PAPER No. 465

Remodelling of Rohri Canal System

BY

Engr. Barkat Ali Luna

B Sc. Engg. (Civil), MASCE (USA), FIE (Pak).
Ex-Project Manager for Remodelling Rohri Canal System
and now Chairman, National Development Consultants

Engr. S. N. H. Mashhadi

B Sc. Engg. (Mech), B.Sc. Engg. (Civil), MASCE (USA), FIE (Pak)
Ex-Deputy Project Manager for Remodelling Rohri Canal System
and now Managing Partner, National Development Consultants.

Paper No.465

REMODELLING OF ROHRI CANAL SYSTEM

By

(*) (**)

Engr. Barkat Ali Luna & Engr. S.N.H.Mashhadi

1.0 INTRODUCTION

The Rohri Canal, the longest single Canal in the country, takes off from the left flank of Sukkur Barrage on the Indus River. As shown in the Location Map on Fig-1, this Canal System is located in the Sind Province of Pakistan and its command is defined by - Khairpur District on the North; a continuous chain of river bunds on the West; a vast uncultivated sandy desert extending upto the command of Jamrao Canal on the East; and Badin District on the South.

The System, originally designed with a head capacity of 10,887 cusecs and a C.C.A. of 2.613 million acres, comprises irrigation channels measuring 2,291 canal miles spread over an area of 4,425 sq. miles. The network of this canal system is shown on Figure-2.

2.0 NEED FOR REMODELLING

2.1 General

In normal irrigation practice remodelling of existing channels is indicated when any or all of the following symptoms are diagnosed in the working of the system:

(i) Chronic shortage of supplies at the tails.
(ii) Wide-spread complaints of individual outlets.

(*) B.Sc. Engg. (Civil), MASCE (USA)., FIE (Pak)., Ex-Project Manager for Remodelling Rohri Canal System and now Chairman, National Development Consultants.

(**) B.Sc. Engg. (Mech), B.Sc. Engg. (Civil), MASCE (USA)., FIE (Pak)., Ex-Deputy Project Manager for Remodelling Rohri Canal System and now Managing Partner, National Development Consultants.

(iii) Excessive silting-up in the beds of channels and frequent silt-clearance.

(iv) Practice of running excessive supply over and above the authorised full supply discharge at heads of the channels to feed the tails.

(v) Poor command at the heads of distributaries or at the heads of minors.

(vi) Widening of bed width and shallowing of the depth as compared to the design parameters of the channels.

(vii) Revision in the design criteria of the old channels.

(viii) Obsolescence of structures or change in their functions with the passage of time, such as class of Loading for bridges with the advent of bigger and heavier vehicles.

(ix) Interception of the system channels by a newly constructed canal with such F.S. Levels that can feed the lower stems of the intercepted channels from the new source. This results in radical re-modelling of the upper stems of intercepted channels.

(x) Change in the silt grade and silt charge of the channel due to switching over to a new source of water supply - as experienced after implementation of Indus Waters Treaty of 1960.

The functional deficiencies and factors justifying the need for remodelling of Rohri Canal System, in particular, have been discussed in paragraph 2.2 hereunder.

2.2 Functional Deficiencies in the Rohri Canal System

The Rohri Canal System was originally constructed during the period from 1923 to 1933. The Main Canal was commissioned in 1932 and thereafter its discharge followed an upward trend at a very slow but steady pace. In 1947, when Pakistan came into being as an independent state,

Rohri Canal was still in an under-developed state. Greater momentum was, however, gathered after independence in expanding agriculture to attain self-sufficiency in food and fibre requirements. The discharge climbed a relatively steeper curve, surpassed the designed mark of 10,887 Cs. in 1952 and continued growing in the following years till it reportedly attained the level of about 16,000 Cs. (Refer Hydrograph in Figure-3) in 1975; beyond which further increases were strictly constrained by the capacities of structures and the channels of the System. As the discharge increased progressively it exerted extra pressure on the structures in particular and on the channel sections in general. Many important structures along the Main Canal were damaged while a few completely collapsed. Conscious of the fact that Rohri Canal was running at high stakes, the Irrigation and Power Department, Government of Sind (I&P.D., G.O.S.) seriously considered the remodelling of the existing canal system. Under the "Grow-More-Food" campaign more and more supplies were diverted to Rohri Canal for rapid development and intensified cropping. In spite of the enormous increase over the designed discharge the demand is still rising. The excessive load of running high supplies has overstrained the canal system and the abnormal operation with very high and low supplies in different reaches, has confronted the channels with unsurmountable problems necessitating remodelling of the entire system. Such problems include but are not limited to the following factors:

2.2.1 Failure of Structures due to Inadequate Capacity and Unsafe Design.

The high discharges passing through the structures coupled with the excessive fluming built in the original

design and the thin floors on the downstream sides, led to the inevitable result that many important structures along the main canal completely collapsed and many were partially damaged. To save the failing structures, a phased programme of constructing by-pass structures is being implemented by the I.&P.D., Government of Sind. Till the writing of this paper, 9 by-pass structures had been constructed on the Rohri Main Canal and about 8 were on the waiting list.

2.2.2 Inadequate Capacity of Channels

The channel sections have been heavily taxed by forcing high discharges through the system channels. Consequently the berms were taken over and included in the active channel width at several places with the result that the side-slopes are irregular, broken and battered and the free-board is rarely available.

2.2.3 Silting and Scouring of Channels

The head-regulators of many channels are defective inasmuch as they allow entry of excessive silt charge which drops in the head reaches thus incapacitating the the channels to carry even their designed discharges.

2.2.4 Chronic Shortage at Tails

The phenomenon of silting and scouring led to an imbalance in the distribution of water supplies among various sections of the system. Tails of numerous channels receive no supply and consequently, such areas have been abandoned or put on to other sources.

2.2.5 Disparity between North and South Zones

As a result of inequitable distribution a wide disparity exists between the North and the South Zones of this canal system. In the North Zone (above Kumblime Cross-Regulator R.D. 705), the channels are receiving a

much larger share of the supplies while the South Zone (below Kumblime) is suffering from chronic shortages.

2.2.6 Inequitable Regulation

The extra supplies made available due to construction of by-pass structures in the northern reach are being passed into various channels of the North Zone according to the carrying capacity of such channels. The regulation pattern has thus been completely upset. The silting problem is also responsible for the inequitable distribution.

2.2.7 Inadequate Water Allowance

The originally designed water-allowance on the Rohri command was 2.7 cusecs per thousand acres of CCA which is too meagre to sustain agriculture at the present day scientific needs. The crop-water requirements indicate an average water allowance of 5.03 Cs. in summer and 3.43 Cs. in winter.

2.2.8 Insufficient Maintenance Funds

Maintenance funds for the Rohri Canal System which constitutes the life-line for production of food and fibre for millions of needy people, are drastically low. It is not possible to maintain irrigation channels in safe conditions with petty amounts. The system has to be strengthened through capital expenditure.

3.0 ASSIGNMENT FOR REMODELLING OF ROHRI CANAL SYSTEM

The I.&P.D., G.O.S. decided to get the Remodelling Project prepared through the Pakistan Water & Power Development Authority (WAPDA) who in turn retained the services of local consultants M/s. Engineering and Technical Consultants (ETC) of Lahore to provide the engineering services for the Project Planning and Detailed Project Preparation. For accomplishment of this task E. T. C.

had to collect all the available data pertaining to the canal system and also to observe at site what was not available. In order to provide a base for redesigning of various channels it was decided to get the hydraulic and sediment data of Rohri Main Canal and its direct off-takes observed through the cooperation of Alluvial Channels Observation Project (ACOP) WAPDA for a period of one year covering one Kharif and one Rabi season. To facilitate the collection of data and information pertaining to the existing canal system from the concerned offices of I & P.D., G.O.S. and other Government Departments at Hyderabad, Sukkur and Karachi and for carrying out field surveys and investigations, ETC associated with a South-based firm M/s. National Technical Services (NTS), Hyderabad. Through their experience of local conditions the task of data collection and field surveys and liaison with the local Government Departments was very much eased out.

4.0 ORIGINAL DESIGN OF THE EXISTING SYSTEM

Before describing the essential features of the Remodelling Plan suggested by the Consultants, it is pertinent to apprise the readers about the original design concepts of the existing system. These are briefly described in the following paragraphs.

4.1 Design Concept for Channels

As gathered from the Completion Reports of Sukkur Barrage and Off-taking canals, the guiding factors in designing the canals in this system were the alignment, command and areas to be brought under cultivation. The following broad principles were kept in view while designing the various channels.

4.1.1 Fixation of F.S. Levels and Hydraulic Gradients

The discharge required at each distributary head being known, the full supply at the distributary head

was fixed for the purpose of designing the main canal on the following principles:

a) The bed of the distributary at its tail must not be below ground level.

b) The full supply level in the distributary should nowhere be less than one foot above the highest ground level along the alignment.

c) The hydraulic gradients adopted for the channels of various sizes were as given in Table-1 below:

TABLE-1

HYDRAULIC GRADIENTS ADOPTED IN ORIGINAL DESIGN

Capacity of Channels (Cs.) From	To	Hydraulic Gradient (Not flatter than)
0	50	1 in 7,000
51	100	1 in 8,000
101	200	1 in 9,000
201	500	1 in 10,000
500	above	Still Flatter

1.1.2 Side-Slopes, Critical Velocity Ratio, Value of 'n', Transit Losses & Bed-width to Depth Ratios.

The gradients necessary in various reaches of the canal system being known as also the discharge and full supply levels at various points in the main canals and branches, following broad principles were adopted in working out the designs:

a) The side-slopes of the channels were taken as 1:1 for design as well as for construction.

b) The scouring velocity for Sind soil was taken as 3.50 ft./sec.

c) The Rohri Canal was designed with a full supply depth of 12 feet and a hydraulic gradient of 1 in 11,700 in the head-reach, giving a critical velocity of 3.50 ft./sec.

d) The value of 'n' (Manning's roughness co-efficient) was adopted as 0.020 for all channels over 200 cusecs discharge while for channels of capacity lower than 200 cusecs the value of 'n' adopted was 0.0225.

e) Transit losses were calculated at the rate of 8 cusecs per million square feet of wetted perimeter for all channels.

f) The discharge and hydraulic gradients to be adopted having been determined, the bed width and depth were so selected that the mean velocity in channel was never less than the Sind critical velocity. However, as a rule the bed width-depth ratio was never made less than 3.

The resulting Rohri Canal discharges, bed width and depths in various reaches were as indicated in Table-2.(page-214).

4.2 The Original Concept for Design of Structures

The following concepts for the design of various structures were adopted in the original project.

4.2.1 Falls and Cross-Regulators

Waterway for falls, fall-regulators and flumed-regulators were calculated from the common broad-crested weir formula. However, the long and thin upstream and downstream floors of the regulators and falls were apparently designed on the Bligh's Creep Theory, since the modern Khosla's Theory of Exit Gradients and independent Variables for working out the floor length and its thickness and the depth of downstream cut-offs had not been established at that time.

TABLE - 2

MAIN HYDRAULIC DESIGN FEATURES IN DIFFERENT REACHES OF ROHRI MAIN CANAL

Regulator	Location (R.D)		Hydraulic Features(1) Bed Width (ft)	Full Supply Depth (ft)	Mean Velocity (ft/sec)	Discharge (cfs)
(2)						
1.Head	0+000		247	12	3.50	10,887
2.Naulakhi	205+163	U/S	236	12	-do-	10,465
(3)		D/S	246	12	-do-	10,117
3.Kandiaro	328+456	U/S	229	12	-do-	9,542
		D/S	181	12	-do-	7,350
4.Chanesar	617+772	U/S	141.5	12	-do-	5,870
		D/S	137.5	12	-do-	5,663
5.Kumblima	70+870	U/S	130.5	12	-do-	5,512
		D/S	119.0	12	-do-	4,666
6.Oderolal	890+985	U/S	97.0	11	-do-	3,670
(4)		D/S	42	9	-do-	1,259
7.Tail	1038+000		41.5	6	3.50	536

(1) With an assumed gradient of 1 in 11,700 and 'n' value of 0.020 throughout.
(2) Cross-Sectional area of 3,100 sft.
(3) The increase was due to the critical velocity ratio being reduced from the normal 0.85 to 0.80 downstream of Naulakhi Regulator.
(4) Cross-Sectional area of 247 sft.

Although the typical designs of structures were established after carrying out model experiments at Bombay and Poona, no proper energy-dissipation devices could be introduced due to lack of knowledge at that time, regarding the theory of hydraulic-jump and the standing wave.

5.0 THE NEW DESIGN CONCEPTS

The following basic concepts have been utilized in re-designing the Rohri Canal System:

5.1 ACOP Studies for Design Parameters

In order to study the behaviour of the existing Rohri Canal, the staff of the Alluvial Channel Observation Project (ACOP) WAPDA was deployed to take equilibrium data observations in four specially selected study reaches in the head, upper middle, lower middle and tail segments of Rohri Canal. These observations included site measurements of hydraulic parameters like sectional area, velocity, surface width, average depth, water surface width, wetted perimeter, hydraulic mean radius, Manning's co-efficient of roughness ('n') and Lacey's silt factor (f) etc. ACOP was fortunately well-equipped with modern instruments, latest techniques and trained personnel inasmuch as it was working on major Link Canals in the Punjab for a Research Programme jointly sponsored by the U.S. Science Foundation and the Colorado State University. This observation programme continued over a period of one year. The main observations having bearing on the design parameters of channels are given in Table-3 below:

TABLE-3

LACEY'S SILT FACTOR 'f' AS OBSERVED BY ACOP

Reach	Average Velocity (ft./sec)	Average Slope	Lacey's Silt Factor (f)
Head reach (RD 180-188)	2.755	1 in 18,200	0.68
Upper Middle reach (RD 385-393).	2.417	1 in 16,257	0.66
Lower Middle Reach (RD 594-602)	2.353	1 in 12,983	0.62
Tail reach (RD 825-833)	2.340	1 in 11,315	0.59

The above figures have been utilized as a basis for fixing the 'f' values of Lacey's Silt Factor and longitudinal slopes for the designs of channels.

5.2 Basis For Design of Channels

Redesigning of channels was done on the Lacey's theory based on detailed ACOP studies. The 'f' values as determined from the equilibrium data observations abstracted in Table-3 were discussed with the authorities of the Irrigation Department, Government of Sind who, by virtue of their experience of operation of canals in Sind, recommended that a uniform 'f' value = 0.7 should be adopted for the Rohri Main Canal (R.M.C). However, for branches, distributaries and minors this value was further increased or decreased upto 10% depending upon the site conditions in order to improve silt carrying capacity and command in smaller channels which are mostly silting in the Lower Indus Region. (In a few exceptional cases 'f' values were reduced below 0.7). It is also a proven experience on Sind canals that channels slightly deeper than those indicated by design considerations are relatively more stable. Accordingly in existing channels where more depth was available, the proposed depth worked out from Lacey's curves was increased upto 10% (depending upon the depth available) and the proposed bed width

was reduced accordingly keeping the cross-sectional area intact. It will be explained in subsequent paragraph 6.1 that the entire remodelling process has been phased out in two stages, keeping in view the prevalent conditions, future needs and the availability of resources. With the 'f' value taken at 0.7, the longitudinal slopes in various reaches of R.M.C. in the First Stage Project of Remodelling Rohri Canal System are illustrated in Table-4. The longitudinal sections of R.M.C. showing the last designed, existing and proposed parameters are shown on Figures-4 through Figure-6 while typical cross-sections are given in Figure-7.

5.3 Basis for Design of Structures

All Cross-Regulators and Falls were originally designed on the old and obsolete concept of Bligh's Creep Theory. The new designs have been based on Khosla's Theory. The existing floor thicknesses are too small (15" only). They have been increased adequately to take care of hydro-static pressures. No cistern depths were provided at cross-regulators and falls in the old designs of 1932. Suitable depths have been added for proper dissipation of energy. The clear water-way that was squeezed and throttled in the old design has been suitably increased to pass the new discharges at various sites.

TABLE - 4

L - SLOPES - ROHRI MAIN CANAL

(For First - Stage Project)

Sr. No.	Reach	Proposed Q in reach Phase-I (Cs)	Last Des. I/S	Exist I/S	'f' adopted	Slopes I/S	Slope % adopted	Equivalent slope I/S adopted
1.	0-15+000	16,500	12,000	16,000		16,798	0.060	16,667
2.	15+000-118+000	16,454	12,000	16,000		16,791	0.060	16,667
3.	118+000-205+160	16,139	12,000	16,000		16,736	0.060	16,667
4.	205+160-264+470	15,392	13,500	16,000		16,614	0.060	16,667
5.	264+470-328+456	14,735	14,000	16,000		16,488	0.060	16,667
6.	328+456-424+859	10,855	14,000	16,000		15,667	0.065	15,385
7.	424+859-442+161	9,565	13,000	19,000		15,347	0.065	15,385
8.	442+161-496+500	9,526	14,300	12,200		15,335	0.065	15,385
9.	496+500-522+767	8,786	14,000	14,300		15,138	0.065	15,385
10.	522+767-578+522	8,692	14,000	18,500	(0.70)	15,119	0.065	15,385
11.	578+522-587+500	8,326	16,000	25,000		15,004	0.065	15,385
12.	587+500-617+770	8,307	16,000	25,000		15,000	0.065	15,385
13.	617+770-646+571	7,926	16,000	18,000		14,888	0.065	15,385
14.	646+571-705+000	7,587 to	14,000 to 12,500	14,000 to 12,200		14,786	0.070	14,286
15.	705+000-764+650	6,352	12,500	11,000		14,380	0.070	14,286
16.	764+650-807+476	6,153	12,500	11,000		14,306	0.070	14,286
17.	807+476-890+985	4,932	12,500	11,000		13,787	0.075	13,333
18.	890+985-929+320	1,851	10,000	11,000		11,703	0.085	11,765
19.	992+320-970+077	1,728	10,000	11,000		11,575	0.085	11,765
20.	970+077-1038+000	748	10,000	11,000		10,067	0.100	10,000

5.4 Fixation of Channel Capacities

Channel capacities have been fixed on different criteria in the First-Stage Project and the Second-Stage Project. The two positions are explained separately below.

5.4.1 First-Stage Project

Head capacities of all channels have been worked out on the basis of C.C.A. of the individual outlets and uniform water allowance of 4.6 cusecs per thousand acres of C.C.A. Losses in the various reaches were worked out with the Formula $QA = 0.0133\ L \times (Q)^{0.5625}$ which gave results quite close to the concept of "8 cusecs per million square feet of the wetted perimeter". In fixing channel capacities it was kept in view that as far as possible the discharges already drawn by the system channels are not reduced. Working upwards from the tails of all channels on the above lines, a design capacity of 16,150 Cs. was obtained at the head of Rohri Main Canal (Refer Annexure-A).

5.4.2 Second-Stage Project

The water allowance was increased to 8 cusecs per thousand acres as discussed subsequently in this paper and water losses were added by the same formula $QA = 0.0133\ L \times (Q)^{0.5625}$ applied to the dual channel system along all branch canals and distributaries above 50 Cs. The designed discharge at Sukkur for the North Rohri Canal works out to be 15,525 cusecs; that for the South Rohri Canal at Kumblima (D/S) works out to be 10,932 cusecs. (Refer Annexure-A). Water allowance in the Second-Stage was provided according to the consumptive-use of crops as briefly discussed in the next paragraph.

5.4.3 Consumptive Use of Crops

Irrigation water requirements were determined from the crop consumptive use, proposed cropping patterns and cropping intensities for the Second-Stage Project. To arrive at total irrigation requirements, calculations for

individual crop requirements were made and then aggregated for the cropping pattern and cropping intensities. The ten-daily consumptive use of water by crops has been computed by using crop co-efficients, the crop calendar and the free water surface evaporation estimated by the U.S. Weather Bureau Method, which takes into account the climatic data. The three Pakistan Meteorological Service tations namely Padiden, Nawabshah and Hyderabad fall in the Project area and have been considered representative climatic stations for northern, central and southern zones of the Project area respectively. The crop consumptive use values worked out on the above method were adjusted for pre-sowing irrigation, soil moisture depletion and effective rainfall. Irrigation water requirements at the water course head were then obtained by taking into account the farm irrigation efficiency, for which a value of 67.5 per cent has been assumed (10 percent losses in the water course and 22.5 per cent in the farm fields) for the purpose of calculations. It is further assumed that leaching requirements will be adequately met by field losses under high delta irrigation application. Table-5 shows the monthly requirements at water course head per 1000 acres C.C.A for different cropping intensities of 120%, 135% and 150%. The canal head requirements for the three levels of cropping intensity are given in Table-6 assuming 25 per cent losses from W.C. Head to Canal Head.

It may be mentioned that the crop-water requirements as worked out above, no doubt cover the crop needs on monthly basis, but without a radical change in the existing system of weekly rotational irrigation, the full benefits of water application at the right time and in right quantum would not be achieved. A detailed study is needed to formulate a new concept in place of the traditional rotation system. It was, however, assumed that by the time, the Second-Stage Project is ripe for implementation outlines of the new concept would clear out and the same would be provided when project preparation for the Second-Stage is undertaken.

TABLE - 5

WATER COURSE HEAD REQUIREMENTS
WATER ALLOWANCE PER 1000 ACRES CCA FOR DIFFERENT LEVEL OF CROPPING INTENSITIES (CUSECS)

Months	108% Intensity	120% Intensity	135% Intensity	150% Intensity
April	3.14	3.51	4.16	4.75
May	4.15	4.64	5.50	6.22
June	5.30	5.91	7.07	7.97
July	6.36	7.08	8.36	9.35
August	7.31	8.13	9.56	10.67
September	5.52	6.13	7.40	8.40
October	3.69	4.15	4.88	5.62
November	4.06	4.49	4.82	5.26
December	2.71	3.00	3.20	3.51
January	4.19	4.65	4.89	5.27
February	6.35	6.99	7.35	7.86
March	5.56	6.11	6.62	7.19

TABLE -6

CANAL HEAD REQUIREMENTS
FOR DIFFERENT LEVELS OF CROPPING INTENSITIES (CUSECS)

Months	108% Intensity	120% Intensity	135% Intensity	150% Intensity
April	10,955	12,229	14,483	16,565
May	14,476	16,179	19,157	21,684
June	18,484	20,589	24,561	27,777
July	22,168	24,683	29,131	32,592
August	25,471	28,313	33,319	37,183
September	19,252	21,368	25,789	29,283
October	12,855	14,449	17,025	19,604
November	14,155	15,643	16,787	18,315
December	9,448	10,484	11,152	12,215
January	14,603	16,187	17,035	18,376
February	22,140	24,343	25,629	27,377
March	19,400	21,275	23,071	25,072

5.4.4 Dual Channel System

The major change in channel layout in the Second-Stage Project would be that while the R.M.C. would run single in both Rohri North Zone and Rohri South Zone, all the branch canals and distributaries above 50 cusecs discharge would have a dual channel system. Alongside the existing channel a parallel channel would be constructed either on right or left of the existing channel. All the off-takes or outlets on the right side will be fed from the right channel while those on the left from the left channel. The capacities of the new parallel channels have been so fixed (by adjustment from tail off-takes) that the discharges of the first-stage channels do not vary substantially from those of the second stage). Accordingly the first-stage channels at the time of the second-stage project will mostly need no remodelling. The revised capacities of the system channels under the two stages are shown in Annexure-A.

6.0 THE REMODELLING PLAN

The Rohri Canal Project area covers more or less the civil districts of Sukkur, Khairpur, Nawabshah, Sanghar, Mirpur Khas, Hyderabad and Badin. The area is fairly level flood plain composed of alluvial deposits from the Indus River. Its climate can simply be described as arid and hot. Rainfall varies from 3" (76 mm) in the North to 10" (254 mm) in the South. The existence of high summer temperatures and low rainfall naturally require artificial irrigation for agricultural development. This is provided by the vast network of the Rohri Canal System. Suffering from the functional deficiencies, enumerated in para 2.2 above, as the existing Rohri Canal is, the following plan is proposed for achieving intensified agriculture in the fertile command of this canal.

6.1 Remodelling in Two Stages

The remodelling of the Rohri Canal System has been planned in two stages namely, (i) the First-Stage Project, which is planned to meet the present emergency conditions, particularly to ensure safety of the structures simultaneously providing adequate capacity in the structures and the channels with proper working grades; and (ii) the Second-Stage Project, which aims a meeting the future needs for developing an intensity of 120% in the Saline Ground Water (SGW) areas and 150% in the Fresh Ground Water (FGW) areas. Splitting of the Project in two phases is essential under the existing financial constraints and the emergent necessity of safe-guarding the existing canal system without bracketting it with the plan of highly intensified agriculture which is likely to take its due time.

6.2 Alternatives for First-Stage Project

The following alternatives were considered to remodel the system for the existing conditions in the First-Stage Project.

i) Remodelling for 16,000 Cs. discharge which the Rohri Main Canal reportedly passed at its head sometime in 1975.

ii) Remodelling for 20,908 cusecs discharge at head which includes extra margin to meet the growing demand in the immediate future.

iii) Remodelling for 13,500 cusecs discharge at head which will be the future discharge at head of North Rohri Canal when the south Rohri Canal would be separated in the Second-Stage Project.

After considering all the pros and cons of the above three alternatives remodelling for 16,000 cusecs discharge at head was considered to be the best alternative fitting into the existing conditions on the Rohri Canal System.

In this Alternative, the designed water allowance would be raised to 4.6 Cs. against 2.7 Cs. in the original Project.

It is on the record of the Irrigation Deptt. that a maximum discharge of 16,385 Cs. has been passed into Rohri Main Canal at its head for 7 days. However, the factual position established after first-class discharge observations by ACOP and comparing the corresponding gauge readings with the record of the Irrigation Deptt. indicates that the highest discharge passed into Rohri Canal equalled to 13,628 Cs. In actual operations also the value of maximum discharge has been around 13,500 Cs. Thus remodelling the System for 16,000 Cs. in First-Stage would practically mean enhancing the Canal discharge by about 2,500 Cs, which can easily cater for the increased demand for the next couple of years.

6.3 Engineering Works in the First-Stage Project

Important engineering works in the First-Stage Project would be as below:

i) Refixing capacities of channels according to the enhanced water allowance of 4.6 cusecs, giving a total discharge of 16,150 cusecs at head of R.M.C.

ii) Regrading and resectioning channels to remove channel deficiencies for proper operation with the increased discharge.

A total length of 2,291 miles of channels would be rehabilitated.

iii) Remodelling Structures for proper safety and adequate capacity.

A total of 1,270 structures on Main Canal, Branches, Distributaries and Minors would be reconditioned.

iv) Rectification of Cross-regulators and Head-Regulators of Offtaking channels for ensuring equitable silt distribution.

Model experiments for this purpose were carried out at Nandipur and Hyderabad Research Laboratories. The experimental results have been utilized in redesigning the defective Head-Regulators, Cross Regulators and By-pass Channels. (Refer Figure-8).

v) Provision of Escapes:

Two additional escapes discharging into the Left Bank Outfall Drain (L.B.O.D.) at suitable places, will be constructed to improve regulation and maintenance of the system. The three existing escapes would be remodelled for proper functioning and larger capacity.

vi) Remodelling Outlets:

All the outlets on the System Channels would be remodelled to draw a water allowance of 4.6 cusecs per thousand acres of C.C.A. The job will be done in stages by the I&P.D., G.O.S. and as and when the revised conditions of flow are established in various channels.

vii) Head-regulator of R.M.C:

No remodelling is required as the capacity of existing Head regulator at the Sukkur Barrage is adequate to pass the increased discharge of 16,150 cusecs into R.M.C.

The First-Stage Project is only an interim scheme to tide over the present emergency conditions. It will no doubt increase the water allowance to 4.6 cusecs but this is not enough to meet the consumptive-use requirements of crops. The thin application of water as existing at present would continue and the present average intensity of 91% would rise to 108%. The disparity among different areas may also continue due to the deficient water allowance. However, to make-up these deficiencies with high level development in future, the Second-Stage Project has been proposed wherein irrigation water supply will be provided on the basis of consumptive-use requirements of crops.

6.4 Alternative for the Second-Stage Project

Different remodelling alternatives were considered for future development both with and without integration of tubewell supplies to attain 120%, 135% and 150% intensities. Studies with integrated use of tubewell and canal supplies were not found to be workable because

tubewell supplies being variable and unreliable, the canal supplies would vary from area to area, from distributary to distributary and also on the same distributary. Many distributaries passing from the Fresh Ground Water (FGW) area to Saline Ground Water (SGW) area would have different canal water allowance in the two areas. The most practicable solution was considered to keep the tubewell supply as a "Bonus" for the FGW areas and provide canal supplies on the basis of uniform water allowance for all areas. The alternatives given in Table-7 below were studied for high level development on this concept.

TABLE - 7

VARIOUS ALTERNATIVES FOR HIGH LEVEL DEVELOPMENT

Alternative	Intensity from canal supplies	Water allowance from canal supplies	Intensity from Tubewells in SCARP area	Water Allowance from Tubewells Rohri North / Rohri South	Maximum Discharge at head of Rohri Canal
1	2	3	4	5	6
A	120 %	8 Cs	30 % to attain 150 %.	2.9 / 2.58	17,877 Cs
B	135 %	9 Cs	15 % to attain 150 % or more as practicable	Tubewells under-utilized	31,363 Cs
C	150 %	10 Cs	0 to attain 150 % or more as practicable	Tubewells un-utilized	34,847 Cs

Alternative-A with 120% intensity from canal supplies at a uniform water allowance of 8 Cs. all over the project area was the most suitable which is practically reachable. The tubewells installed/to be installed in the SCARP areas would be utilized to raise the intensity further in FGW areas from 120% to 150%. It was found that the pumpage actually available from tubewells would be just enough to give an intensity-raise of 30%. This is also in line with the planned target of 150% in the two Salinity Control and Reclamation Projects (SCARPS) of North Rohri and South Rohri. In Alternative-B with 135% intensity and a canal water allowance of 9 Cs. the tube-wells in SCARP areas would remain under-utilized, because a small margin of only 15% intensity-raise is left for the tubewells. In Alternative-C with 150% intensity and a uniform water allowance of 10 Cs. the tubewells would remain unutilized with no margin of intensity-raise for the tubewells.

Alternative-A was, therefore, proposed for future development in the Second-Stage Project with the engineering works briefly described in para 6.5 hereunder:

6.5 Engineering Works in the Second-Stage Project

The following major engineering works would be required for the implementation of the Second-Stage Project:

6.5.1 Refixing channel capacities with the increased water allowance of 8.0 cusecs per thousand acres of C.C.A:

The channel capacities would almost be doubled. it is proposed that "Dual Channels" should be constructed along all branches and major distributaries with discharge above 50 cusecs. All channels/outlets on the right will have their off-takes on the right channel while those on the left will take off from the left channel. The channels of the Second-Stage Project will be so adjusted

that their new discharges remain close to the First-Stage discharges so as to avoid any major remodelling operations. This is quite possible. An illustration of the proposed "Dual Channel System" can be seen in Figures-9 and 10.

6.5.2 Separation of South Rohri Canal

The existing Rohri Main Canal which is 207 miles long, will be split into North Rohri Canal (N.R.Canal) and South Rohri Canal (S.R.Canal); the former serving the Northern Zone upto Kumblima R.D.705 and the latter serving all offtaking channels below Kumblima. The designed discharge of S.R. Canal at this point would be 10,932 cusecs against 7,329 cusecs in the First-Stage Project. The S.R. Canal will be widened to accommodate this discharge, all major structures having been already constructed in the First-Stage Project for enough capacity to obviate any difficulties during the implementation of the Second-Stage Project.

6.5.3 North Rohri Canal:

The R.M.C. designed for 16,150 Cs. discharge in the First-Stage Project would require certain adjustments for the Second-Stage Project. When completely separated from S.R. Canal; the N.R. Canal would be required to carry 15,425 Cs. at its head. Further to that, the discharge of N.R. Canal would go on reducing as given in Table-8 below till it tails off at Kumblima.

TABLE-8

REDUCTION OF DISCHARGES OF NORTH ROHRI CANAL IN VARIOUS REACHES

R.D.	Cross-Regulator	Capacity in F.S.P. Q(Cs)	Capacity in S.S.P. Q(Cs)	Reduction in Capacity Q(Cs)
328+456	Kandiaro	10,621	9,047	1,574
424+859	Naushero	9,385	4,562	4,823
496+500	Usif Dahri	8,646	3,429	5,217
578+522	Jamal Shah	8,205	2,865	5,340
617+170	Chenesar	7,825	2,322	5,503
646+571	Sakrand	7,487	1,751	5,736
705+000	Kumblima			

This reduction in capacity would be done by brush-wood spurs which would induce silting thus increasing berms on either side. The capacities of structures would be reduced by closing bays/raising of crests etc.

For L-Sections of North Rohri and South Rohri Canals in the Second-Stage Project Refer Figures-11 and 12.

6.5.4 Feeding of South Rohri Canal from Sehwan Barrage:

The South Rohri Canal is proposed to be fed at Kumblima from the proposed Sehwan Barrage through a 40 miles long Sehwan-Rohri Feeder as shown in Figure-13. With a head discharge of 11,429 Cs. this Feeder would deliver 10,932 Cs. into the South Rohri Canal D/S Kumblima. Other alternative sources for feeding South Rohri Canal from Sukkur (including the use of Nara Channel) have been considered, but the one from Sehwan Barrage is adjudged to be best in the interest of over-all development of the South Region. For L-Section of Sehwan-Rohri Feeder refer Figure-14.

6.5.5 The Sehwan Barrage:

The new Sehwan Barrage on the Indus River would be the key structure in the development of South Command. The new Sehwan-Rohri Feeder taking off from the left flank would link the Barrage with the South Rohri Canal D/S Kumblima. The essential features of the Barrage would be the same as drawn out by M/s. Hunting Technical Services in 1969 in the Project Planning Report on Sehwan Barrage Complex without storage. The main points of the Barrage and the Feeder are given in Table-9

TABLE-9

ESSENTIAL FEATURES OF SEHWAN BARRAGE AND SEHWAN - ROHRI FEEDER

a)	Length of Barrage		3,062 feet.
b)	Designed discharge		9,50,000 Cs.
c)	Working Pond Levels		113.0 - 116.4
d)	Length or Sehwan-Rohri Feeder		40 miles
e)	Capacity of Sehwan-Rohri Feeder	i)	11,429 Cs.(at head)
		ii)	10,932 Cs. (D/S Kumblima)
f)	F.S.L. Sehwan-Rohri Feeder	i)	R.L. 111.39 (at head)
		ii)	R.L. 98.78 (D/S Kumblima)
g)	Water surface slope in Sehwan-Rohri Feeder.		0.063 ft/1000 ft. or 1 in 16,000 ft.(approx)

6.5.6 Remodelling of Outlets:

All the outlets on the System channels would be remodelled according to a water allowance of 8.0 Cs. but this job will be done by the I & P.D., G.O.S. as in the First-Stage Project.

6.6 Limitations of the Second-Stage Project

Although high class development is planned with the Second-Stage Project, certain limitations given below have to be paid due attention to achieve the planned development.

The drainage of S.G.W. areas in the wake of high delta application of water can be achieved only if the drainage arrangements in the S.G.W. area of Rohri Command as per drainage scheme of the L.B.O.D. System are adequately planned and implemented. Early completion of the drainage schemes in the S.G.W. area would mean early implementation of the Second-Stage Project.

7.0 PROJECT IMPLEMENTATION

7.1 The First-Stage Project

The implementation of the First-Stage Project as originally planned was proposed to be carried out in a period of five years from 1981 to 1985. Detailed Project Preparation was completed by February, 1980 and it would have been possible after prequalification of contractors, inevitation of tenders and award of contract to start mobilization by the beginning of 1981 according to the Implementation Schedule given in Fig-15. The actual implementation of this gigantic Project, however, may have to be re-scheduled according to the availability of funds and the priority given to it in the overall national budget. In view of the immensity of the work it was proposed to divide the work in six units. Four units comprised a portion of R.M.C. and the off-taking channels

therefrom; the 5th covered the entire system of Nasrat Branch and the 6th that of the Nasir Branch. Six different contractors would be engaged; one for each unit so that the work proceeds concurrently and expeditiously for completion in time. If not completed in time, not only the flow of benefits would be delayed but also the price escalation, compound interest and other overheads would unnecessarily inflate the project costs.

7.2 The Second-Stage Project

The Second-Stage Project was proposed for implementation by the close of the 20th century over a period of seven years from 1995-2002. In addition to some remodelling operations on the existing system (particularly S.R. Canal), this phase involves major construction operations such as the new Sehwan Barrage, the Sehwan-Rohri Feeder and parallel channels along all branches and major distributaries. The entire work in this case would be divided into eight units. Apart from the six units prescribed in the First-Stage Project, the 7th and 8th units would cover the Sehwan Barrage and the Sehwan-Rohri Feeder. A period of seven years has been considered appropriate for this project. Details are shown in the Implementation Schedule for the Second-Stage Project in Fig-16. After completion of each job, post-construction maintenance would be carried out by the respective contractors for a period of one year and they will make good any construction deficiencies surfaced during the maintenance period.

8.0 PROJECT COSTS AND BENEFITS

8.1 Project Costs

The total estimated cost of the two projects together with the foreign exchange component in each case based on 1977 price index with provision for escalation for three years upto 1980 was as given in Table-10 (P-232).

TABLE-10

ESTIMATED COST (MILLION RUPEES)
(As on June, 1977)

Description	First-Stage Project	Second-Stage Project
CANAL REMODELLING		
1. Cost of Works	1,075.66	2,597.60
2. Overheads	537.83	1,298.80
Total:	1,613.49	3,896.40
Interest charges	421.94	2,343.26
Grand Total:	2,035.43	6,239.66
3. Foreign Exchange		
- For Expatriate Contractors	555.00	1,560.00
- For Pakistani Contractors	185.00	525.00

The foreign exchange is needed for the import of earthmoving equipment such as excavators, scraper units, dozers and tractors etc., required for under-water excavation and its handling, fill earth-work and other allied operations. The dry earth-work of minor canals would be done by labour-intensive methods employing local resources. Apart from the cost of works and land, the estimates include extra costs for Engineering and Supervision of Construction, Contractor's and Engineer's Camps, Transport and insurance and Contingencies etc.

8.2 Project Benefits

The benefits estimated to accrue from the projects are given below:

i) Total Net Benefits from the First-Stage Project (Over a life span of 35 years) Rs 40,664 Millions.

ii) Total Net Benefits from the Second-Stage Project (Over a life span of 50 years). Rs.97,916 Millions.

The benefits from the First-Stage Project correspond to an intensity of 108% which will be attained with an improvement of the prevalent cropping pattern and thin application of water. The Second-Stage Project, however, aims at intensive cropping with high delta application of water according to the consumptive-use of crops. An intensity of 120% would be achieved in the NON-SCARP areas while it will rise to 150% in the SCARP areas of North Rohri and South Rohri. Benefits in SCARP areas have been taken only upto 120% development which would take place with the remodelled canal supplies. No benefits have been taken for the use of tubewell supplies. Similarly no direct benefits on account of the damage to crops averted as a result of rehabilitation of structures, have been taken. It may be mentioned that in the recent past cash crops like wheat etc., were imported at high prices. For working out benefits from wheat crop international border price adjusted to farm-gate has been applied while for other crops, local market prices adjusted to farm-gate have been adopted.

8.3 Economic Analysis

In the economic analysis Discounted Cash Flow was worked out for 35 years (including the period of construction) for the First-Stage Project and for 50 years for the Second-Stage Project. Project present worth has been calculated in each case at 10.5 and 15 percent discount rates separately and Benefit-Cost Ratio was worked out corresponding to each rate of discount. The Internal Rate of Return was also calculated. The ultimate results of economic analysis are abstracted below for both the Projects:

	First-Stage Project	Second-Stage Project
1. Benefit-Cost-Ratio at:		
10.5% discount rate	4.32	2.70
15% discount rate	2.83	1.65
2. Net Present Worth (Rs.Million)		
at 10.5 %	4,408	5,032
at 15%	2,023	1,555
3. Internal Rate of Return	30%	20.41%

From these results it is obvious that both the First-Stage Project and the Second-Stage Project are economically feasible,rather highly attractive. Implementation of the First-Stage Project is an inevitable necessity to safeguard the vital irrigation system from complete collapse. Its implementation on a high priority level has been strongly recommended. The Second-Stage Project can, however, wait till the deep rooted existing practices of water use in the farms are changed to water utilization according to the consumptive-use of crops and drainage schemes in the saline ground water areas are completed to receive the high delta application of water.

9.0 COMPLEMENTARY INPUTS

The fertile land under command of the Rohri Canal System is capable of producing 3 to 5 times its present level depending upon the efficient and integrated use of water with other inputs like good seeds, fertilizers and insecticides etc., at the appropriate time and in the right quantum.together with proper farm management and extension service. The advanced countries of the world have already achieved this level by following the five fundamental principles of the Green Revolution Technology.