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Concept, Planning and Design of Khairwala Drainage Project

BY

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SUMMARY

Lower Rechna Doab was introduced to canal irrigation with the commissioning of L.C.C. system when the sub-soil water table was at about 60' to 80' depth and the rainfall scanty. With the passage of time and development, water table slowly and gradually started rising leading to serious problem of waterlogging and salinity. Such events proceeded along the land slope i.e. from North to South and necessitated provision of drainage systems. By 1978 the whole of Upper Rechna and a portion of Lower Rechna Doab had been covered with horizontal and vertical drainage. However, the areas lying west of Rakh Branch and South of Chakbandi Drainage Basin were still without any drainage facility.

At present a major part of Faisalabad District is badly water logged. A vast area lying between Jhang Branch and Bhowana Branch, Rakh Branch and Nasrana Disty: constituting base lines and depression is almost completely water-logged. About 54% of the total area of 3,33,440 Acres (521 sq.miles) has a sub-soil water table depth of less than 5' and some thing like 14% remains submerged for the most part of the year.

To cover this area, the Irrigation and Power Department conducted detailed survey and prepared a project for

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construction of 124 miles of trunk drains named as Khairwala Drainage Project. The PC-I for this Project included not only the construction of the surface drains but also 98 major masonry structures and other allied minor structures, like water-course crossings and inlets, etc. The Project approved by the Federal Government for Rs.195 million in May, 1981, is now in an advanced stage of execution and is scheduled for completion by the end of 1984-85.

This paper presents the concept, planning and design of the Project; the construction and evaluation part has been intentionally omitted to reduce the length of the paper.

1.0 PROJECT LOCATION

The area covered by Khairwala Drainage Project lies between latitude 31°-15' to 31°-27' North and longitude 72°-45' to 73°-05' East in the Western part of Lower Rechna in all the three Districts of Faisalabad Civil Division. The Project area has been shown in Fig.I.

2.0 PROJECT AREA (DESCRIPTION)

The project covers a gross area of 521 square miles (3,33,440 Acres). The district-wise break-up of this area is as under:

1. Faisalabad District	1,47,000 Acres
2. Jhang District	1,52,960
3. Toba Tek Singh District	33,480

Physiographically, the project area consists of mainly bar up-land category in the Indus plain where alluvial deposits date back to the late Pleistocene period. The alluvium consists mainly of unconsolidated sand and silt with small amounts of clay and Kankar.

2.1 Climate

The area experiences large seasonal variations in both temperature and rainfall. The average annual rainfall varies between 10" to 14" and almost 80% of this occurs during monsoon season. The day temperatures during winter range between 10°C to 27°C while in summer these may vary between 32°C to 49°C.

2.2 Geology

According to the data observed by WASID during 1957-62 the area is underlain by a good sand aquifer with the characteristic values of specific draw-down, transmissibility, and specific yield of the order of 7.44 feet per cusec, 0.394 Cs. per foot and 0.18 respectively.

2.3 Soils

The soils in the area have well developed profile characteristics and are invariably calcareous with organic matter percentage in surface crest generally limited to 0.5. The P.H. for normal soil is about 8.2, but in Alkali soils the values are as high as 9.6.

2.3.1 The area constitutes three main soil associations as shown below (After SSOP-1968):

SOIL ASSOCIATION	PERCENTAGE OF G.A.
Hafizabad Association	62.2
Lyallpur Association	31.6
Khurrianwala Association	6.2

2.3.2 The Project soils mainly consist of Hafizabad and Lyallpur Associations which are well drained and except for very small saline portions have very high agricultural potential.

According to WASID's Report of soil survey four soil series have been identified in the Project area in the upper six feet of soil profile and are listed in Table No.2.

2.3.3 WASID's Report did not indicate any surface salinity in 1956-57 but later investigations conducted by Master Planning Division in 1977-78 showed about 15% of the area to be under varying degrees of surface salinity.

The distribution of such area under various salinity categories appears below:

SALINITY CLASSES	PERCENTAGE OF G.A.
Normal	85.2
Slightly saline	8.6
Moderately saline	4.1
Strongly Saline	2.1
Total:	100.0

Soil Survey of Pakistan also gave similar classification in 1968.

2.4 Irrigation

The project area lies in the well developed irrigated zone of Rechna Doab. It receives irrigation supplies from distributary channels of Jhang Branch, Lower and Rakh Branch of L.C.C. system. The annual intensity of irrigation in the Project area works out to 125% against 75% originally designed. The ground water in Faisalabad district and Toba Tek Singh is brakish and does not contribute to crop requirements. Hence there is a scope of increase in cropping intensity if more canal irrigation supplies can be arranged. However, in Jhang District the ground water is generally of good or acceptable quality and supplements the canal supplies.

2.5 Drainage

No drainage facilities, surface or sub-surface, horizontal or vertical, exist in the area. Natural drainage through existing base lines is also impeded by highway, rail roads and canals traversing the drainage basin, thus obstructing surface flow wherever aligned across the base-lines. The surface flow so obstructed accumulates and damages crops, roads and railway tracks.

2.5.1 There is eventually no net outflow of rain water from the Project area due to lack of drains. Rain water partly infiltrates or evaporates at one place or the other and recharges the ground-water resulting in increased water logging and more damage to crops and other properties.

2.5.2 The area between Jhang Branch Lower and Bhowana Branch canals is water-logged and is drained by old Budh which in ancient times used to be a river creek. This creek originating from upstream of Chiniot Town has been channelized upto right bank of Bhowana Branch by the construction of Chakbandi drain. Thus lower portion yet needs to be channelized as it has been blocked at many places and the rain/flood water continues to play havoc in the vast area. The damage to area is further aggravated by frequent operation of Khairwala and Bhowana escapes of Jhang Branch Lower and Bhowana Branch canals respectively. The escapage spreads all over the depression area in the form of ponds as there is no proper outlet in length of about 42 miles and in a width of 1 to 5 miles is full of jungle growth and has turned into a permanent habitat of wild boars which cause heavy damages to crops in the vicinity.

2.5.3 The sub-soil water level in the area around Faisalabad city between Jhang Branch, and Rakh Branch canals is constantly rising with continuing canal irrigation. The effects of water logging and salinity are fast appearing in this zone, particularly in the relatively low lying areas where the boundary of the canal systems meet. Vertical drainage in this zone has also not been possible in private sector due to salinity of ground-water which is injurious to crops. In the monsoon season the seepage and rain water get accumulated in the areas

along the base-line which apart from damaging the cropped area/village abadies, tends to disrupt the means of communication as under:

i) Faisalabad-Aminpur, Faisalabad-Jhang Pansra-Dijkot and Pansra-Gojra, Metalled Roads.

ii) Innumerable kacha roads leading from various towns to villages.

iii) Railway line from Faisalabad to Gojra between Abbaspur and Sarshamir Railway Stations.

iv) Approaches to Faisalabad Airport.

2.6 Ground Water and Its Quality

Ground water in the area occurs under water-table conditions in the unconsolidated alluvium. Introduction of canal irrigation in the area disturbed the hydrologic balance and the water-table. At present about 54% of the Project area has ground water-table at a depth of less than 5 feet.

2.6.1 The deep ground water quality in Khairwala Project was determined on the basis of data of test holes drilled by WASID during their general investigation programme and by the Project Planning Organization of WAPDA upto a depth of 260 feet. The shallow water quality has been determined on the basis of 3 private tubewells, 4 open wells and on bore holes drilled by the Project Planning Organization (Central Zone) to a depth of 100 feet.

2.6.2 The deep as well as shallow water quality of Khairwala unit is of hazardous nature. The elctrical conductivity of the deep sources varies from 3,000 to 4,900 microhos/cm, SAR 11 to 31 and RSC 0 to 13,70 meq/L. In case of shallow sources the EC varies from 1800 to

17000 micromhos/cm, SAR 9.2 to 44 and RSC 0 to 15.50 meq/L.

2.7 Socio-Economic Features

The Project area lies in a very well developed part of the Punjab and was initially introduced to canal irrigation in late nineteenth century. The area has well developed socio-political sense. It is linked with other parts of the Punjab by rail and roads. Many metalled and Katcha roads connect villages and other cities for easy communication and transportation of agricultural product and farm inputs. Faisalabad, Gojra, Jhang, Pansra and Dijkot serve the area as regular markets. Three sugar mills are within easy access of the area. Many educational institutions lying within and close to the area serve its needs very well.

3.0 THE PROBLEM

The constraints in the development of agriculture in the area are multi-disciplinary and are encountered in all its component resources, i.e. land, water and other agriculture inputs. The problems faced by present agriculture are high water-table and poor surface drainage in the area. The water table depths in the Project area are depicted below:

WATER TABLE CONDITIONS

DEPTH TO WATER TABLE	AREA		PERCENTAGE OF TOTAL
	Sq: Miles	Acres	
0-5	281	1,79,840	54%
5.10	100	64,000	10.2%
10-15	140	83,600	26.8%

3.1 Reduction in Crop Yields and Rain Flood Losses

The high water table causes drastic reduction in crop yields. The sowing of Rabi Crop is hampered as the soil remains too wet for sowing operation till late in the season. The reduction in crop yields due to high watertable is depicted in Table-1 (a&b).

3.1.1 In addition to reduction in crop yields frequent rainstorms and high watertable result in both agricultural and non-agricultural damages. The average annual flood damages in the area are estimated at 6.31 million rupees. The losses due to reduction in crop yields come to Rs 31.4 million annually.

4.0 REMEDIAL MEASURES

The basic solution to the problem lies in providing adequate drainage facilities to the effected area to:

a. drain off rain water out of the Project area quickly to save the crops from damage; and

b. lower the water table to a safe depth by removing the drainable surplus.

4.0.1 The drainage facilities to be provided in a drainage basin can be of the following types:

i. Horizontal Drains.

i(a) Surface drains. These include natural or man-made/dug out channels.

i(b) Sub-surface drains. These include the tile drains/tube drains.

ii. vertical drains. These consist of shallow or deep tubewells.

iii. A combination of the above two systems.

4.1 Selection of Drain Type

Considering the physical features of the Project

area and prohibitive cost of tile drains, a combination of surface drains and tubewells had to be adopted.

4.2 The Drainage Basin

The area of lower Rechna Doab ((Remaining) to which no drainage facilities have yet been provided is shown in Fig.II. This area has been divided into two separate basins named as Khairwala and Gojra Drainage basins respectively. The drainage system from each of the two basins are to outfall separately in River Chenab. The Khairwala main drain will outfall in river Chenab about 15 miles up-stream of Trimmu Head Works while the Gojra main drain will carry the drainable surplus from Gojra basin to river Chenab and discharge it about 22 miles down-stream of Trimmu Head Works.

4.2.1 Incidentally M/s. Tipton and Kalm-bach Inc. knit the two systems into one proposing the drainage from both the basins to be routed through Gojra main drain below Trimmu Head Works.

4.2.2 This large consolidated project could not be implemented and the Irrigation and Power Department, Punjab proposed two separate drainage basins because:

(a) The rivers flowing on the two sides of a Doab serve as natural drains for the "DOAB"; and

(b) the surface drains excavated in the "DOAB" to effect surface drainage thus outfall into the Rivers.

4.3 Drainage Alternatives

In irrigated areas, the anti-water logging/storm water drainage systems can be planned and executed in two ways.

4.3.1 (a) Tackling the whole Doab in one operation immediately as the need arises, by aligning

the surface drains along the already established base lines to follow the natural depressions separating the command of enclosing irrigation channels which will either traverse their independent routes to the rivers individually or merge into one another and finally reach the river as one channel which would be capable of taking the runoff from the whole "DOAB".

4.3.2 (b) Taking the "DOAB" in portions, progressively from North to South as the need arises with the sub-soil water level rising gradually towards the South requiring drainage facilities.

4.3.3 In such a case, each portion is provided with main and branch drains of its own which diverge from the main baseline at certain points to cut across the riges in some high areas, at various points to outfall in the river at intervals that are thus necessitated.

4.3.4 The alternative at a) above requires a prohibitive amount of funds which cannot possibly be made available in one go in our country. Obviously, provision of drains in any area which does not need it immediately is a luxury which we cannot afford.

4.3.5 The only alternative left is as mentioned at (b) above i.e. the areas requiring drainage are tackled individually as the need arises. This is being followed by Punjab Irrigation Department as a policy for almost half a century now.

1. Serious water logging conditions prevailing in Khairwala basin warranted immediately arrangements, while in Gojra basin area the water table conditions were much better and there was no immediate need for drainage facilities. Moreover, the cost of the

drainage system for such a large area in one network, would have been prohibitive; and

2. the maintenance of such a long system, with the main drain more than 110 miles long, would have been a problem in itself.

4.3.6 It was, therefore, considered that immediate solution of problem in Khairwala basin only bears real urgency, while Gojra basin could be handled later.

4.3 The Project

It was therefore proposed to provide the following facilities in Khairwala basin:

4.3.1 Surface Drains

S.No.	Name of Drain	Length (Miles)	C.A. Sq.Miles	Q at outfall (Cs.)
1.	Khairwala Main Drain	59.2	521	1042
2.	Dijkot Branch Drain	49.4	282	564
3.	Nasrana Branch Drain	15.6	81	162
	Total:	124.2		

Only trunk drains were considered essential in the first instance and tributary drains were expected to come up later just like Satiana Samundri Project.

4.3.2 Drainage Tubewells

Wapda in their Scarp-V Project provided for installation of 96 tubewells of 2.5 Cs. capacity each in the low lying pockets in the catchment of Dijkot and Nasrana Branch Drain. The rough siting and alignment of carrier channels is shown below and also in Fig-III.

S.No.	Drain/disposal channel	Approximate Reach RD.	No.of T/wells
1.	Dijkot Branch Drain	49-245	38
2.	Nasrana Branch Drain	0-60	10
3.	I-R disposal channel	0-32	8
4.	2-R disposal channel	0-11	3
5.	3-R disposal channel	0-17	5
6.	I-L disposal channel	0-21	7
7.	2-L disposal channel	0-35	11
8.	3-L disposal channel	0-36	8
9.	4-L disposal channel	0-25	6
		Total:	96

This part of proposal will, however, be implemented by Wapda after completion of surface drains detailed above.

The salient data of the Project is contained in Table No.3.

5.0 DESIGN

The design of a surface drainage project encompasses the alignment of the drains, determination of the drain capacities, channel prisms,longitudinal slopes and Hydraulic and structural designs of the various allied ancillary/ consequential masonry structures and other works, the design criteria/procedure of each one of the above items as adopted in Khairwala Drainage Project appear in the succeeding paragraphs:

(a) Alignments

For flat areas like we have, (slope less than 2%) the following four systems of lay-out/alignments of drains are more commonly used.

(i) Bedding System

This system basically envisages drain Furrows at regular intervals. These furrows create movement problems.

(ii) Parallel Field Drain System

This system is fairly similar to the first one. The only edge it has over the previous one is the built-in easy movement across the field drains.

(iii) Parallel Open Ditch System

This system though better than the first two as regards conveyance of seepage water, has deeper channels and thus cuts off normal movement of equipment on account of drain depths.

(iv) Random System

Basically this system is used in areas containing scattered ponds, the field drain connecting one or more of them to the main drain without any consideration as to the regular spacing or existance of turns and twists in the connector drain.

5.1.5 The first three methods can only be used beneficially when the drainage system is to be provided to well graded new areas, but in our case the area though flat contains depression lines on the junction of two Irrigation systems (on irrigation boundaries) alongwith scattered depressions. Thus only the method No.IV and that too in a modified shape can be applicable to our conditions. We therefore, run our tributaries, sub-drains branch drains and main drains more or less along such base-lines except for minor adjustments here and there when the base-lines are too zig-zag or the drain cuts across some ridge and comes back to its own base line later.

5.1.6 In Khairwala Drainage Project only trunk drains are being constructed the sub drains and link drains will come later, on completion of the trunk drains indicated below;

S.No.	Name of the Drainage.	Length in miles
1.	Khairwala Main Drain.	59.2
2.	Dijkot Branch Drain.	49.4
3.	Nasrana Branch Drain.	15.6
	Total:	124.2

5.1.7 All these three are aligned more or less in the base-lines except in some lengths where the drain has to cut through a ridge to its outfall or an extraordinary long loop is to be eliminated by cutting across the neck of the loop or whenever, no base-line is available, such as in riverian areas etc.

5.2 Physical Parameters of The Drain Section

The design of surface drainage systems in addition to lay out plan and alignment of drains, includes the determination of longitudinal slopes, shape and characteristics, which depend on so many variables. These are explained in the succeeding paragraphs.

5.2.1 Longitudinal Slopes

The longitudinal slopes of the drain depends largely on the available country relief and drain depths with reference to watertable depth and drain discharge. An effort has been made to keep the drain slopes as steep as possible in order to maintain an optimum non-silting non-scouring

velocity in the channels subject to the dictates of general country relief and sub soil water table in the project area or compartments thereof. The slopes of the drains adopted in different reaches are indicated on the L-Sections Figures:V(a-e).

6.0 TOTAL COST AND FINANCIAL ANALYSIS

The total cost of the Project (surface drains only) as approved by ECNEC ins May 1981 is Rs.194.84 million. The sub-headwise breakup of the cost is exhibited in Table-4. The annual recurring cost of maintenance after completion has been worked out as Rs 1.62 million (details appear in Table-5).

6.1 BENEFITS AND BENEFIT COST RATIO

(a) Benefits

Benefits of this Project can be classed into two categories as below:

(a) Agricultural Benefits

These can be easily quantified and divided into following sub-categories:

i) Increase in cropped area

Some area which is at present lying uncultivated due to high water table will again come under crops and thus add to the cropped area.

ii) Increase in yields

On completion and commissioning of the drainage system, the existing high water table will gradually fall and consequently, the average crop yields will increase substantially. Details are as under:

1. The yield is likely to be increased by 20% after efficient Drainage of area. Hence increase in yield is as under:

Total area to be benefitted = 1,80,128 acres.

Existing intensity of irrigation of this area. = 125%.

Area effected: $\frac{180128 \times 125}{100}$ = 225160 acres.

Kharif intensity 70% area under Kharif Crop. = 126080 acres.

Rabi intensity 55% area under Rabi crop. = 99070 acres.

Total = 225160 acres.

KHARIF		Rupees
1.	Rice 4 Mds x 10087 Acres = 40348 Mds x 55/per Mds	22,19,140/-
2.	Sugarcane 70 Mds x 27740 Acres =1941800 x 6.50 "	1,26,21,700/-
3.	Cotton 1.4 Mds x 33305 Acres = 94427 x 120/- "	59,31,240/-
4.	Maize 4 Mds x 20174 " = 80696 x 40/- "	32,27,840/-
5.	Fodder 60 Mds x 18914 = 1134840 Mds x 9/- "	90,78,720/-
6.	Other crops 40/- x 13870	5,54,800/-
	Total:	3,36,33,440/-

RABI		
1.	Wheat 5 Mds x 65386 = 326930 Mds @ 45/- per Md.	1,47,11,850/-
2.	Fodder 60 Mds x 29721 = 1783260 Mds @ Rs.8/- per Md.	1,42,66,080/-
3.	Other crops 50/- x 3963	1,98,150/-
	Total:	2,91,76,080/-
	Gross increase in Kharif and Rabi.	6,28,09,520/-
	Deduct 50% production expenses.	3,14,04,760/-
	Net value of production.	3,14,04,760/-
	SAY:	3,14,05,000/-

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iii) Change in the Cropping Pattern

It is expected that with improved working conditions created by lowering of water table an adequate increase in cropping intensity will not be possible because of reduction of sub-irrigational effect and thus change in the cropping pattern in the form of a shift from high delta crops to low delta crops can be expected.

6.1.2 b) Flood damages Averted

The project on implementation and development will also avert the damages on account of rain-storm floods. The quantum of such damages has been indicated in an earlier paragraph and included in the benefit cost ratio analysis and is also reproduced below.

Annual Benefits

Losses due to floods:	Rupees
22000 Acres crops damaged @ 600/- per acre.	1,32,00,000/-
40000 Houses damaged @ 500/- each.	2,00,00,000/-
6000 Houses collapsed @ 3000/- each.	1,80,00,000/-
Double lane road damaged in Jhang Municipal Limit.	10,00,000/-
5 miles single land Jhang Chiniot road washed away @ Rs. 1,00,000/- per mile.	5,00,000/-
2 miles double lane Jhang Shorkot Road washed away @ Rs. 2,00,000/- per mile.	4,00,000/-
Invisible losses due to disruption in agricultural and Industrial production (L.S.)	1,00,00,000/-
Total:	6,31,00,000/-.

Total Annual Benefits = 31405000 + 6310000 3,77,15,000/-

6.2 Benefit Cost Ratio and Internal Rate of Return.

The benefit cost ratio @ 15% discount rate worked out to be 1:13:1 and internal rate of return as 16% for surface drains part only.

These figures for the overall project including tubewells as arrived at by Wapda on the basis of input trends and yield are 1:1 and 15% respectively.

6.3 Finances

The Project is being financed from Federal Government allocation under accelerated programme. Funds are released in instalments through Wapda. The proposed/ planned annual financial phasing/utilization is as under:

F-Y 1980-81	Rs. 15.0 Million
F-Y 1981-82	Rs. 30.6 Million
F-Y 1982-83	Rs. 35.0 Million
F-Y 1983-84	Rs. 45.0 Million
F-Y 1984-85	Rs. 40.0 Million
Interest charges.	Rs. 29.24 "
Total:	Rs.194.84 Million

6.4 Impelentation Schedule

The Project is under execution and in an advanced stage of implementation. It is expected to be completed by 30th June, 1985 (Inshallah). The Implementation Schedule in the form of Bar Diagram appears as Fig.IV.

7.0 DRAIN SECTIONS

(a) Hydrological Factors and Hydrologic Parameters

7.1 (i) Drain Capacity

The drain has to cater for both sub-surface and surface (over-land) run-off which we can term as the direct run-off. This consists of seepage and storm run-off. Since the quantity of seepage is negligible in comparison to storm water run-off, the drain capacity is generally fixed with reference to storm run-off only, except in rare cases where the sub-soil is so well drained, that the sub-surface flow quantity is large enough to be accounted for. In our case the storm water dominates completely and the drain capacities have, therefore, been fixed in accordance with the rain-fall/storm run off factor.

7.2 Determination of Run-Off Factor

The run-off factor i.e. the run off which the drainage system has to carry for each unit area (square mile) of the drainage basin was computed by several methods. Some of these are purely empirical in nature, while others do have some rational basic. These formulae are introduced briefly in the following paragraphs:

7.3 Cypress Creek Formula

This formula developed between 1935-37 for flat areas in the United States is purely empirical in nature and was based on the measurements and other related data in humid regions. The formula is expressed as:

$$Q = CA^{P}$$

where Q = Run off discharge.

C = A coefficient depending on land use.

A = Area in square miles.

P = A coefficient dependent on hydrologic, topographic and antecedent moisture conditions of the drainage basin.

The value of P was usually taken as 5/6.

The value of C was assumed according to prevalent conditions. Stephen and Mills (1965) gave the following derivation for flat Florida U.S.A.

$$C = 16.39 + 14.75\ Re$$

where Re is the rainfall excess of a storm event expressed in inches.

7.3.1 T and K in their Design Manual for link canals also used the original equation i.e. $Q = CA^{5/6}$ with the value of C varying between 15-40, Dickens presented the same as $Q = CA^{3/4}$ with C = 50.

7.3.2 In Pakistan, this formula was used as F.F. Haigs relationship in the form $Q=CA^{2/3}$ where value of C was taken as 12 for areas not subjected to floods while this value was increased to 16 for areas subjected to floods.. Naturally this gave a value of Q much less than the original relationship. M/s. Gulhati and Khungar suggested the equation $Q = CA^{\frac{1}{2}}$ in which the value of C depends upon the intensity of rainfall. These two adaptations yielded fairly reasonable values of surface run off for drainage basins in the Punjab, but with a substantial change that has accrued in the rainfall, ground water table, cropping pattern, topography and social practices these now give values very much on lower side Haig's adaptation still work, but only if value of C can

be fixed with reasonable accuracy which may vary considerably even within one drainage basin. Haig's formula yields an average run off factor value of just 2 Cs.per square mile with value of C equal to 15 while Gulhati's equation gives the same discharge with the value of C as 45.

7.4 2. Rational Formula

This formula was originally developed for urban catchments and can be applied to small agricultural basins of 100 to 200. Acres (Chow,1964). This formula can be expressed as:

$$Q_p = CIA$$

where Q_p = Peak Run off rate.

'C' is the run-off coefficient.

'I' is mean rain fall intensity over a period equal to time of concentration.

'A' is the area of the water shed.

7.4.1 The basic principle of this formula is that the maximum/peak run off rate is expected when the rainfall duration equals the time of the catchment. Thus to satisfy the basic requirement, the concentration time and mean intensity alongwith the value C has to be determined for a particular basin before this formula can be expected to yield reasonable results.

7.4.2 The time of concentration was defined by Ramser (1929) as the time required for rise in water level from low to the maximum stage at the gauging station in the drainage channel. With this definition in view KIRPICH (1940) gave the following equation:

$$Tc = 0.0195\ K^{0.770}$$

Where $K = \frac{L}{\sqrt{S}}$ & $S = \frac{H}{L}$

T_c = Time of concentration (minutes)

L = Maximum length of travel (meters)

S = Land slope.

7.3.4 The value of(run off coefficient) may vary from place to place and moment to moment on account of changes in factors effecting the surface run off, specially the soil moisture condition. For design purposes, the value of C pertaining to saturated soil at the start of rainfall, is adopted which means a built-in unknown factor of safety because every storm does not start on a saturated soil. The average value of C most widely used in the U.S. and other countries for flat arable lands with sandy loam, ranges between 0.2 to 0.3 for antecedent moisture conditions type II and III.

7.5 3. Cook's Method

This is also an empirical method developed by the U.S. Soil Conservation Services for small areas less than 600 acreas and is expressed as;

Q_p = PRF

where Q_p = Peak run off rate

p = The unadjusted peak run off rate (obtained from Cook's graphs).

7.5.1 This value of p is dependent on run off producing characteristics i.e. relief, soil infilteration, vegetable cover and surface storage.

R = Rainfall factor. This is obtained from rain fall factor maps prepared by Hamilton and Jepson (1940) and rainfall intensity frequency chart by U.S. Weather Bureau (1961).

F = The frequency factor. It is read off from the frequency factor tables by V.T. Chow.

reaches its crest is essentially the same for all storms producing rainfall excess of a duration that is shorter than the unit storm period.

7.7.3 The unit hydrograph is the hydrograph of direct run off resulting from a rainfall excess of one surface inch uniformly distributed over the whole basin and of a duration equal to or shorter than the unit storm period. The derivation of the unit hydrograph is based on the simultaneous analysis of:

Continuous hydrographs of basin rain fall, obtained from the records of a sufficient number of stations in or near the basin. The hydrograph of run off from the drainage basin, based on continuous gauging at the outlet and covering the same period as the rain fall data.

7.7.4 A number of isolated flood waves caused by short periods of rain fall excess are selected from the hydrograph of run off. Next the base flow is deducted from these flood hydrographs. For each wave the area enclosed under the obtained hydrograph of direct run off designates the total volume of direct run off. This volume is divided by the area of the basin thus expressing the total direct run off in surface. This volume is divided by the area of the basin thus expressing the total direct run off in surface inches. All ordinates of the hydrograph are then divided by this number of surface inches, yielding one shape of the unit hydrograph.

7.7.5 A number of such graphs are derived and converted in a single set of coordinates on the same average base length to yield an average composite graph for the whole basin.

7.7.6 Applying theory of probability the return period for certain highest discharge can be determined.

The available composite unit hydrograph is converted into a distribution graph by changing the ordinate scale from cubic feet per second to percentage of total run off. Ordinates to the distribution graph represent volume per unit storm period rather than rate of discharge; hence the graph necessarily has a stepped form. These successive percentages can now be applied in turn to the volumes of rain fall excess in each unit storm period, yielding an equal number of overlapping hydrographs. By adding the coinciding ordinates the hydrograph of direct run off is obtained.

In larger drainage basin, the application of this method becomes rather complicated because of major difference in duration, distribution, intensity of rainfall and varying soil conditions in various components of the basins. This method is most useful and yields accurate results for gauged basins. In case of ungauged basins however synthesis of unit hydrograph has to be resorted to.

8.0 RUN OFF FACTOR FOR KHAIRWALA DRAINAGE BASIN

The Project Planning Organization of Wapda also conducted a study for lower Rechna Doab. Brief discription relating to Khairwala Drainage basin is contained in the following paragraphs. For details, the original Project Report for Scarp-V Vol:2 (1980) may be referred.

8.1 Precipitation Analysis.

For the purpose of analysis daily precipitation data from 5 rain-gauge stations in and around the Project area was collected for 26 years (1953-77). Since the Project area is only 521 sq. miles it gives a density of 104 square miles per rain gauge station against the limit of 230 to 350 square miles prescribed by the World Meteorological Organization standards for normal tolerance in respect of flat areas in sub-tropical zones.

8.1.1. The daily data was analysed for maximum precipitation during any 24 and 48 hours in each year for each station for the period of record, and appears in Table-6. The data for Faisalabad Aminpur Narwala, Jhang and Lakhlana was used for frequency analysis.

8.1.2 The recurrence interval of various rainfall intensities was developed by "Station years" method on a maximum annual rainfall for each station for the period of record. The rainfall data was rearranged in order of discending magnitude and the recurrence interval was computed for each rainfall storm using the following equation:

$$T_r = \frac{n + 1}{m}$$

where T_r = Recurrence interval in years

n = Number of station years of record
= (Number of stations x No. of years of record.

m = Order of magnitude of rainfall event or the No. of times the event was equalled or exceeded.

Rain-fall in inches (24 & 48 hours) has been plotted against recurrence interval (T) in years and the frequency curves thus developed are shown IN Figure-VI.

For evaluation purpose, 24 and 48 hours storms have been adopted and run-off calculations have been made to compute the anticipated discharges for different recurrence intervals. The point rainfall for the selected storms is read from the curves for 24 and 48 hours.

8.2 Application of Synthetic Unit Hydrograph Method

8.2.1 Peak of Unit Hydrograph

The drainage basin is still ungauged. Therefore, to estimate the run-off at various points, the synthetic unit hydrograph method was used. The symbols and the procedure used to determine the peak of unit hydrograph are briefly explained below:

L = Length of the basin in miles measured from the point of interest to the upper catchment area divide.

L_{ca} = Length of the channel in miles measured along the major channel from the point of interest to the point on the channel opposite the centroid of the catchment area.

S = Mean slope of the stream or channel. Where more than one slope is known the mean slope can be computed by the equation.

$$S = \left[\frac{N}{\frac{1}{\sum / S_L}} \right]^2$$

Where N = Number of channel reaches of equal length;

S_L = Slope of the individual channel reaches in feet per foot.

A= Catchment area in square miles, which drains to a point of interest.

t_r = Unit storm duration in hours.

t_p = Lag time, in hours, from the centroid of the unit rainfall excess to the time when the unit hydrograph peak discharge occurs. In other words it is the time from mid-point of duration t_r to peak of a unit hydrograph, in hours.

$Q_{u.p}$ = Unit hydrograph peak discharge in cusec per sq. mile.

$q_{u.p}$ = Average unit hydrograph peak discharge (weighted average of all sub-basins) in cusecs per square mile for 1 inch of direct run-off.

Q_{up} = Catchment area unit hydrograph peak discharge in cusecs.

q_p = Peak discharge per sq. mile of catchment area resulting from a rain of recurfence interval T_r.

R_e = Rainfall excess (volume of rain converted to direct surface runoff) resulting from a rain of recurrence interval T_r

8.2.2 The basic relationships for computing the lag time and unit hydrograph peak discharge q_p from drainage basin data are as follows:

$$t_p = C_t \times \left[\frac{L \times Lca}{\sqrt{s}}\right]^n$$

$$q_{u.p} = \frac{640 \times C_p}{t_p}$$

$$Q_{u.p} = q_{u.p} \times A$$

$$q_{u.p} = \frac{\Sigma Q_{u.p}}{\Sigma A}$$

$$q_p = q_{u.p} \times R_e$$