JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

IRRIGATION AND POWER DEPARTMENT
GOVERNMENT OF PUNJAB
THE ISLAMIC REPUBLIC OF PAKISTAN

THE STUDY ON THE LINING OF DISTRIBUTARIES AND MINORS IN PUNJAB IN THE ISLAMIC REPUBLIC OF PAKISTAN

Volume II

ANNEXES-I

JULY 1997

NIPPON KOEI CO., LTD.
NIPPON GIKEN INC.

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A.1 Present Conditions of the Study Area

A.1.1 Rivers and Canal Network

Diversion of river waters into off-taking canals is made through diversion structures (headworks/barrage) which are gated diversion weirs. The main canals and branch canals function as conveyance channels up to distributaries and minors.

The quantitiy of water diverted to each canal is according to the framed water rights program, which is implemented on the basis of availability of water at each headworks/barrage on ten-daily period for the whole of Rabi and early Kharif seasons. Canal regulation presently being practiced in Punjab, has been evolved as a result of long experience by PID.

Based on the actual flows from the rivers during the Rabi season, adjustments in the short time ten-daily period schedules are prepared for the canals. Any shortage in the first ten-daily period at the certain canal heads are made up in the next ten-daily period from the allocation of other canals which have drawn relatively more water during the first ten-daily period. For normal maintenance of canal systems the annual closure are for four to six weeks spreading over a period of two months. This period is normally from December to middle of February (Rabi season) every year.

Relations between the river discharge and withdrawals for the respective systems of the Lower Jhelum, Lower Chenab and CBDC are examined based on the publication of the historic rivers and canals discharge data of the Indus plains compiled by the Water Resources Management Directorate (WRMD) at WAPDA Headquarters during the period of ten years from 1985/86 to 1994/95 (see Table A.1.1-1).

Irrigation water for the Lower Jhelum System is diverted from the Jhelum river through the LJC Feeder offtake from the left bank of the Rasul Barrage with a full supply discharge of 3,700 cusecs and supplemented by the Upper Jhelum, which offtakes from the left bank of the Mangla Reservoir. The Lower Jhelum Canal combines the discharge from the said channels and conveys to the Lower Jhelum System, with a full supply discharge of 5,300 cusecs. This canal branches off to Shah Pur Branch, Northern Feeder and Southern Feeder with respective full supply discharges of 460 cusecs, 850 cusecs and 460 cusecs. The GCA under these channels is 1.63 million acres (6,600km^2) and the CCA is 1.50 million acres (6,050km^2).

Annual discharge of the Jhelum river fluctuates from 11.70 MAF (14.45 B m^3) in 1985/86 to 30.65 MAF (37.85 B m^3) in 1992/93 with an average of 22.36 MAF (27.61 B m^3) at Rasul Barrage, whereas the annual offtake through the Lower Jhelum Canal ranges from 2.55 MAF (3.15 B m^3) to 3.26 MAF (4.03 B m^3) averaging 2.99 MAF (3.69 B m^3), which is equivalent to 13% of the river discharge.

Irrigation water for the Lower Chenab System is diverted from the Chenab river through Lower Chenab Canal. This canal offtakes from the left bank of Khanki Headworks with a full supply discharge of 11,530 cusecs. It branches off to Upper Jhang Branch, Upper Gugera Branch and Burala Branch with full supply discharge of 1,140 cusecs, 1,550 cusecs and 1,530 cusecs, respectively. The GCA under these channels is 3.39 million acres (13,700km^2) and the CCA is 2.98 million acres (12,090km^2).

Annual discharge of the Chenab river at Khanki Barrage fluctuates from 17.62 MAF (21.76 B m^3) in 1993/94 to 30.42 MAF (37.57 B m^3) in 1988/89 with an average of 22.73 MAF (28.07 B m^3), whereas the annual offtake through Lower Chenab Canal ranges between 6.77 MAF (8.36 B m^3) and 8.35 MAF (10.31 B m^3) averaging 7.51 MAF (9.29 B m^3), which is equivalent to 33% of the river discharge at Khanki Barrage.

In April 1948, India stopped the supplies in those channels of the Upper Bari Doab canal system which enter Pakistan. The channels were renamed as CBD Canal System and now linked with BRBD Link Canal with the capacity of 5,000 cusecs which originates from Marala Barrage. The CBD Canal, branching off from the BRBD has a full supply discharge of 2,600 cusecs. The G.C.A. under this canal is 0.80 million acres (3,240km^2) and the CCA is 0.65 million acres (2,620km^2).

Annual discharge of the Chenab river at Marala Barrage varies from 22.97 MAF (28.37 B m^3) in 1993/94 to 32.69 MAF (40.37 B m^3) in 1988/89 with an average of 27.50 MAF (33.96 B m^3), whereas the annual diversion discharge of the CBD canal ranges from 1.27 MAF (1.57 B m^3) to 1.52 MAF (1.88 B m^3) averaging 1.45 MAF (1.79 B m^3), which is equivalent to 5% of the river discharge at Marala Barrage.

Average withdrawal of 10 years from 1985/86 to 1994/95 is estimated at 84% of the design discharge, which is equivalent to approx. 300 irrigation days per year.

A.1.2 Distributaries and Minors

(1) General

The main canals and the branches have some sort of control structures to limit the distribution of water into the distributaries. There is, however, no control on the distributary/minor generally. When a proper quantity of water enters the head of these channels, it is distributed to each outlet automatically according to its capacity.

The distributary/minor is aligned on the local watershed. The natural drainage line forms a limit of the distributary/minor. It is aligned that the length of a watercourse taking-off does not exceed two miles, and is kept at a reasonable distance from villages and towns.

It is important to note that the canal system was designed in the second half of the 19th century during the British regime, with the objective of extensive irrigation to bring more areas under irrigation in order to settle more people without considering the crop water requirements. The perennial canal system, therefore, is not designed for maximum production on irrigated land but only to eliminate the possibility of famines. In order to maintain a cropping intensity of 75% the canal are generally allocated one cusec of water for every 333-350 acres of culturable command area.

(2) Status of Distributaries and Minors

The unlined channels are designed as regime or non-silting and non-scouring channels, requiring careful control on silt entry, and a continuous flows close to design discharges special in summer months when river waters are fairly silt laden. They are designed to operate successfully and distribute water equitably while flowing close to full supply (i.e. designed) conditions.

The first step in the design of the distributary/minor is to determine the capacity of each outlet at the head of the watercourses. For this purpose a capacity statement is prepared on the line as 1) Measure the gross command area (GCA), 2) Measure the uncommand area, 3) Determine the cultulable command area (CCA), 4) Determine the area for which water is to be applied based on irrigation intensity, 5) Calculate discharge of each outlet in cusecs per acre, and 6) Determine water allowance for the area to be irrigated in cusecs/1,000 acres of CCA.

Having determined the capacity of each off-take through the capacity statement, the next step is to find the capacity of the channel reach by reach. For preparing this statement of draw-off is prepared on the line as, 1) Determine the capacity of each outlet or off-take, 2) Determine the total draw-off of the off-takes in the reach, 3) Determine the absorption (or losses) in this reach, 4) Add together the total draw-off and the absorption (or losses) and 5) Determine the design discharge of the channel from reach to reach in this way.

An outlet is a common structure through which water is admitted from the Government ditributary/minor into the farmer's watercourse. It is the border where the state management ends and the farmer's management starts. It is a device to measure the discharge flowing through it and hence it is a means of great interest both to the government and the farmer. The outlets are designed as semi-modular devices with their discharge varying proportionally with the change in full supply levels in the channel.

The irrigation branch method is based on the experience gained by the Department during the last hundred years. After assuming the full supply discharge, the next step is to fix the intensity of irrigation, which is the percentage of the CCA irrigated during a base period or annually. The entire CCA is not generally irrigated as discussed in the foregoing paragraph and for the following reasons;

1) Shortage of water available

When the supply of water is inadequate the supply of irrigation for a certain area is decreased. As a general practice, the minimum intensity is kept 40% or more.

2) Rest of land

It is imperative that land is given rest according to cropping pattern, farming practice, labor requirement, etc. Thus the water need not be supplied to the whole of the CCA.

3) Remedial measure for waterlogging

A low intensity of irrigation is provided to an area or tract which is likely to be threatened with waterlogging. This encourages the cultivator to sink tube-wells and make use of the sub-soil water.

There are two cropping seasons namely Kharif (April - September) and Rabi (October - March), major Kharif crops are valuable as they fetch foreign exchange. These crops require more than those of Rabi. The major Kharif crops such as sugarcane and cotton keep the land occupied when it is time for sowing the major crops. The result is that for irrigation purposes the area for Kharif and Rabi crops are treated separately .

It is noted, however, that since the canal system is continuously deteriorating, the system is not functioning as expected in view of water conservation and hydraulic performance. In terms of water conservation, it is observed that breaching and overtopping of water frequently occur due to low freeboard of earth embankment, that steeling of water is a common practice near the upper reach of the channels either by breaking and increasing the size of outlets, and that considerable seepage losses are inevitable because of unlined condition. In fact, water does not reach to the tail in some channels due to the above reasons. In terms of hydraulic performance, it is observed that water is not appropriately conveyed to the downstream due to scoring/silting, sliding of side slopes, weed hazard and irregular cross section of channels. Distribution of water is not proportionally made due to deteriorating/ breaking of structures, especially outlets to the minors and watercourses.

(3) Original Design Concept

One of the main objectives of the study is to formulate the methodology for canal lining. In this paragraph, therefore, original design of the distributaries and minors on regime concept is examined based on the longitudinal sections of the three schemes of LJC, LCC and CBDC.

Irrigation channels in the Study area were constructed in alluvial soils without lining. These channels take river water which carries sediment held in suspension. If the velocity in a channel is very high, the water will erode its bed; if the velocity is very low, the sediment held in suspension will settle down. A channel was, therefore, designed for a velocity such that neither the bed is eroded nor silt is deposited but is transported to the fields. It is found out that the velocity ranges between 0.79 ft/sec to 2.27 ft/sec for the most of the distributaries in the three schemes. It is also understood that larger the design discharge, the higher the velocity is. The velocity is higher than 1.52 ft/sec in case that the design discharge exceeds 100 cusecs, it ranges between 1.32 ft/sec and 1.68 ft/sec in case that the design discharge ranges from 50 cusecs to 100 cusecs, and it ranges between 0.79 ft/sec to 1.61 ft/sec in case that the design discharge is less than 50 cusecs.

From the perusal of flow equations, it is evident that greater the discharge the lesser is the slope required to produce the same discharge. It is found out that the longitudinal slope varies from 0.018% to 0.035% for the most of the distributaries in the Study areas. The slope ranges between 0.018% and 0.025% in case that the design discharge exceeds 100 cusecs, it ranges between 0.020% and 0.030% in case that the design discharge ranges from 50 cusecs to 100 cusecs, and it ranges between 0.020% to 0.035% in case that the design discharge is less than 50 cusecs. The facts stated in these two paragraphs indicate that silt might have been deposited in some of the distributaries at their tail end.

The Kennedy equation does not take the width, depth and slope into account. In other words, there can be large number of different combinations of bed width and slope of the channel for a given discharge and satisfying critical velocity ratio. It is, however, understood from the available longitudinal sections that the channel section was proportioned by simple rules, and longitudinal slope of the channel was adjusted accordingly. The B/D ratios to canal capacities in the Study area are more or less consistent with the relationship recommended by the Central Water Commission of India.

According to initial Lacey's equations, the channel cross section is fixed for a given discharge and silt factor. In order to reduce errors resulting by adopting the Lacey's equation, some fitted equations were evolved. It is acknowledged that there is a clear trend between discharge and hydraulic mean depth of channels. In the Study area, the best fitted relation is given in the following equation:

$$\log Q = 3.0 \log R + 0.92$$

where; Q = Design discharge in cusecs,
R = Hydraulic mean depth in feet.

A.1.3 Canal Seepage

Seepage measurement of distributaries and minors was sublet to the Irrigation Research Institute of PID. Seepage loss was measured by two methods, inflow-outflow method and ponding method.

For inflow-outflow tests, canal reaches were selected in certain length depending upon the structures situated in the test reach or any change in the canal geometry/condition likewise unlined or lined sections. Before starting the test, a temporary gauge was installed on head of the test reach to check the uniformity of flow. The flow was maintained uniform approximately one day before the test. Discharge measurements were carried out by using Price current meter, and Pygmy meter and cut-throat meter to measure the discharge in watercourses.

For ponding method, the test reaches were selected so as to have the minimum variation in the cross sectional area of the channel. Temporary water dikes were constructed to isolate channel reaches. The dike heights were kept at the bank level of the channels and dike widths conformed to existing channel cross sections. Gauges to observe water levels were installed at about 250 to 350 feet from the upstream diked end. Observation wells were installed to indicate the water table fluctuations over time during the test.

Twenty four and 3 canal reaches were selected in the LJC System for inflow-outflow method and ponding method, 27 and 4 in the LCC System, and 6 and 1 in the CBDC System, respectively. The test results are shown in Tables A.1.3-1 (1/3) - (3/3). It is understood that average seepage rates excluding lined channels and rock excavated channels are 6.77 cfs/msf in the LJC System, 5.56 cfs/msf in the LCC System and 8.48 cfs/msf in he CBDC Systems, respectively.

It is understood that although the measured seepage rates disperse largely depending on the respective channels and their status, distribution ranges (maximum and minimum) of values measured by the two methods, inflow-outflow and ponding are more or less the same regardless of the measuring method. Due to the dispersed nature of the measured values, however, it is anticipated that they are too large (or small) when they are deemed to represent the seepage rates which are peculiar to the respective channels. Therefore, it is considered that the measured values are not peculiar to each channel, but are assumed as samples of a population of the Study area. On this assumption, they are treated as frequency in a certain range of the values, and Fig. A 1.3-1 was borne out as a result. Followings are the findings from the figure.

(1) As far as the values measured by inflow-outflow method are concerned, frequency decreases from low to high seepage rates with a certain trend of disbursement.

(2) The values measured by ponding method seem to be evenly dispersed, though the number of samples is too small to judge.

(3) The average values obtained from the two methods and that of all the measurements are very close each other (6.35, 6.13 and 6.32 cfs/msf, respectively).

(4) The median of the frequency distribution is equal to approx. 5 cfs/msf.

(5) The average seepage rate of the concrete lined channels newly constructed is estimated at 1.47 cfs/mfs.

As a result of the above findings, the criterion in terms of seepage rate was determined to be 5 cfs/mfs or more for the selection of the channels to be taken up for lining. In estimating the seepage rates of the existing unlined channels and the proposed lined channels, the average of the unlined channels stated above and that of the newly lined channels were deemed to represent the Study area Therefore, the saving rate after lining is calculated as a difference between the former seepage rate and the latter as indicated in Tables A 1.3-2 (1/3) - (3/3).

A.1.4 Inequitable Distribution of Water

Despite the fact that inequitable distribution of water in terms of upper and downstream reaches of distributary and minor canals are often complained about by local farmers, so far, it has not been scientifically studied based on field data. In order to clarify the situation, data of seepage tests performed for selected canals in L.J.C., L.C.C. and C.B.D.C. were used. Ratios between measured and designed discharge were taken to show the extent of water sufficiency. Ratios between reduced distances of test sites from canal heads and the total distances of corresponding canals are also taken to indicate the location of test sites quantitatively. These data are plotted in scatter graphs as shown in Fig.A.1.4-1. In each irrigation system, correlation factors between the former and the latter parameter were calculated and they show negative values and consequently, it can be concluded that inequity of water is prevailing in the Project Area as was pointed out by local farmers.

During the seepage test, in addition to discharge measurement at seepage measurement spots, diversion to watercourses were also measured. In Table A.1.4-1, total measured and authorized discharge are compared and the results are summarized. Except for 2 out of 14 test sections, ratios of measured over authorized discharge are more than 100%, which means that discharge of Distributary canals become smaller and designed quantity is not conveyed as it approaches downstream.

A.1.5 Tubewells in FGW and SGW Areas

In the Study Area, in order to compensate deficit of surface water, groundwater irrigation through tubewells is extensively applied. Tubewells are broadly divided into two types; ones are SCARP tubewells owned by WAPDA with discharge about 85 lit /sec and the others are farmer owned private tubewell with discharge about 28 lit / sec. The total annual discharge is estimated to be 16.9 billion tons. In the following table, estimated nos. of the tubewells and annual discharge are summarized.

No. and Annual Discharge of Tubewells

Irrigation System	SCARP Tubewell nos.	Private Tubewell nos.	Total nos.	Annual Discharge (million tons)
L.J.C.	2,300	10,300	12,600	3,400
L.C.C.	1,800	58,300	60,100	11,200
C.B.D.C.	400	11,800	12,200	2,300
Total	4,500	80,400	84,900	16,900

Tubewells are used to supplement the canal water supplies in some specific areas accordint to the data from Agriculture Department. The tendency to use tubewell water gives reflection regarding the distribution of saline and fresh groundwater almost completely. The agriculture in the Tehsils located in the saline ground water zone like Sargodha, Faisalabad, etc, depends on the canal water almost completely. However, contrasting observations have been recorded with respect to the agriculture in Tehsils lying in fresh ground water zones like Bhalwal, Kamalia, etc, where tubewell supplementation appears quite common. In line with Agriculture Census in 1990, the percentage of irrigation areas classified by irrigation method/source are categorized as follows:

1) Conjunctive use, surface and tube well water: 52%
2) Surface water only: 28%
3) Tubewell water only: 20%

A.1.6 Operation and Maintenance (Technical Aspects)

Present Status of Irrigation Structures

Appropriate operation and maintenance fully depends on hydraulic performance of the canal systems. As discussed in the preceding paragraphs, it is observed that water is not properly conveyed to downstream reaches due to scoring, silting, sliding of side slopes, weed hazard, irregular canal section of the channels, etc. in the Study Area. Distribution of water is not proportionally made due to deteriorating and breakage of structures, of which present status is discussed hereinafter based on the inventory survey.

(1) Outlet Structures

Outlet Structures and their measure devices are of utmost concern to O & M staff among all the irrigation structures since effective Operation of the Distributary systems totally depends upon how accurately water can be supplied through them. Checking of Outlet Registers collected from PID irrigation offices for selected 13 Distributary systems clarified the following facts:-

-There exist 1,084 Outlet Structures in total on the selected Distributaries and Minors, comprising 320 in L.J.C, 608 in L.C.C and 156 for C.B.D.C. With respect to Structure Types, 640 (59.0%) of which are A.P.Ms, 365(33.6%) are Open Flumes and the others (Pipe, etc.) are 79 (7.4%). Their discharges are decided and distributed based on the traditional design concept called Warabandi which was established during the British Regime period. The nos. and types of Outlet Structures categorized by selected Distributary and Minors in each canal system are shown as below:-

No. of Outlet Structures by Structure Type for L.J.C

Distributary	A.P.M..(*)	Open Flume	Others	Total
Pindi	2	7	1	10
Hujjan and Minors	59	61	2	122
Kirana and Minors	90	89	9	188
Total	151	157	12	320

(*)...Adjustable Proportional Module

No. of Outlet Structures by Structure Type for L.C.C

Distributary	A.P.M..(*)	Open Flume	Others	Total
Sarangwala	41	11	4	56
Nasrana & Minors	112	49	14	175
Gojra and Minors	24	15	0	39
Mungi and Minors	72	24	1	97
Janiwala/Hamza & Minors	28	3	0	31
Pirmahal & Minors	45	33	18	96
Killianwala & Minors	85	26	3	114
Total	407	161	40	608

(*)...Adjustable Proportional Module

No. of Outlet Structures by Structure Type for C.B.D.C

Distributary	A.P.M..(*)	Open Flume	Others	Total
Thamman	39	13	16	68
China	43	34	11	88
Total	82	47	27	156

(*)...Adjustable Proportional Module

Generally, these three types of outlet structures are not fully functioned and some are damaged and clogged with soil and weed. It is proposed that all the outlets be replaced in designing of lining of Distributaries and Minors due to following reasons found during the site inspection:

1) As most of the outlets are brick structures which are not neat enough and functional accuracy is questionable,

2) All the outlets are considerably deteriorated and hence many damaged parts are observed, especially at the head of the outlets,

3) Since the canal banks near the outlets are eroded and the head of the structures seem to have stretched out into parent canals, hydraulic performance at the outlets are no more as originally designed,

4) Siltation on the watercourses causes damming up of water which hinders to flow designed discharge.

5) As regards pipe type outlets, many of them are corrupted or clogged with silt and weed and not functioning,

6) Some of the bottom of the open flume type outlets are higher than the low water levels of the parents canals, and are not fully functioning,

7) There exist numerous traces of breach of canal banks for additional flow to farm lands.

Observation of the status of the outlet structures as described above will be fully incorporated in the design in terms of type and dimensions according to the design discharge of the parent channels and watercourses.

(2) Other Structures

Other Canal and its related structures concerning Operation and Maintenance Work observed during site inspection include:-

- Meter Flume,
- Proportional Distributors,
- Cattle Ghats,
- Bridges, and
- Aqueducts.

For the selected canals, inventory survey was carried out to examine the utility of the existing structures so unnecessary removal of the structures will be minimized in lining work. They are mostly built of brick masonry, brick paving and brick pitching, are outlined after a century of usage and are not supposed to be functioning properly to meet operational requirement due to deterioration. Most of them will be removed when lining construction is performed in accordance with lining design concept. In addition to the above, the following maintenance works should be paid more attention which are supposed to be easier to perform after canal lining is completed, :-

- Maintenance of Bridges and Inspection Roads,
- Weed control on canal banks,
- Sediment Control on canals.

A.1.7 On-Farm Water Management

(1) General

In order to make sustainable agriculture possible in the Study Area where not only water deficit but also salinity and water logging are becoming serious, comprehensive water management from distributary up to field level will be more important. During the site inspection, it was found out that significant irrigation water loss occurs from century old irrigation structures, poorly maintained distributaries, minors and watercourses. A considerable amount of water wastage is also supposed to takes place as application losses due to undulated farmer's field as a result of adopting traditional agricultural and irrigation practices at on-farm level. In Punjab, recognition of these problems at on-farm level led to implementation of Pilot On-farm Water Management Development Project during 1976-1977 with USDA assistance. After this scheme was successfully completed during 1978-1980, one year ahead of its scheduled period, On-Farm Water Management Projects financed by the World Bank, IDA, USAID, IFAD, ADB and OECF followed in all irrigated area in Punjab. Principal objectives of the OFWM program are:-

- Increase agricultural productivity with watercourse improvement, precision land levelling and improved agronomic practices,

- Improving water management techniques and institutional arrangements including that of Water Users Associations,

- Promoting adoption of improved farm level water use practices by the farmers through organizing regular training courses and effective field demonstrations,

- Serve as a transition model for future OFWM programs that could be effectively replicated in the commands of all the watercourses in the Punjab,

- Strengthening the capability of the OFWM staff to plan and implement expanded OFWM schemes.

According to On-farm Water Management Program in Punjab (Directorate General Agriculture, 1996), as of the end of 1995, 21,147 watercourses are improved, 122,400 ha precision land levelling were performed and 17,781 demonstration centres were laid out in Punjab. Achievement of OFWM Projects is admirable, however, it is to be noted that these programs managed by PAD are conducted on watercourses and downwards basis and PID is not involved at all. Since comprehensive water management from distributary through field level is quite important to realize sustainable agriculture, it is necessary to consider water management under the co-operation of both organizations.

(2) Crop and Irrigation method

The representative Kharif crop (from April to September) in the Study Area are paddy and cotton while in Rabi (from October to March), wheat, a staple food in the country, covers about 70% of farm land. Sugarcane is in the field throughout a year. Irrigation method widely used in the Study area is furrow irrigation method for wheat, vegetable etc. and basin method for paddy, sugarcane, fodder, orchard crop, etc.. Sprinkler and trickle irrigation have not been seen during the site inspection. Rotational irrigation called "Warabandi" is widely applied. The irrigation rotation period is usually seven days when every farmer receives water allotted to his land. In addition to surface irrigation, ground water pumped up through tubewells are utilised extensively in the Study Area.

(3) On-farm Water Management Practices

In parallel with the program so far achieved under On-Farm Water Management Projects such as watercourse improvement and precision land levelling, followings should be paid more attention and transfer of knowledge should be performed to achieve these through demonstration centres as on-farm water management practices. However, it is of course to be noted that all these practices will not be effective unless prevention of seepage from canals in adequate methods and installation of drainage system as well as institutional reformation are implemented.

(a) Adequate lowering of water table: a permanent lowering of water table under the farmer's control so that a rise of water above a given elevation in the soil for any length of time may be wholly prevented,

(b) Satisfactory water infiltration: the rate of water infiltration into soils depends on soil texture structure, degree of soil dispersion, and also on the depth to water table. Chemical amendment, minimized surface tillage etc., depending on the site condition are sometimes necessitated,

(c) Leaching excess salts out of the soil: is usually essential that large depths of water be applied to saline and alkali lands and be made to percolate through the soil in order to leach out excess salt. Maintaining a favourable salt balance in the soil requires proper and efficient irrigation methods.

A.1.8 Water and Salt Balance

Provisional Estimate of Irrigation Water Requirements

(1) General

Irrigation water requirement comprises mainly three factors:-

i) Consumptive use or evapotranspiration, which is defined as the amount of water lost in a field, completely covered with green vegetation in an active stage of growth under non-limiting moisture supply, is the sum of transpiration through plant leaves and evaporation from plants and farm soil surface and is affected by various conditions like, type of crop and soil, climate, location, irrigation method, growing season and stage of crop growth,

ii) Effective rainfall, which is a part of precipitation consumed for plant growth, makes up for a part of irrigation water demand, and

iii) Efficiency of irrigation systems as a result of water conveyance loss and management loss which occurs during the irrigation period.

Potential evapotranspiration was estimated with modified Penman equation. Usually, this method gives more accurate results as compared with other calculation method, however, requires various meteorological data such as temperature, relative humidity, wind velocity, solar radiation, etc.. Necessary meteorological data for the calculation are collected from three stations, Sargodha for L.J.C., Faisalabad for L.C.C. and Lahore for C.B.D.C.. By modified Penman equation, evapotranspiration is described as follows;

$$ETo = c\{W \times Rn + (1-w) \times f(u) \times (ea-ed)\}$$

where,

ETo : potential crop evapotranspiration (mm//day),

c : adjustment factor to compensate for the effect of day and night weather conditions,

W : temperature related weighting factor

Rn : net radiation in equivalent evaporation (mm/day)

f(u) : wind-related function

(ea-ed) : difference between the saturation vapor pressure at mean air temperature and the mean actual vapor pressure of the air both in mbar.

The calculation results based on the meteorological data collected from the above mentioned three stations are summarized below.

ETo (Potential Evapotranspiration) (mm/day)

Region	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Avg.
Sargodha (L.J.C.)	2.9	3.9	5.3	7.3	9.3	9.6	7.8	7.1	6.5	6.1	3.8	2.7	6.0
Faisalabad (L.C.C.)	3.1	4.2	5.9	8.2	10.1	10.1	8.4	7.6	7.0	6.8	4.1	3.0	6.5
Lahore (C.B.D.C.)	3.2	4.4	5.8	8.2	9.8	9.9	7.7	6.8	6.5	6.7	4.3	3.0	6.4

Details of ETo calculation are shown in Table A.1.8-1 (1/3) ~ (3/3).

(2) Crop Consumptive Use

Crop consumptive use for five representative crops in the Project Area, namely, wheat, maize, paddy, cotton and sugarcane were estimated through crop coefficients which are presented to relate potential evapotranspiration (ETo) to crop consumptive use in order to account for the effect of the crop growth characteristics.

$$ETc = Kc \times ETo$$

where,

ETc : Crop Consumptive Use(mm/day)

Kc : Crop Coefficient ,

ETo : potential evapotranspiration (mm/day)

Crop consumptive use for representative crops through growing stage in Punjab are summarized below. "Approximate Range of Crop Consumptive Use" given in FAO Irrigation and Drainage Paper, No.24, are also shown for reference.

Crop Consumptive Use, L.J.C. (mm/year)

Crop	Growth Period	Calculated Crop Consumptive Use	Approx. Range given by FAO
L.J.C			
Wheat	Beg.Nov - Mid.May	337.2	300-450
Maize	Mid.Jul - End.Nov	415.0	400-750
Paddy(Basmati)	Beg.July - Mid.Nov	847.7	500-950
Paddy(IRRI)	End.Jun - Mid.Oct	628.8	500-950
Cotton	Beg.May - End.Nov	842.4	550-950
Sugarcane	Mid.Feb - End.Dec	1375.0	1,000-1,500

Crop Consumptive Use, L.C.C. (mm/year)

Crop	Growth Period	Calculated Crop Consumptive Use	Approx. Range given by FAO
L.C.C			
Wheat	Beg.Nov - Mid.May	367.8	300-450
Maize	Mid.Jul - End.Nov	451.8	400-750
Paddy(Basmati)	Beg.July - Mid.Nov	918.3	500-950
Paddy(IRRI)	End.Jun - Mid.Oct	675.8	500-950
Cotton	Beg.May - End.Nov	907.4	550-950
Sugarcane	Mid.Feb - End.Dec	1488.6	1,000-1,500

Crop Consumptive Use, C.B.D.C. (mm/year)

Crop	Growth Period	Calculated Crop Consumptive Use	Approx. Range given by FAO
C.B.D			
Wheat	Beg.Nov - Mid.May	373.7	300-450
Maize	Mid.Jul - End.Nov	426.8	400-750
Paddy(Basmati)	Beg.July - Mid.Nov	855.1	500-950
Paddy(IRRI)	End.Jun - Mid.Oct	617.5	500-950
Cotton	Beg.May - End.Nov	844.6	550-950
Sugarcane	Mid.Feb - End.Dec	1424.8	1,000-1,500

(3) Effective Rainfall

Based on the methods estimating effective rainfall presented in "Effective Rainfall in Irrigated Agriculture, Irrigation and Drainage Paper, No.25, FAO", 70% of average seasonal rainfall has been taken as effective rainfall and summarized as below.

Effective Rainfall (mm/month)

Canal System	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov	Dec.	Avg
Sargodha (L.J.C.)	4.2	22.5	40.3	26.5	14.6	23.2	96.1	67.5	44.8	8.7	1.7	14.5	30.4
Faisalabad (L.C.C.)	7.1	13.9	14.9	17.9	15.1	21.2	57.1	38.4	31.9	0.3	0.1	4.7	18.6
Lahore (C.B.D.C.)	17.0	33.7	25.4	13.2	15.7	29.7	112.9	126.0	57.7	4.5	2.5	11.3	37.5

(4) Net Irrigation Water Requirement for Crops

Net Irrigation Water Requirement is defined here as the amount of irrigation water to meet the evapotranspiration need of the crop as well as the other needs such as land preparation, leaching requirement, etc. and exclusive of effective rainfall.

$$NIR = ETc + LP + LR - Re$$

where,

NIR	: Net Irrigation Requirement(mm/day),
ETc	: Crop Consumptive Use(mm/day),
LP	: Land Preparation (mm/day),
LR	: Leaching Requirement (mm/day),
Re	: Effective Rainfall (mm/day)

Estimated net irrigation water requirements for representative crops were calculated based on the assumption stated above and summarized on monthly basis in the tables below.

Net Irrigation Water Requirement for Representative Crops, L.J.C. (mm)

Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
L.J.C													
Wheat	3.4						15.0	40.3	57.8	87.7	79.1	27.8	311.1
Maize					31.2	142.2	146.5	10.8					330.7
Rice			37.2	180.8	227.3	245.8	218.4	17.1					926.5
Cotton	7.7	68.7	72.0	105.0	180.6	160.8	95.3						689.9
Sugarcane	118.1	216.6	238.8	129.3	132.9	112.0	107.6	37.0		16.8	21.2	54.9	1185.2

Net Irrigation Water Requirement for Representative Crops, L.C.C. (mm)

Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
L.C.C													
Wheat	11.4						18.3	44.2	75.0	90.6	89.5	64.0	393.0
Maize				4.2	69.3	171.2	173.8	12.3					430.8
Rice			37.9	231.8	274.0	277.6	248.1	18.7					1088.1
Cotton	11.7	72.1	79.2	164.1	230.6	191.2	116.6						865.5

Sugarcane	145.5	236.0	255.4	190.4	179.6	138.5	130.2	42.1	4.0	15.6	28.6	92.0	1457.9

Net Irrigation Water Requirement for Representative Crops, C.B.D.C. (mm)

Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
C.B.D.C													
Wheat	15.0						16.7	42.9	67.4	82.9	72.6	51.0	348.5
Maize						126.0	166.7	12.0					304.7
Rice			34.8	162.0	158.6	231.0	241.1	18.5					846.0
Cotton	13.5	69.9	67.5	83.9	105.6	144.5	110.4						595.3
Sugarcane	150.9	227.7	239.6	107.9	60.0	95.7	123.9	41.4	1.5	11.7	15.5	78.9	1154.7

Details of net irrigation requirement are shown in Table.A.1.8-2(1/15) ~ (15/15).

(5) Irrigation Efficiency

Following definition is used in the Study in order to account for water loss incurred during conveyance and application to the field,

Distribution Efficiency:- ratio between water received at the inlet of fields and that released at the project headworks,

Field Application Efficiency:- ratio between water directly available to the crop and that received at the field inlet.

(6) Status of Canal Water Application

General

Irrigation system in Indus Basin was designed about a century ago during the period of British regime for the main purpose of eliminating famine which repeatedly occurred in the 19th century. For this system, crop intensity was assumed 75% so that as much area is to be brought under irrigation to save as many people from famine. Hence, the concept of the irrigation system in Indus Basin is different from that of modern irrigation system in which water is designed to be conveyed to the field in response to crop calendar and water requirement for the maximum crop production and efficient water use as well. However, with increase of crop intensity almost to 150% under the pressure of growing population in recent years, the system is not working properly without supplemental ground water supply from tubewells.

Comparison of Water Requirement to Actual Application

Comparison of net irrigation requirement to the actual water supply was made on monthly basis for the three canal systems from canal discharge, cropping calendar, crop area, meteorological data and irrigation efficiency. Distribution and field application efficiency were assumed to be 70% and 60% respectively. As is shown in the table below actual surface water application is far from sufficient as compared with estimated net irrigation water requirement. Consequently, it was clarified that farmers in the Study Area would be in serious shortage of irrigation water without supplemental supply from tubewells.

Net Irrigation Requirement and Actual Application: L.J.C. (unit: million tons)

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
L.J.C. Actual Surface Water Supply*	119	158	162	159	158	154	151	125	106	32	115	112	1551
NIR	132	240	389	404	468	600	422	269	281	384	394	270	4253
Balance	-13	-82	-227	-245	-310	-446	-271	-144	-175	-352	-279	-158	-2702
Depth/GCA (mm)	-2	-12	-34	-37	-47	-67	-41	-22	-26	-53	-42	-24	-407

Net Irrigation Requirement and Actual Application: L.C.C. (unit: million tons)

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
L.C.C. Actual Surface Water Supply*	327	371	374	371	372	376	366	347	325	116	198	335	3878
NIR	344	486	709	941	1186	1406	1252	586	666	813	912	730	10031
Balance	-17	-115	-335	-570	-814	-1030	-886	-239	-341	-697	-714	-395	-6153
Depth/GCA (mm)	-1	-8	-22	-38	-54	-69	-59	-16	-23	-47	-48	-26	-411

Net Irrigation Requirement and Actual Application: C.B.D.C. (unit: million tons)

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
C.B.D.C. Actual Surface Water Supply*	65	70	75	71	72	71	68	71	63	12	49	64	751
NIR	59	61	116	130	124	217	211	114	129	158	163	124	1606
Balance	6	9	-41	-59	-52	-146	-143	-43	-66	-146	-114	-60	-855
Depth/GCA (mm)	2	3	-14	-21	-18	-51	-50	-15	-23	-51	-40	-21	-300

* Discharge at Canal Head x 0.7 x 0.6

(7) Status of Ground Water Application

General

As mentioned in the previous section, surface water availability is not satisfactory for water requirement and ground water is being utilized and large number of government and, private tubewells are installed for the purpose in the Study Area. According to 1995 Statistical Hand book of Pakistan, it is estimated that there are more than 80,000 private tubewells owned by farmers as of 1996 and the pumpage amounts to 13.5 billion cubic meters in total in the three canal systems. Government tubewells are supposed to be approximately 4,900 as of 1996 and discharge is estimated 3.7 billion cubic meters, however they are being replaced by private tubewells under the governmental policy.

Ground Water Abstraction

Ground water application for each canal system, namely, L.J.C., L.C.C. and C.B.D.C. was estimated through calculation based on the following assumptions taken from literature.

Private Tubewells

Average discharge	0.028(m^3/sec)
Utilization factor	21%
Non operating Tubewells	10%

SCARP Tubewells

Average discharge	0.085 (m^3/sec)
Utilization factor	35%
Non operating Tubewells	20%

Annual ground water pumpage for the three canal systems was calculated and summarized as shown in the table below.

Annual ground water pumpage for the three canal systems

Canal System	Annual Ground Water Pumpage (10^6 ton)		Total Discharge (10^6 ton)	G.C.A (km2)	Pumpage Depth (mm)
	Private Tubewells	Government Tubewells			
L.J.C.	1,742	1,703	3,445	6,630	520
L.C.C.	9,834	1,369	11,203	14,974	748
C.B.D.C.	1,986	273	2,259	2.846	794
Total	13,562	3345	16,907	24,450	Avg. 691

Balance between irrigation water supply including ground water and water requirement was performed. In L.J.C. and L.C.C., even with supplemental supply of ground water, water requirement is not satisfied. In L.J.C. as much as 23% deficit of water requirement was estimated since ground water supply, 520 mm is relatively small as compared with those in other canal systems. In L.C.C., situation is not so serious, however, still about 6% of deficit was figured out. On the contrary, 17% surplus water was found in C.B.D.C. because of more annual rainfall than the other systems and the largest ground water supply, 794 mm.

Irrigation Water Supply and Water Requirement

Canal System	(1)Annual Actual Surface Water Supply (10^6 ton)*	(2)Annual Actual Ground Water Supply (10^6 ton)**	(3)Net Irrigation Water Requirement (10^6 ton)	Balance (1)+(2)-(3) (10^6 ton)
L.J.C	1,551	1,723	4,253	-979
	(234 mm/GCA)	(243 mm/GCA)	(641 mm/GCA)	(-147 mm/GCA)
L.C.C	3,871	5,602	10,031	-558
	(259 mm/GCA)	(120 mm/GCA)	(670 mm/GCA)	(-37 mm/GCA)
C.B.D.C	751	1,130	1,606	+275
	(264 mm/GCA)	(121 mm/GCA)	(564mm/GCA)	(+97 mm/GCA)
Total	6,181	8,455	15,890	-1,262

* : Surface Water Supply x 0.42

**: Ground water pumpage x 0.5

(8) Surface and Subsurface Drainage

General

Continuous seepage from unlined canals, flat topography and lack of natural surface and subsurface drainage resulted in waterlogging and salinity in irrigated areas. In order to improve the situation, SCARP(Salinity Control and Reclamation Project) has been started by WAPDA since 1960s which intends to control ground water depth through tubewell pumpage and still on going nation wide. Although SCARP seemed to be successful at first, deteriorated and aged tubewells which led to the economic inefficiency of the project, and the recognition of possible deterioration of irrigation land through applying ground water with high salt concentration change the situation. It was understood that introduction of comprehensive drainage system is the only long term solution and in 1991, Government of Pakistan undertook a study for the environmental assessment of the irrigation-related drainage in the country, including preparation of a conceptual framework for the National Drainage Programme (NDP) financed mainly by the World Bank. The Government agreed to undertook NDP after the evaluation of Drainage Sector Environmental Assessment-National Drainage Program in 1993. The first phase of NDP is intended to cover six years from 1995 to 2001.

Surface and Subsurface Drainage

It is well known that crop yield decreases to great extent when watertable depth is within 1.5m. According to NDP report, area with depth to watertable less than 1.5 m during April/June 1989-1990 was estimated as much as 712,000 ha and future drainage requirement is estimated as 1,060,000 ha for surface drainage and 2,007,000 ha for sub-surface drainage for Punjab. Water tables can be lowered by preventing excessive seepage losses from canals, by careful and efficient application of water on the farms, and by providing artificial drainage on areas for which natural drainage is inadequate. Although, in some part of the Study Area, drainage facilities had been already completed, because of deferred maintenance, much of it is in ill-repair and not capable of handling runoff of heavy rains, drainage problems are reappearing and has to be improved to keep watertable depth from rising. Under these circumstances, drainage system in the Study Area, which include surface drainage and sub-surface drainage comprising tubewell and tile drainage, will be developed in accordance with the development concept of NDP.

Watertable Depth and Reduction of Crop Yield

Watertable Depth (m)	Wheat	Cotton	Oilseed	Sugarcane	Kharif Fodder	Rabi Fodder
0.00 --- 0.25	79	98	91	91	80	77
0.25 --- 0.50	49	57	66	66	27	45
0.50 --- 0.75	28	35	46	46	0	24
0.75 --- 1.00	29	21	29	29	0	9
1.00 --- 1.25	2	12	5	5	0	2
1.25 --- 1.50	0	5	1	1	0	0
1.50 --- 1.75	0	1	1	1	0	0
Over 1.75	0	0	0	0	0	0

Source: LBOD, Integrated Irrigation and Drainage in Pakistan, ICID XIII Congress, Special Session, 1987

(9) Ground Water and Salt Balance Study

Ground water Balance

Each canal system was divided into fresh and saline water area for ground water balance study, since conditions are quite different in fresh and saline water areas. Taking into the difference of conditions like ground water irrigation, watertable depth, salt concentration of ground water, etc., it is more reasonable to perform the study for fresh and saline water area separately for each of the three canal systems. Basic principle of the ground water balance of the system is:

$$GW_r = GW_{in} - GW_{out}$$

where,
- GW_r : Ground water Recharge
- GW_{in} : Ground water Inflow due to seepage
- GW_{out}: Ground water Outflow due to Pumpage, Evaporation, etc.

Results of ground water balance calculation are summarized for the three canal systems in the table below. It can be interpreted from the results that at fresh water zones, the ground water table has a tendency of going down mainly due to large abstraction of ground water for irrigation and at saline water zones it is going up mainly due to seepage from canals and field irrigation water supply seepage. These ground water balance results coincided the observation in the Study Area.

Ground Water Balance (Unit:million ton)

	L.J.C. FW	L.J.C. SW	L.C.C. FW	L.C.C. SW	C.B.D.C. FW	C.B.D.C. SW
Geographical Area (km2)	4331	2860	9667	6490	1890	2011
Inflows (mil. ton)						
Seepage to Ground water						
Rainfall	153	101	209	140	83	88
Private Tubewells	401		2262		457	
Goverment Tubewells	613		493		98	
Canal Seepage	510	367	1051	818	197	306
Watercourses and Fields	686	601	1487	1062	294	469
Link Canal Seepage	281	213	586	435	74	49
Rivers	-37	-257	-232	-130	-89	-58
subtotal	2607	1025	5856	2325	1114	855
Outflows (mil. ton)						
Private Tubewells	1742		9834		1987	
Goverment Tubewells	1703		1369		273	
subtotal	3445		11203		2260	
Evaporation	150	620	288	1548	39	541
G/W Recharge(mil. ton)	-987	+405	-5635	+777	-1185	+314
G/W Recharge(m)	-0.23	+0.14	-0.58	+0.12	-0.63	+0.16

(Source:Irrigation Planning with Environmental Considerations, World Bank Technical Publications No.166)

Salt Balance

Salt Balance Study to illustrate the movement of salt between ground water and soil was performed based on the data and information collected during the Phase-I Study in Pakistan. Given conditions such as average salt content for surface water, ground water and soil saturation extract, etc., which are necessary for calculation are as follows:

Basic Condition of Salt Balance Study

Item	Fresh Water Zone	Saline Water Zone
Canal Water Concentration (ppm)	200	200
Ground water Concentration (ppm)	800	3,000
Soil saturation extract Concentration (ppm)	1,500	4,000
Depth of Soil (m)	1.8	1.8
Soil Moisture Storage Coefficient	0.2	0.2

Ground Water Storage Coefficient	0.25	0.25
Aquifer Depth (m)	120	90
Beginning Water Table Depth (m)	3.6	1.8

(Source:Irrigation Planning with Environmental Considerations, World Bank Technical Publications No.166)

Results are summarized as shown in the table below:

Salt Balance between Soil and Ground water

	L.J.C./FW	L.J.C./SW	L.C.C./FW	L.C.C./SW	C.B.D.C./FW	C.B.D.C./SW
Geographical Area (km2)	4,330	2,860	9,670	6,490	1,890	2,010
Salt Addition to Soil (million tons)	1.1	0.5	5.3	1.7	0.9	0.2
(tons/ha)	(+2.5)	(+1.7)	(+5.5)	(+2.6)	(+4.8)	(+1.0)
Salt Addition to Ground water (million tons)	-0.8	-0.8	-4.4	-1.2	-0.9	-0.2

From the results, it is understood that through continuous irrigation, both in fresh and saline ground water zone, salt moves to and accumulates in the soil. In fresh water zones, pumpage of ground water is thought to be the main cause of allocation of salt from ground water to soil. For saline area, capillary movement of water in evaporation is the cause of salt accumulation in soil, which means that, if the present situation continues, salt accumulation in soil might be detrimental to irrigation agriculture in long term in the Study Area.

From the analysis of water and salt balance study, the followings can be pointed out as far as implementation of canal lining is concerned:

(1) Canal losses through fresh ground water areas is not of concern since they serve to offset tubewell pumping and hence dampen the process of aquifer mining.

(2) Canal losses through saline areas are destructive. The water is not only lost forever for purposes of irrigation as it mixes with highly saline ground water, it is environmentally detrimental as it contributes to waterlogging.

Canal lining should be implemented first of all in saline areas to mitigate the serious waterlogging and salinity problem as a first treatment. In saline area, salt accumulation is already serious and washout of salt out of soil is impossible without installation of dense drainage network and application of considerable amount of fresh water. Canal lining could contribute to lowering of water table depth and reduction of evaporation, which diminishes salt accumulation in soil. Under the present circumstances, it is quite difficult to solve the problem completely, however, canal lining is considered to be a practical supplemental measure to keep the present situation from worsening.

A.1.9 Current Status of Lining of Distributaries and Minors

(1) Resaerch and Study

Several types of canal linings as listed in Table A 1.9-1 have been under experiment in Irrigation Research Institute for their water tightness, long-term degradation, durability against damages by root penetration, rodent attack and temperature fluctuation over five (5) years. Test section within Thathi Uttar minor carries EPDM rubber sheet lining covered by 4.5 inch thick brick. Performances and remarks of each types are shown in Table A 1.9-1 and findings derived from the research results are;

1) Exposed membrane are obviously observed to be damaged by cattle or farm machines in actual case and concluded not practical. They are suggesting 9 inch surface protection by earth material since penetration depth by sheep foot observed are 6 inch,
2) Buried membrane showed good water-seal-effect at the beginning of their application but relative weakness against penetration by rodents and weed. Some protection are suggested beneath the membrane. Rubber showed much higher protection than polyethylene sheet,
3) In case of brick or ceramic tile lining, loosening by rodent are reported as most vital damage and each pieces are observed separated at their joint especially at toe of canal slope. Ceramic tile seemed more vulnerable than brick and hence it may prove that thickness is important factor to long-term resistance against weed. Joints were proved to be weakest points for lining by pieces and further research is necessary and
4) Among of all types, brick with surface cover by mortar and synthesized rubber sheet showed good performance for long term but requesting Periodical repair. Rubber sheets with and without fiber reinforcement are

tested and fiber-reinforced-sheet showed higher resistance against damage by weed and rodent.

The captioned project is at the first tender stage by World Bank Loan including improvement of drainage, watercourses and sub-surface drainage as well as several research programs as project components besides canal lining component for distributaries and minors of about 178 km planning to apply geo-membrane/geo-textile for lining material. As a research component, several types of lining material, their combination and ways of construction are to be tested. Canal lining methods for the test are; a)Concrete in-situ with geo-membrane, b) Concrete tiles/slabs, c) Brick lining in geo-membrane under brick on edge protection and d) Double tiles sandwiched with mortar bottom and top.

Several joint sealers will be tested together in actual canals within the project area. Construction of the canals for research purpose will start in 1996 as Phase I and the results of the research would have significant meanings for the Project. According to their current progress report, a kind of impermeable geo-membrane, Flexible Propylene Alloy (FPA) protected by permeable geo-textile on top will be used for the field research. For other canals for productive lining will be lined using one material from six(6) pre-selected materials such as HDPE, LDPE, LLDPE, PVC, Alkoplan and FPA by contractor's choice. For testing of the materials to be applied, a research laboratory will also be constructed at site.

Preference of concrete lining to brick lining was concluded in the Study Report for Lining of Irrigation Channels in Punjab conducted by Government of Punjab in 1995 and application of membrane is also proposed within limited canal reaches where seepage loss are high. Project area covers entire Punjab except where projects have been completed or on-going with more emphasis on water salvage than the canal lining projects and programs ever executed in Pakistan.

Bottom only lining, a concept stated by USBR, using polyethylene sheet and compacted soil cover is concluded to be applied except where horizontal seepage loss are anticipated significant or near by towns, to which reaches concrete lining are proposed in the Feasibility Study Report for Punjab Water Conservation Project conducted by ADB in 1995. Three(3) subprojects are selected as sample area for the first implementation group and among of them Dijkot distributary branched out from Pakh Branch is located within the Lower Chenab Canal System, to which buried membrane lining is proposed.

(2) Site Condition

There are several canal lining programs so far as listed below conducted within the Project area (LCC, LJC and CBDC) and concrete lining of 3 inch thick, brick lining of 4.5 inch thick[1] and brick side protection of 4.5 inch thick are major lining methods. Canal bank improvement works have been also conducted. Double brick lining was applied for some portions of Brach, Main and Link Canals and damages by uplift pressure have been reported. Linings are applied to relatively small channels or downstream or where nearby town or where there are canal maintenance were vital for proper operation and maintenance as well as even distribution of water through to the tail reach. Selection criteria of lining types is soil salinity rather than seepage or ground water quality and concrete lining were chosen to saline area generally.

- Irrigation System Rehabilitation Project (ISRP) Phase I and II, financed by World Bank, USAID and Government of Netherlands.
- Annual Development Program (ADP), by Government of Punjab.
- Member of Provincial or Federal Assembly Grant (MPA Grant)
- Maintenance and Repair Program (M&R), by Government of Punjab.
- Command Water Management Program (CWMP), by USAID, etc.
- Khushab Salinity Control and Reclamation Project (SCARP), by World Bank.
- SCARP Transition Pilot Project (S.T.P.P.), by World Bank

Most of canal lining works were completed within 1-8 years under the program above. Canals lined either by concrete or brick and protected by brick at inside slope within the Study Area under the above program are summarized in Tables A.1.9-2 (1/10) - (10/10) Cost data are relatively undependable due to data lacking and mixture of canal lining works with appurtenant earth works. Canal lining ratio for distributaries and minors in Lower Jhelum, Lower Chenab and CBD canal systems are 4, 10 and 16% respectively concluding that much less input of canal lining have been given to LJC than the other two systems. Brick lining is dominant in LCC and concrete lining in LJC while Slope-protection lining is scarcely seen in CBDC. Specifications of canal lining are similar among the projects above. 3 inches thickness is for concrete lining and 4.5 inched for brick lining on edge supported on 0.75 inched mortar plaster[2]. Side

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[1] Thickness of flat brick tile is 3 inch and 4.5 inch thick for brick on edge alignment. Brick on edge lining is a improved alternative lining type prevailed.

[2] Mortar Mixing; 1:6 mixing is common for plaster under lining. 1:3 mixing is commonly used for brick and masonry work.

slope of 1: 1 is common but 1:0.5 is applied for smaller canal. There are three(3) types of outlets such as pipe/barrel type, open flume type and orifice type have been adopted beside tail cluster at tail. Some of outlets are observed superannuated and lost its function. Concrete slab bridges are common beside some of brick-made bridges. Major constraints observed in the field are;

1) Quality control of concrete lining for the initial construction are not satisfactory and deep and hair cracks are observed. Joints damages are much observed for brick lining especially where weeding occur from inside of lining.

2) Siltation which have caused berm formation and weeding within the canal prism consequently are much observed in LCC downstream reach of channels commonly than LJC and CBDC. Sample collection of the siltation from each site concluded that soil category of the siltation is sandy-silt in LCC and clayey-silt in the rest of two system. Sharp decrease of discharge and velocity in lower reach by over-deliver or water-steel in the upper reach may have caused the siltation.

3) It was observed that there are enough right of way for the lining work by diversion method through year round for the canals whose discharge are less than 100 cusec.

4) Damages of canal lining by cattle passage were reported in several places and a countermeasure was proposed by a site engineer that small ponds for cattle use would be arranged by each side of a canal to avoid cattle access to canal prism. The damage seems significant in CBDC due to population pressure.

Results of inventory surevey of canal related structures are shown in Tables A.1.9-3 (1/3) - (3/3). There found outlet, drop, bridge,steps, aquiduct, watercourse crossing, pipe culvert and escape within the distributaries and minors in the study area. Types of outlet at present condition are tabulated by area in the following table. APM(Adjustable Proportional Module) is predominant and open flume type follows. Combined open flumes outlet (Tail Cluster) is common at the end of channels. Total numbers of outlet surveyed are 1,085, out of which only 35 nos outlet are in good condition and keep initial function, 725 nos of outlets are observed somewhat damaged and requesting repair and 324 nos outlets seem lost functions and requesting replacement.

Inclined type is major category of drop but not small numbers of drops are quite damaged so that original type could not be identified. Total numbers of drop surveyed are 176, out of which 82 nos of drop are observed requesting repair or replacement. Total numbers of bridge in the study area are 433, out of which 244 nos of bridges are requesting repair and 150 nos are obviously reqired to be replaced. Railway bridge in the study area are 12 nos. Brick bridge are common and concrete slab are used for the rest of bridges. There are 85 steps, out of which 27 nos steps request repair and replacement is necessary for 22 nos.

Soil mechanics survey was conducted on 10 points within the study area and its results show dominance of sandy silt in LCC area and more clayey silt in the other areas. Permeability are relatively low in all area Inside friction angles and cohesion show that earth material acquired near by canals are suitable for embankment and that canal inside slope could be designed as sharp as 1: 1.

According to the data[3] by ISRIP and their analysis, diameters of soil particles of suspended load at 90% pass and 50% pass are 0.066 mm and 0.027 mm for LJC area and 0.185 mm and 0.112 mm in LCC area. Concentrations of suspended load above 0.062 mm are 7.7 PPM only in LJC and 245.0 PPM in LCC area. The data above show that water flowing in LJC area are of less silt suspension and most of the suspended load can be washed throughout to farm land by normal flow velocity (1-1.5 ft/sec). Condition in LCC on the other hand requests special treatment since most suspended load precipitates within distributaries and minors canal reaches and concentrations are high.

(3) Material Availability and Price

Supply of aggregate, sand and brick are confirmed available within the Project area. Aggregate are produced nearby Sargodha and delivered to entire Punjab, sand can be taken from Chenab Liver and brick production are prevailed anywhere. Price of aggregate are most varied by location, cheapest at Sargodha and highest in Lahore. Price variation for the other materials are much small. Portland cement is produced in Sargodha area and partially imported but plenty volume of cement are available in market. Lining Material unavailable to be imported are most of geo-membranes such as rubber sheet, PVC/EVA sheet and geo-textiles since they are not available in domestic market or in too low quality to be applied. Price list of canal lining materiel are shown in Annex E.

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[3] Siltation Data taken by ISRIP for 1982-1984 for branches and distributaries in LCC and main canal in LJC.

(4) Construction Period, Method and Machinery for the Construction

Regarding construction period, there are two types 1) construction through year round and 2) only in irrigation interval period. For most of distributaries and minors inspected, construction period are 1 year to 1.5 years through. Repair work and lining work for the larger canal have been made in the irrigation interval period of about one month in December and January. Most of the construction works have been conducted on contract basis and average package price for a contract is about 5 mil. Rs. covering a minor or distributary. In case of exceeding 10 mil Rs. for a canal, works are to be divided into some packages. Per linear meter average expenditure derived out from base data of Table 3.5.2 for concrete and brick lining are roughly about Rs. 700 for the two type.

Canal diversion method has been applied where perennial construction are possible since there are enough right of way. According to site engineers comments and results of site investigation, it seems that the canal discharging more than 100 cusec does not have enough area by side for diversion. Ordinary length of a diversion work is reported from 1,000 - 5,000 feet for construction period of 1 to 5 weeks. Another alternative method is to construct new channel by the side of the original channel and to shift after completion as observed in case of CMWP as stated in the feasibility study on lining of irrigation channels in Punjab. In the alternative case, canal bank are to be constructed on the original channel line and all structures are to be re-constructed or modified widely. Third alternative method is to construct within the canal closure period in December to January. Lining machine or motor driven slip form have never used for canal lining work.

A.2 Selection of Priority Canals and Areas

A.2.1 Priority Canals

(1) Problems Encountered in the Study Area

Irrigation systems of the Study area are characterized by deviation from their supplies to crop water requirements. Even in those areas where ground water has been developed as a supplemental to canal irrigation, the mismatch persists. Water and salt balance study brought out significant variations (both surplus and shortage) between crop requirements and irrigation supplies, and salinity/waterlogging problems especially where ground water is high and saline.

The major problems of canal irrigation causing low agricultural productivity in the Study area variously perceived as follows:

(1) Supplies falling short of the crop-water requirements during the growing periods or at critical stages of growth.

(2) Irrigation supplies in excess of the crop requirements and/or conveyance and application losses causing drainage problems and resulting in waterlogging and salinity.

(3) Inadequacy and unreliability of supplies at the time of sowing of crops resulting in protracted sowing periods beyond the proper time, and also restricting the area from practicing planned cropping pattern.

(4) Status of the system restricting more supplies and anticipated distribution of water due to irregular canal prism and low earth freeboard even if sufficient water is available.

As for (1) of the above, it should be noted that the canal system was designed in the second half of the 19th century during the British regime, with the objective of extensive irrigation to bring more areas under irrigation in order to settle more people without considering the crop-water requirements. The perennial canal system, therefore, is not designed for maximum production on irrigated land but only to eliminate the possibility of famines. In this regard, supplemental irrigation is practiced using the ground water lifted up through the public and private tubewells share of which is considerable.

Concerning water conservation as stated (2) of the above, since the canal system is designed to operate and distribute water equitably while flowing close to full supply (i.e. constant) conditions nonetheless the water demands fluctuate according to the season and the growing stage of crops, irrigation supplies could be in excess when they exceed the demands from place to place. Also significant amount of seepage losses from the canals and field application losses are inevitable because the system is of unlined channel and flood (gravity) irrigation is the most prominent method in the Study area, respectively.

Deterioration of the system and poor water management are attributed to the problems stated (3) of the above. Design concept of the outlet from a branch canal to distributaries is to be regulated by gates. But the outlet from the distributary/minor to watercourses (called Moga) is designed based on automatic and proportional distribution concept with no gate. Crump open flume, adjustable proportional module or adjustable orifice semi-module are normally used for this purpose. The basic idea is to deliver water to watercourse most equitably, with least operation cost, and without any human intervention. Also these structures are designed to keep the distributary/minor itself free from silt. It seems that the design concept is excellent and most suitable for the Indus basin irrigation system together with the Warabandi system.

However, there are a number of researches and reports which indicate that the design concept of Moga has already collapsed due to deterioration and deferred maintenance of the facilities, and tremendous inequity of water of water distribution prevails. One paper says that head-enders of distributaries take 3-6 times more water than tail-enders. Our interviews with farmers and field officers also revealed that there were lots of problems regarding management at distributary/minor level. They include the theft of water, distorted water distribution due to political interference, misconduct of canal supervisions, etc.

In view of hydraulic performance of the canals as discussed (4) of the above, it is observed that water is not appropriately conveyed to the downstream reach due to low freeboard, scoring, silting, sliding of side slopes, weed hazard and irregular cross section of channels, and hence distribution of water is not properly made to the outlets of minors and watercourses.

(2) Function of Canal Lining

It is expected that lining of the distributaries and minors will solve the above problems to a considerable extent. Major functions of lining may be broadly classified into four; the first is controlling of seepage, the second is modernization of system operation and maintenance, the third is environmental improvement and the forth is others. Effects and benefits derived from these functions are as follows:

(1) Seepage control

- (i) Water conservation, high irrigation efficiency, and increase in cropping intensity and agricultural production;
- (ii) Reduction of amount of unretreavable ground water in SGW areas;
- (iii) Alleviation of waterlogging and salinity; and
- (iv) Minimization of drainage surplus.

(2) Modernization of System Operation and Management
   (i) Alleviation of the head-end/tail-end problem assuring more equitable distribution of irrigation water;
   (ii) Reduction of water theft;
   (iii) Reduction of canal breach;
   (iv) Reduction of siltation at the downstream reach of canal; and
   (v) Saving of operation and maintenance costs.

(3) Environmental Improvement and Other Effects
   (i) Environmental improvement and prevention of diseases through supply of fresh drinking water and decrease in swampy areas; and
   (ii) Creation of beautiful landscape.

(4) Others
   (i) provision of incentives to farmers for participatory management of irrigation system and creation of autonomous FOs.

(3) Selection of Priority Canals and Areas

The Study area is located in the province of Punjab in the Upper Indus plain. It is divided into doabs, or lands lying between the rivers, and consists of the Lower Jhelum System (LJC), the Lower Chenab System (LCC) and the Central Bari Doab System (CBDC).

Geographical area, gross command area (GCA) and culturable command area (CCA) of the Study area are 27,250 km, 24,450 km, and 21,160 km, respectively, and broken down as shown in the following table:

Area of the Three Irrigation Systems

Irrigation System	Geographical Area (km^2)	Gross Command Area (km^2)	Culturable Command Area (km^2)
Lower Jhelum	7,190	1,630	6,140
Lower Chenab	16,160	14,970	12,360
CBDC	3,900	2,850	2,660
Total	27,250	24,450	21,160

The number and length of the distributaries and minors are (i) 261 and 1,981 km in LJC, (ii) 399 and 3,787 km in LCC, and 102 and 847 km in CBDC, totaling 717 and 6,615 km as summarized in the following table (see Table A.2.1-1 in detail)

Number and Length of Distributaries and Minors

IrrigationSystems	Distributaries		Minors		Total	
	Number	Length (km)	Number	Length (km)	Number	Length (km)
LowerJhelum	87	1,320	129	661	216	1,981
LowerChenab	178	2,681	221	1,106	399	3,787
Central Bari Doab	34	510	68	337	102	847
Total	299	4511	418	2,104	717	6,615

(4) Criteria for Selection of Priority Canals

During the Interim Stage in Phase-I, selection of the priority canals was made in accordance with the following criteria:

(1) Degree of salt concentration of ground water and its level. Salt concentration is to be more than 1,000ppm.

(2) Degree of seepage losses through distributaries and minors. Seepage rate should be more than 5cfs/msf to be economically liable.

(3) Status of Water Users Association for watercourses. Condition of watercourses, lined or unlined is to be considered.

(4) A distributary with its minors is regarded as one system,. If the distributary is located in the saline area (more than 30% in length), its minors are deemed to be the same.

(5) Field Work in Phase-I

The initial step for the selection of the priority canals was to classify the Study area into two, in accordance with the salinity of the ground water, so-called the saline area (more than 1,000ppm) and the fresh area (less than 1,000ppm) using the ground water salinity map prepared by WAPDA in 1971.

Secondly, the reference was made to the selection of the canals for the seepage tests in the list of the priority channels for lining which was prepared by PID based on: (1) degree of deterioration and (2) degree of salinity, since the number of seepage tests was limited to 60 locations only (50 by inflow-outflow method and 10 by ponding method).

Based on the above information, the following selection standards were prepared:

(1) To select distributaries located in the high saline areas, but not to concentrate locally,

(2) To select two points along the long distributaries for the comparison of seepage rates at upper and lower reaches,

(3) To select minors equivalent to approx. one-fourth (14 points) for the comparison with the distriburaries,

(4) To select representative sections of concrete lining, brick lining and rock excavation (7 points) for the comparison with unlined sections, and

(5) To select canals at appropriate intervals (every 3 or 4 intervals) so as to estimate seepage rates of other channels without tests.

Careful arrangements were made in the selection of canals to be adopted for the seepage tests so as to enable to estimate seepage rate of any other canals, considering that there would be some discrepancies in the distribution of salinity between the two observations of WAPDA in 1971 and JICA in 1996. The name of the canals selected for the seepage test and results are shown in Table A.1.3-1 (1/3) - (3/3).

(6) Selection During The Interim Stage

The selection criteria (1) and (2) of the preceding section of 5.1.2 were the ground water salinity map prepared by IRI as a subcontracted ground water quality survey, and the seepage rate measured by IRI also as a sublet seepage test. The criterion (3) consists of the information on the outlets and watercourses (a. Outlet register, including information on kind of outlet, size and authorized discharge, and b. Watercourse list, including information on culturable command area, status of lining and WUA).

Number and length of distributaries including minors thus selected are 25 and 210 km in the LJC System, 39 and 471 km in the LCC System, and 2 and 51 km in the CBDC System. Therefore, the channels preliminary selected are 66 in number and 732 km in length.

In the LCC System, since the Asian Development Bank has already taken up the two distributary systems of Dijkot and Khewra for comprehensive development including canal lining in its Water Conservation Project, it was decided to delete these systems from the list made in the third selection. Therefore, the distributaries and minors provisionally selected are 51 in number, 553 km in length and 176,856 ha in area (CCA).

(7) Field Work in Phase-II

It should be noted that the ground water quality map prepared for the Inception Stage was somewhat modified according to the subsequent additional investigation conducted by IRI. Minor rearrangement of the selected canals was made accordingly based on the modified contour-map within the range of the total length stated in the Inception Report, together with the Chief Engineers and/or Superintending Engineers of the respective zones.

The canal systems thus finally selected are listed below. The number, length (excluding the length of lined section) and area are, respectively, four canal systems, 184 km and 63,844 ha in the LJC System, seven canal systems, 290 km and 113,779 ha in the LCC System, and two canal systems, 67 km and 26,206 ha in the CBDC Systems, totaling 12 canal systems, 542 km and 203,829 ha (see Table A.2.1-2 (1/3) - (3/3).

Distributary Systems and Selected for Canal Lining

System/Distributary	Cultulable Command Area C.C.A. (ha)	Length of Distributaries and Minors (km)	Proposed Lining Length (km)
1. Lower Jhelum			
Pindi	2,285	6.86	6.86
Hujjan	25,236	80.13	78.18
Kirana	50,765	138.08	96.49
Sub-total	78,286	225.07	181.53
2. Lower Chenab			
Sarangwala	6,627	25.04	24.74
Nasrana	34,677	81.42	75.77
Gojra	7,540	17.77	15.52
Mungi	19,161	41.29	37.31
Janiwala/Hamza	6,513	18.58	18.51
Pirmahal	18,242	82.13	82.13
Killianwala	27,798	57.17	36.98
Sub-total	120,558	323.40	291.03
3. Central Bari Doab			
Thamman	25,877	64.54	33.87

China	16,390	33.27	33.08
Sub-total	42,267	97.81	66.95
Grand Total	241,111	646.28	539.51

(8) Summary of the Current Study

In selecting distributaries and minors for lining, firstly, saline areas were delineated based on the sublet ground water quality investigation. The second selection was based on the seepage rates of the canals, of which survey was also sub-contracted. The third selection criterion was the accomplishment of FO and lining of watercourses. As discussed in the preceding paragraphs 5.1.4 and 5.1.5, twelve distributaries and 33 minors were finally selected. It should be noted however that further investigations is necessary for the canals which have not been chosen in this Study, since the number of the seepage survey was limited to 60 (39 for the distributaries) and accomplishment of FO and lining of watercourses are progressing. In this regard, classification of all the distributaries and minors are made in accordance with the location in terms of salinity, accomplishment of seepage tests, test results and other conditions, as shown in the following table (see Tables A.2.1-3 and A.2.1-4 (1/26) - (26/26) in detail):

Summary Table of Distributaries and Minors for the Current Study

Classification of fresh/salinity areas, status of seepage test	LJC		LCC		CBDC		Total	
	No. of canal	Length (km)	No. of canal	Length (km)	No. of canal	Length (km)	No. of canal	Length (km)
A. Entire canal	216	1,981	399	3,787	102	847	717	6,615
B. Canals in fresh areas	89	852	186	1,779	36	250	311	2,882
C. Canals in saline areas	127	1,129	213	2,008	66	547	406	3,734
1.Seepage tests completed	43	421	60	678	15	188	118	1,288
(1) Selected in this stege	20	201	24	324	9	132	53	656
(2) To be selected in the next	13	129	1	19	6	57	20	205
(3) Other projects, ADB	0	0	17	153	0	0	17	153
(4) Little lining effect	10	91	18	183	0	0	28	247
2. Seepage tests to be done	84	707	153	1,330	51	409	288	2,446

A.2.2 Demarcation of the Project Area

Demarcation of command areas in accurately contour-lined maps is essential for establishing development plan of irrigation projects. However, due to lack of satisfactory topographic maps encompassing the Project Area, it is quite difficult to clarify the boundary of the irrigation command areas. The best possible way is to demarcate them as accurately as possible based on Chuck Plans collected from PID irrigation offices, some of which are without revision irrespective of changes occurred for long time period, and additionaly referring to Outlet Registers and Warabandi Parts showing village names being irrigated through the selected canals. The estimated boundary of irrigated areas are schematically presented in General Plan of Selected Canals and their Command Areas (see Table A.2.2-1).

A.2.3 Description of the Selected Canals

(1) Lower Jhelum Canal System

Pindi Distributary was taken up for canal lining because the seepage loss is large and the ground water is highly saline in the surrounding areas. The length of the channel is 6.86 km, which serve 2,285 ha of CCA. The number of outlets is 10, and no watercourse is lined so far. Although the head reach of the channel seems to be fairly in good condition, middle to tail sections of the channel are highly deteriorated due to breaching of the side slopes. Weed hazard is prominent in these sections, and hence water does not reach to the tail from time to time.

Hujjan Distributary System consists of one distributary and eight minors with a total length of 80.13 km, of which 1.95 km has been already lined with brick. It serves 25,236 ha of CCA. The length of channels which are located in the area with high salt concentration ground water is estimated at 59.28 km. The number of outlets of this system is 122 and the watercourses lined is 66 or 54% , which are operated and maintained by the water users associations. In the Hujjan Distributsry, many traces of breaching and sliding of side slopes are observed especially on the right bank. In many of the minors, irregular channel sections and weed hazard are predominant.

Kirana Distributary has nine minors with a total length of 138.08 km (including Chokera Distributary and its minors), out of which, 96.49 km is proposed to be lined with concrete. The system serves water for 36,323 ha of CCA. The length of channels situated in the area with saline ground water is estimated at 84.04 km. The number of outlets in this system is 188 and watercourses already lined is 87 or 46% which are operated and maintained by the water users associations themselves. The upper reach of Kirana Distributary has been maintained in a fairly good condition though there are plenty of traces of breaching on the right bank. From the middle to tail reaches, the channel section becomes rather irregular due to sliding of the banks, which are protected by bamboo stakes. There are many traces of breaching on the canal banks. Weed hazard is the main problem in the middle to the tail of the channels. Hydraulic performance of the most of the minors of Kirana Distributary is rather poor due to irregular channel section caused by sliding of banks, and weed hazard. Seepage rate of this channel is significant.

(2) Lower Chenab Canal System

Sarangwala Distributary serves 6,627 ha of CCA with a channel length of 25.04 km, of which 0.30 km is protected with brick for the both sides of the bank. The entire length of the channel is situated in the area with saline ground water. The number of outlets in this distributary is 56 and watercourses already lined is 6 or 11% which are operated and maintained by the existing water users associations. Maintenance of this channel is rather poor. Fairly large scale breaching of the left bank was observe during the inventory survey (December 1, 1996), and hence the entire canal was not functioning.

Nasurana Distributary system consists of one distributary and six minors with a total length of 81.42 km, of which 5.65 km have been already lined with brick, and serves 34,677 ha of CCA. The length of the channels, which is located in the area with saline ground water, is estimated at 81.42 km, which are equivalent to 100% of the total length. The number of outlets in this system is 175 and watercourses already lined is 96 or 55% which are operated and maintained by the existing water users associations. It seems that this system is functioning well in view of hydraulic performance in the upper reach. However, channel section in the middle to tail reach is irregular due to sliding of side slopes and weed. Maintenance of minors in this system is made by means of side protection with brick from place to place. Most of the structures, especially outlets to watercourses are deteriorated, but their function seems to be fairy good so far.

Gojra Distributary and Zeera Minor system are 17.77 km in length and serve water for 7,540 ha in CCA. The entire length of the channels is located in the area of high salt concentration ground water. The number of outlets in this system is 39 and watercourses already lined is 23 or 59%. The channels and related structures seem to be functioning well though they are deteriorated.

Mungi Distributary and Minor system is 41.29 km in length and serve water for 19,161 ha in CCA. The whole length of the channel is situated in the area with saline ground water. The number of outlets in this system is 97 and watercourses already lined is 34 or 35%, which is operated and maintained by the existing water users association. Due to various hazards in view of hydraulic performance, it was observed that water had not reached to the tail during the field inspection (November 19, 1996).

Janiwala/Hamza Distributary system consists of two distributaries and one minor with a total length of 18.58 km, which serve 6,513 ha in CCA. The entire length of the channels is situated in the area with saline ground water. The number of outlets in this system is 31 and watercourses already lined is 18 or 58% which are operated and maintained by the existing water users associations themselves. As this system is supplied water from the two distributaries, Janiwala and Hamza, without changing the original authorized discharge, sufficient discharge is being supplied illegally. Adjustment of authorized discharges should be made for the two distributaries.

Pirmahal Distributary diverts water to the four minors. The total length of the system is 82.13 km. No lining of canal has been performed for the distributary and minors. The area being irrigated by the system is 18,242 ha in CCA. The canal length situated in the area with saline ground water is 61.08 km, or 74% of the total canal length. The number of outlets in this system is 96 and watercourses already lined is 14 or 15% which are operated and maintained by the existing water users associations themselves. Pir Mahal system is suffering from silting especially during summer months when canal water is silt laden. Since the canal section decreases due to silting and weed, discharge to the down stream decreases accordingly. Therefore, water does not reach to the tails of the distributary and the minors from time to time. It seems that canal conservation work is made periodically to maintain the capacity for the authorized discharges.

Killianwala Distributary has three minors, Minors #3, #7 and #8. Of the three, #7 and #8 have been already lined by PID and hence, these are excluded from the priority canals for lining. Therefore, the length taken up for the Feasibility Study is 57.17 km (of which 20.19 km are lined with brick), which serve 27,798 ha of CCA. The length of the channels which are located in the area with saline ground water is estimated at 48.36 km. The number of outlets in this system is 144 and watercourses lined is 43 or 30% which are operated and maintained by the existing water users associations themselves. Due to silting, weed and large seepage loss, the tail portion of the channel is suffering from shortage of water. No water was observed during the inspection period (December 2, 1996).

(3) Central Bari Doab Canal System

Thamman Distributary system has five minors. Due to the restriction of the budget, finally selected channels are Thamman Distributary and Saharan Minor. The total length of the two channels is 37.09 km, of which 3.02 km have been already lined with brick. The total area of the System is 25,877 ha in terms of CCA. The length of channels which are located in the area with the high salt concentration ground water is estimated at 30.84 km or 83% of the selected length. The number of the outlets in the two channels is 68 and the watercourses lined are 14 or 21%, which are operated and maintained by the existing water users association. Due to irregular channel section, weed and high seepage rate, the tail portion of Thamman Distributary and Saharan Minor are suffering from shortage of water.

China Distributary system consists of China Distributary and Kala Minor with a total length of 33.27 km. No lining has been conducted in this system. CCA of the system is 16,390 ha. The length of the channels which are situated in the area with saline ground water is estimated at 22.44 km. The number of outlets along the two channels is 88 and watercourses lined is 28 or 32% which are operated and maintained by the existing water users association. The hydraulic performance of the channels is poor due to very low freeboard.

A.2.4 Effect of Canal Lining on Ground Water

From the analysis of water and salt balance study, the followings can be pointed out as far as implementation of canal lining is concerned:

(1) Canal losses through fresh ground water areas is not of concern since they serve to offset tubewell pumping and hence dampen the process of aquifer mining.

(2) Canal losses through saline areas are destructive. The water is not only lost forever for purposes of irrigation as it mixes with highly saline ground water, it is environmentally detrimental as it contributes to waterlogging.

Canal lining should be implemented first of all in saline areas to mitigate the serious waterlogging and salinity problem as a first treatment. In saline area, salt accumulation is already serious and washout of salt out of soil is impossible without installation of dense drainage network and application of considerable amount of fresh water. Canal lining could contribute to lowering of water table depth and reduction of evaporation, which diminishes salt accumulation in soil. Under the present circumstances, it is quite difficult to solve the problem completely, however, canal lining is considered to be a practical supplemental measure to keep the present situation from worsening.