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A RATIONAL APPROACH IN THE REDESIGNING OF CANAL NETWORKS IN THE EXISTING MAJOR/MEDIUM IRRIGATION SCHEMES

by

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Synopsis

The subject of this paper is the approach adopted for the redesign of the canal networks in the existing major/medium irrigation schemes which were taken up for rehabilitation under the National Irrigation Rehabilitation Project (1992-1997). According to the stipulations in the IDA Staff Appraisal Report (which was the governing document for the project), the rehabilitation was expected to "Cover the works to restore the respective scheme to design parameters including repairs and replacement of structures". However, during the rehabilitation studies, it was evident that practically all the schemes had been patched up time and again. Further, additional areas and canal lengths added thereto. These factors caused the canal systems to drift away from their original parameters to such an extent that it was no longer possible to restore them to original status.

The schemes taken up for the rehabilitation were thus studied on a case by case basis without following a rigid set of rehabilitation criteria but broadly confirming to a consistent set of operation principles.

The approach adopted for the redesign of their 'Headworks' has been documented elsewhere. (Please refer to the paper presented by the same author to 'Water Related Infrastructure Competition - 1997, conducted by the IESL.) This paper describes the approach adopted for the redesign of canal networks. It is based on the work done by the writer and several other members of the consultancy team appointed by the Irrigation Department for the preparation of scheme feasibility reports.

1.0 Design of Distribution Systems - Historical situation - Sri Lankan context [M.K.1]

The very first (documented) attempt to define a criteria for the design of irrigation Head works and canals in Sri Lanka was made by late Mr. S.Arumugam, the then Deputy Director of Irrigation in 1957. His widely read publication titled DEVELOPMENT OF VILLAGE IRRIGATION WORKS deals with the subject of canal design in a two pronged approach.

He determined the full flow velocity V ft/sec in a canal of given sectional parameters by using the Mannings Formula. Then he computed a flow velocity called 'non silting non scouring' velocity by using a formula known as Kennedy's formula ($V_c = 0.84MD^{0.64}$, where M was called Critical Velocity Ratio having values between 1.1 and 1.25, while D being the depth of flow in feet). Hence, critical velocity ratio $V/0.84D^{0.64}$ could be kept within the expected values. He also introduced maximum values for design discharges in earthen canals (3.5ft/sec for large canals and 2.5ft/sec for small canals, but he did not specify large and small canals further).

However, he missed the most important fact that the canals did not always flow at their full flow velocities. In practice, the canals flowing less than their full capacity developed lower velocities and were subject to recurrent silting, contrary to his expectations.

The next serious attempt to document irrigation design criteria was made by late Mr. A.J.P.Ponrajah during 1977-1984 period when he was the Deputy Director (Designs) and subsequently the Director of irrigation.

His widely used 'Technical Notes' were published by the Irrigation Department in 1989 as 'Technical Guidelines for Irrigation Works'. These guidelines too did not deviate from the approach taken by Mr. Arumugam, except;

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a) increasing the range of acceptable Critical Velocity ratios from 0..9 to 1.25 ; and

b) defining a three-tier structure for maximum velocities in canals depending upon their design discharges.

Accordingly, earthen-canals upto 25 cusecs capacity was to have a maximum velocity of 1.5 ft./sec. From 25 cusecs upto 300 cusecs, the maximum velocity of 2.5 ft./sec and those with capacities above 300 cusecs were to have a maximum velocity of 3.5 ft./sec.

The fact that the canals did not always carry the full discharge was ignored here too. The practical situations of canals carrying different discharges at different times causing changes in the flow velocities was not considered. Further, the subject of Irrigation Scheduling did not find a place in these Design Guidelines. In fact, the Irrigation Department never had any design guidelines for rehabilitation designs. Hence, the designs done using available guidelines did not ensure trouble free operation of rehabilitated canal networks.

let us first get an understanding of the principal problems in the existing canal networks. Of the 40 odd major/medium Irrigation Schemes taken up for studies, majority had the following common problems in their canal networks.

1. Plans of operation based on actual requirements and priorities were absent. Main canals were being shut for one or more days in the week, water being issued on trial and error methods and in ad-hoc manner causing erratic flows.

2. There were no pre-planned gate settings to suit particular discharges.

3. Tail ends did not receive adequate water even when the head works possessed adequate water resources.

4. Most of the Main and D canals had to cater to extents larger than their original command areas due to progressive annexing of reservations as well as neighboring state/private lands.

5. Canals were of uneven sections and their beds were recurrently silting up.

6. Turnouts did not deliver adequate flow within the stipulated time durations.

7. Contour canals often-crossed lateral valleys, presence of which caused undue conveyance delays during rotational canal closures.

In many schemes, several of these problems occurred together, thus compounding the situation. Hence, a sequential strategy of prioritizing and elimination had to be adopted to resolve them. Features of this strategy are discussed in the following paragraphs.

2.0 Procedure followed in the preparation of Feasibility Reports

1. Before going into further technical aspects of this presentation, it would be apt to set out the procedure, which was followed in the preparation of the Feasibility Reports from an administrative point of view. The procedure followed can be briefly listed as follows.

2. Team members study the relevant project documents (such as Appraisal Report, Project Inception Report, available documents on the irrigation practices currently followed by the Irrigation Department Sri Lanka, and also in other south Asian countries.)

3. Make preliminarily site visits and compile relevant information by inspection and discussion with O&M officials as well as the beneficiary farmers. Attend a formal meeting of the farmer organization to enlighten them of the proposed rehabilitation effort and to appraise them of the cooperation and contribution anticipated from them. At this meeting, the farmers are given an opportunity to bring out their opinions of the problems in the scheme.

4. Determine the requirements of detailed investigations such as surveying and leveling and collection of maps (FVPs, ariel maps of the cachement areas, tank bed surveys, command area surveys, issue trees etc.) and list the required details on current O&M rules, cultivation statistics, input costs and output prices. Initiate action to procure same through relevant authorities.

5. While the above studies are done and details gathered by the respective authorities, team members carry out detailed field inspections jointly and severally to make qualitative assessments of the current status of the scheme. Disciplines represented in the study team were; Irrigation, Operation and Maintainence, Agronomy, Institutional development, Sociology, Environmental Evaluation, Farmer organization and Agricultural Economics.

6. In the detailed desk study phase each member analyses the data gathered and the documents collected by them and carefully identify the current and historical problems of the scheme (Engineering, Operational Agronomic, Institutional, Social, Environmental, Farmer organizational, costs and benefits etc.).

7. Hold a round table discussion among the team members to evaluate the identified problems and to map up strategies for rehabilitation to cover the problems of all aspects.

8. Prepare draft Feasibility Report, work out cost estimates and carry out economic evaluations and sensitivity studies.

9. Hold another round table discussion to evaluate the merits/demerits of optional proposals and reach consensus on the ranking of options.

10. Call a formal meeting of the relevant farmer organization and make a presentation of the findings of the detailed studies to receive feedback. Enlighten them of their mandatory 10% contribution towards rehabilitation effort, answer further questions and attempt to accommodate their final requests where justified.

11. The Farmer Organization thereafter proposes and adopts a resolution to the effect that the study proposals are accepted by them. (Such acceptances are almost unanimous)

12. Formal release of the Feasibility Report to the client, incorporating a certified copy of the resolution adopted by the Farmer Organization.

At this stage, it would be appropriate to get back to the main theme.

3.0 Determination of Design Discharges

This is the primary step to be followed in the process. The salient points of which are;

1. Carry out a comprehensive water-resources study, using best available information to determine the crops, cropping calendars and cropped extents, which could be supported through a continuous period of at least 20 years. However, the subject of Water Resources study is outside the scope of this paper and has already been dealt with elsewhere.

2. Prepare an Issue Tree to match with the currently cropped extents and the available distribution network.

3. Determine the hierarchy of title of the existing cropped area and pick out the areas enjoying priority water rights (riparian rights).

4. Examine existing operational plans, rotational practices if any, giving credit to riparian rights.

5. By taking into account of the trial crop (or crops) and their cropping calendar, compute 'net field' water demands of the respective crop areas (each of which is fed by a specific field canal) through a full one year crop cycle on a weekly basis (assuming 7 days continuous flow) excluding effective rain fall.

6. Identify the weeks of peak water demands (which will be based on crop ET values during different growth stages). Compute the peak demands in liters/ha (see Error! Bookmark not defined. for a typical set of field water requirements computed for Usgala Siyambalagamuwa scheme).

1) Accordingly, calculate the discharge requirements through each of the field turnout, under peak flow conditions, for the existing gate diameters and canal sections. At this stage, adequate allowances have to be made to account for field-canal conveyance losses.

2) Whenever these discharges are too small to be delivered within the currently adopted rotations, telescope their durations until acceptable durations are obtained. This will need the resizing of turnout gates. (Error! Bookmark not defined.).

3) On the above basis (and for any current or assumed rotational reaches in the main canals), check the design flow through each turnout on a daily day/night basis. (Note that the minimum duration of water delivery to a specific turnout was taken at 12hrs due to practical limitations of the irrigators.)

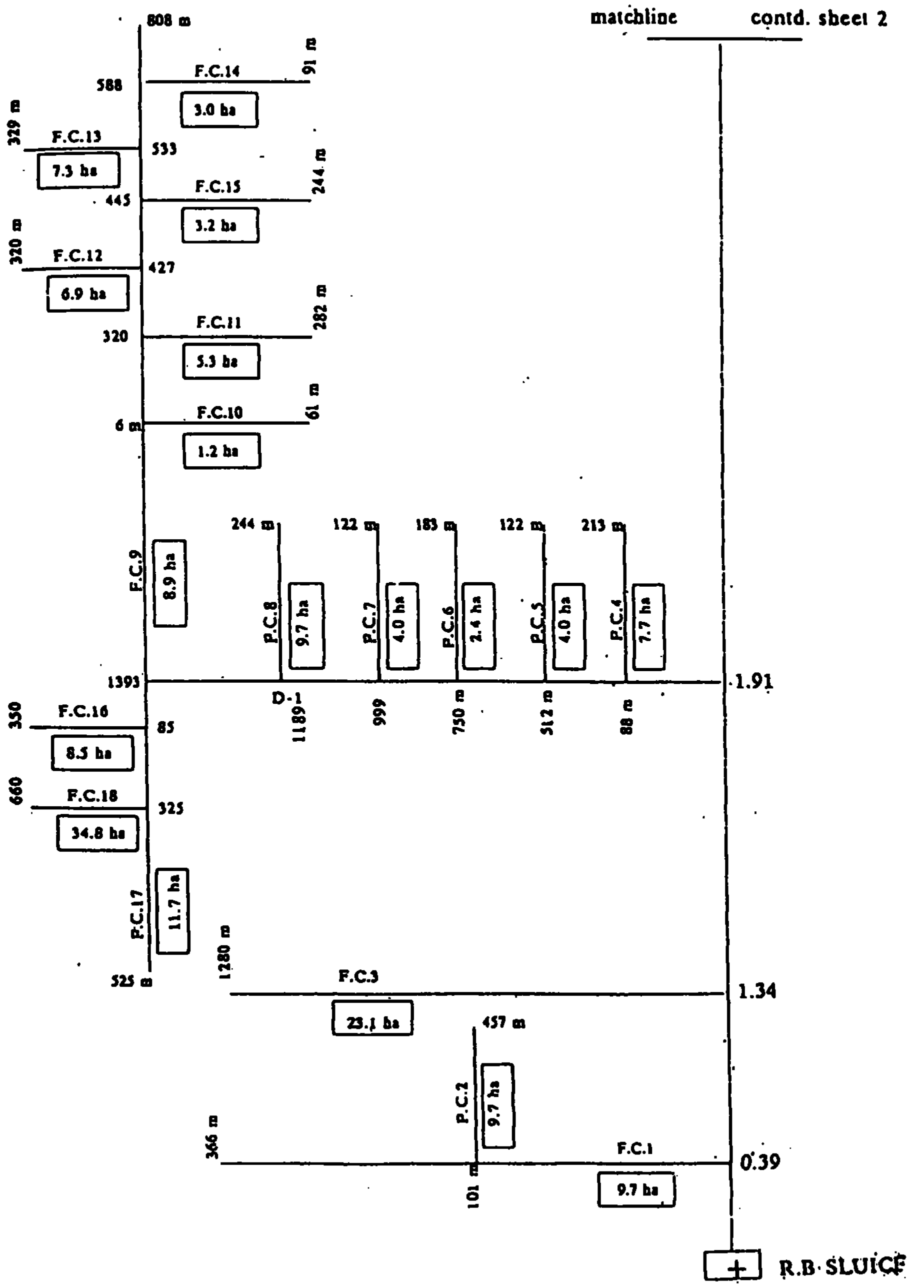
Table 3-1 Average Farm Water Requirements

Maha Season		Yala Season	
Week	Water REquirement 1/sec	Week Nos	Water Requirement 1/sec
4th-8th	1.23	5th-7th	1.27
9th-16th	1.30	8th-14th	1.55
17th-18th	1.35	15th-16th	1.12
19th	1.28	17th-22th	0.32
20th-21th	0.95	23th-24th	0.15

4) Obtain the arithmetic sums for each D-canal serving a network of field canals on a daily day/night basis; check the degree of fluctuations in the flow of the respective D-canals through the week. (Note that some D-canals may be open only for a few days in a week with peak or near peak flows and be totally shut during the remaining days.) Steps (7) to (10) are repeated to arrive at a delivery schedule with least flow fluctuations in each D-canal as far as practicable. For this exercise, the current carrying capacities of the D-canals have to be disregarded. A typical set of rotational schedules developed on this basis by trial and error process for Usgala Siyambalagamuwa Scheme is given in Annex 1.2 Sheets 1 and 3 to 11. These should be read in conjunction with Error! Bookmark not defined. being the Issue Tree of the scheme.

ANNEX 1.1 (Sheet 1 of 3)

ISSUE TREE OF R.B.CHANNEL SYSTEM
USGALA SIYAMBALANGAMUWA SCHEME

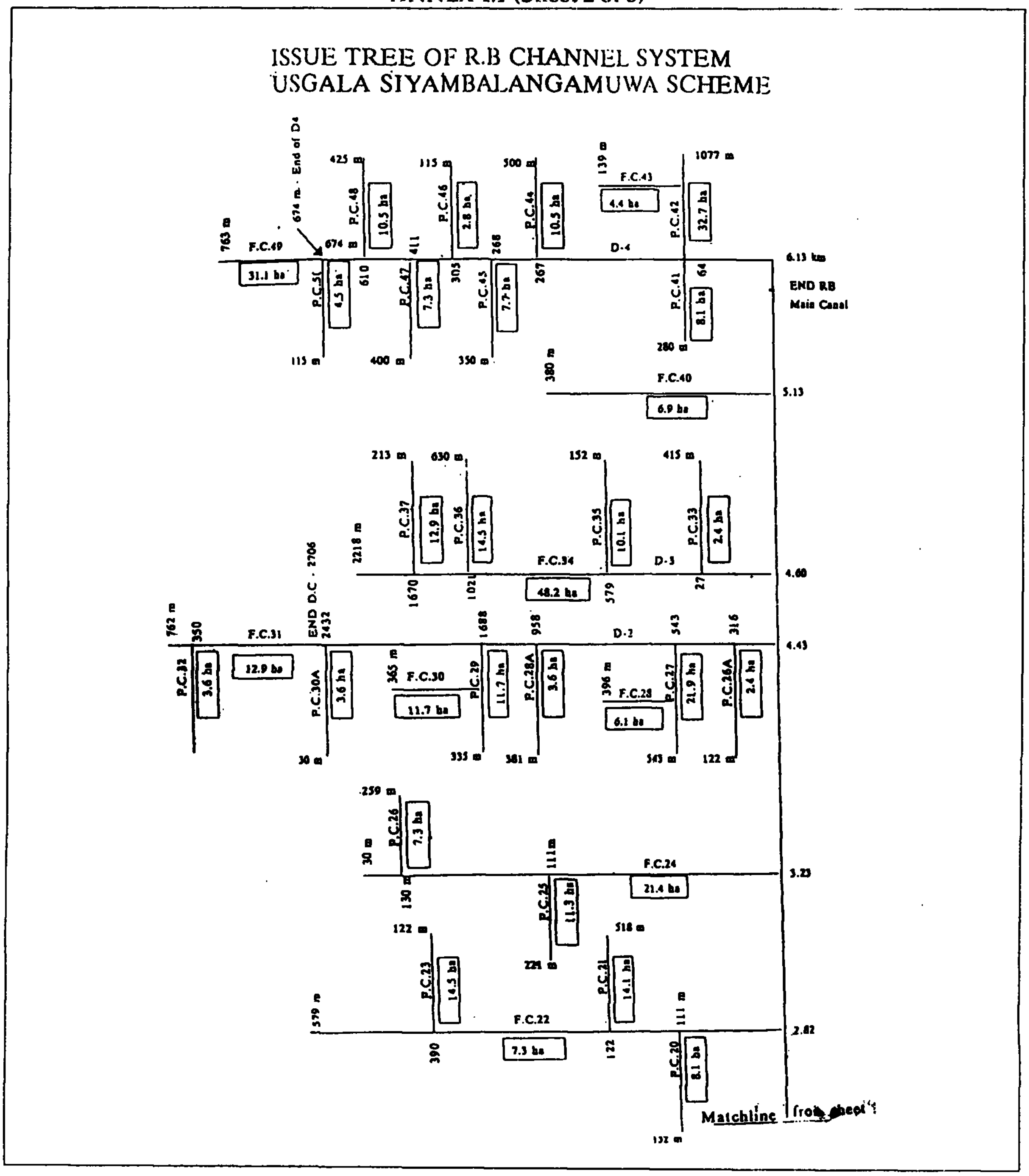


5) Once the optimum delivery schedules are found for each D-canal, it would be possible to determine the reachwise operational boundaries for the main canal catering to them. It would be advisable to try to maintain the main canal at its full flow level right throughout the week and to identify two or three reach boundaries (called as head, middle or tail reaches). Thus, each reach will consume the entire flow delivered by the main canal through a period of two or three days (if there are three reaches). If two reaches are adequate, each reach may consume the main canal flow for three to four days.

6) The reach boundaries so identified will have reach isolation regulators and measuring devices to regulate and monitor the flow to the reach (see Error! Bookmark not defined. Error! Bookmark not defined.).

7) Examine the carrying capacities of the Main and D canals to deliver the required quantities of water on a daily basis within a weekly rotation. On the above basis, calculate the peak discharges that will have to be carried by each D-canal and each operational reach of the main canals. A typical summation done for Usgala Siyambalagamuwa Scheme meeting with the above-mentioned considerations is given in Annex 1.2 Sheets 2 and 12.

ANNEX 1.1 (Sheet 2 of 3)



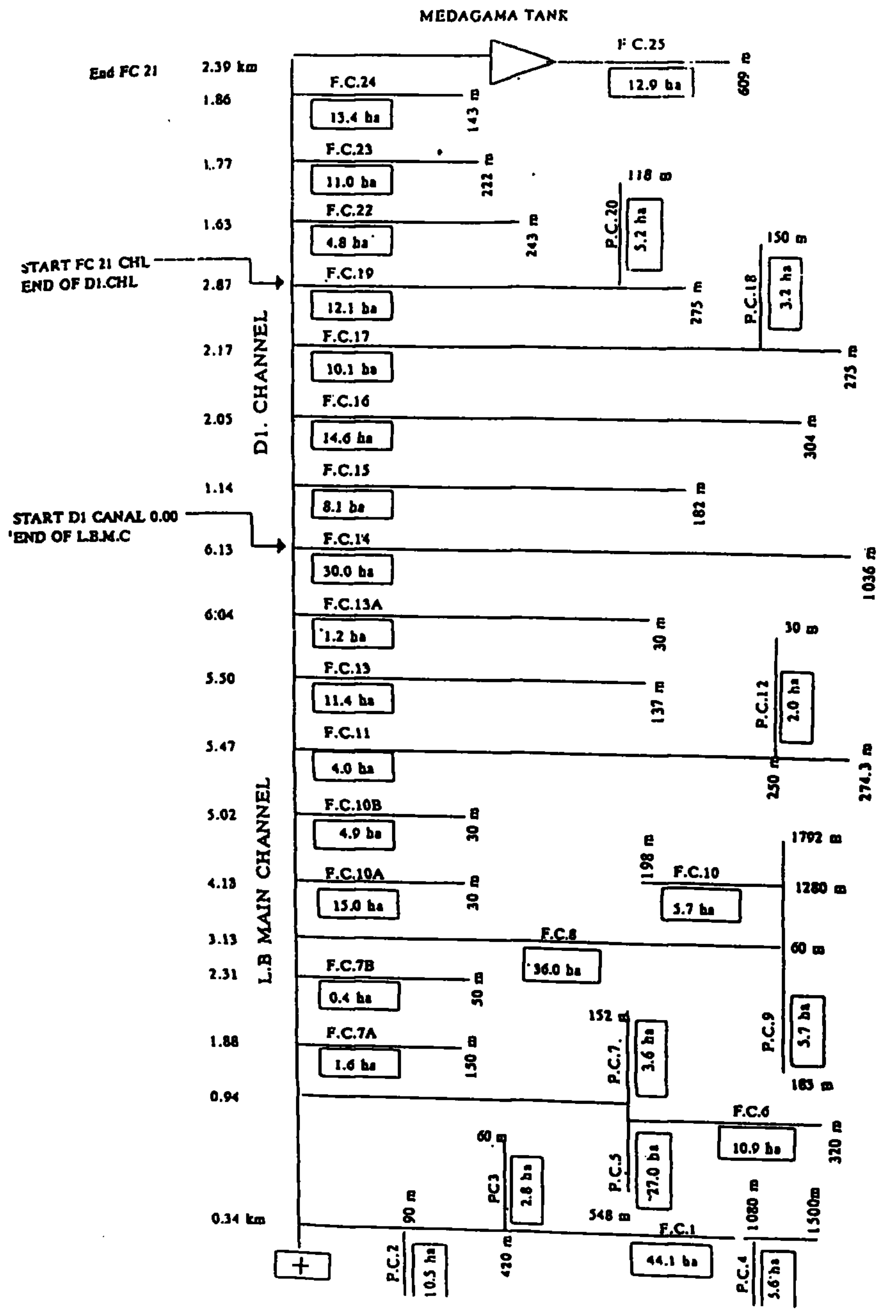
8) The option of keeping all turnouts continuously open was discouraged due to yielding of low delivery velocities (this is the cause of silting at the tail reaches of all control structures, canal bends etc.). Options with full flows of shorter durations were given preference.

9) Deliveries under partial openings of comparatively large sized control structures too were discouraged to avoid possible generation of undesirably low velocities.

10)Openings of control structures were kept to generate flow velocities as close as possible to the full capacity flows of the canals into which they were discharging.

ANNEX 1.1 (Sheet 3 of 3)

ISSUE TREE OF L.B.CHANNEL SYSTEM
USGALA SIYAMBALANGAMUWA SCHEME



ANNEX 1.2 (Sheet 1 of 12)

IRRIGATION SCHEDULE - LB SYSTEM

SEASON MAHA

LB Main Canal

FROM 9th wk TO 10th wk

F.C. NO.	AREA	CONT. SUPPLY MAX DISCH. (HA)	ROTATION SUPPLY MAX DISCH. (L/S)	ROTATION SUPPLY DURA (DAYS)	DAYS OF CANAL OPERATION DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
FC_1	44.1	66.2	120.0	4.0							
FC_2	10.5	15.8	30.0	2.5							
FC_3	2.8	4.2	15.0	2.0							
FC_4	5.6	8.4	15.0	4.0							
FC_5	27.0	40.5	90.0	3.0							
FC_6	10.9	16.4	30.0	4.0							
FC_7	3.6	5.4	15.0	2.5							
FC_{7A}	1.6	2.4	15.0	1.0							
FC_{7B}	0.4	0.6	15.0	0.5							
FC_8	36.0	54.0	90.0	4.0							
FC_9	5.7	8.6	30.0	2.0							
FC_{10}	5.7	8.6	30.0	2.0							
FC_{10A}	15.0	22.5	60.0	3.0							
FC_{10B}	4.9	7.4	15.0	3.5							
FC_{11}	4.0	6.0	15.0	3.0							
FC_{12}	2.0	3.0	15.0	1.5							
FC_{13}	11.4	7.1	60.0	2.0							
FC_{13A}	1.2	1.8	15.0	1.0							
FC_{14}	30.0	45.0	90.0	3.0							
FC_{15}	8.1	12.2	30.0	3.0							
FC_{16}	14.6	21.9	60.0	2.5							
FC_{17}	10.1	15.2	60.0	2.0							
FC_{18}	3.2	4.8	15.0	2.0							
FC_{19}	12.1	18.2	60.0	2.0							
FC_{20}	5.2	7.8	15.0	3.5							
FC_{21}	4.8	7.2	15.0	3.5							
FC_{23}	11.0	16.5	30.0	4.0							
FC_{24}	13.4	20.1	30.0	4.0							
FC_{25}	12.9	19.4	30.0	4.0							

LB MAIN CANAL

Row No		DAYS OF WEEK 1	2	3	4	5	6	7
1	$(FC_{21} - FC_{25})$ Net	–	–	–	90 120	120 120	120 120	120 120
2	$(FC_{15} - FC_{9})$ Net	–	–	–	–	165 165	165 165	90 30
3	$(FC_{1} - FC_{14})$ Net	600 585	660 645	645 630	420 405	–	–	–
4	Sub Total D1, net (= Row Nos 1+2)	–	–	–	90 120	285 285	285 285	210 150
5	Sub Total D_1, Gross = Row No 4x 1.15	–	–	–	100 140	330 330	330 330	240 170
6	Total LB Main Canal, Net (= Row Nos 1+2+3)	600 585	660 645	645 630	510 525	285 285	285 285	210 150
7	Total LB Main Canal, Gross = Row No 6 x 1.15	690 670	760 740	740 720	580 600	330 330	330 330	240 170

ANNEX 1.2 (Sheet 3 of 12)

IRRIGATION SCHEDULE - RB SYSTEM

SEASON MAHA

R.B. CANAL FC_1 & FC_2

FROM 9th WK TO 18th WK

F.C.NO.	AREA	CONT. SUPPLY MAX DISCH. (HA)	ROTATION SUPPLY MAX DISCH. (L/S)	ROTATION SUPPLY DURA. (DAYS)	DAYS OF CANAL OPERATION DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
FC_1	9.7	14.6	30.0	3.5							
FC_2	9.7	14.6	30.0	3.5							
Total in reach excluding DC losses					60 / 60	60 / 60	60 / 60	60 / 0			

ANNEX 1.2 (Sheet 4 of 12)

IRRIGATION SCHEDULE - RB SYSTEM

SEASON MAHA

R.B. CANAL FC_3

FROM : 9th WK TO: 18th WK

F.C.NO.	AREA	CONT. SUPPLY MAX DISCH. (HA)	ROTATION SUPPLY MAX DISCH. (L/S)	ROTATION SUPPLY DURA. (DAYS)	DAYS OF CANAL OPERATION DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
FC_3	23.10	34.6	90.0	3.0							
Total in reach excluding DC losses					90 / 90	90 / 90	90 / 90				

ANNEX 1.2 (sheet 5 of 12)

IRRIGATION SCHEDULE - RB SYSTEM

SEASON MAHA

R.B. Canal D_1

FROM 9th WK TO 18th WK

F.C.NO.	AREA	CONT. SUPPLY MAX DISCH. (HA)	ROTATION SUPPLY MAX DISCH. (L/S)	ROTATION SUPPLY DURA. (DAYS)	DAYS OF CANAL OPERATION DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
FC_4	7.7	11.6	30.0	3.0							
FC_5	4	6.0	15.0	3.0							
FC_6	2.4	3.6	15.0	2.0							
FC_7	4	6.0	15.0	3.0							
FC_8	9.7	14.6	30.0	3.5							
FC_9	8.9	13.4	30.0	3.0							
FC_{10}	1.2	1.8	15.0	1.0							
FC_{11}	5.3	8.0	30.0	2.0							
FC_{12}	6.9	10.4	30.0	2.5							
FC_{13}	4.9	7.4	30.0	2.0							
FC_{14}	7.3	11.0	30.0	2.5							
FC_{15}	3.2	4.8	15.0	2.0							
FC_{16}	8.5	12.8	30.0	3.0							
FC_{17}	11.7	17.6	30.0	4.0							
FC_{18}	34.8	52.2	90.0	4.0							
Total in reach excluding DC losses					195 195	180 180	165 165	210 210	180 180	195 195	180 180

ANNEX 1.2 (Sheet 6 of 12)

IRRIGATION SCHEDULE - RB SYSTEM

SEASON MAHA

R.B. Canal FC_{22}

FROM 9th WK TO 18th WK

F.C.NO.	AREA	CONT. SUPPLY MAX DISCH. (HA)	ROTATION SUPPLY MAX DISCH. (L/S)	ROTATION SUPPLY DURA. (DAYS)	DAYS OF CANAL OPERATION DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
FC_{20}	8.1	12.2	30.0	3.0							
FC ,	14.1	21.2	30.0	5.0							
FC_{22}	7.3	11.0	30.0	2.5							
FC_{23}	14.5	21.8	30.0	5.0							
Total in reach excluding DC losses					120 120	120 120	120 90	60 60	60 60	0 0	0 0

ANNEX 1.2 (Sheet 7 of 12)

IRRIGATION SCHEDULE - RB SYSTEM

SEASON MAHA

R.B. Canal FC_{24}

FROM 9 th WK TO 18th WK

F.C.NO.	AREA	CONT. SUPPLY MAX DISCH. (HA)	ROTATION SUPPLY MAX DISCH. (L/S)	DURA. (DAYS)	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
FC_{24}	21.40	32.1	60.0	4.0							
FC_{25}	11.30	17.0	30.0	4.0							
FC_{26}	7.30	11.0	30.0	2.5							
Total in reach excluding DC losses					120	120	120	90	0	0	90
					120	120	90	90	0	0	90

ANNEX 1.2 (Sheet 8 of 12)

IRRIGATION SCHEDULE - RB SYSTEM

SEASON MAHA

R.B. Canal D_2

FROM 9 th WK TO 18th WK

F.C.NO.	AREA	CONT. SUPPLY MAX DISCH. (HA)	ROTATION SUPPLY MAX DISCH. (L/S)	DURA. (DAYS)	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
FC_{26}	2.4	3.6	15.0	1.5							
FC_{27}	21.9	32.9	60.0	4.0							
FC_{28}	6.1	9.2	15.0	4.0							
FC_{28A}	3.6	5.4	15.0	2.5							
FC_{29}	11.7	17.6	30.0	4.0							
FC_{30}	11.7	17.6	30.0	4.0							
FC_{30A}	3.6	5.4	15.0	2.5							
FC_{31}	12.9	19.4	30.0	4.5							
FC_{32}	3.6	5.4	15.0	2.5							
Total in reach excluding DC losses					150	165	135	135	75	75	75
					150	165	135	135	75	75	75

ANNEX 1.2 (Sheet 9 of 12)

IRRIGATION SCHEDULE - RB SYSTEM

SEASON MAHA

R.B. Canal D_3

FROM 9 th WK TO 18^{th} WK

F.C.NO.	AREA	CONT. SUPPLY	ROTATION SUPPLY		DAYS OF CANAL OPERATION						
		MAX DISCH. (HA)	MAX DISCH. (L/S)	DURA. (DAYS)	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
FC_{33}	2.4	3.6	15.0	2.0							
FC_{34}	48.2	72.3	90.0	5.5							
FC_{35}	10.1	15.2	30.0	3.5							
FC_{36}	14.5	21.8	30.0	5.0							
FC_{37}	12.9	19.4	30.0	4.5							
Total in reach excluding DC losses					165 / 135	135 / 135	150 / 150	150 / 150	150 / 150	180 / 60	60 / 60

ANNEX 1.2 (Sheet 10 of 12)

IRRIGATION SCHEDULE - RB SYSTEM

SEASON: MAHA

R.B. Canal FC_{40}

FROM : 9 th WK TO: 18^{th} WK

F.C.NO.	AREA	CONT. SUPPLY	ROTATION SUPPLY		DAYS OF CANAL OPERATION						
		MAX DISCH. (HA)	MAX DISCH. (L/S)	DURA. (DAYS)	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
FC_{40}	6.90	10.3	30.0	2.5							
Total in reach excluding DC losses					30 / 30	30 / 30	30 / 0	0 / 0	0 / 0	0 / 0	0 / 0

IRRIGATION SCHEDULE – RB SYSTEM

SEASON MAHA

RB Canal D_4

FROM: 9th wk TO: 18th wk

F.C. NO.	AREA	CONT. SUPPLY MAX DISCH. (HA)	ROTATION SUPPLY MAX DISCH. (L/S)	ROTATION SUPPLY DURA. (DAYS)	DAYS OF CANAL OPERATION DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
FC_{41}	8.1	12.2	30.0	3.0							
FC_{42}	22.7	34.1	90.0	2.5							
FC_{43}	4.4	6.6	15.0	3.0							
FC_{44}	10.5	15.8	30.0	3.5							
FC_{45}	7.7	11.6	30.0	3.0							
FC_{46}	2.8	4.2	15.0	2.0							
FC_{47}	7.3	11.0	30.0	2.5							
FC_{48}	10.5	15.8	30.0	3.5							
FC_{49}	31.1	47	90.0	3.5							
FC_{50}	4.8	7.2	15.0	3.5							
Total in reach excluding DC losses					105/105	165/165	180/180	150/150	180/165	180/180	165/165

RB SYSTEM MAIN CANAL

Row No		DAYS OF WEEK						
		1	2	3	4	5	6	7
1	D_4 Net (SHEET 9)	105 / 105	165 / 165	180 / 180	150 / 150	180 / 165	180 / 180	165 / 165
2	FC_{40} Net (SHEET 8)	120 / 120	120 / 120	120 / 90	90 / 90	0 / 0	0 / 0	0 / 0
3	D_3 Net (SHEET 7)	165 / 135	135 / 135	150 / 150	150 / 150	150 / 150	180 / 60	60 / 60
4	Sub total Reach (D_3 – D_4) Net	390 / 360	420 / 420	450 / 420	390 / 390	330 / 315	360 / 240	225 / 225
5	Sub total Reach (D_3 to D_4) Gross (= Row No 4 x 1.15)	450 / 415	490 / 490	520 / 490	450 / 450	380 / 370	415 / 280	260 / 260
6	D_2 Net (SHEET 6)	150 / 150	165 / 165	135 / 135	135 / 135	75 / 75	75 / 75	75 / 75
7	FC_{24} Net (SHEET 5)	120 / 120	120 / 120	120 / 90	90 / 90	0 / 0	0 / 0	0 / 0
8	FC_{22} Net (SHEET 4)	120 / 120	120 / 120	120 / 90	60 / 60	60 / 60	0 / 0	0 / 0
9	Sub total Reach (FC_{22} to D_2) Net	390 / 390	405 / 405	375 / 315	285 / 285	135 / 135	75 / 75	75 / 75
10	Sub total Reach (FC_{22} to D_2) Gross (= Row No 9 x 1.15)	450 / 450	470 / 470	430 / 370	330 / 330	160 / 160	90 / 90	90 / 90
11	D_1 Net (SHEET 3)	195 / 195	180 / 180	165 / 135	210 / 210	180 / 180	195 / 195	160 / 180
12	FC_3 Net (SHEET 2)	90 / 90	90 / 90	90 / 90	-	-	-	-
13	(FC_1 & FC_2) Net (SHEET 1)	60 / 60	60 / 60	60 / 60	60 / 0	-	-	-
14	Sub total Reach (FC_1 to D_1) Net	345 / 345	330 / 330	315 / 285	270 / 210	180 / 180	195 / 195	180 / 180
15	Sub total Reach (FC_1 to D_1) Gross (= Row No 14 x 1.15)	400 / 400	380 / 380	370 / 330	310 / 240	210 / 210	230 / 230	210 / 210
16	RB Main Canal Reach D_3 – D_4 (= Row No 5)	450 / 415	490 / 490	520 / 490	450 / 450	380 / 370	415 / 280	260 / 260
17	RB Main Canal Reach (FC_{22} to D_2) (= Row Nos 16 + 10)	900 / 865	960 / 960	950 / 860	780 / 780	540 / 530	505 / 370	350 / 350
18	RB Main Canal Reach (FC_1 to D_1) (= Row Nos 17 + 14)	1245 / 1210	1290 / 1290	1265 / 1145	1050 / 990	720 / 710	700 / 565	530 / 530

4.0 Determination of canal sections

To start with the determination of canal sections, a computer based iterative procedure was developed to solve the Manning's equation for which the following trial inputs were fed in.

1. Design Discharge
2. Manning's n values
3. Side slopes of trapezoidal sections
4. Bed slopes
5. Bed width to depth (of flow) ratios

The outputs obtained were;

1. Depths of flow for assumed bed widths
2. The flow velocity for a given ratio of bed width to depth
3. Froude number for given discharge, bed width and depth
4. Critical velocity (against scouring) for computed depth of flow

This approach enabled the comparison of a wide range of bed widths, depths, actual velocities and scouring velocities for a given design discharge.

Accordingly, the canals were sized to minimize velocity fluctuations for different flow levels. Since the minimum operating depth of a canal is taken as 2/3 rd FSD, the velocity of uniform flow discharge corresponding to 2/3 rd FSD and that of full flow had to be nearly same. The range of depth to bed width ratios, which satisfied this condition, was found to be between 1.2 and 1.5. Hence, the rehabilitated canals and their control structures were sized accordingly. In fact this yielded larger depths of flow and enhanced the regulating flexibility in the canals. A set of typical canal sections proposed for Usgala Siyambalangamuwa scheme on this basis are given in Error! Bookmark not defined 4-1. Canals with such parameters generated eroding velocities. The idea was to encourage self-cleaning of silt, which is deposited during partial, or retarding flow situations (for example, during rotational canal closures).

Table 5.1 Designed Sections for Canals

Range of Disch. l/sec.	Bed Slope	Side Slope	Manning n	Bed Width mm	Range of FSD mm	Remarks
1300 / 1000	0.00035	1 on 1	0.04	2000	1140 / 990	RBMC Reach 1
1300 / 1000	0.00035	1 on 1.5	0.04	2000	1045 / 910	- do -
999 / 800	0.00035	1 on 1	0.04	1500	1115 / 995	RBMC Reach 2
999 / 800	0.00035	1 on 1.5	0.04	1500	1010 / 900	- do -
799/600	0.00035	1 on 1	0.04	1300	1050 / 905	LBMC
799/600	0.00035	1 on 1.5	0.04	1300	945 / 820	- do -
599 / 400	0.00035	1 on 1	0.04	1000	995 / 810	RBMC Reach 3
599 / 400	0.00035	1 on 1.5	0.04	1000	885 / 730	- do -
599 / 400	0.00035	1 on 1	0.04	1200	935 / 755	- do -
599 / 400	0.00035	1 on 1.5	0.04	1200	840 / 690	- do -
399 / 300	0.00035	1 on 1	0.04	1000	810 / 700	LB / D1
399 / 300	0.00035	1 on 1.5	0.04	900	750 / 655	- do -
299 / 200	0.00035	1 on 1	0.04	800	755 / 615	RB / D1, D4
299 / 200	0.0004	1 on 1	0.04	800	730 / 595	LB / FC1
199 / 150	0.00035	1 on 1	0.04	700	645 / 560	RB /D2, D3
199 / 150	0.0004	1 on 1	0.04	700	625 / 540	LB / FC8, FC5
149 / 100	0.00035	1 on 1	0.04	600	590 / 480	RB / FC22, FC24
149 / 100	0.0004	1 on 1	0.04	600	570 / 465	RB / D1 / FC9,FC17 LB / D1 / FC21
99 / 60	0.00035	1 on 1	0.04	600	480 / 370	LB / D1 / FC10,
99 / 60	0.0004	1 on 1	0.04	500	495 / 385	- do - / FC13, FC14 - do - / FC17, FC19

The above approach brought in a 2 pronged benefit. On one hand, it made canal operations easier since the number of adjustments of control structures were minimized. On the other hand, it helped to control the silting up of canal beds since they flowed in erosive velocities during most of the operational period.

Similar exercises were done for other growth stages too. However, during these growth stages, the overall flow rates would be less. In such circumstances, (although the number of canal fluctuations could be minimized), the flow velocities could not be kept at their optimum levels. Hence, there could be a certain amount of silting up. Remedial action to be taken for such situations is described in Error! Bookmark not defined..

5.0 Sizing of Turnouts

The next requirement is the sizing of turnouts to ensure that the required flows could be delivered within the stipulated durations. As the first step to ensure this, a series of calculations were made to derive the head losses through the standard turnouts of different diameters and barrel lengths. The FSDs of respective parent canals and their minors were compared in relation to discharge requirements computed as per Error! Bookmark not defined. above. Thereafter, turnouts of different diameters were matched by trial and error to ensure the delivery of required discharges within the already determined flow schedule. This exercise in some instances showed that more than one turnout of the same diameter or two different diameters were required to ensure the expected flow levels. Error! Bookmark not defined. was used as the basis for this exercise. Error! Bookmark not defined. gives the turnouts proposed to the RB canal network of Usgala Siyambalangamuwa scheme as a specific example.

6.0 Regulating requirements

According to the recommendations of the ID technical guidelines referred to in paragraph 2 above, regulators in Irrigation Canals need to be at a spacing of FSD/3S where FSD is the full supply depth and S is the bed slope. Hence, in the Irrigation Canals designed and/or rehabilitated by the ID designers it is customary to locate regulators at spacings determined by this criterion.

However, the introduction of regulators into a canal will change its flow conditions from 'uniform' to 'gradually varied or accelerating and retarding flow conditions' if one uses 'Hydraulic Jargon' to explain the situation. The retarding flows enhance buildup of silt behind the regulators and the accelerating flows enhance erosion beyond them. On the other hand, more regulators will act as further constraints in conveying water to tail reaches.

Based on these considerations it was decided that the regulators be provided only at 'reach boundaries' as determined by the canal operation study outcomes. Primary purpose of these regulators would be to cut off water beyond the reach boundary to enable diversion of full flow of the parent canal into the pre-determined reach. However, with this arrangement, some turnouts that are placed further up in the reach may be deprived of their driving heads. Such turnouts are identified and a suitable pair of turnouts is introduced to operate at the lowest operating head, which is 2/3 rd FSD. (This corresponds to about 50% of the design discharge.) It must be noted that these settings are only applicable to canals running on contours. Canals running along ridges will invariably have drop structures, and it is customary for each drop structure to have planking arrangements so that the delivery heads could be ensured. Hence, the question of heading up using regulators will not arise in the case of ridge canals.

Table 5-1 Criteria used to determine Turnout Gates

Extent* ha	Max.disch l/sec	Gate dia mm	No.of gates	Min.driving head mm
0-3	7.0	100	1	150
3-7	15.0	150	1	225
7-15	30.0	225	1	300
15-25	50.0	300	1	400
25-35	75.0	380	1	500
35-60	120.0	450	1	600
60-75	150.0	380	2	500
75-100	200.0	600	1	750
100-120	24.0	450	2	600

Table 6.2 Proposed Design Discharges and Turnout Diameters - Rb System

Canal / Canal Reach	Max. Discharge l/sec	Turnout Dia. mm and No. of gates
RBMC / FC1	30	1/225
/ FC2	30	- do -
/ FC3	90	2/300
RB / D1 / FC 4	30	- do -
/ FC5	15	1/150
/ FC6	15	- do -
/ FC7	15	- do -
/ FC8	30	1/225
RB / D1 / FC9 / FC10	15	1/150
/ FC11	30	1/225
/ FC12	30	- do -
/ FC13	30	- do -
/ FC14	30	- do -
/ FC15	15	1/150
RB / D1 / FC9	105	1/380 + 1/225
RB / D1 / FC17 / FC16	30	1/225
/ FC18	90	2/300
RB / D1 / FC17	135	2/380
RB / D1	240	2/450
RB / FC22 / FC20	30	1/225
/ FC21	30	- do -
/ FC23	30	- do -
RB / FC22	135	2/380
RB / FC24 / FC25	30	1/225
/ FC26	30	1/225
RB / FC24	135	2/380

Canal / Canal Reach	Max. Discharge l/sec	Turnout Dia mm and No of gates
RB / D2 / FC 26	15	1/150
27	60	2/225
28	15	1/150
28 A	15	- do -
29	30	1/225
30	30	1/225
30 A	15	1/150
31	30	1/225
32	15	1/150
RB / D2	180	1/450 + 1/380
RB / D2 / FC 33	15	1/150
/ FC 34	90	2/300
/ FC 35	30	1/225
/ FC 36	30	- do -
/ FC 37	30	- do -
RB / D3	180	1/450 + 1/380
RB / FC40	30	1/225
RB / D2 / FC 41	30	- do -
/ FC 42	90	2/300
/ FC 43	15	1/150
/ FC 44	30	1/225
/ FC 45	30	- do -
/ FC 46	15	1/150
/ FC 47	30	1/225
/ FC 48	30	- do -
/ FC 49	90	2/300
/ FC 50	15	1/150
RB / D4	210	2/450
RBMC / Start to D1	1290	-
/ D1 to D2	960	-
/ D2 to End	520	-

7.0 Measuring devices

For rotational issues to be successfully practiced, monitoring of water deliveries would be essential. However, it would be cumbersome to monitor a number of points since it may eventually negate the purpose for which measuring facilities are introduced. Hence, the number of points to be monitored will be reduced to the head sluices and the boundaries of each rotational-reaches. Here too, care is taken not to introduce any structures with humps, which are likely to hamper free flow during low head conditions in the head sluices. Hence, simplified rectangular concrete lined sections with built in throats were adopted as measuring devices.

8.0 Criteria to be followed during non-peak situations of flow.

The next step shall be the determination of criteria to be adopted during;

a) period of land preparation.
b) periods of less than peak flow.
c) water short situations.
d) periods with effective rainfall in command area.

Suggested criteria to be followed during such situations are discussed below

a) Period of land preparation

Land preparation requirements and the methods of application will vary depending upon the crops to be cultivated. Paddy needs continuous flooding (a total of 175mm of water) whereas vegetables and pulses will require 3 separate issues (a total of about 75mm) within a duration of normally two weeks. Consideration must also be given for staggers, especially during paddy cropping, since,

i) the farmers are usually unable to deploy all the resources required for land preparation within a single stagger of two weeks duration, and;

ii) the canal capacities as designed above will not be adequate to deliver the land preparation requirement simultaneously to full command area.

Hence, during land preparation period, the three operational reaches in the main canals (head, middle and tail reaches) are taken for the 1st, 2nd and 3rd staggers or vice versa. For paddy cultivation, each reach is thus given continuous irrigation for two weeks; and the total duration for all three staggers will be 6 weeks. For other crops, generally 3 separate issues are given to each cropped area, while the Main Canals are flowing full.

b) Periods of less than peak flow.

Following the procedure described in Error! Bookmark not defined. above, the operation staff is required to compute the discharge requirements in each reach for each growth stage of less than peak flow. Accordingly, shorter duration rotations will be determined for the D-canals. The reduced durations of the D canal rotations may require closure of Main canal for a couple of days per week after catering to the requirements of all three reaches. These rotations should be such that the respective canals flow full whenever they are open, to minimize siltation.

c) Water short situation

This will be an emergency-situation for a short period and thus, flow fluctuation upto 50% design flow would be tolerated. This approximately corresponds to 2/3rd FSD and hence, the gate openings of the turnouts nearer to the regulator will have to be reduced to ensure equitable flows. If the water short situation persists, decisions to cut off water to selected areas will have to be made with the consent of the respective farmer organizations (Error! Bookmark not defined.).

d) Periods of effective rainfall

If there is effective rainfall in the command area on a given day, water issues from the head sluices shall be reduced proportionately on the following days. The deliveries to relevant FCs shall be suspended for a specified duration depending upon the magnitude of the effective rainfall. Error! Bookmark not defined. shall be a suitable guide for such suspension/ reduction of water issues. When the flow in the Main canal is reduced, the depth of flow will become less. Hence, the schedules prepared for b) or c) above shall be applied.

Table 8.1 Irrigation Suspension Limits

Rainafall mm/day	Period of suspension in FCS (Days)
0-4	Nil
5-11	1
12-21	2
22-32	3
33-45	4
46-60	5
61-75	6

9.0 Determination of future operation plan.

General steps that were followed in preparing scheme specific operation plans were discussed in the fore going sections. An operation plan so prepared can have the following salient features.

1. Based on the head works operation study (which is outside the score of the present paper), make recommendations on a suitable cropping pattern and a cultivation calendar.

2. Identify present operational problems in the scheme (Error! Bookmark not defined.).

3. Determine peak water requirements in each reach, section or sub section of the command area to suit the above cropping pattern and a cultivation calendar (Error! Bookmark not defined.).

4. Determine a suitable rotational schedule for peak flows (see section 4).

5. Determine peak flows in each field canal, distributory canal as well as each operational reach of the main canal (see section 4).

6. Size the canals and turnouts to ensure delivery of these flows within the stipulated rotational durations (Error! Bookmark not defined. Error! Bookmark not defined.).

7. Determine regulating and measuring requirements to enable adequate control and monitoring of the flows (Error! Bookmark not defined. Error! Bookmark not defined.).

8. Determine criteria to be applied for non- peak flow periods (Error! Bookmark not defined.).

9. All the above steps would be of no use unless there is positive commitment by all concerned to put into practice the relevant recommendations. Hence, the general responsibilities and the procedures to be followed by the farmers, Farmer Organization, various line agencies etc. during actual operations were identified and documented in the form of an O&M Manual. This manual shall be the basis for preparation of scheme-specific O&M manuals that are to be prepared by the respective operation staff of each rehabilitated scheme. Such manuals shall be the control documents for future operation and maintainence of the each rehabilitated scheme. No further details on this subject will be presented at this stage, as it would be outside the scope of the present paper.

10.0 Conclusion

Historical design considerations in relation to irrigation canal networks in Sri Lanka were explained. Reasons for their inadequacy in carrying out rehabilitation designs were given. Absence of any design criteria for rehabilitation designs was highlighted. A comprehensive methodology for analyzing the commonly observed problems in existing canal networks and suggested solutions for them were presented. Salient features of a proposed operation plan for rehabilitated irrigation schemes were listed. Specific examples extracted from the study of Usgala Siyambalagamuwa scheme were included to improve the clarity of presentation.

Accordingly, the foregoing presentations can be treated as a suitable basis for the preparation of comprehensive design criteria to perform rehabilitation designs of canal networks in existing Major/Medium irrigation schemes.

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Lastly, he recalls with appreciation, his son Thejaka who (silently bearing the impatient manners of the author) did an excellent job of computer document preparation.

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