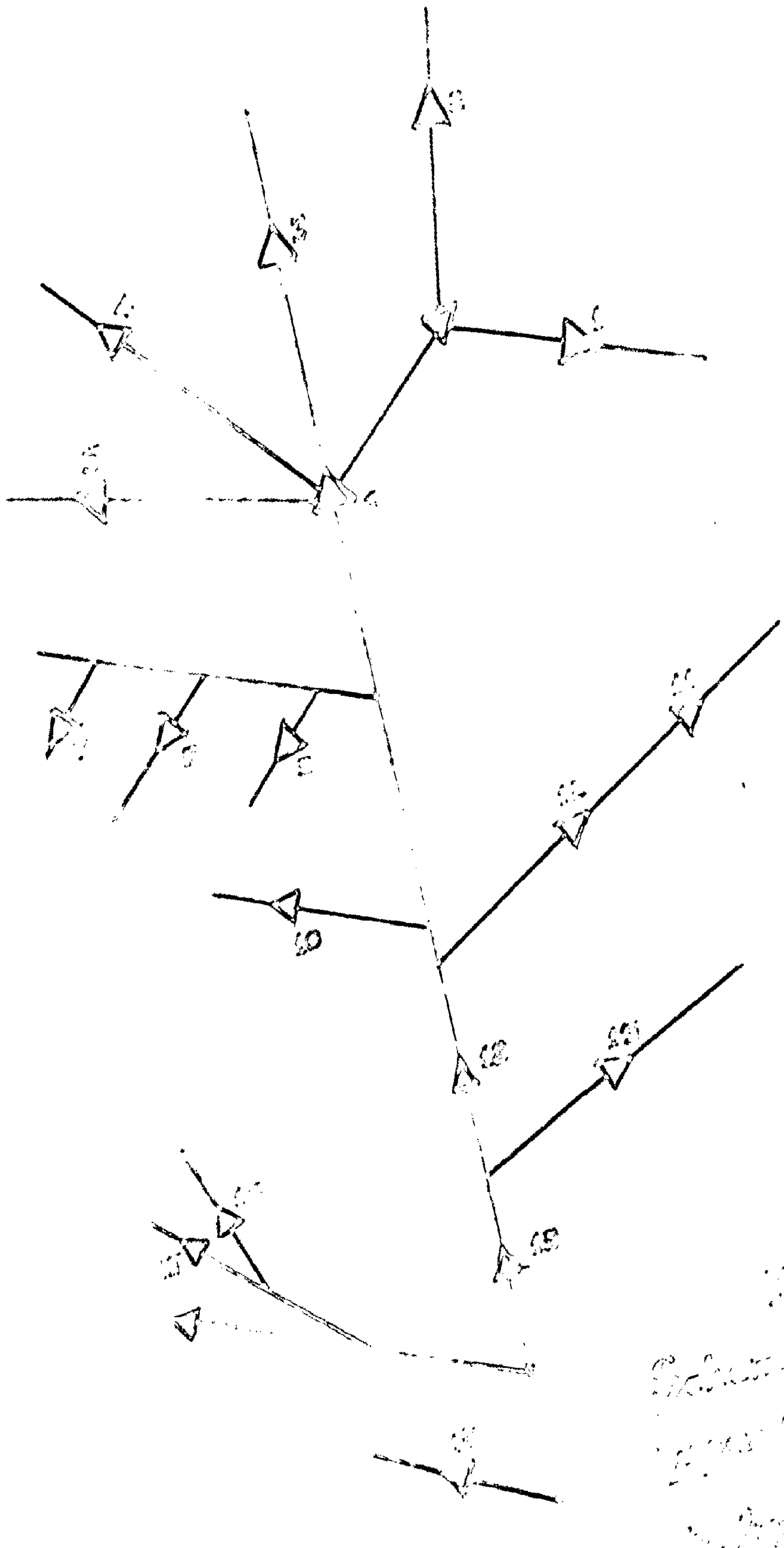


PLATE 5

Schematic diagram [illegible]

TABLE - A

NORMAL ANNUAL RAINFALL IN MMs.

S.No.	Raingauge Station	Rainfall	S.No.	Raingauge Station	Rainfall
(1)	(2)	(3)	(4)	(5)	(6)
1.	Bhagamandala	6032.3	21.	Mudigere	2339.2
2.	Pullingoth	5940.7	22.	Belur	1001.0
3.	Mercara	3265.4	23.	Sanivarasanthi	1883.7
4.	Napoklu	3105.3	24.	Alur	1053.9
5.	Virajpet	2671.8			
6.	Sunticoppa	1763.8	25.	Arkalgud	947.9
7.	Ammathi	2240.2	26.	Hassan	878.7
8.	Fraserpet	1120.0	27.	Holenarsinpur	708.7
9.	Dubare	1287.2	28.	Channarayapatna	713.1
10.	Hudugur	1154.1	29.	K.R.Pet	742.0
11.	K.R.Nagar	680.5	30.	Karike	4855.9
12.	Somwarpet	2175.2	31.	Makut	5054.3
13.	Srimangala	2878.8	32.	Belcove	1868.4
14.	Ponnampet	2421	33.	Murkhal	1427.3
15.	Karmad	1667.5	34.	Tumkur	806.9
16.	Thitimati	1320.9	35.	Tiptur	615.2
17.	Periyapatna	845.8	36.	Thurvekere	708.9
18.	Hunsur	762.8	37.	Gubbi	771.6
19.	Chikmagalur	921.8	38.	Kunigal	764.5
20.	Sakleshpur	2348.7	39.	Magadi	777.2

S.No.	Raingauge Station	Rainfall
40.	Nagamangala	675.9
41.	Mandya	688.5
42.	Maddur	680.9
43.	Doballapur	741.2
44.	Nelamangala	760.1
45.	Bangalore	888.9
46.	Ramanagaram	844.8
47.	Ankal	804.6
48.	Kanakapura	805.2
49.	Channapatna	839.5
50.	Thally	853.5

Source: PP. 21, 23, 25 of APPENDIX-I of the Master Plan of the Cauvery Basin.

TABLE - B

GAUGE DISCHARGE SITES ON THE UPPER CAUVERY RIVER SYSTEM

S.No.	Name of the gauging station	Name of the river or tributary	Data available from	Method of gauging	REMARKS
1.	Kushalnagar	Cauvery	1967	Current-meter	-
2.	Chunchanakatte	-do-	1916	-do-	Data used
3.	Krishnarajasagar	-do-	1934	Reservoir	Data used
4.	Dhanagere Ane	-do-	1948	Weir	-
5.	Hudgur	Hasangi	1964	-do-	-
6.	Sree Rama Devaru Ane	Hemavathi	1950	-do-	-
7.	Akkihebbal	-do-	1916	Current meter	Data used
8.	Unduwadi	Lakshmanathirtha	1916	-do-	Data used
9.	Nugu dam	Nugu/Kabini	1961	Reservoir	-
10.	Hullahalli	Kabini	1916	Weir	Data used
11.	Marconahalli	Shimsha	1940	Reservoir	Data used
12.	Kanua reservoir	Kanva/Shimsha	1949	-do-	-
13.	Torekadanahalli bridge	Shimsha	1970	Current-meter	-
14.	Chamarajasagar	Arkavathi	1937	Reservoir	Data used
15.	Kanakapura bridge	-do-	1970	Current-meter	-

Source: P.25 of Part III of the Master Plan of the Cauvery Basin.

Sl. No.	Nam	MI LIGHT	CROPPED AREA	DIVERSION IN TMC
1.	Vot	-	53.0	2.2
2.	Nag	101.0	142.0	4.2
3.	Cau	170.0	405.0	13.0
4.	Chi	-	22.0	0.9
5.	Lak	-	28.0	1.1
6.	Ext	496.0	1089.0	22.2
7.	Sag	8.0	22.0	0.4
8.	Kud	-	20.0	0.3
9.	Nal	-	16.0	0.3
10.	Heb	4.0	12.0	0.2
11.	Upp	40.0	80.0	1.8
12.	Igg	11.0	43.0	1.3
13.	Ark	26.0	74.0	2.5
17 14.	Min	9.0	24.0	1.2
15.	Cha	22.0	49.0	1.2
16.	Dod	-	12.0	0.2
14 17.	Udu	-	66.0	1.5
18.	Mak	-	-	181.7
19.	Mut	-	-	178.7

VI of the

Sl. No.	Name of the scheme	Live storage in TMC	Ayacut	IRRIGATION Perennial	KHARIF PADDY	KHARIF LIGHT	RABI PADDY	RABI LIGHT	CROPPED AREA	DIVERSION IN TMC
			In Hundred Hectares							
1.	Votehole	0.9	53.0	-	26.0	27.0	-	-	53.0	2.2
2.	Yagachi	1.0	142.0	-	41.0	-	-	101.0	142.0	4.2
3.	Cauvery Reservoir	5.1	405.0	65.0	-	170.0	-	170.0	405.0	13.0
4.	Chicklihole	0.2	22.0	-	22.0	-	-	-	22.0	0.9
5.	Lakshmanathirtha	0.7	28.0	-	28.0	-	-	-	28.0	1.1
6.	Extension under KRS	-	749.0	283.0	92.0	218.0	-	496.0	1089.0	22.2
7.	Sagaredoddakere	0.2	14.0	-	-	14.0	-	8.0	22.0	0.4
8.	Kuduregondihalla	0.3	20.0	-	-	20.0	-	-	20.0	0.3
9.	Nalluramanikere	0.4	16.0	-	-	16.0	-	-	16.0	0.3
10.	Hebbahalla	0.1	8.0	4.0	4.0	-	-	4.0	12.0	0.2
11.	Upper Shimsha	1.0	40.0	-	-	40.0	-	40.0	80.0	1.8
12.	Iggalur	-	32.0	12.0	14.0	6.0	-	11.0	43.0	1.3
13.	Arkavathy	1.5	49.0	22.0	20.0	6.0	-	26.0	74.0	2.5
14. [17]	Minnattuhalla	0.5	12.0	-	12.0	-	3.0	9.0	24.0	1.2
15.	Changawadi	0.3	26.0	4.0	9.0	13.0	-	22.0	49.0	1.2
16.	Doddihalla	0.2	12.0	2.0	-	10.0	-	-	12.0	0.2
17. [14]	Uduthorehalla	0.8	66.0	10.0	24.0	32.0	-	-	66.0	1.5
18.	Mekedatu hydel	-	Operating head = 167 feet (average)					-	-	181.7
19.	Muttati Hydel	108.7	Operating head = 592 feet (Average)					-	-	178.7

Source : PP5 -12 of Appendix V and P.8 of Appendix VI of the Master Plan of the Cauvery Basin.

TABLE - D

BENEFITS FROM PROJECTS

1. CROP YIELD AND CROP RATES

S.No.	CROP	Yield in Quintals/ hectare		Rate in Rs./ Quintal		Gross Value	Cost of cultivation per hectare	Net benefit Rs./hect
		Grain	Straw	Grain	Straw			
	(1) WITH IRRIGATION							
1.	Sugar-cane	900	-	14	-	12600	2600	10000
2.	Malbarry	-	-	-	-	-	-	4500
3.	Kh.Paddy	50	50	80	15	4750	1000	3750
4.	Kh. semi dry	15	12	70	15	1230	600	630
5.	Rabi semi dry	8	10	70	15	710	410	300
	(2) WITHOUT IRRIGATION							
1.	Kh.paddy	20	25	80	15	1975	725	1200
2.	Kh. semi dry	10	8	70	15	820	390	430
3.	Mulberry	-	-	-	-	-	-	1500

Note: Yield of crops and rates are suitably assumed

BENEFITS FROM IRRIGATION PROJECTS

Sl. No.	Name of the project	Cropping Pattern in hectares: Sugercane	Mulbery	Kharif paddy	Kharif light	Rabi light	Net Benefit with Irrigation In Rupees lakhs: Sugercane	Mulberry	Kharif Paddy	Kharif light	Rabi light	Total	Net Benefit without Irrigation In Rupees lakhs: Sugercane	Mulbery	Kharif Paddy	Kharif light	Rabi light	Total	Actual Benefit
1.	Cauvery Reservoir Project	3200+ 1650	-	-	17000	17000	320 + 165	-	-	107.1	51.00	643.10	-	-	-	73.10	-	73.10	570.00
2.	Chicklihole Project		-	2200	-	-	-	-	82.50	-	-	82.50	-	-	6.37	-	-	6.37	76.13
3.	Lakshmanathirtha Project		-	2800	-	-	-	-	105.00	-	-	-	-	-	-	-	-	-	105.00
4.	Votehole Project		-	2600	2600	-	-	-	97.5	16.4	-	113.9	-	-	-	11.0	-	11.0	102.9
5.	Yagachi Project		-	4100	-	10100	-	-	153.75	-	30.30	184.05	-	-	-	-	-	-	184.05
6.	Iggalur Pick Up		1200	1400	600	1190	-	54.0	52.50	3.78	3.30	113.58	-	18.0	-	2.58	-	20.58	93.00
7.	Arkavathy Project		2200	2000	600	2600	-	99.0	75.0	3.78	7.80	185.58	-	33.0	-	2.58	-	35.58	150.00
8.	Extension Under KRS		28300	9200	21800	49600	-	1273.5	345.0	137.34	148.80	904.64	-	424.5	-	93.74	-	518.24	1386.40
9.	Sagaredoddakere		-	-	1400	800	-	-	-	8.82	2.40	11.22	-	-	-	6.02	-	6.02	5.20
10.	Kuduregondihalla		-	-	2000	-	-	-	-	12.60	-	-	-	-	-	8.60	-	8.60	4.00
11.	Hebbahalla		400	400	-	400	-	18.00	15.00	-	4.20	34.20	-	6.00	-	-	-	6.00	28.40
12.	Minnattuhalla		-	1200	-	900	-	-	45.00	-	11.25 +2.7	58.95	-	-	-	-	-	-	58.95
13.	Changawadi		400	900 Rabi paddy 300	1300	2200	-	18.00	33.75	8.19	6.60	66.54	-	6.00	-	5.59	-	11.59	54.95
14.	Doddihalla		200	-	1000	-	-	9.0	-	6.30	-	15.30	-	3.00	-	4.30	-	7.30	8.00
15.	Uduthorehalla		1000	2400	3200	-	-	45.00	90.00	20.16	-	155.16	-	15.00	-	13.76	-	28.76	126.40
16.	Malluramanikere		-	-	1600	-	-	-	-	10.08	-	10.08	-	-	-	6.88	-	6.88	3.20
17.	Upper Shemsha		-	-	4000	4000	-	-	-	25.2	12.0	37.20	-	-	-	17.2	-	17.2	20.00

(TABLE -D contd.)

3. BENEFITS FROM POWER SXHEME

Total cost of the power projects	Rs. 45000 lakhs
Interest at 10 %	= Rs. 45000 lakhs
Depreciation at 1.8%	Rs. 810 lakhs
Operation and Maintenance at 1 %	Rs. 450 lakhs
TOTAL	Rs. 5760 lakhs

Total Units generated 2700 million

Cost per unit generated $\frac{5760 \times 10^5}{2700 \times 10^6}$ = 0.24

i.e. 21.4 payse/unit

		Benefit in Rs. lakhs
Muttati	2098 units	5245.00
Mekkedatu	602 million units	1505.00

Note: Depreciation rate of 1.8 % is assumed based on other hydel projects of Karnataka State

Source: Appendix-VI of the Master Plan of the Cauvery Basin

TABLE - E

ANNUAL COSTS OF PROJECTS

S.No.	Name of the Project	Estimated capital cost in Rs.lakhs	Interest on capital at 10%	O and M charges at 1%	Deprecations at 1%	Total annual cost
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	Cauvery Reservoir	2850	285.0	28.5	28.5	342.0
2.	Chickklihole	230	23.0	2.3	2.3	27.6
3.	Lakshmanathirtha	230	23.0	2.3	2.3	27.6
4.	Votehole	480	48.0	4.8	4.8	57.6
5.	Yagachi	1060	106.0	10.6	10.6	127.2
6.	Iggahur	290	29.0	2.9	2.9	34.8
7.	Arkavathy	855	85.5	8.55	8.55	102.60
8.	Extension under KRS	5800	580.0	58.0	58.0	696.0
9.	Sagaredoddakere	132	13.2	1.32	1.32	15.84
10.	Kuduregondihalla	130	13.0	1.3	1.3	15.6
11.	Hebbahalla	130	13.0	1.3	1.3	15.6
12.	Minnathuhalla	232	23.2	2.32	2.32	27.84
13.	Changawadi	170	17.0	1.7	1.7	20.4
14.	Doddihalla	101	10.1	1.01	1.01	12.12
15.	Uduthorchalla	850	85.0	8.5	8.5	102.0
16.	Nalluramanikere	125	12.5	1.25	1.25	15.0
17.	Upper Shimsha	262	26.2	2.62	2.62	31.44
18.	Muttati	30000	3000	300	300	3600.00
19.	Mekedatu	15000	1500	150	150	1800.0

Notes: Project costs are based on information obtained from Karnataka State

TABLE - F

HYDROLOGY

1. CONVERSION FACTORS

S.No.	Name of the Project	At the project site C.A. sq.kms	At the project site R.F. mms	At the project site R.Gs considered	Discharge site	At the project site C.A. sq.kms	At the project site R.F. mms	At the project site R.Gs considered	Conversion factor = f = (Col.3 X Col.4) / (Col.7 X Col.8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1.	Cauvery Reservoir	1011	4146	1-5,7, 30,31	Chunchankatte	2966	2862	1-12 23,30,31	0.5
2.	Chicklihole	55	1763.8	6	-do-	2966	2862	-do-	0.0114
3.	Lakshmanathirtha	116.5	2878.8	13	Unduwadi	1502	1541.5	11,13-18 32,33	0.145
4.	Votehole	11.5	1670.0	19,22	Akkihebbal	5191	1231	19-29	0.0292
5.	Yaggachi	545	1421	19,20,22	-do-	5191	1231	-do-	0.125
6.	Iggalur	7050	714	40,42 34-38	Marconahally	1595	734	34-38	4.30
7.	Arkavathy	3560	812.8	39,43-50	Chamarajasagar	1437	759.2	39,43,44	2.64
8.	Hemavathy	2810	1591.4	19-24	Akkihebbal	5191	1231	19-29	0.70

Source: C.A. figures are based on information obtained from Karnataka State

TABLE - F (Continued)

2. INFLOW FROM INDEPENDENT CATCHMENT AREAS OF PROJECTS (From November 1964 to May 1967)

Periods	Cauvery Reservoir Project		Chicklihole Project		Lakshmanathirtha Project		Votehole Project	
	At Chunchanakatte	At Project Site	At Chunchankatte	At Project Site	At Unduwadi	At Project site	At Akkihebbal	At Project site
1.	2.	3.	4.	5.	6.	7.	8.	9.
November 1964	2520	f = 0.5 107970 x 0.5 = 53985 Annual inflow = 53985 x 12 / 31 = 20950 or 59.5 thm	Same as in column 2	f = 0.0114 107970 x 0.0114 = 1233 Annual inflow = 1233 x 12 / 31 = 480 or 1.36 thm.	750	f = 0.145 12500 x 0.145 = 1820 Annual inflow = 1820 x 12 / 31 = 710 or 2.10 tm.	7830	f = 0.0292 120076 x0.0292 = 3509 Annual inflow = 3509 x 12 / 31 = 1360 or 3.85 thm.
Dec.64 to May 65	2070				480		7460	
June 65 to Nov. 65	54770				7370		46330	
Dec. 65 to May 66	2460				140		5150	
June 66 to Nov. 66	43150				3560		46736	
Dec.66 to May 67	3000				200		6570	
	107970				12500		120076	

Periods	Yagachi Project		Iggalur Project		Krishnaraja Sagar Project		Hemavathy Project	
	At Akkihebbal	At project site	At Maroonahalli	At Project Site	At KRS		Akkihebbal	At Project site
	10.	11.	12.	13.	14.	15.	16.	17.
November 1964	Same as in Column 8	f = 0.125 120076 x 0.125 = 15013 Annual inflow 15013 x 12 / 31 = 5810 or 16.4 tm.	9525	f = 4.3 31241 x 4.3 = 134280 Annual inflow = 134280 x 12 / 31 = 52000 or 147 thm.	8811	Inflow from Independent c.a. = 253915 - (Col.3 + Col.5 + Col.7 + Col.17) = 112817 Annual inflow = 112817 x 12 / 31 = 43750 or 125.5 thm.	Same as in column 8	f = 0.7 120076 x 0.7 = 84060 Inflow from independent c.a. = 84060 - (Col.9 + Col. 11) = 65538 Annual inflow = 65538 x 12 / 31 = 25400 or 72.0 thm.
Dec. 64 to May 65			856		6223			
June 65 to Nov. 65			309		111287			
Dec.65 to May 66			132		8066			
June 66 to Nov. 66			16994		109841			
Dec. 66 to May 67			3425		9687			

Note:- All Figures in Million Cubic Ft. unless specified.

(TABLE -F contd.)

Period	Arkavathy Reservoir Project	
	At C.R.S.	At project Site
	(18)	(19)
Nov.64	6455	f = 2.64
Dec.64 to May 64	9312	
June 65 to Nov. 65	813	24236 x 2.64
Dec. 65 to May 66	260	= 64028
June 66 to N Nov. 66	6858	Annual
Dec. 66 to May 67	538	64028 x 12 / 31 = 24,800
	24236	or 70.2 t.h.m.

Source: pp 6-7, 16-17, 20-21, 28-29, 34-35 of Appendix-II and pp 14-20 of Appendix-IV of the Master Plan of the Cauvery Basin.

(TABLE F - contd.)

3. INFLOW FROM INDEPENDENT CATCHMENT AREA OF MUTTATI

(for the critical period)

1. River gains and losses from KRS to Mettur (pp-48-49 of Appendix-II of the Master Plan) 52.54 + 31.45 + 35.83 + 8.15 + 118.02 + 12.08	258.07 TMC
2. Add Kabini at Hullahalli (pp 24-25 of Appendix-II of the Master Plan) 9.30 + 10.51 + 66.72 + 8.08 + 61.15 + 10.10	165.86 TMC
3. Subtract uses in Kabini sub-basin (vide pp 6-7 of Appendix -V of the Master Plan)	-144.00 TMC
	279.93 TMC
4. Add regeneration 0.55 x (144-17.5)	70.00 TMC
	349.93 TMC
5. Subtract flows in C_7 and C_8 sub-basin (vide table F.31)	- 60.43 TMC
	289.50 TMC
6. Subtract flows between Mekedatu and Muttati (vide table F 3.2)	- 78.61 TMC
	210.89 TMC
7. Deduct Inflow upto Iggalur Project (table F.2)	134.28 TMC
	76.61 TMC

Balance inflow from the independent C.A. of Muttati

$$\text{Annual Inflow} = \frac{76.61 \times 12}{31} = 29.7 \text{ TMC}$$

or 84 t h m.

(TABLE F - contd.)

3.1 NET YIELD OF C7 and C8 SUB BASINS FOR THE CRITICAL PERIOD

	River gains and losses (Mean)	Net yield of sub-basin C7 C8 (Mean)	River gains and losses for the critical period	Net yield of C7 and C8 = Col.3 / Col.2 x Col
(1)	(2)	(3)	(4)	(5)
Nov. 64	14.8	2.1	52.54	7.45
Dec.64 to May 65	22.7	2.3	31.45	3.15
June 65 to Nov. 65	69.7	21.7	35.83	11.10
Dec. 65 to May 66	22.7	2.3	8.15	0.82
June 66 to Nov.66	69.7	21.7	118.02	36.7
Dec. 66 to May 67	22.7	2.3	12.08	1.21
			TOTAL	60.43 TMC

SOURCE: P.77 of the Report P.48-49 of APPENDIX II of the Master Plan of the Cauvery

(TABLE F- contd.)

3.2 FLOWS BETWEEN MUTTATI AND MEKE DATU DURING THE CRITICAL PERIOD

Flow between Muttati and Mekedatu is mainly contributed from the Arkavathy sub-basin and hence it is assumed as

$$= \frac{\text{C.A. between Mekedatu and Muttati}}{\text{C.A. of Arkavathy at its project site}} \times \text{Inflow at Arkavathy project site}$$

$$= \frac{4357}{3560} \times \text{Inflow at Arkavathy project site}$$

$$= 1.225 \times \text{Inflow at Arkavathy project}$$

	Nov.64	Dec.64 to May 64	June65 to Nov.65	Dec.65 to May 66	June 66 to Nov. 66	Dec. 66 to May 67
1. Inflow at Arkavathy Project site	17.08	24.6	2.14	0.68	18.1	1.42
2. Inflow between Muttati and Mekedatu	21.0	30.2	2.62	0.85	22.2	1.74

TOTAL = 78.61 TMC.

(TABLE F - contd.)

4. INFLOW FROM INDEPENDENT C.A. OF MEKEDATU

1.	Inflow between Muttati and Mekedatu (Vide table F 3.2)	78.61 TMC
2.	Deduct Inflow at Arkavathy Project site (Table F.2)	64.03 TMC
	Total Inflow from independent C.A. of Mekedatu	14.58 TMC

Annual $\frac{14.58 \times 12}{31}$ = 5.65 TMC

or 16.00 t h m.

CHAPTER III

FORMULATION OF THE PROBLEM

Initial Screening:

A list of projects which have been proposed are given in the table C could not be considered for our study for the reasons mentioned below.

(1) The benefit cost ratios of these projects computed in table G, indicated that the projects viz.(i) Sagare doddakere (ii) Kudumegondhalla (iii) Doddahalla (iv) Nalluramanikere (v) Upper Shimsha have very low B-C ratios. They have therefore, been deleted for further consideration.

(2) Projects (i) Hebbahalla (ii) Minnattuhalla (iii) Changawadi and (iv) Uduthorehalla are small projects for which discharge data and detailed projects are not available.

Leaving the above nine schemes, from the list of projects in table G, we have considered the rest of the projects for our study. These projects finally selected have been shown in a schematic diagram on Plate-2. These locations are also indicated on Map-I. Required particulars of these projects are given in table H.

Assumptions:

The following assumptions have been made while formulating the problem.

(1) The time scale for the introduction of new projects is chosen to be a five year period. Each new project becomes part of the system at the start of the next five year period.

(2) The total planning periods are three - each of five years duration

(3) Reservoirs are full at the beginning of the study period

(4) Return flow is 55 percent of the withdrawals.

(5) All the projects are designed for the critical period.

(6) Average head have been assumed for hydel projects.

(7) 75 percent of the ~~layout~~ ayacut under Hemavathy project (Node 9) is between Nodes 8 and 10. Regeneration from this will appear at Node 10, as in the schematic diagram.

(8) Discount factor is 0.1, based on rate of discount as 10 percent.

Formulation of the Objective Function:

The general mathematical expression that details the benefits and costs contributed to the selected criterion is known as the objective function. Our criterion is the maximization, over the set of projects, of the sum of the discounted present value of the net benefits over the planning period.

With 3 planning periods, 7 proposed irrigation projects, 2 proposed power projects, 1 extension of an existing irrigation system and 1 existing project (shown in Plate II). Our objective function, expressed in mathematical terms, becomes:-

$$\text{Max } Z = \sum_{t=1}^{3} Ct \left\{ \sum_{j=1}^{7} dj\ D_{jt} + \sum_{j=8} e_j\ E_{jt} + \sum_{j=10}^{11} p_j\ P_{jt} \right\} -$$

$$\sum_{t=1}^{3} Kt \left\{ \sum_{j=1}^{7} CC_j\ RES_{jt} + \sum_{j=8} CC_j EXt_{jt} + \sum_{j=10}^{11} CC_j\ POW_{jt} \right\}$$

where

Ct = Discount factor for annual benefits

Kt = Discount factor for annual costs

D_{jt} = Diversion for irrigation from irrigation Project j during the period t

d_j = Benefit factor for irrigation Project j

E_{jt} = Diversion for irrigation from Extension Project j during the period t

e_j = Benefit factor for extension Project j

P_{jt} = Diversion for power production from hydel Project j during the period t

p_j = Benefit factor for hydel project

CC_j = Capital cost of the Project 'j'

RES_{jt} = 1 or 0 indicates whether the irrigation Project is constructed or not during the period t

EXt_{jt} = 1 or 0 indicates whether the extension Project j is constructed or not during the period t

POW_{jt} = 1 or 0 indicates whether the hydel project j is constructed or not during the period t

Table J lists out the constants and variables used in the model. The values for C_1, C_2, C_3, K_1, K_2, K_3 are computed in table K. The values for benefit factors d_j, e_j and p_j are given in table H. Capital costs of the projects are also given in table H.

Substituting the values of these constants and coefficients, the above equations takes the form as under, on simplification:-

$$\text{Max } Z = (117.5D_{1.1} + 228\ D_{2.1} + 256\ D_{3.1} + 125.5\ D_{4.1} +$$

$$117.5\ D_{5.1} + 192.5\ D_{6.1} + 190\ D_{7.1} + 168E_{8.1} +$$

$$79P_{10.1} + 159\ P_{11.1}) + (59.0D_{1.2} + 114.5D_{2.2} +$$

$128.5D_{3.2} + 63D_{4.2} + 59D_{5.2} + 96.5D_{6.2} + 95.5D_{7.2}$

$+ 84.5E_{8.2} + 39.7P_{10.2} + 80P_{11.2}) + (22.6D_{1.2} +$

$43.8D_{2.3} + 49.2\ D_{3.3} + 24.1\ D_{4.3} + 22.6\ D_{5.3} +$

$37D_{6.3} + 36.5D_{7.3} + 32.3E_{8.3} + 15.2P_{10.3} + 30.6P_{11.3})$

$- (3078.0RES_{1.1} + 248.4\ RES_{2.1} + 248.4\ RES_{3.1} +$

$518.4\ RES_{4.1} + 1144.8RES_{5.1} + 313.2\ RES_{6.1} +$

$923.4\ RES_{7.1} + 6264EXT_{8.1} + 32400POW_{10.1} +$

$16200POW_{11.1}) - (1539RES_{1.2} + 124.2RES_{2.2} + 124.2RES_{3.2}$

$+ 259.2RES_{4.2} + 572.4RES_{5.2} + 156.6\ RES_{6.2} +$

$461.7RES_{7.2} + 3132EXT_{8.2} + 16200POW_{10.2} +$

$8100POW_{11.2}) - (592.8RES_{1.3} + 47.84RES_{2.3} +$

$47.84RES_{3.3} + 99.84\ RES_{4.3} + 220.48RES_{5.3} +$

$60.32RES_{6.3} + 177.84RES_{7.3} + 1206.4EXT_{8.3} +$

$6240POW_{10.3} + 3120POW_{11.3})$

Constraints:

Constraints limit the range of variation of each of the variables, prescribe their relationships to each other and delineate the external influences on the planning. These are hydrology continuity, budget, construction and flow limiting constraints. These are equal and inequal constraints. Another type of constraint, which we are using is the restriction of a variable to being 0 or 1 depending upon whether a project is constructed or not in a particular period.

Hydrology Continuity Constraints:

These are equality constraints. They indicate the actual reservoir operation. The input at any node is made equal to the output from that node. The input is taken as the sum of the inflow into the reservoir from its independent catchment area, the outflow from the upstream reservoirs, the regeneration from the upstream irrigation use and the initial storage in the reservoir (Live storage, in our case, given vide table H). The output is the sum of the diversion towards irrigation, power etc. and the outflow from the reservoir back into the river. Expressing mathematically,

$$D_{jt} + X_{jt} = \sum_{n=1}^{t} S_j RES_{jn} + \sum_{ju=1}^{N} X_{ju.t} + \sum_{ju=1}^{N} R_{ju} D_{ju.t} + Q_j$$

where

D_{jt} = Diversion from the project j for the period t

X_{jt} = Outflow from the Project j for the period t

S_j = Live storage of the Project j

RES_{jn} = Zero-one integer 'zero' designates that the project is not constructed one designates the project is constructed.

$X_{ju.t}$ = Outflow from upstream Project ju for the period t

R_{ju} = Regeneration factor for the upstream Project ju.

$D_{ju.t}$ = Diversion from the upstream Project ju for the period t

N = Number of upstream Projects

Q_j = Inflow from Independent catchment area of the Project j during the critical period.

Node wise, they are as under: (The values for S_j and Q_j vide table H are substituted)

<u>Node: 1</u>

$$D_{11} + X_{11} = 5.6\ RES_{1.1} + 59.5$$

$$D_{1.2} + X_{1.2} = 5.6\ RES_{1.1} + 5.6\ RES_{1.2} + 59.5$$

$$D_{1.3} + X_{1.3} = 5.6\ RES_{1.1} + 5.6\ RES_{1.2} + 5.6\ RES_{1.3} + 59.5$$

<u>Node: 2</u>

$$D_{2.1} + X_{2.1} = 0.22\ RES_{2.1} + 1.36$$

$$D_{2.2} + X_{2.2} = 0.22\ RES_{2.1} + 0.22\ RES_{2.2} + 1.36$$

$$D_{2.3} + X_{2.3} = 0.22\ RES_{2.1} + 0.22\ RES_{2.2} + 0.22\ RES_{2.3} + 1.36$$

Node: 3

$$D_{3.1} + X_{3.1} = 0.77\ RES_{3.1} + 2.10$$

$$D_{3.2} + X_{3.2} = 0.77\ RES_{3.1} + 0.77\ RES_{3.2} + 2.10$$

$$D_{3.3} + X_{3.3} = 0.77\ RES_{3.1} + 0.77\ RES_{3.2} + 0.77 RES_{3.3} + 2.10$$

Node: 4

$$D_{4.1} + X_{4.1} = 0.98\ RES_{4.1} + 3.85$$

$$D_{4.2} + X_{4.2} = 0.98\ RES_{4.1} + 0.98\ RES_{4.2} + 3.85$$

$$D_{4.3} + X_{4.3} = 0.98\ RES_{4.1} + 0.98\ RES_{4.2} + 0.98\ RES_{4.3} + 3.85$$

Node: 5

$$D_{5.1} + X_{5.1} = 1.1\ RES_{5.1} + 16.4$$

$$D_{5.2} + X_{5.2} = 1.1\ RES_{5.1} + 1.1\ RES_{5.2} + 16.4$$

$$D_{5.3} + X_{5.3} = 1.1\ RES_{5.1} + 1.1\ RES_{5.2} + 1.1\ RES_{5.3} + 16.4$$

Node: 6

$$D_{6.1} + X_{6.1} = 147.0$$

$$D_{6.2} + X_{6.2} = 147.0$$

$$D_{6.3} + X_{6.3} = 147.0$$

Node: 7

$$D_{7.1} + X_{7.1} = 1.65\ RES_{7.1} + 70.2$$

$$D_{7.2} + X_{7.2} = 1.65\ RES_{7.1} + 1.65\ RES_{7.2} + 70.2$$

$$D_{7.3} + X_{7.3} = 1.65\ RES_{7.1} + 1.65\ RES_{7.2} + 1.65\ RES_{7.3} + 70.2$$

<u>**Node: 8**</u> $E_{8.1}$ + 128.5 (existing diversion from8) + $X_{8.1} = X_{1.1} + X_{2.1} + X_{3.1} + X_{9.1} + 0.55 (D_{1.1} + D_{2.1} + D_{3.1}) + 0.25 \times 0.55 \times 110$ (Re-generation from 25 percent of the existing withdrawals for irrigation from Project 9) + 174.5 i.e. Live capacity 49.0 + Inflow 125.5 mm

on simplification

$$E_{8.1} + X_{8.1} = X_{1.1} + X_{2.1} + X_{3.1} + X_{4.1} + 0.55 (D_{1.1} + D_{2.1} + D_{3.1}) + 61.125$$

$$E_{8.2} + X_{8.2} = X_{1.2} + X_{2.2} + X_{3.2} + X_{9.2} + 0.55 (D_{1.2} + D_{2.2} + D_{3.2}) + 61.125$$

$$E_{8.3} + X_{8.3} = X_{1.3} + X_{2.3} + X_{3.3} + X_{9.3} + 0.55 (D_{1.3} + D_{2.3} + D_{3.3}) + 61.125$$

<u>**Node: 9**</u> 110 (existing diversion from Project 9) + $X_{9.1} + X_{5.1} + 0.55 (D_{4.1} + D_{5.1}) + 109.4$ i.e. capacity 37.4 + Inflow 72.0

on simplification

$$X_{9.1} = X_{4.1} + X_{5.1} + 0.55 (D_{4.1} + D_{5.1}) -0.6$$

$$X_{9.2} = X_{4.2} + X_{5.2} + 0.55\ (D_{4.2} + D_{5.2}) - 0.6$$

$$X_{9.3} = X_{4.3} + X_{5.3} + 0.55\ (D_{4.3} + D_{5.3}) - 0.6$$

<u>Node: 10</u>

$$P_{10.1} + X_{10.1} = X_{6.1} + X_{8.1} + 0.55\ (D_{6.1} + E_{8.1})$$

$+ 0.55 \times 128.5$ (Regeneration from existing withdrawal for irrigation from Project 8) +

$0.55 \times 0.75 \times 110$ (Regeneration from 75 percent of existing withdrawals for irrigation from Project 9) $+ 119POW_{10.1} + 84$

on simplification

$$P_{10.1} + X_{10.1} = X_{6.1} + X_{8.1} + 0.55\ (D_{6.1} + D_{8.1})$$

$$+ 119POW_{10.1} + 200.05$$

$$P_{10.2} + X_{10.2} = X_{6.2} + X_{8.2} + 0.55\ (D_{6.2} + D_{8.2})$$
$$+ 119POW_{10.1} + 119POW_{10.2} + 200.05$$
$$P_{10.3} + X_{10.3} = X_{6.3} + X_{8.3} + 0.55\ (D_{6.3} + D_{8.3})$$

$$+ 119POW_{10.1} + 119POW_{10.2} + 119POW_{10.3} + 200.05$$

<u>**Node: 11**</u>

$$P_{11.1} + X_{11.1} = X_{10.1} + P_{10.1} + X_{7.1} +$$

$$0.55\ D_{7.1} + 16.0$$

$$P_{11.2} + X_{11.2} = X_{10.2} + P_{10.2} + X_{7.2} +$$

$$0.55 D_{7.2} + 16.0$$

$$P_{11.3} + X_{11.3} + X_{10.3} + P_{10.3} + X_{7.3} +$$

$$0.55\ D_{7.3} + 16.0$$

The logic in the above set of equations is that if the reservoir comes into operation during the period 1, then $RES_{j.1} = 1$ $RES_{j.2} = 0$, $RES_{j.3} = 0$, thereby the storage comes into play in all the three equations. If the reservoir comes into operation during the period II, then the storage comes into play only during periods II and III and not during period I. In such a case $RES_{j.1} = 0$, $RES_{j.2} = 1$ and $RES_{j.3} = 0$ and so on.

<u>**Budget Constraints:**</u>

The budgetary constraint consists of a limit on the availability of capital for new construction from public or private sources.

In our problem we have considered 3 periods, and the availability of capital for each period is assumed to be Rs.30,000 lakhs. During any period, the total capital cost of the projects taken up during the period shall not exceed this limit. This can be expressed mathematically as under:

$$\sum_{j=1}^{7} CC_j \; RES_{jt} + CC_8 \; EXT_{8.t} + CC_{10} \; POW_{10.t}$$

$$+ CC_{11} \; POW_{11.t} \leq BUD_t$$

Substituting the values for the coefficients, they will be as under

1. $2850 \; RES_{1.1} + 230 \; RES_{2.1} + 230 \; RES_{3.1} + 480 \; RES_{4.1}$

   $+ 1060 \; RES_{5.1} + 290 \; RES_{6.1} + 855 + RES_{7.1}$

   $+ 5800 \; EXT_{8.1} + 30000 \; POW_{10.1} + 15000 \; POW_{11.1}$

   $\leq 30{,}000$

2. $2850 \; RES_{1.2} + 230 \; RES_{2.2} + 230 \; RES_{3.2} + 480 \; RES_{4.2}$

   $+ 1060 \; RES_{5.2} + 290 \; RES_{6.2} + 855 \; RES_{7.2} +$

   $5800 \; EXT_{8.2} + 30000 \; POW_{10.2} + 15000 \; POW_{11.2}$

   $\leq 30{,}000$

3. $2850\ RES_{1.3} + 230\ RES_{2.3} + 230\ RES_{3.3} +$

$480\ RES_{4.3} + 1060\ RES_{5.3} + 290\ RES_{6.3} +$

$855\ RES_{7.3} + 5800\ EXT_{8.3} + 30000\ POW_{10.3} +$

$15000\ POW_{11.3} \leq 30{,}000$

Construction Constraints:

These constraints limit the construction of any dam only once. We will assume that each reservoir may be built in only one of the periods i.e.

$$\sum_{t=1}^{3} RES_{jt} \leq 1 \text{ for all } j=1 \text{ to } 7$$

$$\sum_{t=1}^{3} EXT_{8.t} \leq 1$$

$$\sum_{t=1}^{3} POW_{jt} \leq 1 \qquad \text{for } j = 10, 11$$

Expanding them we get

$$RES_{1.1} + RES_{1.2} + RES_{1.3} \leq 1$$

$$RES_{2.1} + RES_{2.1} + RES_{2.3} \leq 1$$

$$RES_{3.1} + RES_{3.2} + RES_{3.3} \leq 1$$

$$RES_{4.1} + RES_{4.2} + RES_{4.3} \leq 1$$

$$RES_{5.1} + RES_{5.2} + RES_{5.3} \leq 1$$

$$RES_{6.1} + RES_{6.2} + RES_{6.3} \leq 1$$

$$RES_{7.1} + RES_{7.2} + RES_{7.3} \leq 1$$

$$EXT_{8.1} + EXT_{8.2} + EXT_{8.3} \leq 1$$

$$POW_{10.1} + POW_{10.2} + POW_{10.3} \leq 1$$

$$POW_{11.1} + POW_{11.2} + POW_{11.3} \leq 1$$

Flow Limiting Constraints:

These constraints limit the diversion for irrigation or for power from any reservoir. This fixes the upper limit for the variables. This constraint can be expressed mathematically, in general as under

$$D_{jt} \leq \sum_{n=1}^{t} F_j \; RES_{jn}$$

here

F_j is the limiting flow from Project j

The values for F_j are given in table H.

Expanding and substituting,

$D_{1.1} \leq 36.8\ RES_{1.1}$

$D_{1.2} \leq 36.8\ RES_{1.1} + 36.8\ RES_{1.2}$

$D_{1.3} \leq 36.8\ RES_{1.1} + 36.8\ RES_{1.2} + 36.8\ RES_{1.3}$

$D_{2.1} \leq 2.54\ RES_{2.1}$

$D_{2.2} \leq 2.54\ RES_{2.2} + 2.54\ RES_{2.1}$

$D_{2.3} \leq 2.54\ RES_{2.1} + 2.54\ RES_{2.2} + 2.54\ RES_{2.3}$

$D_{3.1} \leq 3.12\ RES_{3.1}$

$D_{3.2} \leq 3.12\ RES_{3.1} + 3.12\ RES_{3.2} +$

$D_{3.3} \leq 3.12\ RES_{3.1} + 3.12\ RES_{3.2} + 312\ RES_{3.3}$

$D_{4.1} \leq 6.23\ RES_{4.1}$

$D_{4.2} \leq 6.23\ RES_{4.1} + 6.23\ RES_{4.2}$

$D_{4.3} \leq 6.23\ RES_{4.1} + 6.23\ RES_{4.2} + 6.23\ RES_{4.3}$

$D_{5.1} \leq 11.90\ RES_{5.1}$

$D_{5.2} \leq 11.90\ RES_{5.1} + 11.90\ RES_{5.2}$

$D_{5.3} \leq 11.90\ RES_{5.1} + 11.90_{5.2} + 11.90\ RES_{5.3}$

$D_{6.1} \leq 3.68$ RES 6.1

$D_{6.2} \leq 3.68\ RES_{6.1} + 3.68\ RES_{6.2}$

$D_{6.3} \leq 3.68\ RES_{6.1} + 3.68\ RES_{6.2} + 3.68\ RES_{6.3}$

$D_{7.1} \leq 6.0\ RES_{7.1}$

$D_{7.2} \leq 6.0\ RES_{7.1} + 6.0\ RES_{7.2}$

$D_{7.3} \leq 6.0\ RES_{7.1} + 6.0\ RES_{7.2} + 6.0\ RES_{7.3}$

$E_{8.1} \leq 63.0\ EXT_{8.1}$

$E_{8.2} \leq 63.0\ EXT_{8.1} + 63.0\ EXT_{8.2}$

$E_{8.3} < 63.0\ EXT_{8.1} + 63.0\ EXT_{8.2} + 63.0\ EXT_{8.3}$

$P_{10.1} \leq 650\ POW_{10.1}$

$P_{10.2} \leq 650\ POW_{10.1} + 650\ POW_{10.2}$

$P_{10.3} \leq 650\ POW_{10.1} + 650\ POW_{10.2} + 650\ POW_{10.3}$

$P_{11.1} \leq 650\ POW_{11.1}$

$P_{11.2} \leq 650\ POW_{11.1} + 650\ POW_{11.2}$

$P_{11.3} \leq 650\ POW_{11.1} + 650\ POW_{11.2} + 650\ POW_{11.3}$

In this chapter we have formulated the model for optimal expansion of a water resources system. This model indicates when the project is to be taken up subject to Budgetary and other constraints, for maximizing the net benefits from all the new projects thus taken up during the planning period.

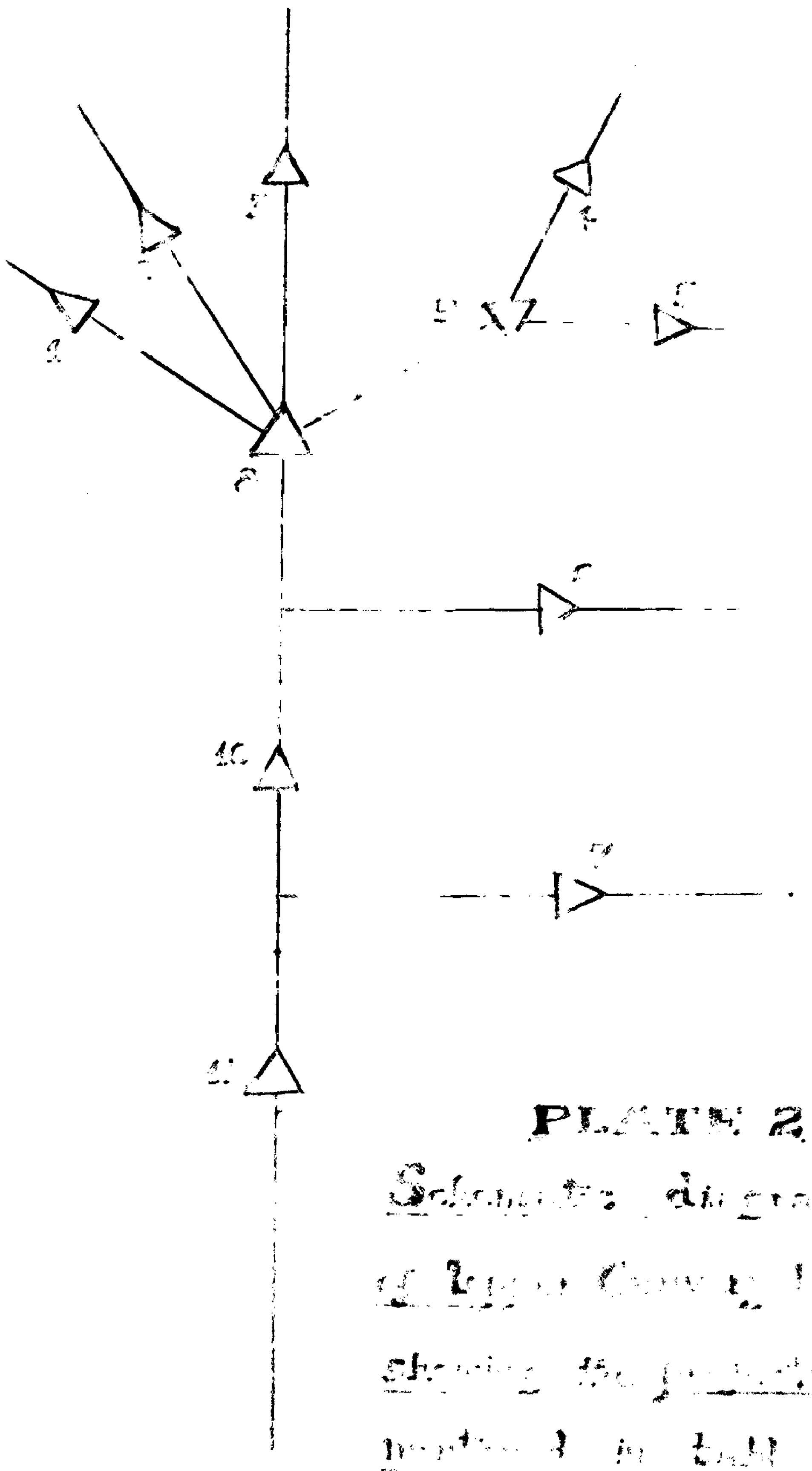


PLATE 2

Schematic diagram
of Upper [illegible]
showing the points
mentioned in table H

T A B L E - G

BENEFIT COST RATIOS OF PROPOSED IRRIGATION PROJECTS

S.No.	Name of the Project	Annual benefit in Rs. lakhs	Annual cost in Rs.lakhs	Benefit cost ratio Col.(3) ÷ Col.(4)	REMRKS
(1)	(2)	(3)	(4)	(5)	(6)
1.	Cauvery Reservoir Project	570.0	340.0	1.67	
2.	Chicklihole	76.13	~~276.6~~ 27.6	2.76	
3.	Lakshmanathirtha	105.0	27.6	3.80	
4.	Votehole	102.9	57.6	1.79	
5.	Yagachi	184.05	127.2	1.45	
6.	Iggalar	93.0	34.8	2.68	
7.	Arkavathy	150.0	102.6	1.46	
8.	Extension under KRS	1386.4	696.0	1.99	
9.	Sagare Dodda-Kere	5.20	15.84	0.33	LOW
10.	Kuduregondihalla	4.0	15.6	0.26	LOW
11.	Hebbahalla	28.4	15.6	1.80	
12.	Minnathuhalla	58.95	27.84	2.12	

(1)	(2)	(3)	(4)	(5)	(6)
13.	Changawadi	54.95	20.4	2.70	
14.	Doddihalla	8.0	12.12	0.67	LOW
15.	Nalluramanikere	3.20	15.0	0.21	LOW
16.	Uduthorehalla	126.40	102.0	1.24	
17.	Upper Shimsha	20.00	31.44	0.64	LOW

REQUIRED PARTICULARS OF THE PROJECT

S.No.	Name of the Project	Capital cost in Rs.Lakhs	For 31 months → Live storage in TMC	Live storage in t h m	Live storage in t h m Annual	Diversion in TMC	Diversion in ~~TMC~~ t.h.m	Annual benefit in Rs. Lakhs	Benefit factor Col.9/Col.8	Inflow from In[illegible] dependent C.[illegible] in t.h.m.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1.	Cauvery Reservoir	2850	5.1	14.42	5.6	13.0	36.8	570	15.48	59.5
2.	Chicklihole	230	0.2	0.57	0.22	0.9	2.54	76.13	30.0	1.36
3.	Lakashmanathirtha	230	0.7	1.98	0.77	1.1	3.12	105.0	33.65	2.10
4.	Votehole	480	0.9	2.54	0.98	2.2	6.23	102.9	16.51	3.85
5.	Yaggachi	1060	1.0	2.83	1.10	4.2	11.90	184.1	15.47	16.4
6.	Iggalar	290	-	-	-	1.3	3.68	93.0	25.27	147.0
7.	Arkavathy	855	1.5	4.25	1.65	2.12	6.00	150.0	25.00	70.2
8A.	Krishnarajasagar(KRS)	-	44.8	126.7	49.0	45.4	128.5	-	-	125.5
8B.	Extension under KRS	5800	-	-	-	22.2	63.0	1386.5	22.08	
9.	Hemavathy	-	34.0	96.5	37.4	39.0	110.0	-	-	72.0
10.	Muttati Power Scheme	30.000	108.7	307.6	119.0	178.7	505.0	5245.0	10.39	84.0
11.	Mekedatu Power Scheme	15,000	-	-	-	181.7	515.0	1505.0	20.92	16.0

TABLE J

LIST OF CONSTANTS, VARIABLES AND COEFFICIENTS

Symbol	Description	Value	Reference
(1)	(2)	(3)	(4)
ε_t	CONSTANTS AND COEFFICIENTS		
C_1	Discount factor for benefit	7.6051	Table K
C_2	Discount factor for benefit	3.8146	Table K
C_3	Discount factor for benefit	1.4618	Table K
K_1	Discount factor for costs	1.08	Table K
K_2	Discount factor for costs	0.54	Table K
K_3	Discount factor for costs	0.208	Table K
CC_j	Capital to build reservoir j	-	Table H
F_j	Design capacity of canal	-	Table H
BUD_t	Capital budget limit for any period	30,000	-
t	No. of periods	3	
N	No. of upstream projects	-	-
S_j	Initial reservoir volume		Table H
Q_j	Independent catchment area inflow during the critical period		Table H

(1)	(2)	(3)	(4)
	VARIABLES		
D_{jt}	Diversion from irrigation project j during period t	Continuous Bound	Maximum value F_j
E_{jt}	Diversion from Extension scheme f 8 during period t	-do-	-do- F_8
P_{jt}	Diversion from Power project during period t	Continuous -Bound	Maximum value 650
RES_{jt}	Integer Variable-designates wehther the reservoir is taken up or not during the period t	Zero or one	
EXt_{jt}	Integer variable-designates whether the extension scheme j is taken up or not during the period t	Zero or one	
POW_{jt}	Integer variable-designates whether the power project j is taken up or not during the period t	Zero or one	
X_{jt}	Outflow from the reservoir j during the period t	Unbounded variable	

TABLE X

I We consider 3 periods of Five years each viz. (i) Zero period (ii) First period (iii) Second period

The projects taken up during zero period will start yielding benefits during the first period and so on. The projects taken up during second period will start yielding benefits during the third period. Hence to consider the net benefit from all projects we have to consider the third pariod also.

C_1 = This factor converts the annual benefits from the projects taken up during the zero period i.e. (from the projects which start yielding benefits from the first period to the end of the third period.(for 15 years) to present value as at the beginning of the I period.

$$= \frac{(1+r)^{15}-1}{r(1+r)^{15}} = 7.6051 \quad \text{taking } r \text{ as } 0.1.$$

C_2 = This factor converts the annual benefits from the projects taken up during the First period to the present value as at the beginning of the First period

$$= \frac{(1+r)^{10}-1}{(1+r)^{15}} = 3.8146 \qquad r = 0.1$$

C_3 = This factor converts the annual benefits from the projects taken up during the second period to the present value as dt the beginning of the first period.

$$= \frac{(1+r)^5 - 1}{(1+r)^{15}} = 1.4618 \qquad r = 0.1$$

II It is assumed that the capital cost of any project taken up during any period is spent as the project uniformly over Five years. During the construction time, the interest on capital cost will be the annual cost whereas after the project is completed, the annual costs will be the sum of operation (maintenance, depreciation and the interest on capital.

K_1 = For the projects taken up during the zero period the capitalised cost as the beginning of the I period is

$$C/5 \left[(1+r)^4 + (1+r)^3 + (1+r)^2 + (1+r) + 1 \right] = \frac{C}{5} \frac{(1+r)^5 - 1}{r} = 1.22\ c$$

$$r = 0.1$$

O and M charges	=	0.01 c
Depreciation	=	0.01 c
Interest on capitalised cost	=	0.10 x 1.22 c
		0.122 c
	=	0.142 c

K_1 converts this annual cost to the P.V. as at the beginning of the I period

$$= \frac{0.142\,[(1+r)^{15}-1]}{(1+r)^{15}} = 1.08 \qquad r = 0.1$$

Similarly K_2 converts the annual costs of the projects taken up during the I period to the P.V. as at the beginning of the I period

$$= \frac{0.42\,[(1+r)^{10}-1]}{(1+r)^{15}} = 0.54 \qquad r = 0.1$$

K_3 converts the annual costs of the projects taken up during the II period to the P.V. as at the beginning of the I period

$$= \frac{0.142\,[(1+r)^{5}-1]}{(1+r)^{15}} = 0.208$$

$C_1 = 7.6051$ $\quad C_2 = 3.8146$ $\quad C_3 = 1.4618$

$K_1 = 1.08$ $\quad K_2 = 0.54$ $\quad K_3 = 0.208$

CHAPTER IV

PROCEDURE FOR SOLVING THE PROBLEM

Algorithms:

Our problem comprises the objective function and various types of constraints, and is a 0-1 mixed Integer Programming problem. All the feasible solutions will contain a mixture of integer and non integer variables; the integer variables are restricted to the values 0 or 1. We want to specify when each dam should be built such that the objective function is maximized.

Possible techniques include the generalized Lagrange multiplier technique, dynamic programming and mixed integer programming (MIP)

Lagrange multiplier technique requires that alternative new projects be independent. But in our problem though the alternative projects are independent with respect to cost factors and required investment, they are inter-related with respect to benefits.

Dynamic programming requires prohivitively large computer core storage as the problem has a large number of state variables.

There are many package programmes to solve a mixed Integer Programming Problem. Of them the important ones are (i) OPHELIE MIXED (Roy, Benayoun and Tergny) 1970

(ii) MPSX-MIP (Benichon M., Gauthier J.M., Girodet P., Henteges G., Ribiere G. and VincentO) - 1970

(iii) UMPIRE (Tomlin) Aug. 1971

(iv) RIP30C (Geoffrion) June 69

(v) MARISABETH (Shell Berre - P. Herve) 1970

(vi) MIDAS - 2 (Aldrich) - 1969

(vii) FMPS -MIP (Childres, J.P.) - 1969

(viii) IPE (INMAN R., and A.S. Manne) 1971

The general algorithmic frame work for these programs is built upon three key notations: Separation, Relaxation and Fathoming. Separation means, that the problem is separated into sub problems with an obvious strategy of divide and conquer. Relaxation means, loosening of certain constraints viz. omission of certain constraints, dropping the integrality conditions, dropping non-negativity constraints, to make the problem easier to solve than the original one.

Fathoming means: Whever a separated problem, called candidate problem (CP) cannot be solved easily then (CP) is relaxed to (CP_r)

Fathoming Criterion-1(FC-1): If this (CP_r) has no feasible solution, then the same is true of (CP). Then (CP) is fathomed

Fathoming Criterion-2 (FC-2): If (CP_r) has no better solution than the incumbent, then also (CP) is said to be fathomed.

Fathoming Crieterion-3 (FC-3): If (CP_r) has an optimal solution, feasible in (CP), then also (CP) is fathomed.

Plate 3 indicates a general procedure

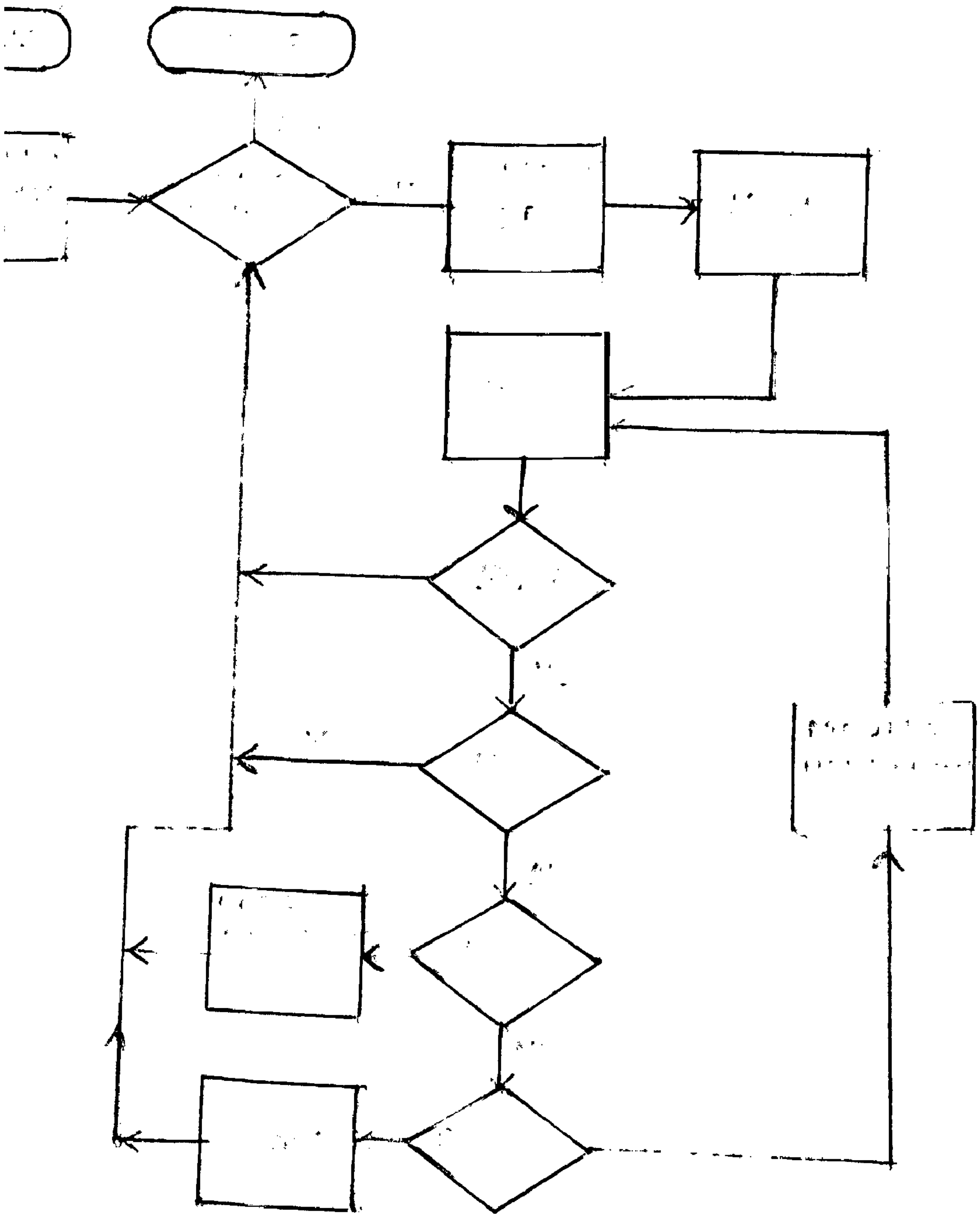
Among the various algorithms that have been proposed, there is considerable variation in the kinds of analysis employed to implement the Fathoming Crieteria.

Our problem was solved by IPE-MPS 360 package on IBM-360/44 system.

<u>Results:</u>

The results are tabulated in table L. As the construction constraints were released initially, our problem had 67 rows and 93 variables. It was solved in 4.75 minutes.

The results revealed that all the irrigation projects (projects Nos. 1 to 8) could be taken up in the zero period. The total cost of all these projects is Rs.21,795 lakhs. Hydel project (i.e. project No.10) could be taken up during the first period. Its cost is Rs. 30,000 lakhs. Hydel project (i.e. project No.11) could be taken up, during the second period. Its cost is Rs. 15,000 lakhs. The total maximized net benefit from these projects would be Rs. 52,280.78 lakhs, over the planning period of 15 years.



CONTROL PROGRAM COMPILER - MPS/360 V2-M9

```
        PROGRAM ('ND')
        INITIALZ
        TITLE ('MP PROBLEM')
ITER    ██(1)
MAXITR  DC(3)
TOL     DC(     )
LUB     DC(     E65)
BEGBASE DC( '    ')
IPEBASE DC'IPETSTB1')
        MOVE (XPENAME,'IPETEST')
        MOVE XOBJ ('MAXNB')
        MOVE (XRHS,'TEST     ')
        FPROJ DC ('RESP    ')
LPROJ   DC('POWP1102')
BOUND   DC('INTBOU01')
        MOVE (XDATA,'STAGING')
        CONVERT
        BCDOUT
        MOVE(XOLDNAME,XPBNAME)
        MOVE(XDATA,'REVDATA')
OBJ     DC(     )
BASE    DC('        ')
        MOVE(BASE,BEGBASE)
        SETUP ('BOUNC',BOUND)
        PICTURE
        SAVE
        GOTO(BEG)
LOOP    ASSIGN('FP1212F001',FT12001,'CARD')
        REVISE('FILE',FT12F001)'
        BCDOUT
        SETUP('BOUND)
        DUAL
BEG     RESTORE('NAME',BASE)
        PRIMAL
        SELECT('ROW',XOBJ,'        ')
        IF(OBJ.GTLUB,SKIP)
        MOVE(BASE,IPEBASE)
        SAVE('NAME',BASE)
        LUB=OBJ
        SOLUTION
*
SKIP    ASSIGN('FT12001', FT12FOO*','COMM')
        PREPOUT'FTF001)
        SOLUTION ('FILE', FT12F001,'CSECTION','2/4/8',RMASKS', '
        'CLIMIT',EPROJ,)
        FRECORE
        IPE(ITER,MAXITR,TOL,BOUND)
        FREECORE
        IF(ITER NE 0, LOOP)
        IPELOG
```

quantities are in thousand hectare meters
ept for col.3)

Project Number	Name	IOD 2					PERIOD 3			
		tal	D_{j2}	X_{j2}	0.55 D_{j2}	X_{ju} + 0.55 D_{ju}	Total	D_{j3}	X_{j3}	0.55 D_{j3}
1.		12.	13.	14.	15.	16.	17.	18.	19.	20.
1.	Cauve Pr	5.1	36.8	28.3 (8)	20.24 (8)	-	=65.1	36.8	28.3 (8)	20.24 (8)
2.	Chick	1.58	1.58	-	0.8690 (8)	-	1.58	1.58	-	0.869 (8)
3.	Laksh	2.87	2.87	-	1.5785 (8)	-	2.87	2.87		1.5785 (8)
4.	Voteh	4.83	4.83	-	2.6565 (9)	-	4.83	4.83		2.6565 (9)
5.	Yaga	17.5	11.90	5.6 (9)	6.545 (9)	-	17.5	11.90	5.6 (9)	6.545 (9)
6.	Igga	+7.0	3.68	143.32 (10)	2.024 (10)	-	147.0	3.68	143.32 (10)	2.024 (10)
7.	Arka	71.85	6.00	65.85 (11)	3.3 (11)	-	71.85	6.00	65.85 (11)	3.3 (11)
8.	Kris	54.814	191.5	63.314 (10)	105.325 (10)	80.314	254.814	191.5	63.314 (10)	105.325 (10)
9.	Hema	24.2015	110.0	14.2015 (8)	15.124 (8) 45.375 (10)	14.8015	124.2015	110.0	14.2015 (8)	15.125 (8)
10.	Mutt	562.358	562.358	-	-	359.358	562.358	562.358	-	45.375 (10)
11.	Meke	47.508	-	647.508	-	631.508	647.508	647.508	=	=

ould be taken up during the period t.

be taken up during the Ist period, Power project No. 10
iod 2, and power project No. 11 may be taken up
e the net benefits.
efit from the proposed projects if they are taken
s.

TABLE - L

RESULTS

All quantities are in thousand hectare meters
(Except for col.3)

Project Number	Name of the Project	Value of RES, EXT, POW	Initial storage S_j	Ind. C.A. Inflow Q_j	PERIOD 1: Outflow & return flow from u/s Projects ($X_{ju} + 0.55D_{ju}$)	PERIOD 1: Total	PERIOD 1: Diversion D_{j1}	PERIOD 1: Outflow (to where it goes) X_{j1}	PERIOD 1: Return flow $0.55 \times D_{j1}$ (to where it goes)	PERIOD 2: $X_{ju} + 0.55 D_{j1}$	PERIOD 2: Total	PERIOD 2: D_{j2}	PERIOD 2: X_{j2}	PERIOD 2: $0.55 D_{j2}$	PERIOD 3: $X_{ju} + 0.55 D_{ju}$	PERIOD 3: Total	PERIOD 3: D_{j3}	PERIOD 3: X_{j3}	PERIOD 3: $0.55 D_{j3}$
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.
1.	Cauvery Reservoir Project	$RES_{1.1}$ = 1.0	5.6	59.5		65.1	36.8	28.3 (8)	20.24 (8)	-	65.1	36.8	28.3 (8)	20.24 (8)	-	=65.1	36.8	28.3 (8)	20.24 (8)
2.	Chicklihole Project	$RES_{2.2}$ = 1.0	0.22	1.36	-	1.58	1.58	-	0.8690 (8)	-	1.58	1.58	-	0.8690 (8)	-	1.58	1.58	-	0.869 (8)
3.	Lakshmanathirtha	$RES_{3.1}$ = 1.0	0.77	2.10	-	2.87	2.87	-	1.5785 (8)	.	2.87	2.87	-	1.5785 (8)	-	2.87	2.87		1.5785 (8)
4.	Votehole	$RES_{4.1}$ = 1.0	0.98	3.85	-	4.83	4.83	-	2.6565 (9)	-	4.83	4.83	-	2.6565 (9)	-	4.83	4.83		2.6565 (9)
5.	Yagachi	$RES_{5.1}$ = 1.0	1.10	16.4	-	17.5	11.90	5.6 (9)	6.545 (9)	-	17.5	11.90	5.6 (9)	6.545 (9)	-	17.5	11.90	5.6 (9)	6.545 (9)
6.	Iggalur	$RES_{6.1}$ = 1.0	-	147.0	-	147.0	3.68	143.32 (10)	2.0240 (10)	-	147.0	3.68	143.32 (10)	2.024 (10)	-	147.0	3.68	143.32 (10)	2.024 (10)
7.	Arkauathy	$RES_{7.1}$ = 1.0	1.65	70.2	-	71.85	6.00	65.85 (11)	3.3 (11)	-	71.85	6.00	65.85 (11)	3.3 (11)	-	71.85	6.00	65.85 (11)	3.3 (11)
8.	Krishnarajasagar	$EXT_{8.1}$ = 1.0	49.0	125.5	80.314	254.814	191.50	63.314 (10)	105.325 (10)	80.314	254.814	191.5	63.314 (10)	105.325 (10)	80.314	254.814	191.5	63.314 (10)	105.325 (10)
9.	Hemavathy	-	37.4	72.0	14.8015	124.2015	110.00	14.2015 (8)	15.125 (8) 45.375 (10)	14.8015	124.2015	110.0	14.2015 (8)	15.124 (8) 45.375 (10)	14.8015	124.2015	110.0	14.2015 (8)	15.125 (8)
10.	Muttati	$POW_{10.2}$ = 1.0	119.0	84.0	359.358	443.358	-	443.358 (11)	-	359.358	562.358	562.358	-	-	359.358	562.358	562.358	-	45.375 (10)
11.	Mekedatu	$POW_{10.3}$ = 1.0	-	16.0	512.508	528.508	-	528.508	-	631.508	647.508	-	647.508	-	631.508	647.508	647.508	=	=

<u>Explanation for Col. 3</u> : RES_{jt} =1 means Reservoir j should be taken up during the period t.
All the projects (1 to 8) may be taken up during the Ist period, Power project No. 10 may be taken up during the period 2, and power project No. 11 may be taken up during the period 3 to maximize the net benefits.
The value of maximized net benefit from the proposed projects if they are taken up as above = Rs. 52280.78 lakhs.

S U M M A R Y

In this study, we have attempted to select from a list of proposed projects, the projects that are to be constructed during consecutive planning periods, so as to maximize the net benefits from them. We made this study with reference to the Upper Cauvery Basin. In the Upper Cauvery basin, out of 10 proposed projects, obtained after initial screening, an attempt has been made to select the sequence of projects to be constructed in the three planning periods, under budget, flow limiting, hydrology continuity and construction constraints. We have made use of computer package programme IPE-MPS 360 available at Delhi University Computer Centre, for solving our problem.

CHAPTER V

CONCLUSIONS

An exact mathematical representation of a water resources development project, even if possible would lead to a large mathematical complexity. It is therefore necessary to make suitable assumptions to attain a reasonable balance between accurate representation and mathematical manageability. Also some variables have to be omitted to make the problem a linear one. Some variables have been omitted because their impact on the optimal design is small. Some variables that are stochastic such as the river flow are treated as deterministic to make the problem simpler. Flood Control, Water quality, Navigation and recreation aspects may also be covered by introducing suitable constraints in the model.

However, it is believed that the model developed here is a reasonably accurate representation of a multipurpose water resources system, for staging and optimization purposes and contains the variables ~~and~~ that are the most relevant for optimal planning.

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