Design Lab # 3,4 & 5

Planning & Design of Surface Irrigation system for a given area:

Part 2 & 3:

It includes the following:

- **Deciding the cropping pattern of the area, Estimation of crop water requirements, design discharge, water allowance, outlet command area and no. of outlets.**
- **Show the alignment of canals and water courses and divide the whole area into outlet command areas, location of each outlet in the scheme.**
- **Design discharge for outlets.**
- **Discharge/capacity statement for the canals.**
- **Design of outlets, design of canals in reaches, design of water courses.**
- **Typical Cross-sections of canals at start, mid, end, cross-section of water course.**
- **Longitudinal profile of canal.**
- **Command statement**
- **Preparation of Warabandi.**

1. Deciding the cropping pattern of the area, Estimation of crop water requirements, design discharge, water allowance, outlet command area and no. of outlets.

Considering a suitable cropping pattern of the area, the crop water requirements for Rabi and Kharif seasons can be estimated as follow:

Gross Command Area = **A**

Non Cultureable command area = 15-20% of A = **B**

Culturable Command Area = **A** – **B** = **C Acres**

CWR for Rabi:

Crop	Crop Period (Days)	Intensity Of Cropping %age	Crop Coefficient Kc	Net ETo (mm/day)	ETc = Kc x ETo (mm/day)	Delta of crops = ETc X Crop period (inch)	Cropped Area (Acres)	Volume (Acre-ft) =AreaXDelta
Wheat	120-150	35-40	0.75	3				
Gram	90-110	15-20	0.60	3				
Barley	120-150	5-10	0.70	3				
Fodder	90-110	10-15	0.65	3				
Sugarcane	330-365 (150-160 days in Rabi)	10-15	0.85	3				

ΣV

CWR for Kharif:

Crop	Crop Period	Intensity Of Cropping %age	Crop Coeff. Kc	Net ETo (mm/day)	ETc = Kc x ETo (mm/day)	Delta of crops = ETc X Crop period (inch)	Cropped Area (Acres)	Volume (Acre-ft)
Rice	120-160	40-45	1.1	7.5				
Cotton	150-180	20-25	0.7	7.5				
Maize/corn	100-125	10-15	0.75	7.5				
Sugarcane	330-365 (180-200 days in kharif)	10-15	0.85	7.5				
Fodder	100-120	5-10	0.8	7.5				

ΣV

Net ETo = ETo – Eff. Rainfall

Potential Evapotranspiration *(ET_o) The highest rate of evapotranspiration (ET) by a short and actively growing crop or vegetation with abundant foliage(leafage) completely shading the ground surface and abundant soil water supply under a given climate.*

Reference Crop: An idealized grass crop with crop height of 0.12 m, albedo (reflected/incoming solar radiations on earth) of 0.23, and a surface resistance of 69 sm^{-1}.

The 'bulk' surface resistance describes the resistance of vapour flow through the transpiring crop and evaporating soil surface. Where the vegetation does not completely cover the soil, the resistance factor should indeed include the effects of the evaporation from the soil surface. If the crop is not transpiring at a potential rate, the resistance depends also on the water status of the vegetation

An extensive surface of short green grass cover of uniform height, actively growing, completely shading the ground and no water shortage resembles the reference crop.

Actual crop Evapotranspiration (ET_{crop}): Rate of evapotranspiration by a particular crop in a given period under prevailing soil water and atmospheric conditions.

Usually calculated by multiplying the Crop Coefficient (Kc) for the period with ET_{rc} : thus

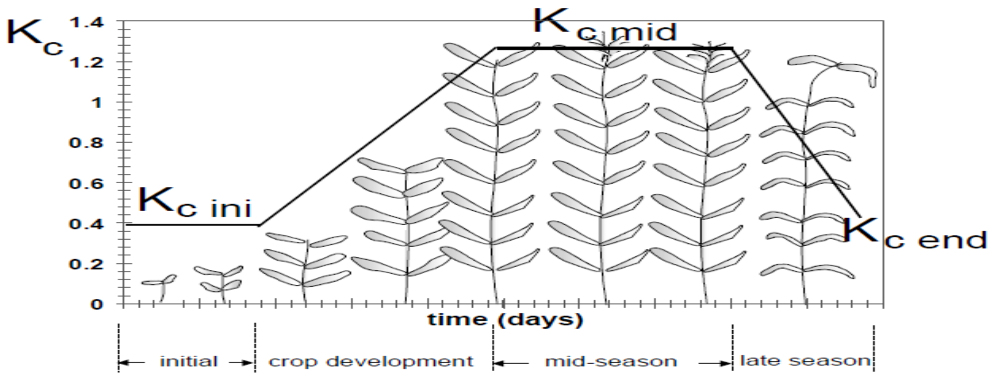
$$ET_{crop} = K.\ ET_{rc}$$

Crop Coefficient (Kc): it is the ratio b/w the reference crop Evapotranspiration to the actual crop evapotranspiration.

Kc = ETo / ETc

It determined experimentally for various crops, Etc is determined by Lysimeter technique and ETo by USWB class A evaporation pan.

Kc is different for different crop and for different crop growth stages. Mainly affected by crop type, soil type and climate of the area.



Rabi Discharge= Qr = ΣVr / rabi period (days) (ft^3/sec)

Rabi Discharge= Qk = ΣVk / kharif period (days) (ft^3/sec)

***Design discharge* = larger of Qr ans Qk**

Water Allowance:

No. of cusecs required to irrigate 1000 acres.

Water Allowance = Q_D x 1000/ CCA (ft^3/sec/1000 acres)

Outlet Command Area:

Generally the outlets used have Q_{outlet} =2-3 cusecs.

Qoutlet = WA x CCA of outlet/1000

CCA of outlet = D Acres

Minimum no of outlet required to irrigate the whole CCA = C / D

2. Divide the whole area into outlet command areas, location of each outlet in the scheme. Show Alignment of canals and water courses.

According to the CCA of each outlet, divide the whole irrigation scheme into no. of blocks (small areas) and the show the proposed alignment of canals and watercourses on the contour map of the area keeping in mind the following points:

- The area commanded by each outlet should be irrigated under gravity flow.
- The length of water courses should not be more than 3Km or 2 miles.
- Minimum idle length of canals in the system.

Based on these conditions, the area allocated for each outlet may be altered and hence the no. of outlet calculated at the start will be different from what are being actually provided in the distribution scheme.

3. *Design discharge for outlets*

Discharge of each outlet is calculated based on its actual area served plus the conveyance losses in the water course (take 10-15%).

Conveyance Losses: Take place from barrage to the field. So design should be according to requirement of water plus losses.

Major loss of water in an irrigation channel is due to:

Seepage (absorption or percolation), mainly absorption losses, vary from 2-50% of canal diversions

Evaporation, vary from 2-3%

In earthen channels losses due to seepage are much more than the losses due to evaporation. The absorption losses depend upon following:

- Type of soil
- Subsoil water
- Age of canal
- Position of FSL w.r.t to NSL
- Amount of Silt carried by canal
- Wetted perimeter

According to **irrigation branch of West Pakistan**:

$$K = 5.0Q^{0.625}$$

K= absorption loss per million square feet of wetted perimeter

Q= Discharge in channel.

According to lacey:

$$Q_A = 0.0133\ L\ Q^{0.5625}$$

QA= Absorption loss

L= Length of channel in thousand feet

Q= discharge in channel

Measurement of Seepage losses:

Direct Methods

- ***Ponded Test method***

- *Canal is made full*
- *Inflow and outflow is stopped*
- *Losses measure through change in level at regular interval (e.g. daily)*
- *Have to close the canal, and not recommended for Main Canals*

- ***Inflow outflow method***

- *Water budgeting is done*
- *Flows are measured at upstream, downstream end and diversions*
- *Seepage = Inflows – Outflows*
- *Relatively Quick, Simple, but depends on accuracy of discharge measurement (Notch Coefficent? Current Meter?)*

Indirect Methods

- ***Steady state method***

- *Knowledge of soil permeability and water table level is required*
- *Flow net is drawn based on water table around canal*
- *Seepage losses are calculated, using Darcy Forumlae*
- $Q = K\,i\,A$
- *Q=Seepage flow*
- *K= Permiability*
- *i = Head Loss Gradient =* H_L/L
- *A = Area of flow*
- *Q/A= discharge velocity (not actual velocity, that depends on capillary* ***area)***

- ***Canal closure method***

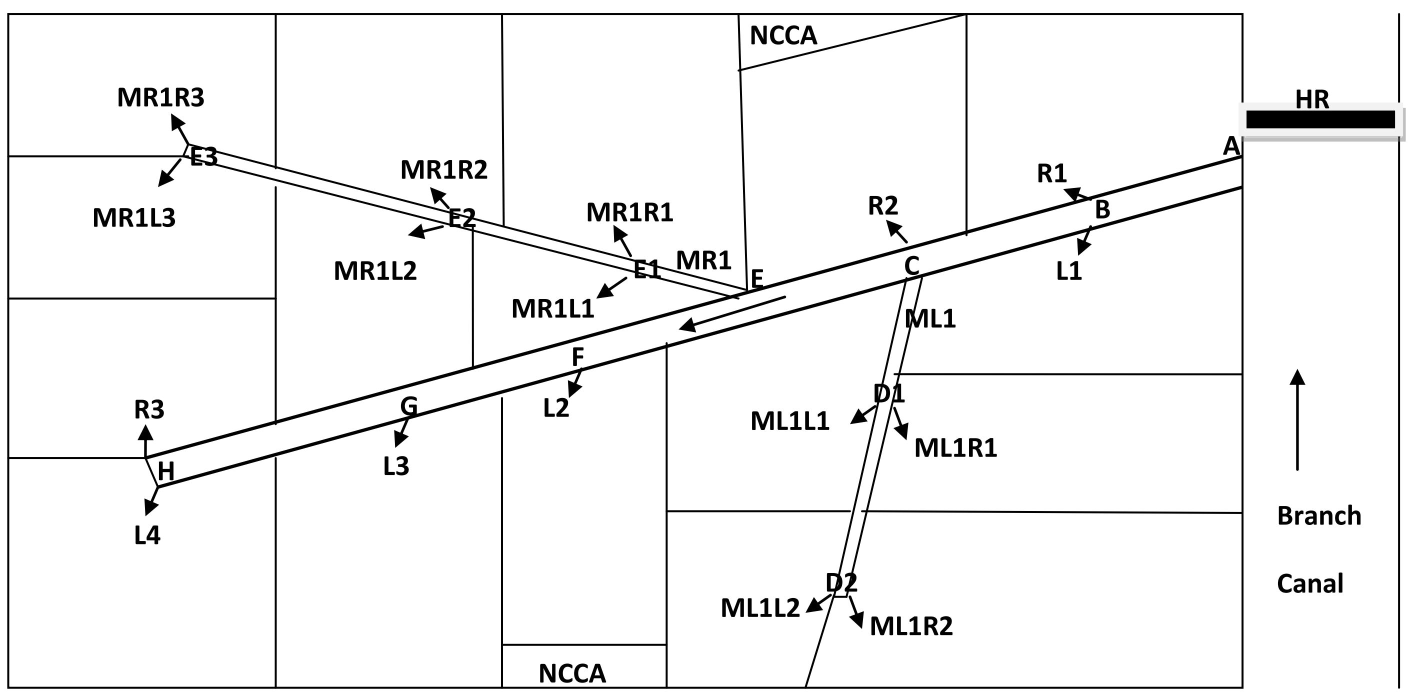
- *Water table levels are measured before, during and after canal closure*
- *flow net is drawn using the observed water tables and observed water levels in canal.*
- *seepage at various canal supply is calculated*

It can be calculated in the tabular form.

RD = Running Distance = 1000 ft

Sr #	RD of outlet (ft)	Side L/R	Designation	GCA (Acres)	NCCA (Acres)	CCA (Acres)	Q_{outlet} (Cusecs)	Qs (losses)	Q_T (Cusecs)
Main canal									
1	1+500	R	R1	a	0	a			
		L	L1	a	0	a			
2	2+000	R	R2	b	c	b-c			
3	4+000	L	L2	d	e	d-e			
4	4+500	L	L3						
5	5+500	R	R3	f	0	f			
		L	L4	g	0	g			
Minor on Left (ML1), at 2+500 RD from Source									
6	1+000	R	ML1R1						
		L	ML1R2						

Similarly it can be done for all the outlets off-taking from distributaries and minors.

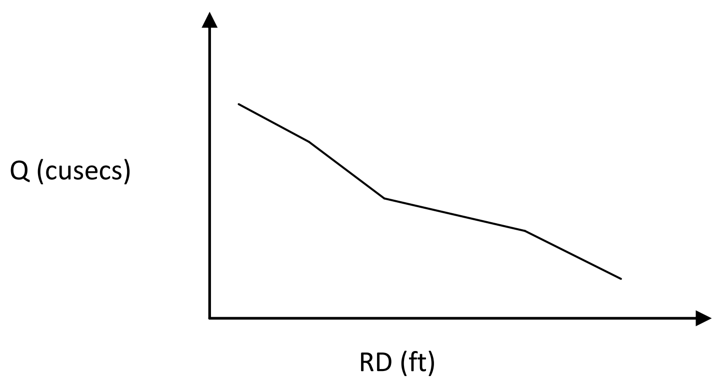


4. *Discharge/capacity statement:*

It gives the information about the discharge / capacity of canal at each section or reach of canal. Preferably it should be started from the last reach and making the calculation of discharges upto the starting reach of canal. Based on this discharge, canals reaches are designed.

Sr #	Canal Reach	Length of Reach (ft)	RD of Outlets In the reach	Outlet Discharge (cusec)			Qs (cusec)	Q in reach (cusec)	Q_T Cusecs
				Q_{Right}	Q_{Left}	Q_T			
1	**HG**	**1000**	**5+500/R4** **5+500/L4**					**A**	**A**
2	**GF**	**500**	**4+500/L3**	**-**				**B**	**A+B**
3	**FE**	**1000**	**4+000/L2**	**-**				**C**	**A+B+C**
Minor on right side (MR1) at RD 3+000 (ft) from source									
4	***E3E2***	**1500**	**3+000/MR1L3** **3+000/MR1R3**					**a1**	**a1**
5	***E2E1***	**1000**	**1+500/MR1L2** **1+500/MR1R2**					**b1**	**b=a1+b1**
6	***E1E***	**500**	**1+500/MR1L1** **1+500/MR1R1**					**c1**	**c=a1+b1+c1**
7	**EC**	**1000**	**1+000/MR1**	**∑a1+b+c**	**-**			**D**	**A+B+C+D**

It can also be shown graphically as:



5. *Design of outlets, design of canals in reaches, design of water courses.*

Design of canals in reaches:

Important points:

- Slope of irrigation channel should not be more than the slope of the tract.
- The water level in the main canal is controlled by the water level in branch canals; while the water level in branch canal is controlled by water level in distributaries, and water level in distributaries is controlled by water level required in water courses. Ultimately the water level in water courses is controlled by the elevation of the field to be irrigated. If the slope of the tract is more than the design slope of the channel, in that case fall should be provided at appropriate sites.

- **Slope of canal** is
  - By following the topography of the area, S = (RLi – RLf)/L
  - Fixed using Lacy's silt factor f as:

$$S = \frac{0.000542}{Q^{\frac{1}{6}}} f^{\frac{5}{3}}$$

- **Lacey silt factor** is determined as:

$$f = 1.76 d^{1/2}$$

Where d is mean diameter of silt particles. = 0.25 mm

- Canals is designed using Lacy's Theory:

$$P = 2.67\sqrt{Q}$$
$$V = \frac{1.346}{n1} R^{\frac{3}{4}} S^{\frac{1}{2}}$$
$$V = 1.1547\sqrt{fR}$$
$$n1 = 0.0225 f^{\frac{1}{4}}$$

In this way each canal reach section can be designed as Trapezoidal & Unlined section using Lacy's formulae. Follow the example 4.3 (dr. Iqbal Ali) on page 134.

Show detailed calculations for atleast one canal reach and rest of the work can be done in tabular form.

Sr #	**Canal Reach**	**Length of Reach (ft)**	**Q_T Cusecs**	**f = $1.76d^{1/2}$**	**S**	**R**	**A**	**B**	**D**

Design of Outlet (Crump's Open Flume type):

$q = C_d W H^{3/2}$

H = Head over the crest of outlet from FSL of canal

C_d = 3.088 (Theoretical)

Actual value of Cd depends on W (throat width)

W = (q/Q) x B, q = outlet discharge, Q = canal discharge, B = Width of distributary canal (4 in-6 in).

W	Cd
0.2 ft – 0.29 ft,	**2.90**
0.3 ft – 0.39 ft	**2.95**
Over 0.4ft	**3.00**

In this way the Head (H) for all the outlets can be determined based on the design discharge for each outlet. Show one detail calculation and rest in tabular form as:

Sr #	RD of outlet (ft)	Side L/R	Designation	Q_T (Cusecs)	W	H (ft)

Design of watercourses:

- Design it as Lines and Rectangular using Manning's formula:

$$Q = 1.49/n\ AR^{2/3}S^{1/2}$$

- Slope of water course = 1:5000 (Normally) varies from 1:3000~1:4000. Min 1:10000
- B = 2D, Velocity = 1 ft/sec, n = 0.013
- Calculate the depth of water in watercourse

Show one detailed calculation and rest in tabular form for all the watercourses.

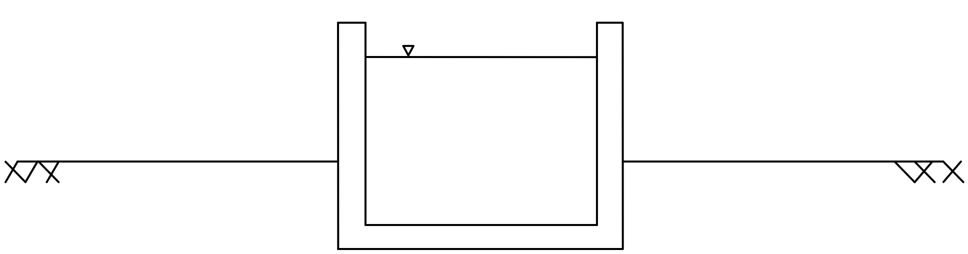
6. Typical Cross-sections of canals at start, mid, end, cross-section of water course.

Typical Cross-sections of canals at start, mid, end:

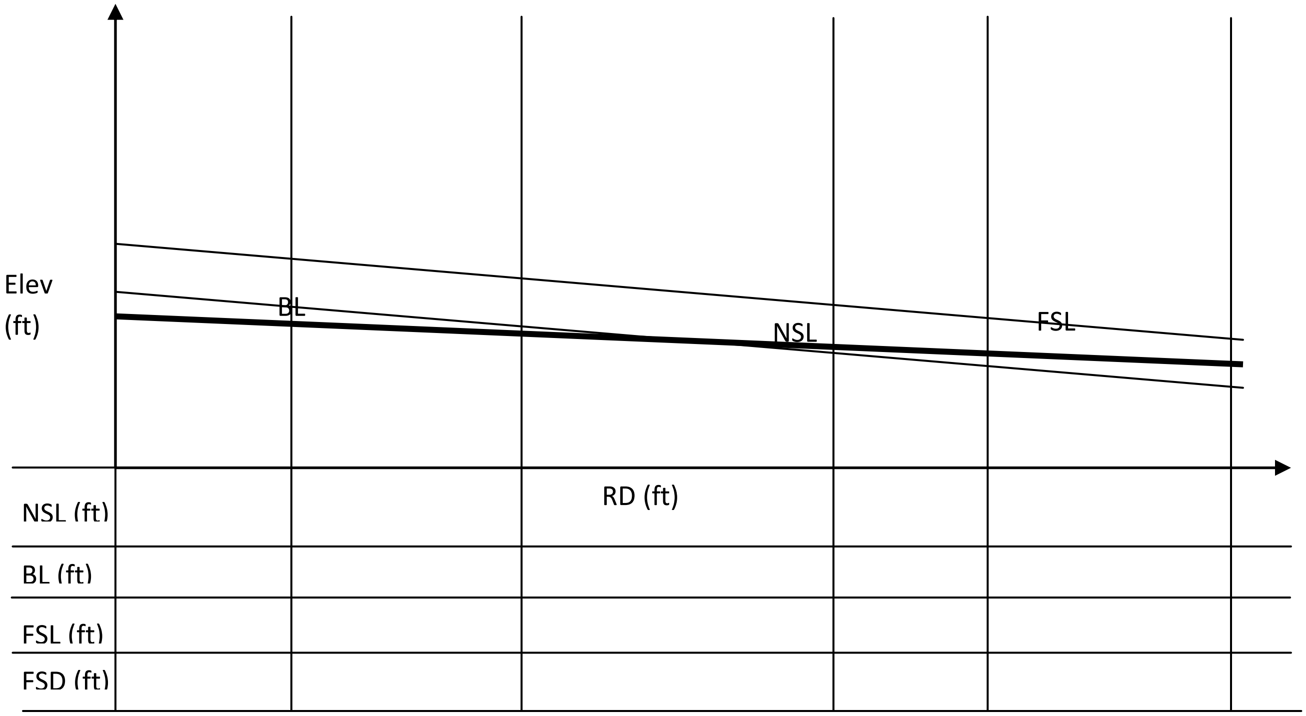
Draw the typical canal cross-sections (3 in no.) showing the bed level, NSL, Full Supply Level, FSD, Bed width, canal banks, side roads, spoil bank etc.

Follow the Book (Dr. Iqbal Ali), page # 183.

Cross-section of water course:



7. *Longitudinal Section of canal showing FSL, BL and NSL*



Longitudinal Cross-section should include the following:

- Natural Surface Level
- Bed Level of Canal
- Full Supply Level
- Full Supply Depth
- Location of canal falls (if any)

8. ***Command Statement***: it is prepared to ensure that the slope of an irrigation channel is capable of commanding the area to be irrigated.

   1. From head to tail (when the water at the head of canal is fixed)
   2. From tail to head (when the topography of the area is dominating and water level at the head can be adjusted)

Section or Reach	Outlet designation	BL of canal at B	FSL of Canal B	Water level in water	Bed level of water course at	Bed level of water course at tail of	Actual field

			=BL + FSD	**course at outlet, H1 = FSL-H**	**outlet, H2= H1 - D**	**water course (field level) = H2 - SXL**	**level**
AB	R1/1000		At pt B	At pt B			

H = head difference b/w FSL and water level in water course

D = Depth of water in water course, S = slope of water course, L = length of water course

9. Preparation of Warabandi for an outlet chak:

<u>Contents:</u>

- **Definition and brief description**
- **Warabandi Management System**
- **Objectives of Warabandi**
- **Types of Warabandi**
- **Benefits of Warabandi**
- **Formulation of Warabandi**
- **Example Problem**

Definition and brief description:

The term Warabandi means "turns" (*wahr*) which are "fixed" (*bandi*).

Warabandi is a rotational method for equitable distribution of the available water in an irrigation system by turns fixed according to predetermined schedule specifying the day, time and duration of supply to each irrigator in proportion to size of his land holding in the outlet command. (Singh 1981, Malhotra 1982)

The warabandi water allocation method practiced in Pakistan's large-scale canal irrigation systems offers some empirical evidence of the relative neglect of water rights as a major issue in agricultural production. In the current practice of warabandi, the actual water distribution is found to deviate substantially from the design stage expectations. The implications of this gap between the design and practice of warabandi are yet to be fully explored.

Malhotra (1982)points out the warabandi is not just distribution of water flowing inside a water course according to a roster but is an integrated water management system extending from source to the farm gate.

The warabandi is a continuous rotation of water in which one complete cycle of rotation that lasts seven days or in some instances, ten days and each farmer in the water course receives water during one turn in this cycle for an already fixed length of time.

The cycle begins at the head and proceeds to the tail of the water course, and during each time turn, the farmer has the right to use all the flowing water in water course. Each year, preferably at canal closer, the warabandi cycle is rotated by twelve hours to give relief to the farmers who had their turns during the night in the preceding year schedule.

Warabandi Management System:

In the large canal irrigation systems in Pakistan, which are jointly managed by government agencies and farmers, warabandi rules and traditions act as the binding glue for an agency-farmer interface. A Central Irrigation Agency/department manages the primary main canal system and its secondary level "distributories" and "minor" canals and deliver water at the head of tertiary level "watercourse" through an outlet called "mogha" which is designed to provide a quantity of water in proportion to CA of water course.

The agency has to ensure a uniform flow in watercourse so that it continuously receives its allotted water duty. Farmer within the watercourse are expected to manage the on-farm water distribution of water according to warabandi schedule officially "sactioned" or established solely on the basis of mutual agreement by the farmers. Once the arrangement of turns has been agreed upon, the agency does not interfere unless a dispute arises among the farmers and it is brought to official notice. . The dispute is resolved through an adjudication process (a legal process) according to prescribed rules.

The warabandi system in Pakistan includes the following **functions and characteristics**, among other things;

1. The main canal distributing points operate at supply levels that would allow distributory canals to operate at no less than 75 percent of full supply level.
2. There is rotation of distributaries, in some instances, when the supply in the main canal system falls further.
3. Only "authorized" outlets draw their allotted share of water from a distributary at the same time and
4. Outlets are ungated and deliver a flow of water proportion to the area commanded. Cooperative behavior among agency staff and water users is an overriding requirement to follow an agreed set of rules.
5. Water users have to maintain the watercourse in good condition.
6. The operating agency has to ensure proper hydraulic performance of the conveyance system.

Objectives of Warabandi:

As an integrated water management system, warabandi is expected to achieve two main objectives,

- High efficiency as well as
- Equity in water use.

➢ Water use efficiency is to be achieved through the imposition of water scarcity on each and every user, and equity in distribution through enforced equal share of scarce water per unit area among all users.

Types of Warabandi:

Official Warabandi:

Warabandi schedule officially determined and recorded in official document.

Note: None of the watercourses in the study sample followed the official Warabandi schedules in actual practice. (D. J. Bandaragoda)

Agreed Warabandi:

Agreed Warabandi is a derivative of the official Warabandi and is mutually agreed upon by the people for their convenience. For instance, a big landowner may divide his water turn into several component turns with the consent of other farmers. This new schedule is not reflected in the official schedule.

The reported reasons for these modifications were:

- Changes in water supply
- Changes in the physical layout of the watercourse
- Changes in landownership
- Other power relationships among the water users

3. Actual Warabandi

Field observations of the actual application of water turns by farmers showed that even the agreed warabandi was not strictly followed, and frequent changes took place on timing and duration of turns almost on a daily basis. While the reasons for introducing some flexibility in developing a more functional warabandi on mutual agreement can be easily understood, the divergence between the official warabandi schedules and what is actually practiced in the field is unexpectedly large.

Two types of warabandi are frequently mentioned in Pakistan.

Kachcha (ordinary or unregulated) Warabandi:

The warabandi which has been decided by the farmers solely on their mutual agreement, without formal involvement of any government agency, is known as *kachcha* (ordinary or unregulated) warabandi,

Pucca Warabandi:

The warabandi decided after field investigation and public inquiry by the Irrigation Department when disputes occurred, and issued in officially recognized warabandi schedules, is called *pucca* warabandi.

Kachcha warabandi became increasingly unpopular as it was prone to exploitation by large landowners. Wherever this pressure could be challenged openly, disputes were registered with the canal authorities, and after prescribed adjudication processes, the kachcha warabandi was converted to official pucca warabandi schedules. The reason for having kachcha warabandi still in operation in some areas of southern Punjab and Sindh is attributed to the more skewed distribution of land favoring larger landowners in these areas. In central Punjab, the majority of watercourses have pucca warabandi.

Benefits of Warabandi:

- Increased cropping intensity
- Irrigation discipline
- Common issues are settled
- Greater economy and dependability
- Simplicity of implementation
- Productivity increment of irrigated agriculture.

Formulation of Warabandi:

The warabandi schedule is framed under Section 68 of the Canal and Drainage Act (VIII of 1873) in which rights to form and maintain water distribution schedules for watercourses are vested (having the rights of ownership) with the Canal Officers of the Irrigation Department. Several amendments and departmental rules were added later.

Theoretically, in calculating the duration of warabandi turn given to a particular farm plot, some allowance is added to compensate for the time taken by the flow to fill that part of watercourse leading to farm plot. This is called ***Khal bharai (filling time).*** Similarly, in some cases, a farm plot may continue to receive water from a filled portion of the watercourse even when it is blocked upstream to divert water to another farm or another part of the watercourse command. This is called ***Nikal (Drainage time)*** and is deduced from the turn duration of that farm plot.

The calculation of Warabandi schedule starts with determining by observation, the total of such filling times (T_F) and total of such drainage time (T_D). Thus for a weekly Warabandi rotation, the ***unit irrigation time (T_U) in hours per hectare/acre*** can be given by

$$\mathbf{T_U = (7x24-T_F+T_D)/CCA = (168-T_F+T_D)/CCA}$$

Where: CCA = Command area of an outlet/watercourse

T_F = Total filling time = $\sum T_f$

T_D = Total drainage time = $\sum T_d$

The value of T_U should be same for all the farmers in the water course.

A ***farmer's Warabandi turn time*** is given by:

$$\mathbf{T_t = T_u x A + T_f - T_d}$$

Where: A= farm area/ area of farmer.

T_f and T_d are filling and drainage time respectively for a farm area.

Only some of the farms in a watercourse may be entitled to filling time or drainage time, or both. The warabandi schedule is prepared on the basis of different turn times calculated for each farm plot on the basis of these values, whenever they occur, and the area of each farm plot.

Warabandi Schedule:

It should be prepared for any one outlet in the irrigation scheme. Divide the whole CCA of outlet into sub areas of 25 acres (01 square = 1100 ft x 990 ft) preferably.

CCA = Outlet Command area
Q = Outlet discharge
V = 1 ft/sec
Time of filling/emptying the watercourse=L/V

$$T_U = (168-T_F+T_D)/CCA$$

$$T_t = T_U x A + T_f - T_d$$

Sr. No	Land Owner Name	Area acre	T_f Hrs	T_d Hrs	T_U Hrs	T_t Hrs	T_t		Clock Time				Starting day	Ending day
							Hrs	Min	Starting		Ending			
									Hrs	Min	Hrs	Min		
1														
2														

3														
4														
5		**Sum**	**T_F**	**T_D**										
			$T_F=\sum T_f$	**$T_D=\sum T_d$**		**$\sum = 168$**								

Comments on Warabandi from Field Experience:

1. Time required for filling and drainage of watercourse is calculated by considering the velocity of water equal to 1m/sec (3.281 ft/sec). In actual practice, 5 minutes are added or subtracted per side of an acre (220 ft or 198 ft) for the same purpose.

2. The above said affair is the base FOR most of the disputes arising in the Warabandi after its implementation. As the actual time required by the watercourse for filling is more than 5 minutes per side of acre and the actual time required for the watercourse to be emptied is less. So in general, *drainage time is very much liked by the irrigators and filling time is avoided.*

3. Conventionally distribution of water is started from head of the watercourse (Head Moga) to tail of the water course with the consideration that at the same point, the land on left side is irrigated first and the land on right side is irrigated latter on. Due to this, at the same nakka points, the land owners having land on left side have to take water filling from the previous nakka (in previous Muraba) which is disliked by the irrigators widely due to above said reason. The solution of the problem which have successfully been implemented in the filed is that when such problem arises, the warabandi should be fixed turn by turn between the two irrigators, irrigating from the nakkas at the same place.

4. “Nikal” is the water left in the water course when the last irrigator irrigates his land. Although drain water subtraction is taken place but on most of the outlets, this dispute arises between the irrigators having their lands at the tail of the watercourse.

Step involved:

- ***Identification of area:***

  Based on the given contour map of the area, draw it on a larger scale and find out the GCA, NCCA and CCA in acre.

- ***Estimation of crop water requirement:***

  This is done based on the given cropping pattern of the area for Rabi and Kharif season

- ***Estimation of design discharge***
- ***Determination of water allowance for the area***
- ***Determination of proposed outlet command area and no. of outlets***
- ***Plottation of irrigation scheme***
  - ***Show alignment of canals (distributary & minors)***
  - ***Alignment of watercourses***
  - ***Location of outlets***
  - ***RD and command area of outlets and minors***
  - ***Designation of canals, outlets***
- ***Design discharge of outlets***
- ***Capacity statement***
- ***Design of canal in reaches***
- ***Design of outlet***
- ***Design of watercourses***
- ***Plotting the typical cross-sections of canal at star mid and end and one typical cross-section of watercourse***
- ***Command statement***
- ***Longitudinal profile of canals***
- ***Warabandi schedule for an outlet command/outlet chak***