A STUDY ON SUITABLE MEASURES FOR CONTROLLING SEEPAGE LOSSES FROM IRRIGATION DISTRIBUTION NET WORK

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

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in

IRRIGATION WATER MANAGEMENT

By

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CANDIDATE'S DECLARATION

I hereby certify that the dissertation entitled **"A STUDY ON SUITABLE MEASURES FOR CONTROLLING SEEPAGE LOSSES FROM IRRIGATION DISTRIBUTION NETWORK"** which has been presented in partial fulfillment of the requirement for the award of the DEGREE OF MASTER OF TECHNOLOGY IN WATER RESOURCES DEVELOPMENT and submitted in the Water Resources Development Training Centre, Indian Institute of Technology Roorkee, Roorkee, is an authentic record of my work carried out during the period from 1st June 2003 to the date of submission under the guidance of Professor Emeritus R.P.Singh and Associate Professor Dr. Deepak Khare, WRDTC, Indian Institute of Technology Roorkee, Roorkee.

I have not submitted the matter embodied in this dissertation for the award of any other degree.

Place: Indian Institute of Technology, Roorkee
Date : ...... June 2004

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This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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ABSTRACT

Irrigation is an essential limiting factor for the production of food grains and other agricultural products necessary to sustain the life as well as to overcome the deficiencies in rainfall for stabilizing the agricultural production in arid and semi-arid regions. At present one sixth of agricultural land in the world has received the irrigation facilities and produces more than one third of the global food production. The requirements of food for the ever-growing world population need the higher agricultural production in which a large share comes from the irrigated lands. As the availability of water resources for irrigation has been increasingly difficult, the water, the cost of water resource development and management thus has also become a limiting factor for enhancing the irrigated agriculture in many of the irrigation projects.

Extensive engineering development works have been undertaken worldwide to make available the adequate amount of water required for irrigation as well as for other purposes such as domestic, urban and industrial use. The growing competition of water demand between agricultural and non-agricultural sectors has increased the concern for the sustainability of irrigated agricultural system. At present approximately 75-80 % of the world available fresh water supply is used for agricultural and food production. The demand for good quality of water has been increasing tremendously since last few decades.

Though the irrigation systems are constructed with high degree of quality control using best knowledge of the modern techniques available, the functional output is not acquired at a desired level. The irrigation systems thus created physically revealed very appreciable but the efficiencies shown is quite disappointing. The percentage of water effectively used in irrigation is around 40 – 60 % in an irrigation system in general. The remaining water is lost in the system, in the farm and on the field through evaporation, seepage and percolation into the ground water or runoff to the drainage system. Part of the lost water can be recovered but additional cost would be incurred. The water, used in whatsoever field is concerned, has multidimensional aspects such as agricultural, social, environmental, political, ecological and so on. Such complex and multi-dimensional resources in nature have to be thought properly for its sustainable use.

Water losses in irrigation are caused due to various reasons. The physical, managerial and the social aspects of irrigation should work in harmony to have an efficient output. The physical system with best planning, proper alignment, good design and excellent construction can prove its existence for better service but certainly needs proper maintenance and operation for sustainability. The involvement of the users and their cooperation in each phase of development is very essential.

Managerial sector, which is lagging behind in most of the developing countries has proved the loss of investment in proportion to the beneficial returns from the irrigation projects. Poor management of irrigation water is one of the principal reasons for the low water use efficiency in irrigation. The inadequate and often unreliable water deliveries in the main system cause farmers to face regular shortage in water supply resulting in reduced yields and incomes as well as much lesser command on area than planned originally. At farm level in appropriate field channels layout, insufficient or poor drainage and mismanagement of delivered water are responsible for seepage losses and reduced yields.

Inefficient or ineffective water use is associated with a range of environmental problems such as water logging, leaching of over used agro-chemicals causing ground water pollution. The soil and ground water salinization due inappropriate use of water are the most burning problems faced in recent years in many countries.

The operation of the system, on the other hand, has the most effective role in acquiring maximum production. The water, if applied adequately in appropriate time and frequency in combination with other agricultural inputs results the crops yields to a higher range. The deciding factor is the irrigation scheduling as when to irrigate the crop and how much to apply. Scheduling is the key means for optimizing the agricultural production and for conserving water as well as improving performance and sustainability of the irrigation system, which requires good knowledge of crops water requirements and soil water characteristics that determine when to irrigate, while the adoption of the irrigation method determines the extent of water quantity to apply.

The end users, however, are the farmers who advocate for the systems' success or failure. The whole attempt is to provide a good serviceable irrigation system to the beneficiaries for their social upliftment but quite often their existence and effectiveness towards the project is either neglected or overlooked. In past decades, the irrigation projects usually came into existence through top-down processes. In the project evolution period, the would be beneficiaries were much neglected in most of the developing countries whereas after completion and at serviceable phase their co-operation and involvement was found very essential for overall well functioning of the system as well as its look after. Their social, cultural and attitudinal behavior has to be synchronized with the need of the project, which, however, would be a long process. The ways and means for developing a notion of feeling of ownness about the project is to be sought for. The beneficiaries should be treated with a status as a co-partner with open mind by the agency with due weight and response to their grievances and pointed shortcomings of the system. This will motivate the beneficiaries to come forward with commitments and eager for the betterment of the system. The process and procedures of system (at the level they are assigned to) construction, maintenance, operation and utilization should be known to them by enhancing their present knowledge through trainings, observation tours, field demonstrations, media advertisement or other suitable procedures making them capable of using the physical, managerial, agricultural aspects of the system in a proper manner for best agricultural production without soil and land degradation for ever. The creation of technically sound, hydraulically efficient and operationally easy system is the basic need

The system design, water allocation and distribution procedures are always made with certain assumptions and approximations which sometimes may not hold good in prevailing field conditions or in implementations which may be reflected by the functioning of the system. The feedbacks from the users, therefore, should get due weightage for discussions and interactions and those found suitable should be incorporated in the system on a real-time basis by the agency. The social need based water supply would primarily be the most important aspect to be considered by the system managers. A good linkage of communication, co-ordination, motivation and co-operation should be established between the users and the agency in all phases of the system development process for the successfulness of the project.

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CHAPTER- 5 MAINTENANCE OF THE CANAL NETWORK

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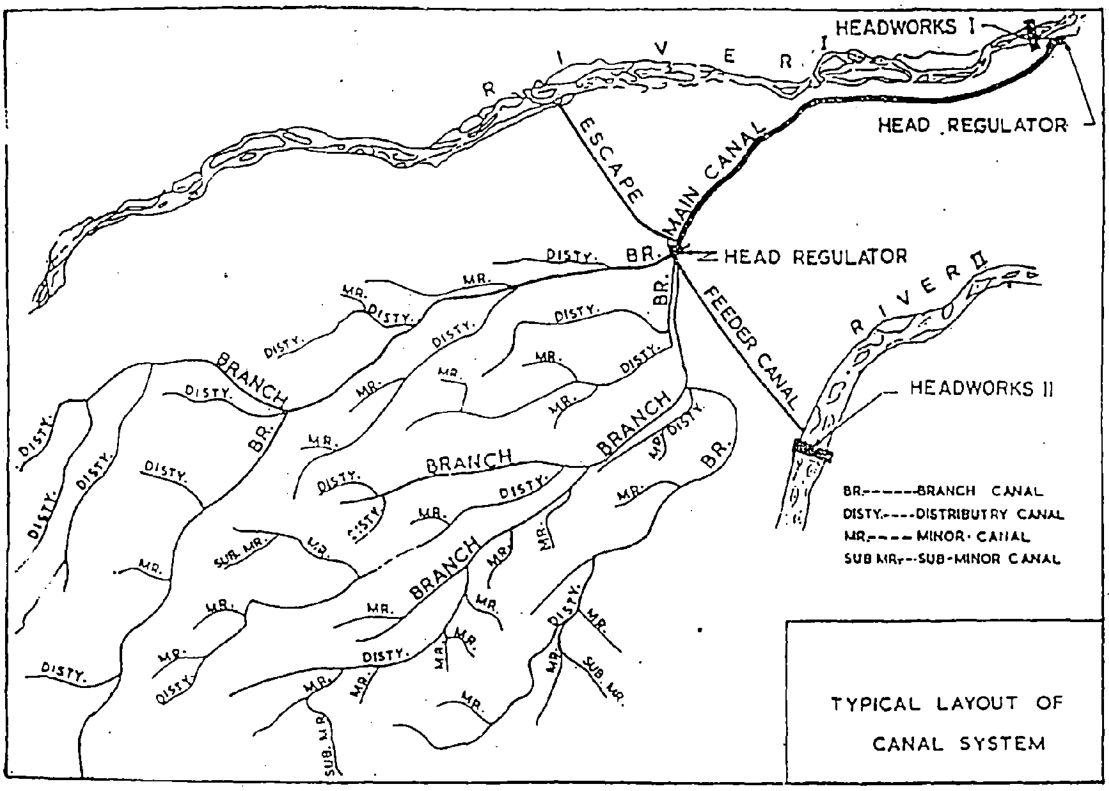
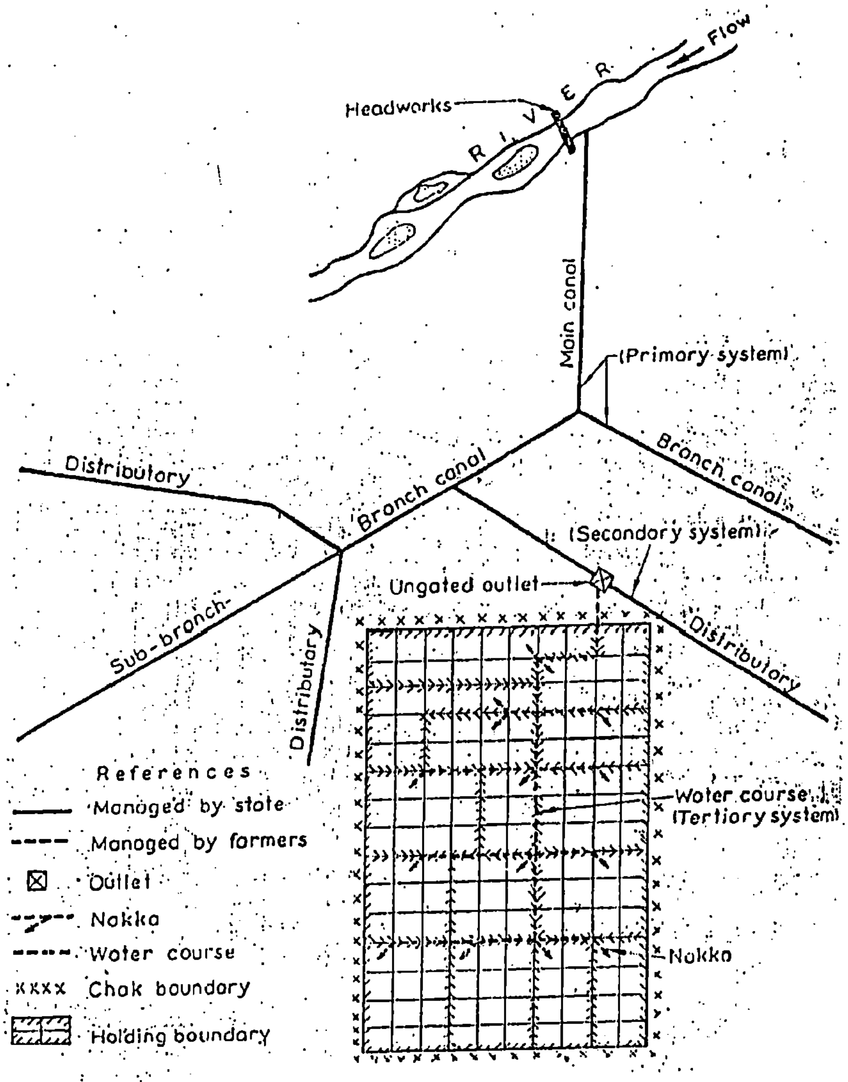
ABBREVIATIONS USED

Br Canal	Branch Canal
H/D	Head Discharge
WUA	Water Users Association
WMA	Water Management Association
ID	Irrigation Department
CADD	Command Area Development Department
USBR	United States Bureau of Reclamation
ICID	International Commission for Irrigation and Drainage
GOI	Government of India
ICOs	Irrigation Committee Organizer
Bk	Brick
Br	Branch
W/Cs	Water Courses
Dys	Distributaries
UGC	Upper Ganga Canal
Mm^2	Million Square Meter
M/C	Main Canal
B/C	Branch Canal
OH/D	Outlet Head Discharge
GWT	Ground Water Table
UGIMP	Upper Ganga Irrigation Modernization Project
DRO	District Revenue Officer


RIVER I
HEADWORKS I
HEAD REGULATOR
ESCAPE
MAIN CANAL
HEAD REGULATOR
RIVER II
FEEDER CANAL
HEADWORKS II
BRANCH
BR.
DISTY.
MR.
SUB MR.
BR.------BRANCH CANAL
DISTY.----DISTRIBUTRY CANAL
MR.----MINOR CANAL
SUB MR.--SUB-MINOR CANAL
TYPICAL LAYOUT OF
CANAL SYSTEM



TYPICAL DISTRIBUTION SYSTEM

CHAPTER - 1

INTRODUCTION

CHAPTER-1

INTRODUCTION

1.1 GENERAL

The demand of water is increasing day by day where as the resources being very limited, the supply has not been able to fulfill the required demand. Moreover neither the water is gained or lost in the water cycle but the amount available to the use may fluctuate because of the variations in the source or more usually in the delivery process. Therefore, the valuable water has to be conserved responsibly by all the users of it in a proper way

The estimated total volume of water available on the earth is $1.36*10^9$ cubic km, out of which 97 % is contained in the ocean spreading over the approximate oceanic basin area of 361.3 m. sq.km with an average depth of 3660meters (Kalinin '71). An additional 4.17mil.cubic km. of salt water is buried underground. Thus the remaining 2.5 % makes up the worlds total supply of fresh water. Even out of this (2.5 %) of water, 87 % remains unusable as polar ice caps as well as glaciers and 12 % of it is in ground water content. Thus the remaining 1 % is available as fresh water stored in lakes, rivers, soils and in the atmosphere. This small amount of water available is very important and is very essential to sustain the life on the earth. This small quantity of water available is estimated to be of the order of$1.3*10^5$ cu.km, out of which $1.25*10^5$ cu. km is in lakes in different parts of the world and the remaining $1.4*10^4$ cu. km is available in the rivers of the world and in atmosphere at any time. Even the lowest amount available for use is not evenly distributed but varies with space and time as well as it is also not available in sufficient quantities as where is needed, when is needed and at what quantities are needed.

The use of water is multi-sectoral and the competitive demand in all the sectors is increasing enormously. In agriculture, irrigation water is the limiting factor for better production. Inadequate and inefficient water supply is the main constraint on agricultural production in most of the developing countries. Water conservation thus presently has become increasingly important as the demand in different sectors is increasing with time where as the supply has always been insufficient to meet the required demand. Therefore most of the water resources projects are always facing unavoidable stresses. The food production has to be increased in proportion to the growing population to feed them adequately with sufficient calorific values. In the past the basis of development was the agriculture so that more and more lands were brought under cultivation and most of the rivers were dammed. The possibilities for further land as well as water resources development are very rare and also the development cost incurring would be very high. Therefore, the primary objective to increase the food production in future would be the utilization of the water resources available more efficiently.

In irrigation sector, there are several reasons for the increasing demand of water. The technology for using available water supplies most efficiently is either lacking or not adopted to the available resources in many of the under developed countries. Many experts agree that farming practices including irrigation management must be modernized in order to achieve higher production. There are important reasons for low crop yields and the slack in agricultural production which includes insufficient water supply to the land (crop), lack of land levelling, lack of irrigation water control, salinity control, lack of water management and extension services, continuation of traditional cropping systems with traditional tools.

The demand of water in agricultural sector is more pressurized by the introduction of HYV crops and modernization of on-farm development. The change brought in cropping pattern and cropping intensities, agricultural mechanization, increase in the standard of living of the farmers are the contributing factors for accelerating water demand. The rapid population growth, industrial development, rapid urbanization are the additional causes of water demand. The energy sector as well as the hydropower, recreation, environmental and ecological aspects are also the shareholders for water demand. Thus the demand for water is endless.

1.2 CANAL SEEPAGE AND ITS IMPORTANCE

Indeed, in most of the cases, the demand of water cannot be met with, and, therefore, an acceptable norm for prioritizing the demand has to be developed, as the amount of water available is limited. As said earlier that the major consumer of water is the agricultural sector for which water is made available through conveyance and distribution system network and from which a substantial amount of water is lost during the process of transportation till to the application in the farmers fields. The losses include conveyance losses, percolation losses and field application losses. The commonly accepted value for the transit losses from unlined canals in the alluvial plains of northern India is 45%of head discharge.

If these losses could be reduced or controlled the surplus water resources created can be utilized for getting more area under command incurring more production, which would prove a step forward in engineering achievement. In most of the irrigation projects, though, the modern construction techniques and high quality control mechanism are applied seepage losses still have been a challenging problem. The best achievement from most of the irrigation projects would be obtained when the quantity of water lost in conveyance and application due seepage be minimized.

1.3 NEED OF THE STUDY

In actual practice there will be a large variation in seepage losses with respect to the climatic differences and physical conditions. The seepage in its cumulative effect taken over time and space causes a lot of valuable water losses as well as shows detrimental effects to soils and crops resulting serious reduction in production and economy also. The history of irrigation has left behind a lesson for engineers and planners and water managers that improper and inefficient water use in 12^{th} & 13^{th} century converted the green fertile land of Mesopotamia into desert within a period of about 100 years and similarly in recent years in Pakistan about 40,000 ha of fertile land is being converted into waterlogged area due to improper use of water.

The involvement of water users with assigned roles and responsibilities to participate in all phases of project activities is basically very essential and it should be looked as co-partner by the agency with due regard. The users should never feel disregarded and are just for the sake of fulfilling the legal bindings. Moral boosts and ever encouragement from the agency side would pursue them (the farmers) remain alert to tackle every possible problems and obstacles with their own initiations at first hand and extending a helpful hand to the agency for the betterment of the system. This would develop good relation with the agency as well as automatic information feedings leading easy rectifications of deficiencies of the system or other administrative refinements. The feeling of wholehearted attachment towards project safe guard is the environment to be created from the agency side.

The problem of water management, nowadays, has been of broader scope. It is not only confined in the engineering periphery but has to be treated with multi-disciplinary approach such as environmental, social, economical, political and so on. To achieve the desired goal of water management social, biological, ecological, environmental scientists and engineers will have to work together as a team with equal partners considering farmers as the basis which can formulate the suitable strategy to utilize efficiently the optimum quantity of water to maximum production without water wastage.

1.4 OBJECTIVE OF THE STUDY

The objective of the dissertation is to collect the possible available literatures, information and data regarding the seepage losses from lined as well as unlined irrigation channels. Suitable remedial measures shall be discussed for controlling the seepage losses from irrigation distribution network in different stages such as project planning, design, construction operation and maintenance (O&M) and management. An attempt will also be made for comparing the results obtained by various theories and empirical formulae with the actual field results found by different studies.

In general, the dissertation shall also address the following aspects:

- The irrigation systems though are created with long past experience and high standard of quality control using modern technologies; even then the seepage has been a challenging problem to the planners and engineers. This reveals that the engineering measures only are not sufficient for controlling seepage but several other factors contribute to it directly or indirectly.

- The need of efficient and effective water management is the times need demand for minimizing the seepage as well as boost production without detrimental effects to soil and crops.

- The construction oriented past concept of water resource development agency (government/ private)/engineers should get diverted equally to the management aspects so as to make the best use of the system created in a sustainable way, working in coordination with the beneficiaries considering the local problems and water culture.

- The importance and attitudinal behaviors of beneficiaries, their consent and consensus towards the project.

- Need of technology transfer to the beneficiaries and make them participate actively in all phases of project development and management works.

CHAPTER – 2

LITERATURE REVIEW

CHAPTER – 2

LITERATURE REVIEW

2.1 GENERAL

Water losses from canals by seepage through bed and banks have been recognized as an actual problem since the inception of irrigation. As far as possible canals through gravelly or sandy soils were avoided and in case of unavoidable situations canal sections were treated with suiTable remedies that bring the losses with in the accepTable ranges. Nowadays it is accepted that different aspects of physical, social, environmental and economic parameters and their possible combination should be studied before making a decision for a particular seepage situation such as water logging, salinization of land and increased salt loading of rivers. The key factors (or parameters) to be considered in all cases however are: (i) the economic value of water saved (ii) the seepage losses (iii) damage due to seepage (or the cost of mitigating the damages). When the economic value of water lost and damage due to it are low/less, the unlined canals commonly are the better choice and conversely as the values as said above increase more expenditure to reduce seepage becomes justified. Most of the irrigation projects in the world were started primarily with unlined canals. Over the past few decades, incurring cost of developing, transmitting and distributing irrigation water as well as the increase in demand of the limited water supplies have resulted in all or parts of much irrigation system being lined. The more water demand of modern agriculture can be expected to accelerate this trend and the reduction in seepage in usually the major benefit from lining.

Before, the decision making for lining the probable seepage value has to be measured/estimated correctly. For this purpose, many researcher and scientists have suggested methods for estimation and prevention of seepage losses from irrigation canals; analytically as well as on field test/experiment basis.

2.2 ANALYTICAL CONTRIBUTIONS FOR SEEPAGE ANALYSIS

- Vedernikov (1936), Muskat (1946) provided the solution for seepage from ditches into permeable layer at shallow depths.

- Hammad (1960) studied seepage problems from many canals, which were identical, equally spaced, parallel canals of different shapes (i.e. of no particular geometric shape).

- Garg and Chawla (1970) found almost exact solution for seepage from trapezoidal canal in homogeneous media with the drainage location at finite distance from the canal considering vertical and horizontal drainage

- Sharma and Chawla (1979) derived a close solution for seepage estimation from canals in homogeneous media (extending to finite depth) to the drainages located at finite distance from the canal, considering both the horizontal and vertical drainage condition. The findings from their analysis was that seepage from canals increases with (i) increase in bed width and depth of impervious layer (ii) decrease with increase in drainage distances. They also indicated that the phreatic surface rises with (i) increase in bed width (ii) increase in drainage distance.

- Kirkos (1993) studied seepage problems from canal running through infinite soil media with drainage placed asymmetrically considering two different cases of canal as (i) canal with negligible water depth (ii) trapezoidal canal with significant water depth considering the seepage from the canal to the drain, which lies on one side of the canal only.

- Rohit Goyal (1994) studies the seepage through the canal on finitely extending soil media with asymmetrically placed infinite drainage length considering the different cases of canal with significant water depth considering the infiltration effect due rain and irrigation.

Herman Bouwer (Director US Water Conservation Laboratory Agriculture Research Service, USDA) with electrical analogy confirmation 91965,1969,19780 covering trapezoidal, rectangular and triangular channels found out the seepage losses in different four conditions of study, which were:

- Condition- (A)-Seepage into uniform soil underlain by material of much higher hydraulic conductivity.

- Condition- (A')-Seepage into uniform soil to a free draining permeable layer.

- Condition- (B)-Seepage into uniform soil underlain by material of much less hydraulic conductivity.

- Condition-(C)-seepage from canals with a thin, slowly permeable layer at the wetted perimeter (i.e. lined condition).

From the above conditional studies, Bouwer concluded that:

1. Seepage from open channels increase with increasing water depth in the channel, but the rate of increase in seepage discharge is not proportional to the rate of increase in canal discharge. The rate of seepage increase is less to the rate of increase in canal discharge.

2. For uniform soil with deep water table, the greatest seepage occurs at the toe of the canal bank as shown in Figure 1 below.

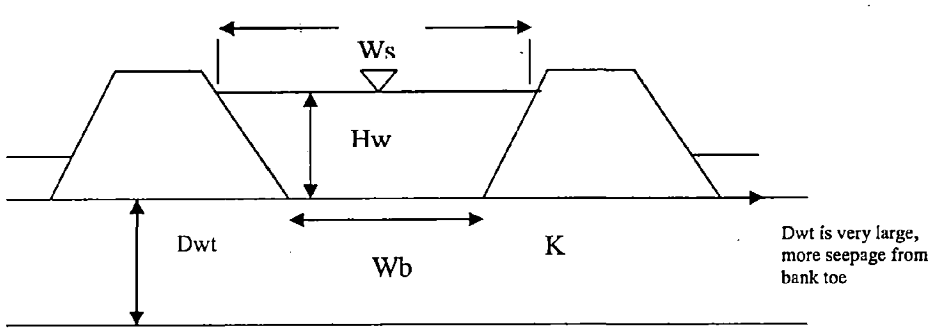


Fig.1: When the distance of ground water Table at large depth, more seepage would occur from the toe of the bank.

3. If the permeable layer is at a short distance below the canal, seepage tends to be concentrated through the canal bed as in Figure 2 below (Dp is very small).

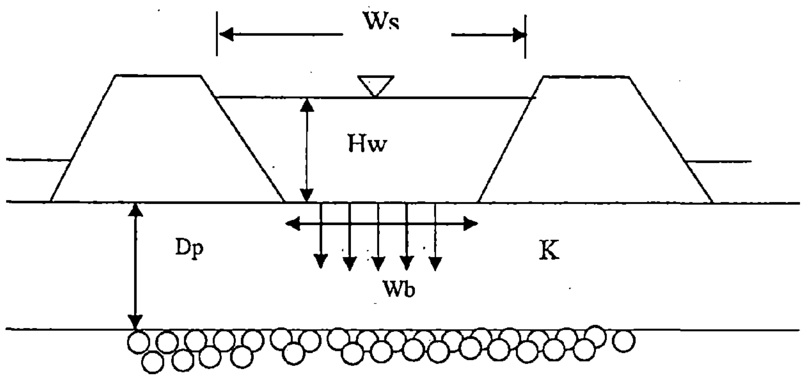


Fig.2: If the permeable layer is at a smaller depth the seepage from the canal section is concentrated on the bottom.

4. If an impermeable layer is located close to the bottom of the canal more seepage occurs through the banks (when Di is very small) as shown in Figure 3 below.

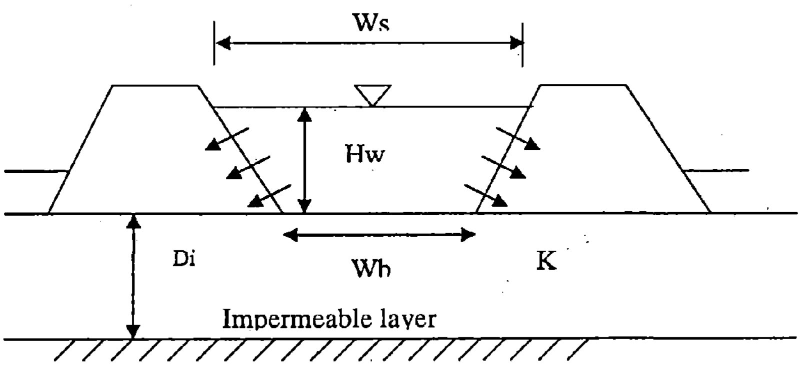


Fig. 3: When the impermeable layer is at a smaller depth (near to the bed), the seepage is more from the sides of the canal section.

5. Since the channel shape has minor effect on seepage (Bouwer, 1965); shape of the channel was trapezoidal with side slope 1:1, lining or sealing only the canal bed provides significant seepage reduction for shallow canals (Wp will be more) or for canals with permeable layer close to the bottom or at small distance from the bottom.

Where these conditions do not exist, relatively small seepage reductions can be excepted unless the canal banks are included in the treatment/lining.

Conclusively, it may be expressed as:

1. For loosing canals (GWT is below the bottom of the canal)

   (i). With clean wetted perimeter

   (a). Seepage rate $\propto$ Depth of GWT (i.e. seepage rate has linear relation with GWT).

   (b). Seepage rate is independent of GWT, if GWT is at large depth.

   (ii). Perimeter covered with a clogging layer (say lining- natural or artificial).

   Seepage is not affected by depth of GWT as far as GWT or the capillary fringe is below the clogging layer of the canal bottom.

2. For gaining canals (GWT is above the bottom of the canal).

   There will be a relation between seepage rate and depth to GWT measured from canal water surface (regardless whether the canal perimeter is clean or clogged).

2.3 EXPERIMENTAL CONTRIBUTIONS FOR SEEPAGE ANALYSIS

Robinson and Rohwer (consulting engineers, ASCE) performed many experiments to find the seepage variables that determine the canal seepage (in USA, 1949-1952) and some of the results found by them are:

1. Rates of seepage as determined with seepage ring ranged from a maximum of 26 ft/d (7.92 m/d) for clay loam with root channels to a minimum of 0.01 ft/d (3mm/d) for silt loam (test results were corrected for evaporation). Over 5 months of testing each season, rates generally to decrease with time but in several cases rates increased after about a month. In most cases rates increased considerably after temporary draw down.

2. Seepage increased with increased depth of water but not always linearly.

3. Seepage increased with increased depth to ground water within 2.5ft (0.76m) range of depth tested except that in sand the correlation ceased when the depth went beyond 1 ft (0.30).

4. Over periods of 24 hrs, seepage rates could vary as much as 10 – 65 % depending on soil type. The expansion and contraction of air bubbles in the soil were believed to be the primary causes of this phenomena. Rates were higher at lower temperatures.

5. On the same sites, with the same soils, with essentially identical waters, with testing performed by highly competent and experienced personnel, measured seepage ring rates varied by as much as 50 % or more.

Hart (6) estimate seepage losses from canals in different types of soil in southern Idaho (USA), as given in Table 1 below.

Table1: Loss rates from canals in Southern Idaho (USA)

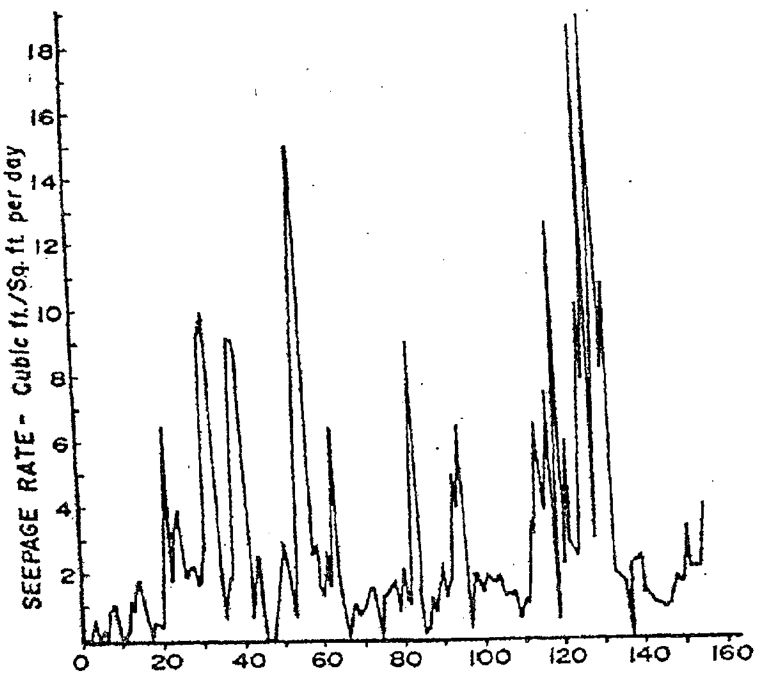
Sn	Types of soil	Loss rate in ft/d (m/d)
1	Medium clay loam	0.5 – 1.5 (0.15 – 0.46)
2	Impervious clay	0.5 (0.15)
3	Medium soils	1.0 (0.30)
4	Somewhat pervious soils	1.5 – 2.0 (0.46 – 0.61)
5	Gravel (Depending on porosity)	2.5 – 5.0 (0.76 – 1.52)

The broadly suggested values of seepage losses for estimation in different soils are as given in Table 2 below. (Seepage Manual)

Table 2: Suggested values of seepage losses

Sn	Soil material	Seepage losses in $m^3/s/10^6m^2$
1	Impervious clay loam	0.92 – 1.20
2	Medium clay loam	1.20 – 1.80
3	Ordinary or sand clay loam	1.80 – 2.70
4	Gravelly or sand clay loam	2.70 – 3.60
5	Sandy loam	3.60 – 5.20
6	Loose sandy soil	5.20 – 6.10
7	Gravelly sandy soils	7.0 – 8.80
8	Porous gravelly soils	8.80 – 10.6
9	Very gravelly soils	10.6 – 21.20

There is always a variation in seepage loss along and across of a large canals. The graph below according to Wortsell shows the variations in seepage rates along the canal in sandy loam soil in Idaho, USA, July 1970.



Distance – Hundreds of Feet

Fig.4: Variations of Seepage Rates measured at 100ft (30-m) intervals along centerline of canal in sandy Loam Soil near Rupert, Idaho, July 1970 [Average rate = 2.58 ft/ day (0.79m/day)].

The seepage loses varies also across the canal section in large canals. The variations in seepage losses measured across a large canal are shown in Figure 5 below (based on the experiment done by Wortsell).

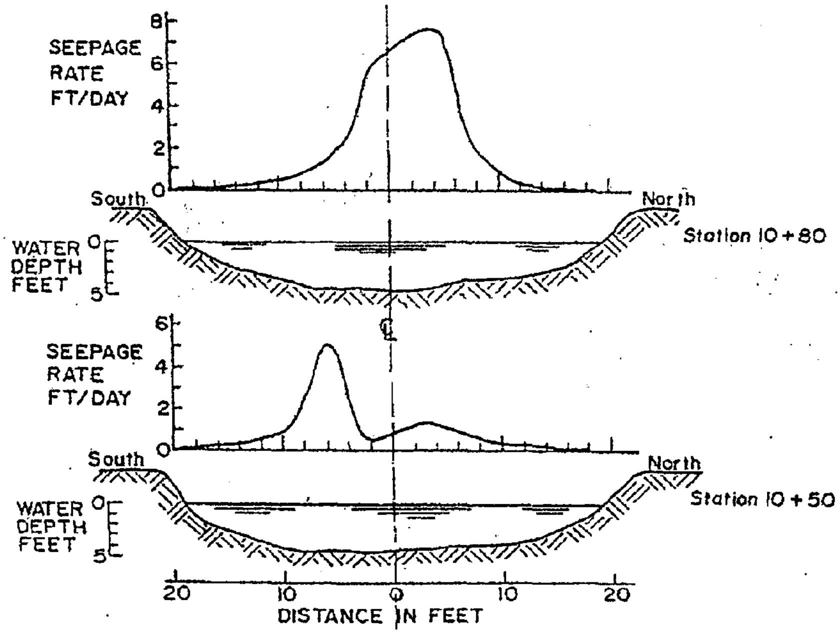


Fig.5: Variations of seepage rates across width of a large canal.

The test result of the average seepage rates for broad soil groups in unlined canals by different tests was found and given in Table 3 as follows.

Table 3: Results of seepage rates for general soil groups found by Ponding and Seepage Meter method

Sn	General soil groups	Ponding Tests		Seepage Meter tests	
		No of tests	Avg. seepage rate in ft/d (m/d)	No of tests	Avg. seepage rate in ft/d (m/d)
1	Clayey soils	20	0.23 (0.07)	3	0.65 (0.20)
2	Silty soils	120	0.80 (0.24)	16	0.55 (0.17)
3	Loamy soils	196	0.94 (0.29)	11	0.85 (0.26)
4	Sandy soils	77	1.56 (0.48)	28	1.91 (0.58)
5	Unspecified	55	1.01 (0.31)	30	1.31 (0.35)

Similarly, the results of seepage rates from lined canals from Ponded test found were as given in Table 4 below.

Table 4: Seepage rates from lined canals (Ponded Seepage)

Sn	Lining type	No of tests	Avg. seepage rate ft/d (m/d)	Seepage range in ft/d (m/d)
1	Concrete	11	0.24 (0.07)	0.03-0.96 (0.009-0.29)
2	Compacted earth	45	0.17 (0.05)	0.01-0.95 (0.003-0.29)
3	Asphalt membrane	32	0.46 (0.14)	0.003-0.92(0.03-0.20)
4	Soil cement	5	0.08 (0.02)	0.03-0.20 (0.009-0.06)
5	Chemical sealant	12	0.70 (0.21)	0.32-8.30 (0.10-2.53)
6	Sediment seal	10	0.78 (0.24)	0.39-1.30 (0.12-0.40)
7	Unlined- all soil types	468	0.99 (0.30)	0.01-17.6 (0.003-5.37)

In the pre-construction stage on the basis of the soil characteristics (permeability range of the soil); size of the canals and their operating levels; the canal seepage estimation can be made with the help of V. Worstell curves as shown in Figure 6 below.

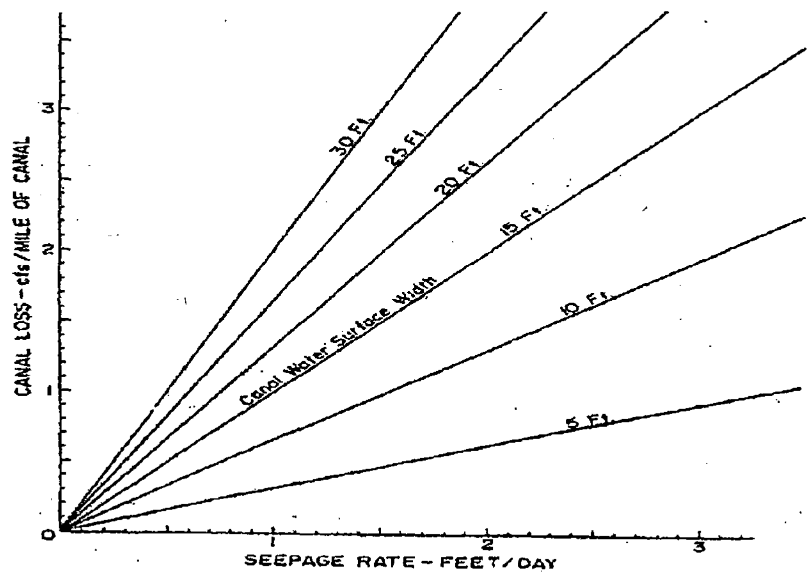


Fig.6: Chart to aid in estimating Flow Loss (for known Seepage Rates and Canal Dimensions)

WATER RESOURCES DEVELOPMENT TRAINING CENTRE
INDIAN INSTITUTE OF TECHNOLOGY - ROORKEE

No. WR/D-2/2004/ 1239

Dated : July 2, 2004
5

Assistant Registrar (PGS&R)
I I T – Roorkee

I am enclosing herewith a copy of M.Tech Dissertation entitled "***A study on suitable measures for controlling seepage losses from irrigation distribution net work***" alongwith a sealed envelope containing Grade Sheet of M. Tech Viva voce examination held on *1/7/2004 of Mr. Bharat Mani Dhital,* Trainee officer of 23rd IWM batch of WRDTC for further necessary action at your end please.

(Deepak Khare)
Associate Professor

Encl : As above

Copy Professor & Head, WRDTC

The seepage losses found by Kennedy (EE-Bari Doab Canal), Dempster and others based on their observations is presented in the Table 5 below.

Table 5: Comparison of losses found by different persons/studies

Sn	Studies done by diff.persons/studies	Place	Canal nature		Remarks
			Unlined	Lined	
1	Kennedy (EE)	Bari Doab	(a) If 100 cft enters a canal	-	
			80 cft enters in dys		
			74 cft enters in w/c		
			25 cft is lost in wasteful application		
			28 cft is actually used by crops in fields		
			(b) He also observed the absorption ratio in different canals as 45:30:17:8	-	Branch canal: Constantantly running dys; tatiled dys: Water c/s
			© 21 % of H/D or 43 % of OH/D in W/C	-	-
2	Dempster (Engg.)		30 % of H/D	-	-
3	WAPCOS (APG)	UGC	4 % per 100m length	-	In running condition
4	WRDTC	Bulandshahar Dys	28% (Kharif)	12%(Rabi)	
		Hardanganj Dys	32 % (Kharif)	16%(Rabi)	

Source: Prof. Raj Pal Singh,'Paper on seepage losses and control on watercourses and field channels'

The comparative statement of losses in Upper Ganga Canal found by various studies is presented in Table 6 below.

Table 6: Comparison of seepage loss rates in UGC (found by different studies)

Sn	Losses as per UPCIP	Losses as per pre-determined share	Losses as per empirical formula (IRIR)	Losses as recorded by G/S at control points (%)	Losses as per field observation	Remarks
1	Lined System Main Canal 5 %	M/C & B/C 8.5 %	8cusecs or 2.44 cumecs per million sq. m. of WP	(i) Upper Main Canal 0.5-2.6% (ii)Main Line Lower 2.84-8.23%	Water courses. (i)Main 11.5-16.29 % (ii) Branch 9-11 %	In running condition
2	Branch Canal 10 %			Branch 8.31-15 %	Field Chak 15-20 %	
3	Distributaries and Minors 15 %	Distributary System7-10 %		Distributary Canal 10.5-16 %	-	
4	Water Courses	-		Water Courses 11.5-16.2	4 %per 100 m length	

Source: Planning Commission, GOI, Pilot Study on Water use efficiency for UGC (UP), WAPCOS, Feb. 2003.

Similarly the other studies/report for the conveyance losses assessed for UGC is produced in Table 7 below.

Table 7: Conveyance losses found by different studies for UGC

Sn	Study report	Unlined canal system	Losses			Remarks
			Seepage	Operational	Total	
1	SAR (Staff Appraisal Report)	Main canal	8.5 cusecs/mil sq.ft.of WP	-	8.5	Measured, I–O Method
		Br. Canal		-	28%, T/DorH/D	Total div.or head dis.
		Anupshahar		-	31 %, H/D	
		Mat.Hathras		-	24 %	
		Dys & minors		-	12 %, H/D	

2	Feasibility Report		32 %, H/D	15 %, H/D	47%, H/D	Effy of the system 53%
3	-	Lined canal	Seepage losses reduced from 32 % to 8 %	Operational losses reduced from 15 % to10 %	18 %,H/D	Efficiency of the system is increased to 82 %

Again the seepage losses with respect to the H/D was found as given in Table 8 below:

Table 8: Showing the relation between discharge and seepage losses from lined and unlined canals

Sn	Head discharge in cumecs	Seepage losses as % of H/D		Remarks
		Unlined canal	Lined canal	For the same channel, seepage loss per cumecs is more when running with less discharge or shallow depth.
1	225	1.02	0.22	
2	60	1.21	0.44	
3	10	5.56	1.18	
4	0.6	24.30	5.05	

The graphical representation of seepage rate with discharge is as shown below.

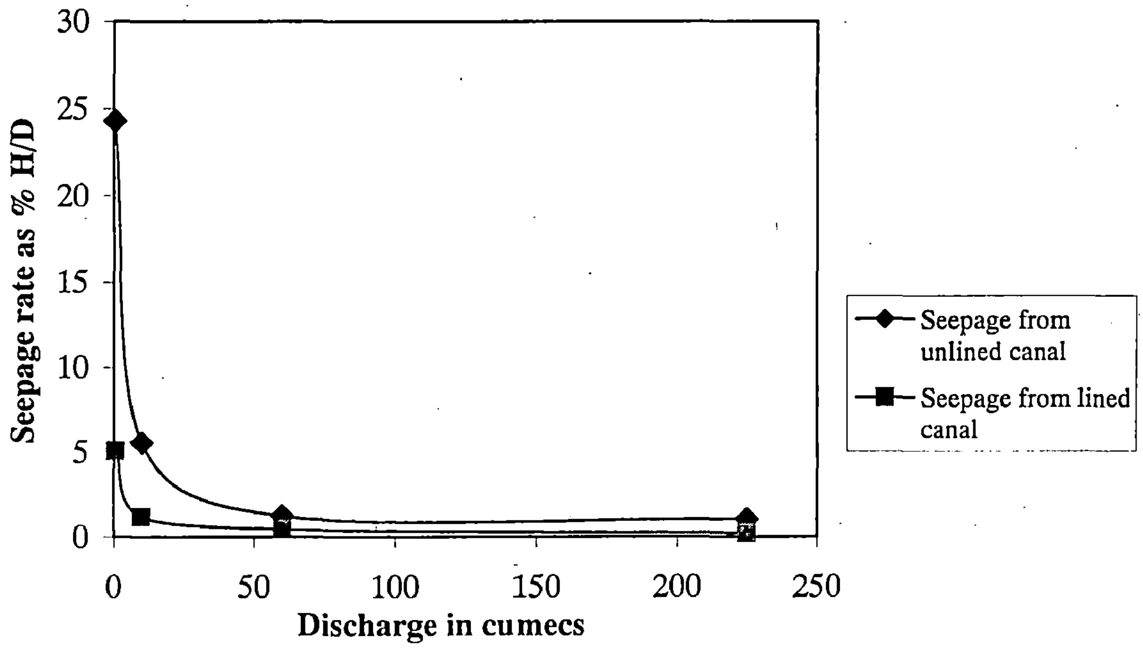


Fig.7:Seepage rate vs Discharge from unlined and lined canal

The seepage losses measurement began since 1876 AD in India and still the study is going but yet the specific methods for accurate seepage measurement and measures to control the same are still in the research phase both in the developed and developing countries.

The tentative history of seepage loss estimation in different parts of the world is presented in Table 9 below:

Table 9: Tentative history of seepage estimation

Sn	Persons/Organization involved	Year	Remarks
1	Red Commission (India)	1876	Formed to study the causes of water logging and found that WL was due construction of big canals and extensive use of irrigation
2	Kennedy (India)	1881	Measured seepage losses in Khandesh Canal in Bombay
		1890	Measured seepage losses in Bari Doab Canal in Sindh (Punjab)
3	1st.Irrigation Commission (India)	1901	Suggested measures for controlling water logging due seepage
4	PWD (Bombay)	1916	Studied the causes of water logging due irrigation in Decan area
5	Punjab Govt., Engineering WL committee	1925	Drainages were constructed with the help of IDA, prior to 1964
6	Vedernikov	1936	Suggested analytical soln.for seepage estimation.
7	Muskat	1946	Do
8	Robinson and Roher (USA)	1952	Carried field tests to find seepage
9	Hammad	1960	Suggested analytical solution for seepage calculation
10	Harman Bouwer	1965	Carried field studies about seepage in Idaho, USA
12	Robert V. Worstell	1970	Performed many field tests in USA, Idaho
13	National Agricultural Commission (India)	1976	Collected the extent of WL areas state wise
14	Sharma and Chawla	1979	Gave analytical soln for seepage calculation
15	Ministry of agri. (India)	1990	Extent of WL area in diff, States
16	Kirkos	1993	Analytical soln.
17	Rohit Goyal	1994	Do

CHAPTER – 3

ESTIMATION OF SEEPAGE

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ESTIMATION OF SEEPAGE

3.1 GENERAL

General definition-The seepage discharge, from the earthen channels, as per Darcy, mainly depends upon the soil types and the hydraulic gradient. The soil characteristic is designated by seepage co-efficient as denoted by k. The other terms used often to express the same property of the soil are the hydraulic conductivity and a co-efficient of permeability. The co-efficient of permeability is defined as the volume of water that passes through unit area in unit time at unit hydraulic gradient. It may also be defined in general as the ability of soil to pass water through it. The hydraulic gradient is the hydraulic head difference between the beginning and end of the seepage path divided by the seepage path length.

3.2 THEORETICAL METHOD

The co-efficient of permeability 'k' also depends on other secondary factors like moisture content of the soil, temperature, soil grain size, vegetation, wetted area of bed and banks, frequency of canal usage, age of canal, the amount of sediment present in water (water quality), weather condition of canal operation, depth of water flow, position of ground water Table in the locality, relative position of irrigation canal and drainage canal and so on. Therefore, for general purpose of seepage calculation the secondary factors may be disregarded and for saturated soils, the seepage co-efficient depends only on the soil type. The co-efficient of permeability of the soil through which canal passes or constitutes the canal bed and bank governs the seepage losses.

The seepage equation developed by Darcy (as per the definition given above) is as,

$$q = Aki$$

Where, q = seepage discharge in cumecs

A = area of x-section in sq.meter

k = co-efficient of permeability

i = hydraulic gradient

Again, $\frac{q}{A}$ = ki,

Or q = ki =V, where, q = discharge per unit area (specific discharge)

Thus velocity V = q = ki, is not a real velocity because water passes through the soil voids only and not through the entire area.

In actual field conditions, the value of seepage co-efficient differs from point to point due to the pressure of the small cracks, wormholes, roots, and stones and so on in the soil. So for this region when we talk about the co-efficient of permeability of the soil, it indicates the representative value of the soil as a whole instead of a particular point value. A rough estimation of seepage losses can be made when the approximate values of co-efficient of permeability of different soil types are known. The standard soil classification with their seepage co-efficient is presented in the Table 10 below (as per B. J Kinori).

Table 10: Showing the soil types and their coefficient of permeability

Sn	Soil type	Co-efficient of permeability (*10^{-5} cm/s)	Remarks
1.	Fat clay; non-organic; high plasticity organic clay	K < 3	Very low < 3
2.	• Lean clay, non organic, low or medium plasticity, sandy clay, silty clay • Elastic silt, silty sand • Organic silt, organic clay with silt, low plasticity • Clayey sand, medium plasticity • Gravelly clay, gravel sand clay	60 > K > 3	Slow 3 – 15 Medium slow 15 – 60 Medium 60 – 170 Med. Quick 170 – 350 Quick 350 – 700
3	• Silty sand, Poorly graded, non- plastic • Non-organic silt, very fine sand • Silty gravel, sand silt gravel, poorly graded, non-plastic	60 > K > 3	Very quick > 700
4.	• Sand well graded (up to 5% fine) • Sand, Poorly graded (up to 5% fine) • Gravel, well graded (up to 5% fine)	700 > K > 60	
5.	Gravel, poorly graded	K > 700	

Once the soil type is classified, it helps the engineers to predict the rough estimation of the seepage losses from the earthen channels.

3.2.1 *ESTIMATION OF SEEPAGE LOSSES FROM THE EARTHEN CHANNELS*

According to B. A. Etchevery, the empirical values of water losses through seepage from earthen channels in different soils obtained from the experiment done in U S A is as shown in Table 11 below.

Table 11: Relation between soil type and seepage loss rate

Sn	Soil type	Seepage losses (m/d)
1	Impervious clay loam	0.07 – 0.01
2	Medium clay loam, impervious layer below the channel bottom, not exceeding 60 – 90 cm in depth	0.01 – 0.15
3	Clay loam, Silty soil	0.15 – 0.23
4	Clay loam with gravel, sandy clay loam, gravel cemented with clay particles	0.23 – 0.30
5	Sandy loam	0.30 – 0.45
6	Sandy soil	0.45 – 0.55
7	Sandy soil with gravel	0.55 – 0.75
8	Pervious gravelly soil	0.75 – 0.90
9	Gravel with some earth	0.90 – 1.80

Remarks: 1.The area in this Table is the wetted perimeter along one meter of the channel.

2.All the values in the Table are quite general, the soil type definition give large soil groups and the experiments on which they are based ignored such important factors as the shape of the channels, the depth of impervious layer and the depth of the GWT. These values are to be considered as general information only.

Source: Manual of surface Drainage Engg. – Vol. 1, B J Kinori

Other hydraulic engineers Pavlovsky, Kozeny, Vendernikov, Muakat, Harr etc have presented the analytical methods for seepage losses calculation more precisely than Etchevery's empirical method. They have taken into consideration the hydraulic conductivity 'k' of the soil, the channel shape, the depth or thickness of the pervious layer below the channel, channel water top width, channel water depth, side slopes and so on.

According to Vendernikov, for trapezoidal channel sections the seepage losses per unit length of channel, when draining layer is at a large depth T, given by,

$$q = k\,(B+Ad)$$

Where, A = channel shape factor, for ease of use the function is given in the form of family of graph for different values channel side slopes.

The flow lines curved downwards and become vertical at a depth of To, given by,

$$To = 1.5\,(B+2d) \quad \ldots\ldots\ldots\ldots(2)$$

A = 2, is taken for canals with elliptical bed and at this depth To, the distance between two extreme flow lines as shown in Figureure 8 below is given as:

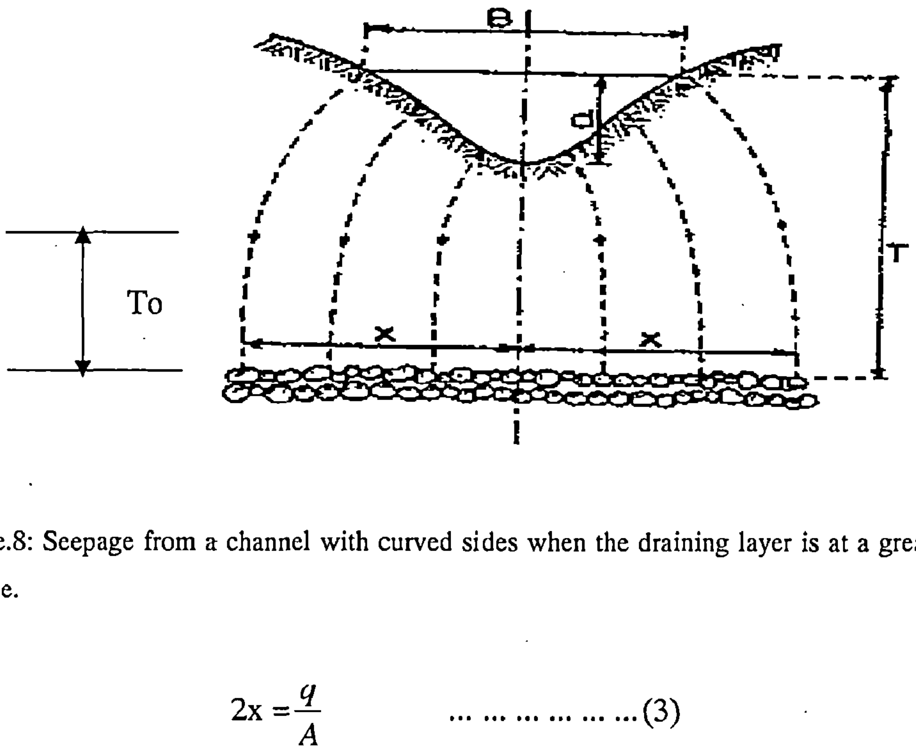

Figure.8: Seepage from a channel with curved sides when the draining layer is at a great depth below the surface.

$$2x = \frac{q}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Substituting in the above equation we get,

$$2x = B+Ad \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

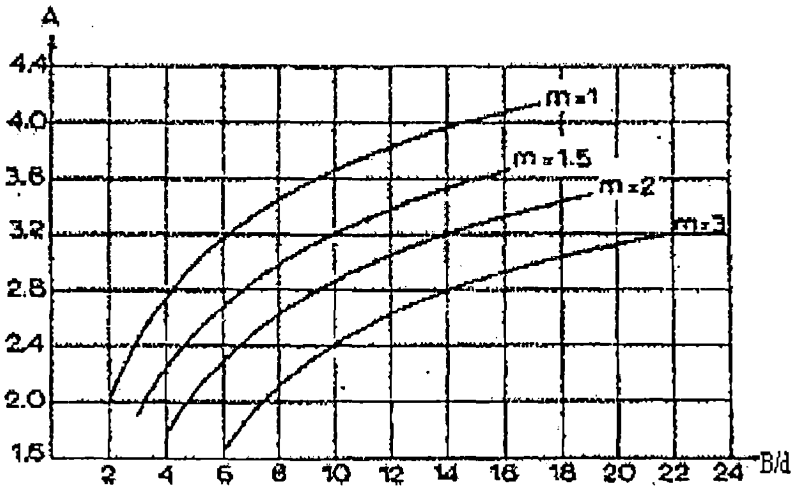

Figure.9: Coefficient 'A' for various side slopes.

The equations (1) and (4) are valid for channels with triangular x-section also.

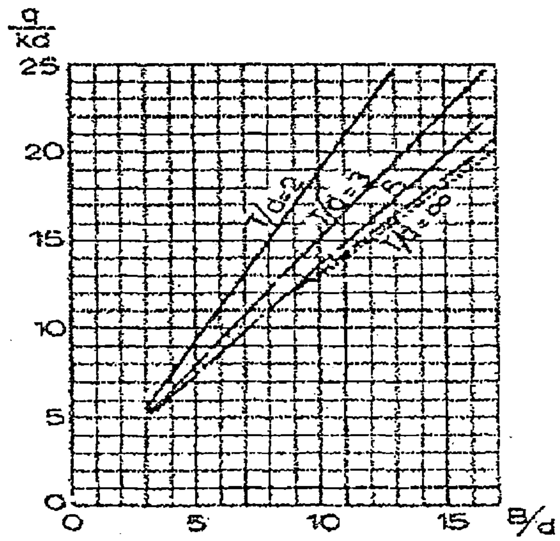

Figure.10: Seepage from a channel when a drain layer is at a small depth .

Muskat had developed a diagram (graph) showing the q/kd as a function of B/d ratio for various values of T/d. This graph is based on the side slope m = 1.5. When the value of m differs from 1.5, say m_1; the value of q/kd obtained from the graph should be corrected as $m_1/1.5$.The value of the side slope also helps in seepage process. The flatter the side slopes or the larger the value of m, the higher the seepage discharge (i.e. The q/kd values) is obtained from small depth method compared to large depth method and vice versa.

However in these two methods it is not indicated that at what depth for practical purposes one method will be invalid and must be replaced by the other. The transition depth recommended by B Z Kinori is as given in eq (2) above. The value of 'To' depends on B, which in turns depends on channel water depth d and side slope m.

$$To = 1.5(B+2d)$$

For the trapezoidal channel, B = (b+2md). In order to deal with dimensionless quantity, let the b/d ratio as x= b/d, substituting in the above equation, we get,

$$To = 1.5(b+2md+2d)$$

$$= 1.5\ (x+2m+2)\ d$$

$$To/d = 1.5(x+2m+2)$$

A graphical solution is developed for the dimensionless function To/d = f (x, m).

When, T/d < To/d, small depth concept is used and

When, T/d > To/d, large depth concept is used.

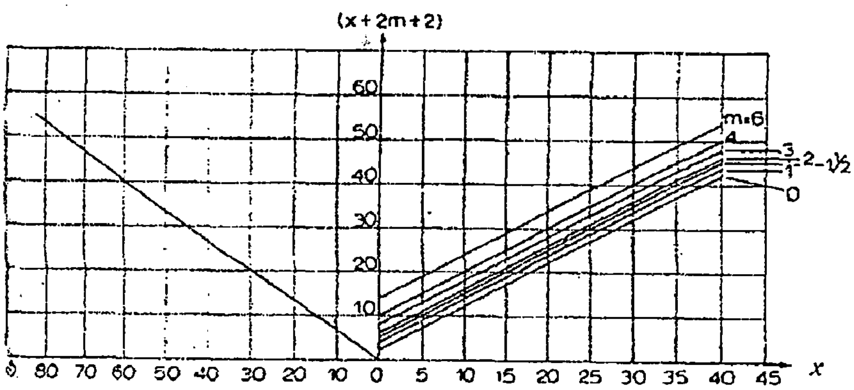

Figure. 11: Determination of the transition depth of the draining layer for seepage calculation.

3.3 EMPIRICAL METHODS FOR SEEPAGE CALCULATION

Empirical equations are generally used for estimating the seepage losses from earthen channels when field experimental observation data are not available. This method holds good for pre-construction seepage estimation. Empirical formulas used in different countries are as follows:

3.3.1 INDIA (ICID_1967)

The formula adopted for calculating losses from a canal is,

$$S = cad$$

Where, S = total losses in cusecs.

a = area of the wetted perimeter in mil. sq. ft

d = depth of water in canal in ft.

c = a constant ranging the value between 1.1 to 1.8 on the basis of the observation made in some important canals in Punjab.

The absorption losses per mill sq ft of wetted perimeter with respect to discharge in the channel is given by,

$$K = 5 * Q^{0.0652},$$

Where, K = losses by absorption per mil.sq.ft. of wetted perimeter

Q = discharge in channel

The total losses in cusecs in a length L ft. of a canal is given by,

$$S = 5 * Q^{0.0652} * W * L * 10^{-6}$$

Where, W & L are the wetted perimeter and length of canal section respectively

According to lacy: substituting the value of $W = 2.66\sqrt{Q}$ and expressing the length (L) in 1000 ft., the formula for total losses takes the form as:

$$S = 0.0133*L*Q^{0.5625}$$

This formula has been used in estimating the seepage losses from unlined canals of Bhakra Canal System.

3.3.2 PAKISTAN

The formula used in Pakistan for estimating the seepage losses from earthen canals is,

$$K = 5*Q^{1/16} = 5*Q^{0.0625}$$

Where, K = absorption losses per mil. sq. ft. of wetted surface in cusecs
Q = canal discharge in cusecs.

3.3.3 UAR (UNITED ARAB REPUBLIC)

The formula used in UAR is,

$$S = CLP\sqrt{R}$$

Where, S = seepage and evaporation losses in cusecs

L = length of canal in km.

P = average wetted perimeter in mts.

R = hydraulic mean depth in mts

C = co-efficient depending on nature of soil varying from 0.0015 – incurring 0.003. In stiffy clay soils co-efficient falls below 0.0015 while in sandy soils it exceeds 0.003

3.3.4 RUSSIA

1. For canals not with direct contact to GWT

$$S = K_B \left(1+\frac{Hk}{2B}\right)(B+2ho)\left(1+\frac{0.60}{\sqrt{t}}\right)$$

Where, S = rate of seepage at time t days from the beginning of seepage

K_B = permeability of partially saturated canal bed (m/d)

B = water surface width in canal in mts

Ho = water depth in canal in mts

$$T = \sqrt{(1.5ho + w1Hk} / Kb$$

Where, w1 = volumetric moisture content of soil

Hk = minimum distance of ground water below bottom in mts

2.For a canal with direct contact to water Table

$$S = 2/\Pi(Ho - To)\sqrt{KTMB}\,/t$$

Where,Ho = initial depth to water Table before seepage in mts

To = critical depth of water surface in canal in mts

K = saturated permeability of canal bed soil (m/d)

T = mean capacity of underlying ground water flow in mts

M = porosity of bed material

B = a width factor, approximately the water surface width in mts

3.3.5 HUNGARY

The formula used for seepage losses from a trapezoidal canal is

$$S = 1700*D_a*H\,(A+Hd)$$

Where, S = seepage loss in cumecs/day/mt.length of canal in permanent region

D_a = active diameter of the soil grains in mts

H = water depth in canal in mts

A = bottom width of canal in mts

D = bed slope of canal

3.3.6 USA

The empirical formula developed by Etchevery B A for unlined canals used in USA is as;

$$Qv = \frac{CmPL}{100}$$

Where, Qv = water loss in cumecs

P = wetted perimeter in mts

L = canal length in kms

C = a proportion factor with the following values depending on the soil as given in the Table 12 below.

Table 12.

Sn	Soil type	Value of c
1	Alkaline	0
2	Impervious clay	0.7-0.95
3	Semi-impervious clay	0.95-1.40
4	Clay loam	1.40-2.05
5	Semi-heavy loam,sandy silt	2.05-2.75
6	Sandy loam	2.75-4.15
7	Loose sand	4.15- 4.85

3.3.7 SEEPAGE LOSSES FROM LINED CANALS

An assessment of probable seepage losses from lined canals can also be made by theoretical methods for steady state condition. The seepage from lined canals depends upon the thickness and permeability of the lining material in addition to the factors contributing seepage losses from unlined canals. The seepage losses (seepage discharge) from the lined canal which is in homogeneous and free from leaky joints is given by:

$$Q = Pk_1 (h_1/t). \quad \dots\dots\dots\dots\dots\dots(1)$$

Where, P = perimeter of the channel

k_1= permeability of lining

h_1 = head loss through lining

t = thickness of lining

The quantity of seepage discharge would flow to the natural drainage through the sub-soil under residual head (h – h1) and is given by

$$q/k\,(h - h1) = f\,(B, d) = C. \quad \ldots\ldots (2)$$

Where, k= permeability of sub-soil material

From equation (1) and (2), eliminating h1 and putting the ratio, r = k/k1, we get the seepage discharge as;

$$Qw = \frac{CPkh}{P + Crt}$$

The free surface due to seepage from the lined canal would have a drop of 'h' through the lining and therefore would correspond to the free surface as obtained for seepage for unlined canal under a residual head of (h – h1). Due to very small quantity of water seeping through the lined canal it would take considerable time to attain steady state condition. For lined canals running intermittently, the steady state condition may not be attainable at all which there by indicating the advantages of lining.

3.3.8 SEEPAGE LOSS VALUES ADOPTED FOR DESIGN OR IN PRE-CONSTRUCTION STAGES IN DIFFERENT STATES OF INDIA (PRACTICES FOLLOWED IN INDIA)

In absence of the field experimental data it is very necessary to assume suiTable seepage loss values for the purpose of design of canals. The seepage values adopted in different states of India are given below in Table 13.

Table 13: Seepage values adopted for canal design in different states of India

Sn	Name of the state	Estimation of seepage losses in cumecs per mil.sq. m.of wp	Remarks: values in bracket represent losses in cusecs/mil.sq.m of wp
1	Andhra Pradesh	1.83, (6)	
2	Bihar	2.44, (8)	Transmission losses in Gandak

			project
3	Gujarat	2.44, (8)	For unlined main and branch canal
		3.96, (3.96)	For unlined dys. and minors
		0.30, (1)	For lined canals
4	Kerala	1.83-2.44, (6-8)	For unlined canals
5	Madhya Pradesh	2.44, (8)	Tawa Project
6	Maharastra	3.48, (15)	When,Q < 250 cusecs, unlined
		3.05, (10)	When,Q > 250 cusecs, unlined
		0.61, (2)	Lined canals
7	Karnataka	2.44, (8)	Unlined canal
		1.52, (5)	Lined canal
8	Orissa	2.44, (8)	Transit losses for main and br. Canals
		10% of the discharge of their off taking channel	For minors and dys
9	Punjab	$P = 5*Q^{0.0625}$	Unlined canal
		$P = 1.25*Q^{0.0625}$	Lined canal
10	Rajasthan	1.83, (6)	For ordinary soil, unlined
		0.61, (2)	For lined canal
11	Tamilnadu	2.44, (8)	Alluvial red soil
		1.52, (5)	Black cotton soil
		3.04, (10)	Decayed rocks or gravels
		0.91, (3)	Rocks
12	Utter Pradesh	$Dq = c\,(B+D)^{2/3}/8$ in FPS units	Dq = losses in cusecs/mile length of canal, c=1,for canals running in rotation and 0.75 for continuous running
		$Dq = (B+D)^{2/3}/200$ in MKS units	Dq = losses in cusecs/km length of canal
13	Mysore	2.44, (8)	-
		1.52, (5)	

14	CWPC Recommendation	2.5cumecs/mil.sq.m. of WP	Unlined
		0.8 cumecs/mil, sq.m. of WP	Lined

3.3.9 NECESSITY OR OBJECTIVE OF MEASUREMENT OF SEEPAGE LOSES FROM EXISTING CANALS

The objective of the seepage loss measurement of canals after use mainly is:

1. To determine the reaches of canal with excessive seepage.

2. To check the seepage in the completed reaches during construction phase with the purpose of predicting seepage rates for the construction of on-going portion and also to modify the design for those parts found necessary.

3. To collect and record seepage rate data from the canal for use in planning and design of other projects in future.

4. To know the quantity of water conveyed in the field and work out the canal efficiency.

3.4 DIRECT MEASUREMENT OF SEEPAGE LOSSES (FIELD MEASUREMENT OF SEEPAGE LOSSES)

In order to have quantitative data, under variable practical conditions, direct measurement of seepage is very essential. Measurement of seepage losses or the conveyance losses is the only way of knowing the quantity of water lost from the open channel system as a whole or in desired portion only. Several methods though are available for seepage loss measurement from canal, each method has its own limitations and the results obtained are quite representative rather than exact. The methods generally adopted for seepage loss measurement are:

1. Inflow-outflow method.
2. Ponding method.
3. Seepage meter method.
4. Tracer technique method.

The first two methods can equally be applied for all sizes of canals, i.e. from main canal up to the watercourse.

3.4.1 INFLOW- OUTFLOW METHOD

The inflow- outflow method for measurement of seepage losses (or overall transmission losses) utilizes the mass balance approach. The quantities of water flowing into (inflow) the test reach and out flow from the test reach of a canal are measured carefully and the difference in the mass balance computation gives the estimate of the transmission (seepage plus others) losses.

In practical conditions, there may be various situations such as the diversion as well as the intervening flows within the selected test reach. In such cases the water flowing into the test reach and the out flow from it has to be measured along with the diversions and intervening inflows as shown in Figure 12.

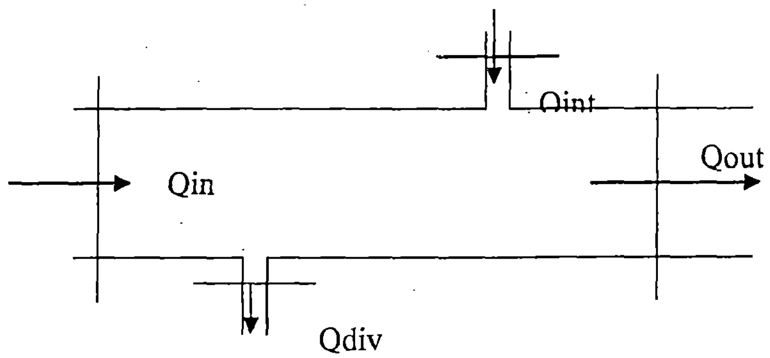

Figure. 12:Showing the intervening and diversion flows in a test reach

The basic equation used in this approach is,

$$Qlt = Qin - Qout + Q\ int - Q\ div,$$

Where, Qlt = quantity of water lost in transmission (seepage plus other losses)

Qin = inflow to the reach

Qout = outflow from the reach

Qint = intervening inflow

Qdiv = total diversion from the canal at the test reach

In cases, where there is no intervening flows or diversions, then the above formula takes the form as,

$$Qlt = Qin - Qout.$$

Existing calibrated weirs and flumes in the canals can be used for measuring the flows but if they are not available permanently (or not constructed in the canals) or are not located at convenient point, temporary gauging stations or weirs can be installed. The ideal gauge site would be the places where the canals have well defined x-sections and straight reaches. Current meters may be used at the gauging stations to measure the velocity from which the rate of flow is estimated. The gauging station should be calibrated if seepage estimation is to be repeated in future too. Then a stage discharge curve can be developed to determine the proportionate discharges.

3.4.1.1 Limitations

The same type and size of measuring instrument should be installed at the observation points (at the beginning and end) so that the biased errors in the instrument (structures) cancel out. Measurements should be taken when the flows become steady. Some time should be given to get the flow stabilized before taking readings; otherwise accuracy in the e measurement shall be disturbed. The measurement should be taken simultaneously in both the observation points.

The losses can be represented in different forms, such as a rate of flow decrease per unit length of canal and is expressed as:

$$Q_L = (Q1 - Q2)/ L$$

Where, Q_L = loss rate per unit length of canal in cumecs/cusecs

Q1 = Flow rate at u/s (entry point)

Q2 = Flow rate at d/s (exit)

L = Length of channel between two observation points in meters.

It may also be expressed in terms of percentage loss in flow per unit length of canal as:

$$Q_{LP} = (Q1 - Q2)*100/Q1*L$$

Where, Q_{LP} = Loss rate in percentage per 'L' meter length of canal.

The loss rate can also be expressed as loss per million square meter of wetted perimeter.

3.4.1.2 Advantages

The following are the advantages of this method.

Reflects actual operating condition.

1. Observations can be made without serious interruption of irrigation scheduling.
2. Equally suiTable for all sizes of canals.

3. Applicable for both lined and unlined canals.

4. During operational conditions, the surface and sub-surface soil conditions are steady, so it provides a direct estimate of overall losses within the entire reach of canal.

3.4.1.3 Disadvantages

The disadvantages are as follows:

1. Trained persons are required to make accurate measurements.

2. It is sometimes very difficult to maintain channel flow in steady state condition for several hours or even days. So monthly, seasonal or even annual measurements should be taken to make the reliable measurements.

3. If existing structures are to be used for measuring discharges, they must be calibrated.

4. During the measurement period if the off-take channel gates are not closed or made water tight, simultaneous measurements of those channels are also to be made involving large number of observation teams, becomes costlier.

5. In cases when the transmission losses are small compared to the discharge of the channel, the measurement error may exceed the seepage loss itself.

6. Since the test is done in a certain reach but the question still remains unanswered as how the seepage loss is distributed in the reach itself.

7. It may reveal representative value rather than exact value.

8. The head loss caused by the measuring device causes more seepage loss than normal. Average loss measured in Pakistan and Colorado, doubled with 5cm. increase in the flow depth (Akram et al.1980, Trout 1979a)

3.4.2 PONDING METHOD

This method involves the creation of artificial pond within the canal reach where test is to be performed by constructing non-leaking bonds both u/s and d/s ends of the created pond. It is also called tapoon method commonly practiced in many countries of the world. The pond is filled with water a bit more than the normal operating level and should be left for sometime for stabilization of water level in the pond at normal operating condition. For the purpose of calculations the reduction in the pond water level from the normal operating level may be measured either by staff gauge or by a water level recorder with respect to the elapsed time till the water level drops enough below the operating level. The water surface width in the pond should also be measured along with the specified time interval of observation to find out the volume of water seeped and leaked.

The frequency of observation should be more or the time interval of taking readings should be less in the beginning because the drop in the water would be more active.
The time interval of observation at start may be decided as per the site condition (soil type) probably not exceeding 5mins and subsequently the rate of declination of water level in canal reduces with time so the time interval for recording may get lengthened (normally 15-30mins) but the recording should be continued till the required water level drops in the pond.

The loss rate is that rate at which the water seeps and leaks from the section ponded and is equivalent to the change in the volume of ponded water with elapsed time. The change in depth in the given time interval times the water surface area also gives the loss rate. A graph drawn between gauge reading verses time and measuring the slope of the curve at the desired depth gives the depth change over time. The change in depth with time at desired depth is multiplied by the top width of the canal; it gives the loss rate per unit length of the canal as:

$$Q_L = \frac{dd}{dt} * T_w * L$$

Where, Q_L = total loss in the ponded length of the canal

dd = change in water depth in cms

dt = change in time(or time elapsed) in hr

T_W = average water top width in canal

L = pond length in m

The seepage from ponding test can also be expressed as:

$$Qs = 24\frac{(e1-e2)}{(t2-t1)} * \frac{Ws}{Wp}$$

Where, qs = estimated seepage rate in cumecs/sq,m/day

e1,e2 = water surface elevations in meter in hrs t1 and t2 respectively

Ws = average surface width (i.e. Water surface width) over length of pond in meter

Wp = average wetted perimeter in meter (of ponded length)

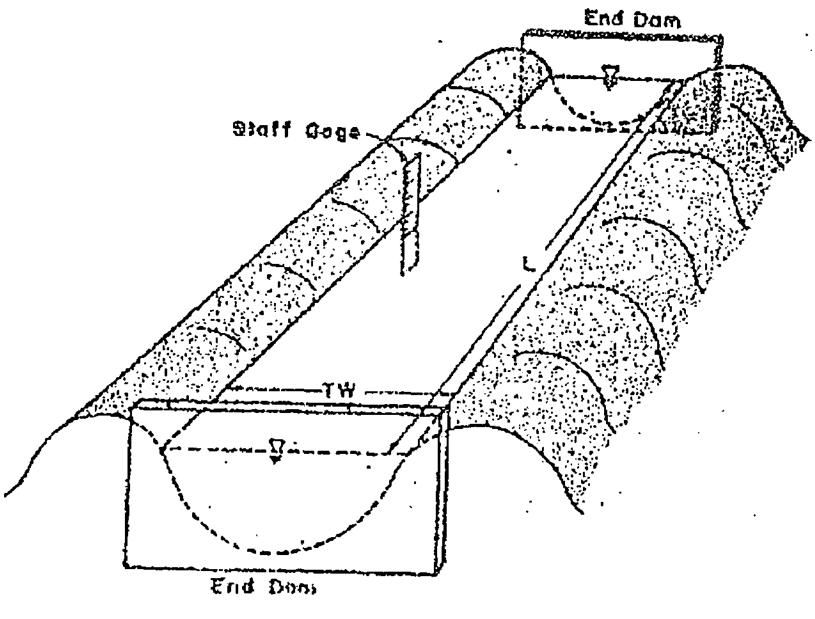

Figure.13: Experimental set up for Ponding Method of seepage measurement.

Source: J.Trout & W Kemper.

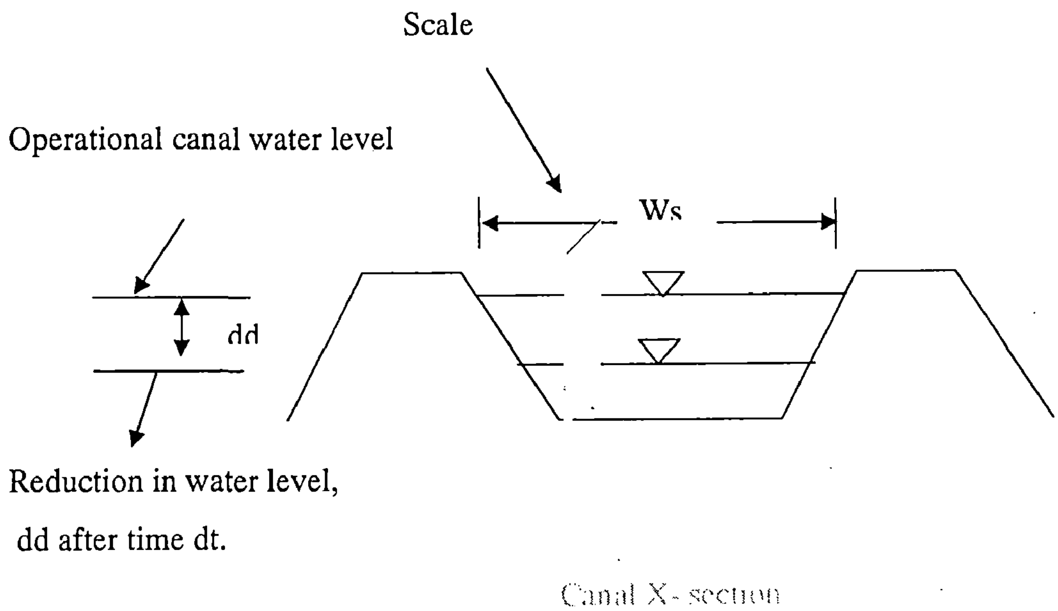

Figure. 14: Water level measurement with respect to elapsed time interval during observation for Ponding Method

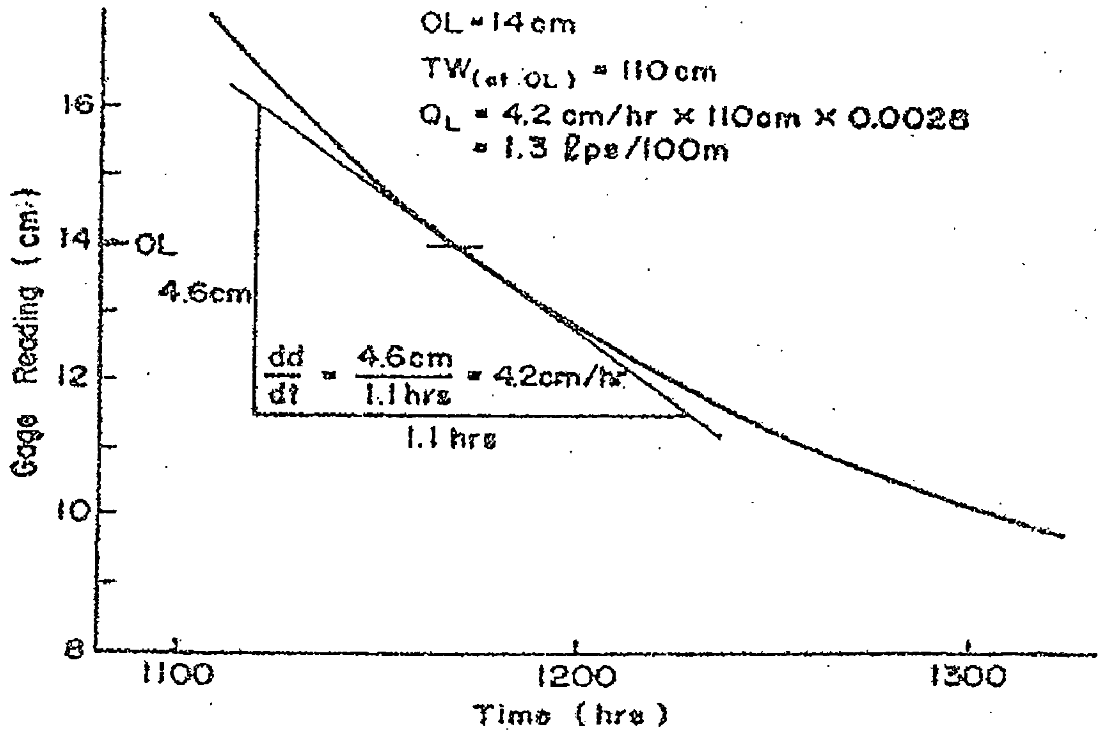

Figure.15: Ponding loss rate calculation- graphical determination of the water surface rate of recession (J.Trout 1980).

3.4.2.1 Advantages

The following are the advantages of this method.

1. The method is simple and the accuracy of the results is generally good but can only measure the loss in short sections.

2. This method can determine that section of the conveyance and distribution system, which is loosing the most water, so helps in isolating the problem.

3. It can be used even during construction stage in completed section of the canal to check for degree of compaction and potential seepage, which may lead to improve work quality.
4. Applicable for both lined and unlined canals.

3.4.2.2 Disadvantages

The disadvantages of this method are as given below.

1. The loss rate varies highly so several measurements have to be taken to find out the accurate rate.

2. Cannot be used while are operating.

3. Does not say any thing about the sediment load in water and its relation to the seepage rate.

3.4.3 TRACER TECHNIQUE METHOD

This method is suitable for homogeneous and isotropic formations. It is less costly than other said methods in view of time, money, study repetition and is a direct approach method for determining the filtration velocity. This method has wide application in different canal conditions like deep canals, canals with turbid water, fast flowing canals, canals with heavy weed growth as well as with different bottom conditions. A radioactive tracer is a mixture of isotopes of an element, which may be incorporated into a sample to make the possible observation of that element either in alone or in combination with a chemical, biological or physical process. The observation is made measuring the radioactivity of the tracer used.

The methods generally used for determining the subsurface flow-using tracer are:

1. Double well method

2. Single well pumping method.

3. Single well dilution method

3.4.3.1 Double well method

In this method the tracer in injected in one well and the observation is taken in another well for the tracer. The distance between two wells is known. The second well or the observation well should be located at a down gradient.

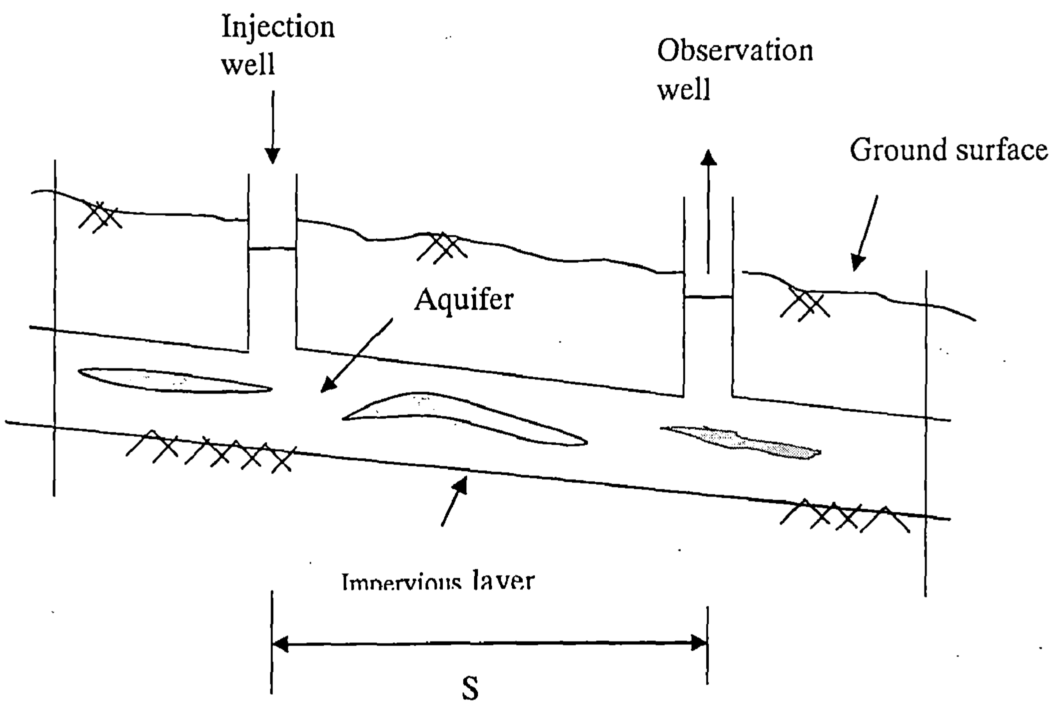

Figure.16: Showing the double well method arrangement

The concentration of the tracer at the observation well is monitored regularly and the time of peak concentration from the time of injection is noted. Then the velocity of flow is calculated as:

$$V = S/T$$

Where, V = the velocity of flow

S = distance between two wells

T = time elapsed from the start of tracer injection till the time of peak concentration.

From Darcy's law, Q = AV = Aki, the seepage discharge can be found out, where 'i' is the hydraulic gradient.

This method is more suitable for high permeable soil and for heavy soils (silty,clayey), the permeability being low or flow is very slow within it, much time will be required to get results.

3.4.3.2 Single well pumping method (pulse method)

A small quantity of tracer is added into the aquifer through a well and is left behind for sometime (generally for known pre-fixed time interval) in order to allow the tracer mix and move along with the natural flow of water in the soil strata. After the elapsed of the pre-fixed time, the tracer is recovered by pumping the water from the same well and is monitored continuously for the radioactivity or the concentration of the tracer. The time elapsed between the injections of the tracer and pumping and the pumping rate of water should be recorded. The flow rate (pumped discharge) when becomes steady (constant) and the presence of the tracer is traced, the subsurface flow rate (seepage discharge rate) can be calculated.

This method is suitable for the areas where more than one well is costlier to drill as well as the availability of volume of water in the well is much high.

3.4.3.3 Single well dilution method

In this method a radiotracer is injected into a well and the dilution of the tracer (concentration extent) is recorded with time after injection. The basic principle of this method is that when the tracer is added to the water in the well it nixes with water uniformly and flows along with water in subsurface flow direction. The fresh water flowing into the well and the tracer mixed water flowing out of the well decreases the concentration extent of the tracer in the well water or gets diluted but the volume of water remains the same. The decrease in the concentration of the tracer with the inflow of fresh water in the well flows an exponential law. The filtration velocity Vf of the horizontal flow of water, supposing all other flows avoided in the well is given by:

$$Vf = \prod d * \frac{\ln(Co / c)}{4\phi t}$$

Where, d = diameter of the bore

co,c = concentration at initial stage at t=0 and final stage

t = time elapsed

$\phi = 2$ for the bore or well without strainer or gravel

The seepage losses can be calculated by determining the horizontal filtration velocity in case of (i) finite depth of porous media, while for (ii) infinite depth of media, from Darcy's law the permeability of the media can be determined by knowing the filtration velocity and local hydraulic gradient.

3.4.4 SEEPAGE METER METHOD

Seepage meters are the suiTable devices for measuring local seepage losses from canals and ponds and generally are used for investigation purpose such as determining the seepage losses in different reaches (section) of the canal. The advantages of the seepage meters are:

1. Seepage meters can be used inside water also and it does not disturb the normal canal operation.

2. Seepage losses from bed as well as from bank of a canal can be measured by seepage meters

3. They are economical in use and also give fast results.

Several types of seepage meters are available in use for seepage measurements. The seepage meters are designed on the principle that the rate of water lost in an isolated surface area of the canal can be measured, provided the water head acting on that area is equal to or identical in nature to the head acting simultaneously on adjacent surface. The submerged flexible bag of the meter developed by Salinity Department of Agriculture, the Well Hook Gauge of the soil conservation service and the variable head seepage meter developed by Bouwer are in use. The UPIRI (UP irrigation Research Institute),Roorkee has developed a seepage meter with constant working head which works on the principle of Marriotte Tube. This is an improvement over the other seepage meter.

The seepage meter designed by UP Irrigation Research Institute, Roorkee is as shown in the Figureure below. The Mariotte siphon principle is used to maintain the constant head of water over the confined area with in the seepage cup (enclosed by the seepage cup) of canal perimeter. Water is supplied to the cup from the burette acting as Mariotte vessel, which also acts as a reservoir. As the water flows out from the vessel (burette) into the seepage cup the water level inside the burette falls down due to the inflow of air into the vessel. The amount of air drawn inside the vessel would adjust itself in a manner such that the combined pressure of water and air inside the vessel at the point E is equal to the canal water surface level during the seepage loss measurement observations because the pressure inside the seepage meter will be equal to the outside pressure.

In the field while taking seepage loss measurement bt seepage meter, the seepage cup is lowered into the canal with its air valve open to allow the entrapped air to escape. The valve then is closed and the seepage cup is gently pressed to the canal bed until the baffle plate comes in contact with the bed of the canal. The tube of constant head vessel is then taken out and the vessel is filled with water up to the top ensuring that all the air entrapped inside the plastic tube is expelled before any observation are taken. The tube is then replaced and the vessel is then clamped to the stand in such a way that the lower end of the tube is in level with water inside the canal. The fall in water level of the gauge tube during a known period of time is noted. From the observed fall in water level, the seepage losses can be calculated.

3.4.4.1 Advantages

1. It is a cheap and quick method of seepage measurement.

2. The normal working of canal is not disturbed.

3. The seepage meter gives the seepage losses from the area enclosed within the seepage cup if the pressure balance inside and outside of the cup and minimum disturbance to the canal bottom (bed) soil is maintained.

3.4.4.2 Disadvantages

1. Since the loss measured is limited for a small area (area enclosed by the cup) and there may be varying soil conditions from point to point, so a number of measurements have to be taken in order to get an average measure of seepage losses.

2. The use seepage meter is difficult in case of deep canal, fast flowing canals and canals with turbid water.

3.4.5 HYDRAULIC CONDUCTIVITY

The USBR experience shows that simple equation, based on seepage theory can reproduce measured canal seepage rates within 15 %, provided that all the necessary field data have been obtained. i.e. seepage value obtained by empirical equation is equal to +/- 15 % of the measured (experimental) value. This approach should be used only if the soil in, under and adjacent to the test section is thoroughly described, tested for hydraulic conductivity and water Table level in relation to the canal is monitored.

3.4.5.1 Advantages

1. Reflects actual operating (dynamic) conditions.
2. Provides seepage estimates, which need not be corrected for evaporation.
3. Observations can be made without interruption of irrigation scheduling.
4. Suitable for all sizes of canals.
5. Requires less resources (money and manpower).

3.4.5.2 Disadvantages

1. Well-trained personnel competent for performing in-situ hydraulic conductivity test with knowledge to engineering aspects of ground water flow.
2. In the sites where two or more canals exist, it may be very difficult or even impossible to estimate the separate contribution of seepage individually.
3. It is very difficult to quantify seepage for relatively short section of canal.
4. Theory not applicable to lined canals but ground water studies can provide values from lined canals but normally time taken will be longer.

3.4.6 COMPARISON OF DIFFERENT METHODS

Table 14: Comparison of different seepage measuring methods

Sn	Inflow-outflow	Ponding method	Seepage meter	Tracer technique	Hydraulic conductivity	Remarks
1	Reflects actual operating condition of canal	Applicable for static condition only	Test is done in actual operating water level in canal	Side wells are constructed and the relative seepage of the underlying layer is found out	Reflects canal operating conditions	No entirely satisfactory method for measuring the seepage has been developed yet. The measurement done by the methods available however indicate the magnitude of seepage rather than the precise quantitative value
2	Test can be performed without interrupting the irrigation schedules	Canals should be closed for performing experiments or experiments cannot be done in operating condition	Test can be done in canal running condition	Done in operating condition	Observations can be made without disturbing irrigation schedule	
3	Suitable for all sizes of canals	Difficult and costlier for bigger canals (making end dams	Not suitable for deep, fast flowing and turbid canals		Suitable for all sizes of canals	
4	Applicable for both lined and unlined canals	Applicable for both lined and unlined canals	Applicable to unlined canal in general		It will take longer period of time for basic ground water distribution to find out seepage	

5	Trained persons are required to make the accurate observations specially for the use of current meter	Ponds may have to be filled several times before seepage rate become stabilized	Loss measured is limited to a small area, so a number of observations have to be taken to predict the average seepage loss		Well trained and competent in performing in-situ hydraulic conductivity tests and supervising personnel competent in aspects of GW flow	
6	Monthly, seasonal or even annual measurement should be taken for reliable measurements because it may sometimes be very difficult to maintain channel in steady state condition for several hours or even days	This method does not say anything about the velocities and sediment load of operating conditions	Seepage meters are not suitable for canals having rocky or rubbly bed and flow velocity more than 2ft/sec	It measures the horizontal filtration velocity from which seepage losses can be roughly estimated	In locations where two or more canals exists it may be very difficult or impossible to estimate the seepage contribution of individual canal	

3.5 ADVERSITY BY SEEPAGE

3..5.1 WATER LOGGING AND SALINISATION

General definition: As per CBIP, the water logged area is defined as " an area is said to be water logged when water Table rise to an extent that soil pores and root zone of a crop become saturated resulting in restriction of natural circulation of air decline in level of oxygen and increase in level of carbon dioxide. The water Table, which is considered harmful, would depend upon the type of crop, type of soil and quality of water. The actual depth of water Table, when it starts affecting the yield of the crop adversely, may vary over a wide range from zero for rice to about 1.5 mts for other crops."

In India, it may be said that the first attempt made for seepage estimation (or water logging) was in 1876, when Red Commission was appointed to study about the deterioration of land that were once fertile. The Red Commission found out the reasons for the deterioration of the land because of the construction of big canals and extensive use of irrigation (ie water logging due irrigation). The First Irrigation Commission, formed in 1901, also suggested measures for controlling the water logging due to irrigation canals. In 1925,Punjab Govt. formed a Water Logging Engineering Committee and much drainage works were carried out with the help of IDA prior to 1964. Similarly Bombay PWD in 1916 took the initiation to study the problems of water logging due irrigation in Decan areas by forming special Irrigation Research Development Division, but all the works were limited to the local area only, until 1972, when the Irrigation Commission made its first attempt to collect the state wise data about the water logging due seepage and afterwards followed by National Agricultural Commission1976 and Ministry of Agriculture 1990.

The available data show that there is no uniformity in the norms in defining water logged areas and there by the measurement and extent of water table below ground level is adopted differently by different states on India, which are given in Table 15 below.

Table 15: Norms for categorization of water logged area in different states of India

Sn	States	Water depth below G. L. in meter
1	U. P. Sarada Sahayak Project	
	(i) Worst zone	<1.0
	(ii) Bad zone	1-2
	(iii) Alarming zone	2-3
	(iv) Safe zone	>3
2	Punjab	
	(i) Very critical	0-1.5
	(ii) Critical	0-2
3	Haryana	
	(i) Critically water logged	0-1.5

	(ii) Moderately water logged	1.5-3
4	Tungabhadra command	0-2
5	Himachal	0-2
6	Maharastra	
	(i) Fully water logged	Water at surface
	(ii) Water logged	0-1.2

Source: Navalawala, BN (1990), keynote address in all India Seminar on 'water logging and drainage' -IE (U), Roorkee.

The norms adopted by " The Central Ground Water Board, Ministry of Water Resources, GOI, for water logging, is the area where water Table occurs within 2.0 mts of the land surface and areas where the depth of water Table is within 2-3mts below GL are considered potential areas for development of water logging.

3.5.2 SALINITY AND ALKALINITY (SODICITY AND ALKALINITY HAZARDS)

Alkalinity is serious problems in irrigated soils. The high sodicity and PH adversely affect the physical properties of the soil. The infiltration of such soil reduces drastically resulting in either stagnation or high run off. The production rate of such soils is also very less in general but the salt resistant crops may be grown.

In the Figure 17, given below, shows that the infiltration rate of the reclaimed soil is higher than that of the unreclaimed soils.

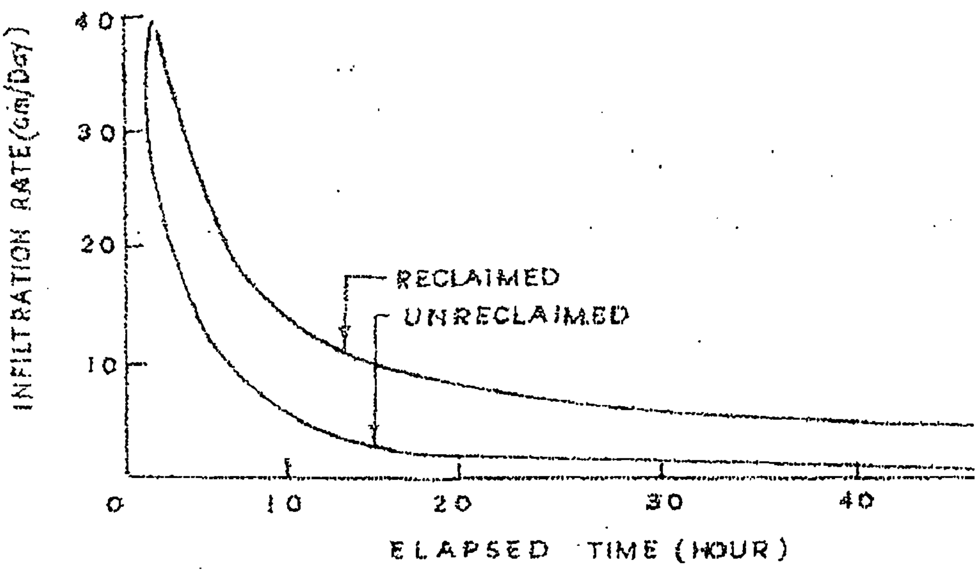

Figure.17: Infiltration rate curve for reclaimed and unclaimed lands. Source, Tyagi, 1980

3.5.3 CAUSES OF WATER LOGGING

The general phenomena of water logging are caused by the rise of sub-surface (sub-soil) water table, which takes place when inflow to it exceeds the outflow from it. There may be several reasons of water logging as:

1. Excessive seepage from canal and distribution network, irrigated fields and ponds and seepage from over irrigated fields.

2. Inefficient water management, adoption of heavy-duty crops resulting excess water supply to irrigated fields.

3. Lack of conjunctive use and selection of proper irrigation methods.

4. Lack of efficient land management such as land leveling and land grading.

5. Inadequate as well as poor design and maintenance of drainage network.

6. Unfavorable sub-soil geology and poor drainage outlets (ie hard pan at shallow depth).

7. Obstruction of free surface runoff from the area due to embankments for roads, rails, canals etc.

8. High infiltration capacity of the soil, thereby more recharge to GW.

9. Low ground water abstraction.

10. Undeveloped drainage due flat topography and absence of natural drainage.

11. Aquifer unable to dispose off the surplus water laterally.

12. Chocking of drains.

3.5.4 EFFECTS OF WATER LOGGING

The ultimate aim of irrigation is to increase the crop production but if due care is not given to use the water in the fields, crops yields are affected adversely by water logging and land become infertile as well as uncultivable due;

1. Obstruction in adequate air circulation within root zone depth.

2. Reduction in temperature obstructing in germination and seedling growth.

3. Accumulation of soil bacteria.

4. Reduction in crop growth due excessive weed growth.

5. Farming operation become difficult.

6. Salinity/Alkalinity may also develop.

7. Deterioration of land quality.

8. Reduction in production.

9. Huge economic loss.

Besides the above said ill effects on agricultural system (or cropping system), it equally affects the human life as well as the physical properties as:

1. Water logged area provide a good environment to mosquitoes breeding resulting malaria diseas to the people living around, high humidity.

2. Water pollution or contamination would cause dieses like diahorrea, dysentery etc.

3. Creation of unpleasant (unhygienic) environment for living.

4. Reduction in soil bearing capacity resulting danger to settlement of buildings, bridges, roads, rails etc.

5. Ponding even due to slight rain.

3.5.5 EXTENT OF WATER LOGGING

Presently, there is no uniformity in defining water logged area and measurement of ground water table level to provide reliable data for total area affected by water logging. The statistics in this regard become further questionable due many variables like type of crops, type of soil, quality of water, climatic conditions, GWT status and so on.

3.5.5.1 Waterlogged area in different states of India

The extent of waterlogged area estimated by various agencies in India is produced in Table 16 below:

Table 16: Extent of waterlogged area estimated by various agencies (in lakh hectares)

S n.	Name of the state	As per National Commission on Irrigation (1972)	As per National Commission on Agriculture (1976	As estimated by Ministry of Agriculture (1990)
1	Andhra Pradesh	NR	3.96	3.39
2	Assam	NR	NR	4.50
3	Bihar	NR	1.17	7.07
4	Gujarat	NR	4.84	4.84
5	Haryana	6.50	6.20	6.20
6	J&K	NR	0.10	0.10
7	Karnataka	0.07	0.10	0.10
8	Kerala	NR	0.61	0.61
9	Madhya Pradesh	0.57	0.57	0.57
10	Maharastra	0.28	1.11	1.11
11	Orissa	NR	0.60	0.60
12	Punjab	10.9	10.9	10.9
13	Rajasthan	NR	0.18	0.18
14	Utter pradesh	8.10	8.10	19.80
15	West Bengal	18.50	18.50	21.80
16	Delhi	NR	0.01	0.01

Remarks: NR: not reported

Source: *Salinity and reclamation in water management S Dinker, Seminar i n Irrigation Water Mgmt, Vol – 2,1992.*

The table above shows that the water logging problem is in increasing trend in Bihar and Utter Pradesh while in other states, it is remaining constant, resulting the wastage of resources invested in irrgation development as well as degrading the land quality and thereby incurring much loss in the national treasury.

The best example of this is the Muktsar area of Punjab as reported by 'Hindustan Times, Sunday, February 2004,Muktsar areas waterlogged once again. The loss incurred is presented in the tabular form below (Table 17).

Table 17: Water logging problem of Muktasar area

State	Year	
Punjab – Muktasar District area, under the command of Rajasthan Feeder canal and Sir hind Canal	1990	2004
	Water logging for continuous 8 years in late 'NINETIES'	Same problem as of NINETIES is re-occurring
	Damaged standing crop of 1.04 lakh acres (42100 hectare) of Muktsar district	Drains are chocked and not cleaned
	Rupees 273 crores, sanctioned in 1997, to construct drains for removal of water. 13 main drains of total 307.8 kilometer and 34 link drains of 175-kilometer was build.	Tube wells not functioning due non-payment of electricity bill
	500 tube wells were constructed to pump water to Sir hind Canal	-
	90,000 acres of water logged land was reclaimed	-

3.5.5.2 Ground water table position in Pakistan

In Pakistan the problem of water logging scenario is as given in Table 18 below.

Table 18: Area under various water Table depths (% of CCA), in Pakistan

Sn	Year	<1.5 m	1.5-3 m	> 3 m
1	1978	11.9	39.5	48.6
2	1982	13.5	43.2	43.3
3	1986	13.0	41.0	46.0
4	1988	9.0	38.2	52.8
5	1990	13.2	36.2	50.6
6	1992	18.3	32.6	49.1
7	1993	16.2	35.7	48.1
8	1994	12.0	36.0	52
9	1995	12.3	36.9	50.8
10	1996	10.4	40.1	49.5
11	1997	17.2	33.2	49.6
12	1998	14.7	36.6	48.7
Average		13.50	37.4	49.1

Source: Water Resources situation in Pakistan, Challenges and Future (SMO unpublished data).

Water logging is also caused by the recharge of GWT due to seepage losses from unlined channels, irrigation return flow and also by ground water irrigation. This is presented in the Table 19 below.

Table 19: Return flow from irrigation

Sn	Water logging due recharge from the canals	Seepage value
1.	Unlined canals (a) Normal type of soil	6 – 8 cusecs /M m^2 of wetted area of canal
	(b) Sandy soil	10 cusecs /M m^2 of wetted area of canal
2.	Lined canals	20 % of the above value
3.	Return seepage from irrigation	35 % of the water delivered at outlet for application in the field
	(a) Irrigation by surface water	

	sources	40 % of the water delivered at outlet for paddy field
4.	Irrigation by ground water	30 % of the water delivered at outlet
		35 % for paddy irrigation

In all the above cases return seepage figures include losses in the field channels and these are not to be accounted separately.

CHAPTER – 4

MEASURES TO CONTROL SEEPAGE LOSSES

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MEASURES TO CONTROL SEEPAGE LOSSES

4.1 GENERAL

Seepage in nature is a complex process and many factors contribute to it. The individual contribution of the these factors practically is very difficult to find out, however, an irrigation distribution system to in excellent working condition it has to be thought carefully in different phases of development.

Planning is the primary cause of any project to be successful, therefore proper care should be given in the process of (i) planning of the network (ii) alignment of the network (iii) design of channels and related structures (iv) construction of the network (v) lining of the channels (vi) involvement of Water Users Association (WUA), of course for all phases, which are discussed subsequently

4.2 PLANNING OF THE NETWORK

During the planning of the distribution network of an irrigation system to control or minimize the seepage losses the essential study or the data required are:

4.2.1 GOOD SOIL SURVEY OF THE PROJECT AREA

The detailed soil survey often is either neglected or overlooked by the engineers and planners at the project perception period or even in the feasibility study period. This might be the root cause of seepage. Soil survey report with description soil texture, porosity, density, depth, permeability range etc helps the planner, at first hand, decide the proper alignment of the canal avoiding the seepage prone areas to the possible extent as well as decide the alternatives possible if such areas could not be avoided. The foresee of such problems could contribute the planner to manage (include) the extra cost required to make the stretch of the canal impervious resulting the longevity of the canal structure with required efficiency too. Moreover such areas are of more concern for the users and water managers for proper care take for operation and maintenance so that the farmers may not suffer with economic losses. The moisture holding capacity of the soil and wilting point fixation may help the planners and water managers to decide and plan accordingly the frequency of watering to the crops without water wastage or even to decide the farm stream size.

4.2.2 GROUND WATER TABLE

The GWT position and its fluctuation is also an important factor in planning. The average rainfall in the area, the sub-surface inflow from outside may add to the causes of sub-surface water level rise. The topography, less or no drainage or very poor and obstructed drainage accelerate the temporary level rise. The anticipated theoretical seepage amount from the canals is the additional contributor to cause ground water Table (GWT) rise.

4.2.3 ESTIMATED SEEPAGE (PRE-CONSTRUTION ESTIMATION) OF NEAR BY AREAS

The theoretical estimation of the seepage, though gives range flexibility for estimation but if the actual field estimated seepage data could be available it will help much to near exactness of predicting the probable values of anticipated seepage correlating the field conditions. If seepage extent comes within tolerable range, unlined canals may be planned. The pre- construction permeability tests may otherwise be the deciding factor. The recommended values of transmission losses by (CWPC) for different soil types are as given in Table 20 below may otherwise be considered.

Table.20: CWPC recommended values of conveyance losses for different soils

Sn	Type of soil	Transmission losses/Mil sq. m of WP in cumecs
1	Rock	0.90
2	Black cotton soil	1.85
3	Alluvial soil	2.75
4	Decayed rock or gravel	10.0

Note: In general soils (even hard and impervious type of soils), for unlined canals, the transmission loss is taken @ 2 cumecs/mil. sq.m of wetted area of the canal section. By lining this may reduce to 0.3 cumecs/mil.sq.m of wetted area.

4.2.4 WATER AVAILABILITY, CROPPING PATTERN, CROPPING INTENSITY

The year round normal flow/ discharge available at the source of supply is the deciding factor for area coverage. More coverage of area than the water availability will create the social conflict between the head and tail enders resulting more wastage as well as seepage of water. The anticipated cropping pattern and the cropping intensities are the major factors to decide the water that should be made available for crop water requirement for healthy crop growth. When the planning could not balance between the water requirement to crops and the water availability, the equiTable, adequate and reliable deliveries could not be met with, resulting pilferation of water by farmers; non-cooperation towards the system management and even and even the deliveries may not be accepted by the users. The main objective of the irrigation to serve the farmers with required water will not be fulfilled and this may indicate and lead to the unsuccessness of the system.

The land leveling as well as land consolidation may also contribute to seepage control to a substantial extent. The field channel lengths and drainage network may get reduced. On- farm development works would be accelerated; water use efficiency would be increased. Extension services, field trials and demonstrations about the seeds, fertilizers, insecticides, and pesticides water use and relative yields etc. would be easy and effective and have practical impact on the farmers about the farming techniques.

4.2.5 MODE OF CANAL OPERATION

The main purpose of operating is to manage and maintain the water supply as how much, when and how long is required to meet the crop water demand (crop- water requirement) as per the cropping pattern which should be finalized at the conception stage itself. In this regard, National Water Policy (1989), India, has emphasized in its articles as:

30.3.1. (a). Water allocation priorities are broadly classified as:

1. Drinking water

2. Irrigation
3. Generation of hydropower
4. Navigation
5. Industrial and other uses

30.3.2. (b). Irrigated and coordinated of surface water and ground water with their conjunctive use, should be taken into account right from the planning stage and should form an essential part of the project.

30.3.2. (c). Water allocation in an irrigation system should be done with due regard to equity and social justice. Disparities in the availability of water between head reach and tail end farmers and between large and small farms should be obviated by adoption of a rotational water distribution system and supply of water on a volumetric basis subject to some ceilings.

Accordingly, two systems of canal operation are practiced in India, which are (1) Demand based system of operation (2) Supply based system of operation.

In northern plains of India, supply based system is in practice while in southern states, demand based supply is adopted. The two systems can be compared for seepage concern as given in Table 21 below.

Table 21.Comparision of flexible and rigid system of irrigation water distribution

Sn	Demand based	Supply Based
1	It is a flexible system	Fully rigid system
2	The parameters of flexibility are: - Quantity (Volume) - Rate of supply (Discharge) - Duration (Time span) - Interval of supply	The aim is to distribute the benefits of irrigation in an equiTable manner among the users with a view of meeting the social objective of irrigation. Small land holdings and

		diversified cropping pattern make difficult to provide the water to individual farmer on demand
3	Schedules of deliveries are controlled by users (farmers)	The deliveries are either controlled by the project or by the group of farmers (WUA)
4	Best use of water, less leakage and seepage	Seepage losses is more
5	Pre-decided cropping pattern	Usual or diversified cropping pattern

4.2.6 ROLE OF USERS (FARMERS/WUA)

The end users of irrigation are the farmers. Their existence and participation with due regard and weightage should be incorporated in planning stage. Their roles and responsibilities assignment in all phases of the project, their capability enhancement, motivation, incentives etc should be the considering aspects in planning phase. In this regard National Water policy, 1987,India has indicated as:

> 30.3.4(d). Efforts should be made to involve the farmers progressively in various aspects of management of irrigation systems, particularly in water distribution and collection of water cess.

In the absence of prescribed national policy, in most of the developing countries including India, the offenders who pilfer water and damage the canals often go unpunished. So even for farmers or WUA, to keep them within legal bindings a national water policy with all legal details may have to be evolved. In the same context, Indian National Water Policy, 1987, has suggested that:

> 30.3.5. In framing such a policy the following factors need be taken into account

1. The water allocation/allowance based on agro-climatic parameter in different parts of the state.

2. Intensive verses extensive irrigation and equity in water allocation.

3. Benefits and dis-benefits of irrigation on ecology and environment.

4. Integration of ground water and minor irrigation system tanks into main system.

5. Government – farmer interface.

6. Participatory management of farmers in main system operation.

The performance of most of the irrigation systems is considerably below optimal though the massive investment has been done in this sector. The reasons may be several but the main are the users and the question of why WUA is necessary is to be answered properly. The probable reasons are:

1. Increase the efficiency of water use.

2. Increase the level of water charge payment.

3. Reduce the extent of damages to the structures in the systems.

4. Reduce the water pilferation frequency.

5. Convince farmers follow up crop plans (pre-planned).

6. Make farmers adhere to water distribution schedule.

7. Reduce level of conflicts between the government and farmers/WUA

8. Increase feelings of ownness towards the project.

Conclusively, the WUA is necessary to balance between the rights and responsibilities about the irrigation system used.

4.2.7 RESPONSIBILITIES OF WUA

The efficient water control and management become possible only when the WUA maintain their degree of responsibilities for project sustainability. The responsibilities of WUA include:

1. Equitable water distribution among themselves.

2. Routine maintenance of the system- to the assigned level.

3. Timely payment for water delivery.

4. Collection of water charges.

5. Prompt communication of relevant information to Govt. Irrigation Organization.

6. Environmental improvement and maintenance.

7. For minor projects, preparation of irrigation and watershed resources use plan.

4.2.8 RIGHTS OF WUA

Adequate legal provisions should be made for the proper rights of WUA for motivating them in active participation in different phases. The right to WUA should include in general as:

1. The right to participate in planning, prioritization and implementation at least at micro level of any construction.

2. The right to clear and defensible water right.

3. The right to information about water availability.

4. The right to timely and reliable water supply.

5. The right to enter in binding negotiations with the government on water scheduling, quantities and quality.

6. The right to federate and have representation in main system management in jointly managed systems.

7. The right to make contracts and earn profits.

8. The right to make contracts with other parties/agencies.eg with the irrigation department for maintenance and repair.

9. The right to evolve multipurpose functions such as supply of inputs or marketing of produce.

10. The right to hire their own technical staffs to operate and or maintain the irrigation system.

11. The right to see the budget the government spends on the system operation and maintenance.

12. The right to obtain loans for system repair and improvement (autonomy in financial administration and management).

13. The right to develop and manage ground water on a community basis.

14. The right to appeal to conflict resolution institutions for redressal of grievances.

15. The right to elect their own leader.

4.2.9 RIGHTS AND RESPONSIBILITIES OF ID (IRRIGATION DEPARTMENT)

4.2.9.1 Rights of ID

1. Partial and proportionate recovery of capital cost of irrigation system on mutually agreed norms.

2. Inspection of physical system.

3. Recourse to redressal of grievances with the WMA (Water Management Association) through mutually agreed arbitration.

4. Information regarding the WMA and equity aspects.

5. For minor irrigation projects, the right to information regarding the WMAs irrigation and watershed resource use plan.

4.2.9.2 Responsibilities of ID

1. Main system operation to deliver assured, predicTable and reliable irrigation supply to the WMA at the minor level.

2. Provision of fund and technical advice to WMA for special repairs below minor.

3. Granting repairs and rehabilitation contracts to WMA on a priority basis.

4. For minor projects, joint development with the WMAs of the irrigation infrastructures to be subsequently turnover to the WMAs.

5. Training to ID and CADD officials, office bearers of the association and society members.

6. Financial support to the societies (WUAs/WMAs) to be withdrawn in phased manner.
7. Gradual conversion of single purpose societies to multipurpose societies.
8. Greater flexibility and simplicity in formation and registration of societies.
9. Identification of committed leadership.
10. Continuous interaction and dialogue with farmers, water managers and other ID officials.

4.2.10 INTEGRATED ROLES AND RESPONSIBILITIES OF GOVERNMENT AGENCIES AND FARMERS

The ultimate objective of maximization of agricultural production with efficient water use depends upon the integrated efforts of:

(a). Farmers

(b). Agricultural support programme from Agriculture Department (or Agri.Support Staffs).

(c). Engineers from ID or CADD.

The integrated roles and responsibilities of government agencies and farmers in given in Table 22 below.

Table 22. Roles and responsibilities of Farmers, Agricultural staffs and Engineers

Sn	Farmers	Agricultural Staffs	Engineers (ID/CADD)
1.	Level and shape the land and extend the field channels	Provide appropriate extension services to farmers on land shaping, water application, farm drainage, operation and maintenance of on-farm system, crop planning and input management.	Irrigation engineers to provide irrigation supplies at the designated points at: - Reliable - Predictable and - Equitable basis
2.	Plan crops to make the best use of allocated water delivered to them	Organize timely and adequate supply of inputs to farmers (such as fertilizers, pesticides, bank credits, etc.)	
3.	Use appropriate farm technology (right tools, improved seeds, required fertilizer, pest and weed control etc.)	Assist in providing adequate ware- housing and market facilities.	
4.	Learn to share water fairly and then co-operate with other farmer	Give advice to scheme managers and engineers on irrigation schedules	

Source: S satish and Sunder

Remarks:

1. Given the proper incentives farmers will rise to challenges.
2. Efficient and productive canal water results participatory and self-regulatory irrigation management integrated with farmers' way of life.

3. Regarding WUAs, as equal and independent parties to ID will boost morally the WUAs feelings to the project ownness.

4. Efficient system operation and timely required maintenance will motivate farmers take care of system sustainability.

4.2.11 Preparation of MOU (memorandum of understanding) for normal and emergency works

The memorandum of understanding between ID and the WUA for normal and emergency works and compensation to crops damage due any mishap make both organization and the farmers responsible and faithful about the system look after. The process and procedures of the maintenance with the specified percentage of participation of the users (both in cash and kind) should also be mentioned in the memorandum. The water distribution, water cess collection and the percentage of the collected amount to be spent by the users for the betterment of the project is the critical aspect to addressed carefully.

4.2.12 Monitoring of the system with periodic evaluation

The time–gap evaluation of the system by qualified independent persons/institutions and the feed back from such studies should carefully be analyses on the basis of which required rectification in the system be carried with due weight to keep the system in good health for serving users to its optimal capacity.

4.2.13 Land acquisition, right of way, land compensation

The land acquition should be made with the consent of the owner(s) convincing him/them about the direct and indirect benefits that would bring by the project to be executed. The land so obtained be given proper compensation and in case any owner if has to become ousted, should get additional cost for his resettlement as well as a job in the programme. The land should be dagbelted for controlling the encroachments by the local inhabitants.

4.3 DESIGN OF THE DISTRIBUTION NETWORK

In designing the canals, the foremost consideration should be the discharge required to commend the land assessed. The velocity with other canal parameters, considered properly should evolve hydraulically most efficient canal section. Designers need specific field information to decide when canal should be lined as well as to decide to decide how to protect both the unlined and lined canals from structural and hydraulic failure. The determination of non-scouring and non-silting velocity in the canal with least wetted perimeter is the required objective to be fulfilled in designing the best canal x-section with least seepage loses.

4.3.1 DETERMINATION OF B/D RATIO TO GET DESIRED VELOCITY

In deciding the b/d ratio, the factors to be considered are:

1. Form of canal x-section having most advantageous hydraulic elements (minimum wetted perimeter, maximum hydraulic radius).

2. Form of canal x-section with minimum seepage losses.

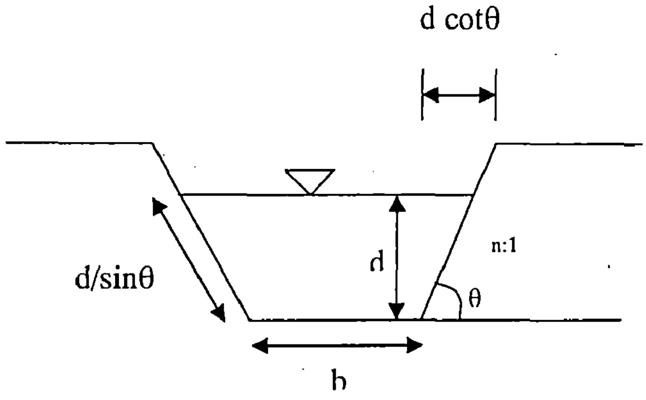
3. The safety against breaks/ breaches.

4. The form of construction (lined/ unlined).

5. The purpose of the canal designed for and location of it.

4.3.1.1 Canal x-section having most advantageous hydraulic elements

The velocity of water is proportional to the square root of the hydraulic radius R. i.e. $V \alpha \sqrt{R}$. When the canal x-sectional area, grade (bed slope) and side slopes are fixed, the form of canal x-section that gives maximum hydraulic radius or least wetted perimeter, will have the maximum velocity and maximum discharge.



Let us assume a section as shown in the figure, above, where,

b = bottom width of canal

d = water depth in canal

θ = side slope angle made with the horizontal

n:1= side slope of n(unit) horizontal to 1(unit) vertical

To obtain a relation in terms of b/d ratio for maximum carrying capacity. An equation of wetted perimeter is to be developed and then solved for minimum value of perimeter.

Perimeter, $P = b+2d/\sin\theta$, $r = b/d$ .... (1)

Area , $A = bd+d^2\cot\theta = d^2(r+\cot\theta)$ .... (2)

$$d = \sqrt{\frac{A}{r+\cot\theta}}$$, putting in (1), we get,

$$P = \left(r+\frac{2}{\sin\theta}\right)\sqrt{\frac{A}{r+\cot\theta}}$$

To get the minimum value of P, taking 1st derivative of P with respect to r and then equating to zero, we get,

$$\frac{dp}{dr} = \frac{d}{dr}\{(r + 2\mathrm{cosec}\theta)\sqrt{\frac{A}{r + \cot\theta}}\} = 0$$

$$\text{Or, } (r + 2\mathrm{cosec}\theta) * \tfrac{1}{2} * (\frac{A}{r + \cot\theta})^{-1/2} * \frac{(-A)}{(r + \cot)2} + \sqrt{\frac{A}{r + \cot\theta}} = 0$$

After simplification we get,

$$r = 2(\frac{1 - \cos\theta}{\sin\theta}) = \frac{b}{d} = 2\tan\frac{\theta}{2}, \text{ and}$$

$$d = (\frac{A\sin\theta}{2 - \cos\theta})^{1/2}$$

$$b = 2d\tan\frac{\theta}{2},$$

$$r = d/2 = 1/2\,(\frac{A\sin\theta}{2 - \cos\theta})$$

Again, the value of θ (side slope angle made with the horizontal) for which the canal x-section produces the least wetted perimeter or highest hydraulic radius with the given ratio of b/d can be found out by getting the first derivative of r with respect to θ and equating to zero, we get,

$$\frac{dr}{d\theta} = 1/2\frac{d}{d\theta}(\frac{A\sin\theta}{2 - \cos\theta})^{1/2} = 0$$

By simplification, we get,

$$\cos\theta = ½, \text{ and } \theta = 60^0$$

If the side slope angle made with the horizontal were kept at 60^0, then the canal x-section will have the most advantageous hydraulic elements.

4.3.1.2 Canal section with minimum seepage losses

The seepage loss mainly varies with the texture of the soil and sub-soil and the difference of the levels between canal water surface and the water table. The seepage is also proportional to the wetted perimeter of the canal section and is affected by the depth. The intensity of seepage losses varies with the square root of canal water depth and the intensity at any point of the canal x-section can be expressed as:

$$S = c\sqrt{d1},$$

Where, S = seepage at depth d1

c = a constant depending on texture of soil, depth to WT etc

d1= depth of canal water at any point

d = full water depth of canal(as shown in figure below) and b and θ are used as usual.

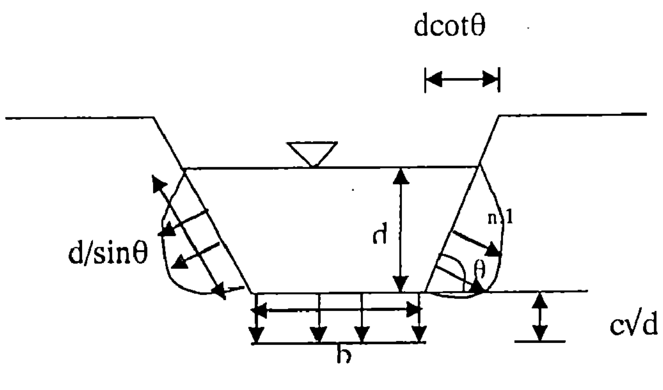


Fig. 18. Canal x-section with seepage intensity.

The diagram represents the intensity of seepage at different points of a canal section. The average intensity on the sides is 2/3 of the intensity on the base (canal bottom) and the total seepage for given canal section can be derived as follows:

Perimeter, $P = b+2d/\sin\theta$, $r = b/d$

Area , $A = bd+d^2\cot\theta = d^2(r+\cot\theta)$

$$d = \sqrt{\frac{A}{r+\cot\theta}}$$

Let , S = the seepage loss per unit of length

$= c\sqrt{d}\,(b+\frac{2}{3}\frac{2d}{\sin\theta})$, because2/3 of base on sloping side

$$= c\sqrt{d}\,(rd+\frac{2}{3}\frac{2d}{\sin\theta})$$

$$= c\, d^{3/2}(r+\frac{4}{3\sin\theta})$$

$$= c\,(\frac{A}{r+\cot\theta})^{3/4}(r+\frac{4}{3\sin\theta})$$

For seepage to be minimum, ds/dr = 0, we get,

$$ds/dr=0 = (\frac{A}{r+\cot\theta})^{3/4} + (r+\frac{4}{3\sin\theta})*3/4*(\frac{A}{r+\cot\theta})^{-1/4} * \frac{(-A)}{(r+\cot\theta)2}$$

After simplification, we get,

$$r = \frac{4(1-\cos\theta)}{\sin\theta}$$

$$d = \sqrt{\frac{A\sin\theta}{4-3\cos\theta}}$$

$$b = 4d\frac{(1-\cos\theta)}{\sin\theta} = 4d\tan\frac{\theta}{2}$$

The value of b/d ratio for minimum seepage loss is 2 times more than that required for maximum hydraulic radius or maximum velocity as given in Table 23.

Table 23 Showing the value of b/d ratio for minimum seepage loss & maximum velocity

Sn	Values of b/d for maximum hydraulic radius or maximum velocity	Values of b/d for minimum seepage loss	Remarks
1	$B = 2d\tan\frac{\theta}{2}$	$b = 4d\tan\frac{\theta}{2}$	B/d ratio required is 2 times more for minimum seepage than for maximum hydraulic radius.
2	$d = (\frac{A\sin\theta}{2-\cos\theta})^{1/2}$	$d = \sqrt{\frac{A\sin\theta}{4-3\cos\theta}}$	
3	$r = d/2 = 1/2\,(\frac{A\sin\theta}{2-\cos\theta})$	$r = \frac{1}{2}\sqrt{\frac{A\sin\theta}{4-3\cos\theta}}$	
4	$\theta = 60^0$		

The importance of b/d ratio in design is not only for discharge considerations but also for the least absorption losses. Colonel Ellis worked out that the loss due to the absorption will be least when b/d ratio is about 4. He recommended the adoption of b/d ratio between 1.25-5 for the design of small channels.

The practice recommended by PG wood for b/d ratio (which is also practiced as Punjab Method) is given below in Table 24 along with the b/d ratio recommended by CWPC against canal discharge.

Table 24. Relation between b/d ratio and discharge

Sn	Canal discharge in cumecs	B/d ratio as per P.G. Wood (also followed as Punjab Method)	B/d ratio recommended by CWPC	Remarks
1.	0.30	2.9	2.9	P.G.Woods section would be bigger for the same discharge. ie wider and shallower section, which may be costlier.
2.	0.75	3.4	3.3	
3.	1.5	3.7	3.7	
4.	3.0	4.2	4.2	
5.	7.5	4.8	4.5	
6.	15.0	5.7	6.0	
7.	30.0	7.6	7.4	
8.	60.0	11.3	9.6	
9.	150.0	22.5	13.5	
10.	300.0	41.0	18.0	

Source: Water Resources Engineering, Principle and Practice, 2nd edition, Satya Narayan Murty challa.

The USBR recommends, adopting the formula for design of channels carrying clear water as $V=c\sqrt{d}$, where, v is the non-scouring velocity in the channel. C is a co-efficient dependent on the soil, usually varying from 0.47 to 0.50 for silty and soft soils, 0.60 for murum, gravelly and harder soils and d is the depth of flow in channel.

4.2.1.3 Safety against breaks

The safety against breaks in normal condition is dependent on depth of water in the canal specially for filled canal section. In deep canals the water pressure on the banks is greater which will produce higher velocity through holes, cracks or breaks due to borrowing animals. Therefore the designers must be very particular about the water depth in the canal.

According to Kennedy, the maximum depth of water that can be allowed in earthen channels (i.e. for channel through soils which can withstand a mean scouring velocity of 1-1.25 m/s) cannot have a fully supply depth more than 3 m. in general, the maximum allowable velocities for different soil types are shown in Table 25 below.

Table 25 Showing maximum allowable velocity for different soils.

Sn	Particulars	Allowable velocity ft/s (m/s)	Remarks
1.	Light sandy soil	1.5-2.0 9 (0.45-0.60)	In India, very few canals exist with velocity more than 3.0 ft/sec (0.90m/s)
2.	Sandy loam	2.5 (0.75)	
3.	Ordinarly form loam	3.0 (0.90)	
4.	Stiff clay or kankar	4.0 (1.20)	
5.	Shingle and boulder	5.0-6.0 (1.50-1.90)	

4.3.1.4 Form of construction (lined/ unlined)

The section with least wetted perimeter will have least x-sectional area to be lined with relatively narrower bed and deeper water depth in nature. The concrete used for lining should remain stable on the sides to withstand the water velocity with out damage. The slope cannot be made steeper than the angle of internal friction of the soil (ie angle of repose) material through which canal passes. So for this even if a moderately shallow section, which will give a slightly greater wetted perimeter, may be negotiated in design though there may be some difference in cost incurred for lining. Otherwise self-slippering of particles (if the slope more than the angle of repose is provided) would take place causing favorable conditions to seepage losses.

4.3.1.5 Purpose of canal design and location of it

The design for canal geometry differs as per its use (such as a diversion canal, main lateral/ branch, distributary or minor). A diversion canal usually is constructed along hillside having deep and narrow section without restriction of b/d ratio. The advantages of such sections are that it causes less volume of excavation than broad-shallow sections for the same water section x-section.

The deeper x-section has the additional advantage that it provides the maximum hydraulic radius or minimum wetted perimeter and will have greater velocity for the same grade as that of a shallower section as well as greater carrying capacity. However the disadvantages are the increase in unit cost of excavation, decrease in safety against breaks.

It is very important that the canal whenever possible should mount the watershed in order to carry a larger volume of water above the land which it commands and facilitates the water diversion to the land providing a cut and fill balanced section so that the seepage losses would be minimum (lesser the b/d ratio lesser will be the seepage losses).

4.3.1.6 Side slopes of canal sections

According to Kennedy, it is assumed that the bed of the channel assumes an even level call bed width but Gerald lacey declared that the channel would take an elliptical section. There arises some controversy between the two theories. However, the channels, in general are designed for a horizontal bed width with specified side slopes. Canals are usually excavated to 1:1 side slopes in soft soils, though they are designed for 0.5:1 side slopes. For silt carrying canals this provision will allow silt deposits on the side slopes, ultimately helps reduce losses.

The side slopes as recommended by CWPC for the canals in cutting and embankment are as produced in Table 26 below.

Table 26. Values of CWPC standards for canals in cutting and embankment

Sn.	Nature of soil	Side slope H: V	
		Cutting	Embankment.
1.	Hard clay and gravel	0.75: 1	1.5: 1
2.	Soft clay and alluvial soil	1: 1	2: 1
3.	Sandy loams	1.5: 1	2; 1
4.	Light sand	2: 1	2: 1- 3: 1
5.	Soft rock	0.25: 1	-
		0.50: 1	-
6.	Hard rock	0.125: 1-0.25: 1	

4.3.1.7 Canal berms

For earthen canals, in cutting, inside berms in general are provided. The principal objectives of providing berms are to:

1. Provide wide waterway at FSL to limit/control the height of rise of water level at time of positive fluctuations.

2. Allow the silt deposit carried by the water on the sides making it less pervious.

3. Recede the canal bank away from the direct canal water.

4. Provide chance for future possibility of increasing the canal capacity by widening it.

Though various practices are adopted in deciding the berm widths according to the site conditions but in general for a channel section with 1.5 : 1 bank slopes and 1 : 1 side slopes (channel in cutting), the minimum berm width on either side should be d/2, where d is the depth of canal cutting.

4.3.1.8 Curves in canal and radius of curvature

It is almost impossible to have the perfect straight alignment of canal from starting point to the end. The planners and designers should follow the ground contours by changing suitably the direction of the alignment by introducing number of intersecting points. At these intersecting points the direction of the canal has to be suitably changed by introducing smooth curves.

The primary factors influencing in deciding the radius of curvature are (i) the size or the capacity of the canal (ii) velocity of flow (iii) soil characteristics and (iv) dimensional element of canal x-section. Several methods are adopted in deciding the curvature radii. One suggested rule is to make the minimum radius 15 times the water width at FSL. It may sufficient for conditions in limited capacity ranges or may be too small particularly for shallow distributaries or for canals with large capacities. Another rule is that radius of curvature should be 3 to 7 times the water the water surface width at FSL. In some states of India a curve with 20 times bed width is adopted. CWPC recommends that large earthen channels should usually have a minimum radius of 6 times the water surface width at FSL.

4.3.1.9 Free board

In general the height of free board is decided considering the factors as: (i) depth of water in canal (ii) the wind action (iii) liabilities of drain or storm water entering the canal and raising the water level (iv) possibilities of water level rise due lack of proper regulation/ operation (v) whether the canal is in cut or fill (vi) whether the canal is in cut or in fill (vii) whether the canal is in straight alignment or in curve.

In deciding the free board, a proper allowance for settlement of the bank should be provided/considered as 10 %. The common practice is to provide a minimum free board of 30 cms. For smaller canals and a maximum of 90 cms. For larger canals but a safe free board within this limit would be to provide the space for free board above the maximum water level equal to 1/3 of the depth of water in the canal (ie FB = d/3).

4.3.1.10 Top width of bank

The top width of the canal bank is generally decided on the basis whether the banks should provide roadways to all or it is to be used only by the canal operators or only for the inspection. So a minimum width of 1.8m is necessary but a width of 2.40m is preferable. For ordinary traffic a minimum width of 3.0 m is desirable but for roadways a minimum width of 3.6m – 4.20m is required. In general, minimum bank width of 0.60 m for smaller canals and maximum of about 3.0m for larger canals may be taken or the bank top width equal to the depth of water in the canal is normally adopted.

According to Colonel Ellis, the berm width, free board and top widths of banks with respect to canal discharge capacity is as given in Table 27 below.

Table 27. Berm widths, free boards & top widths of bank (col. Ellis):

1.	Canal discharge	< 0.3 cumecs	1 – 0.3 cumecs	1 – 5 cumecs	5 – 10 cumecs	10 – 30 cumecs	30 – 150 cumecs
2.	Maximum crest width of the widest bank	1.0 m	1.25 m	2.0 m	2.0 m	2.0 m	5.0 m
3.	Free board	0.5 m	0.5 m	0.75 m	1.0 m	1.0 m	1.0 m
4.	Berm width	0.75+d/2	0.75+d/2	0.75+d/2	1.25+d/2	1.25+d/2	1.25+Q/100+d/2

Note: Q is discharge in canal in cumecs and d is the depth of cutting

The banks, depending on the nature of the soil have to be designed for a hydraulic gradient of 1in 4 to 1 in 6 with required cover in rear side. If the height of the bank is more, additional rear berms may be required to ensure the hydraulic gradient occur at safer limit.

4.4 ALIGNMENT OF THE NETWORK

The alignment of the canal network as far as possible should not pass through the seepage prone areas in order to minimize the seepage losses. The canals should ascend on the watershed to command the more area on either sides and have sufficient gradient for flow. The canals, wherever is possible should not cross the country contour to avoid the x-drainage works. The contour canals will serve the purpose of irrigation on one side of the canal only. The drainages should get proper outfalls for safe disposal of the water from the irrigated areas for all seasons. The main considerations for aligning the main canals are

1. Highest site may involve less depth of cutting but large number of cross drainage works.

2. Unprofitable length may be reduced as far as possible.

3. Inletting of storm flows from numerous small drainage be controlled as it ultimately affects the running of canal during monsoon when frequent storm flow inletting is involved.

4. Control on objectionable entry of sediment load near the head reach be provided. This is normally provided by means of supply channel with steeper gradient, sediment traps, scouring sluices, silt excluders and silt ejectors.

5. Embankment reaches with large lengths and substantial height be minimized or avoided to control cost as well as to minimized seepage losses and risk in safety by breaches.

6. Canals leading from a reservoir on hilly ground normally be carried out by following the contour along foot of the hilly ground- these alignments are normally marked by nature.

7. Main canal should ascend and be carried on water shed as early and as much as possible.

Similarly, for the alignment and layout of the distributary canals the following guidelines should be taken in to consideration.

1. All of them as far as possible should run on watershed.

2. Interference with the x-drainage works should be avoided and should hold full command over the country.

3. Good contour plan of the country to be irrigated is of great assistance to make the proper alignment of the main and other canals.

4.5 CONSTRUCTION OF THE NETWORK

The process and procedures followed for construction should be maintained uniform throughout the construction period. There should be no relaxation on quality control and technical specification as demanded by the design from minor to major classes of works. Proper care should be taken for the construction of the earthen filled canal sections. Good supervision by field staffs and the strict control on quality of the work done at all stages and in whole of the reach is of extreme importance in construction. Subordinates made to realize that "no excuse will be taken for bad works" and "there is only one punishment when deliberate viz dismissal. Surprise visits by inspecting officers to dig into the work to reject and pull down the faulty work. Engineers should also be vigilant to see and satisfy that their juniors insisting on good work.

The compaction plays a vital role in seepage minimization. The compaction if done at OMC the soil will get compacted to its upper limit resulting the dry density of 1.6 – 1.8 gm/cm^3so that seepage from the canal section can be reduced. The canal embankment should be homogeneous in general cases whereas in seepage prone areas or in high fill reaches the zoned type is preferable. The inverted filters of sand and gravels may be employed to cover the area below the downstream toe of tee embankment over which percolating water may escape under an appreciable gradient or head. Their purpose is to allow free flow and dissipation of pressure without loss of fine soil particles and to lower the gradient line and thus keep downstream slope clear (without damage).

4.6 LINING OF CANALS

The main purpose for which the canals should be lined is to transport water at minimum cost with least water losses. Thus the conveyance and distribution system efficiency highly affects the total economy of the project. The decision to be taken for improving efficiency of conveyance and distribution system of an irrigation project is (i) whether the canal lining is essential or not (ii) if essential how to line it.

The decision for lining a canal, however, should be based on the analysis of benefits such as: (i) water conservation (ii) reduction in water logging and drainage requirement (iii) reduction in excavation cost and right of way (i.e. reduction in x-sectional area) (iv) lesser maintenance and operation cost (v) structural safety (vi) decrease in hydraulic roughness (n) (vii) control weed growth (viii) promote movement rather than deposition of sediment (ix) Reduce movement of contaminated ground water plumes and others (x) reduction in travel time (xi) reduction in filling and emptying time.

The selection of type of lining, on the other hand, should be based on careful analysis of the local conditions, which are (i) availability of labour and cost (ii) requirement and availability of lining materials, machines and equipments (iii) access to the working site (transportation facilities) (iv) anticipated irrigation practice (v) mode of canal operation (vi) frequency of canal maintenance

The major working force is the labour. So, among all of the above factors, the availability of normal, semi-skilled and skilled labours locally is the most important basis for deciding the lining type. The irrigation activities more over should create the opportunity for employment in the society, for poverty alleviation. Therefore, highly mechanized techniques in the areas where employment is a serious problem in not advisable.

The achievements by lining of irrigation canal s would be intended towards the following objectives.

4.6.1 WATER CONSERVATION

The saving in water quantity due reduction in seepage and weed control are the main advantages of lining. In fact water conservation has become very important all over the world as the demand of water is increasing rapidly and the new sources of supply are becoming scarce. In such situation, canal lining is the important means to make use of the available water supplies to its maximum extent for agricultural production by reducing the amount of water lost during conveyance up to the farmers fields and control of weeds. Water losses in unlined conveyance systems are usually high. According to prof. Robert Hill, the water lost through unlined canals vary from 21 – 50 % due seepage losses, where as in northern alluvial plains of India the seepage extent up to 45 % of head discharge is accepted. Emergent aquatic weeds also transpire large quantity of water from canals, which can be saved by lining.

The conservation of water, however, has little significance unless the water saved can be put to beneficial use or unless the seepage losses create problems involving losses to human needs. When water saved can be controlled and delivered to productive lands, it would mean, additional yields and increased net income to the individual farmer.

4.6.2 PREVENTION OF WATER LOGGING

Seepage water often disappears into a pervious underground stratum to reappear in low-lying area usually at some distance from the canal. This creates the water logging conditions, in the fields adjacent to the canals, specially if drainage conditions in the area are poor resulting degradation in land fertility greatly. Lining of canal reduces this seepage to water table and is thus helpful in reducing water logging. However, lining of main canals may only practically alleviate the problem unless the distributaries and minors are also lined and farmers apply only that much of water which can be used by the crops and drained away without causing any rise in the existing water table. So while assessing the benefits of lining, in this respect, factors like (a) natural drainage of the area (b) expected irrigation efficiencies (c) probable salt problems (d) loss of land and implications of high water table (due excessive canal losses) should all be considered carefully. It may also be borne in mind that lowering the water table increases seepage from unlined canals and as such gives no solution to the water logging and drainage problems.

4.6.3 REDUCED CANAL DIMENSIONS AND INCREASED DISCHARGE CAPACITY

Canals lined with hard surface exposed materials like cement concrete, masonry stone, bricks can with stand greater velocities of the range of 1.5 – 2.5 m/s, than are normally possible of 0.3 – 0.8 m/s for unlined canals. Although, clay stand velocity op to 1.5m/s, in newly excavated canal, at times the flow the flow resistance may drop considerably due to alternate wetting and drying effects and other structural changes. Consequently due to increased permissible flow velocities and reduced frictional losses a reduced surface area of concrete lining is required to carry a required discharge. The lining, also being erosion resistant, the gradient of the bed can be increased and the side slopes made steeper. The top width is also reduced which means, reduction in land area required for the canal cross section. The right of way cost savings may thus be substantial. A lined canal with the advantage of irrigating a given area in a shorter time, same dimensions as of unlined canal has a greater discharging capacity.

The flexibility is provided by hard surface lining in fixing the canal alignment. Such lined canals even can pass through abrupt contours, since the erosion hazards associated with increased flow velocities on the outer edge of the canal is well controlled. Lined canals can be used even in steeper gradients when considered advantageous. This may eliminate drop structures vital to erosion control in unlined canals of the same slope.

Greater velocities in canals reduce maintenance cost, when silting is a problem, because most of the silt remains in suspension and gets deposited on the land being irrigated instead of filling the canal itself.

4.6.4 REDUCTION IN OPERATION AND MAINTENANCE COST

Maintenance costs are greatly dependent upon local conditions such as (i) climate (ii) period of operation (iii) availability of labour and machinery (iv) type of lining (v) canal characteristics etc. Benefits should therefore be examined in reference to these factors. For example, in case of using a high quality hard surface lining, the savings are due to reduced cost of weed control, less danger from borrowing animals, less silt removal etc. However, in case of earth lining or buried membrane linings many of these factors have very little importance.

One of the largest items of recurring expenditure on maintenance of unlined canal system is the removal of weds and water loving plants from the canal section. High quality hard surface linings, being relatively impermeable by weeds and plants, greatly reduced the maintenance cost of the canal. Hard surface linings, allowing velocities high enough to reduce substantially the deposit of silt, lower the maintenance cost on removal of silt. Buried membrane linings and compacted earth linings using gravel blanket reduce erosion considerably. The gravel blanket also discourages the borrowing animals and provides less favorable conditions to weed growth near to water edge.

4.6.5 STRUCTURAL SAFETY AGAINST EROSION

The stability of slopes and bottom of the canal is often a major problem in areas of silty or sandy soils, particularly when irrigation practices require intermittent running and closing of the canal. Lining provides safety against erosion under such conditions. Lining also reduces the danger of canal breaches resulting from erosion and burrowing animals. This is particularly important when the canal is in filling or has a steep side slope. Lining also prevents water from absorbing salt from the soils, which may be harmful to the crops.

4.7 ECONOMICS OF LINING

The type of lining needed may possibly be determined if the value of the benefit of lining for a given situation is properly estimated. In some cases (situations), the justification for selection of certain type of lining may be so obvious that no benefit cost analysis is necessary. In normal cases, however, a thorough analysis of benefits regarding the initial and current cost of lining is necessary to examine the economic viability and technical sustainability of the proposal.

Although, conservation of water alone may provide ample justification for lining but some other factors like the value of irrigable land, the cost of engineering features and their relative capacity and the quantity of water etc also need be considered to carry out the economic analysis.

Seepage losses from the canal may cause water logging in the low-lying areas adjacent to the canals and may thus impair the productivity of irrigable land. A large and lengthy drainage system may be required for the sole purpose of collecting seepage water and its disposal, however, the cost of construction, operation and maintenance of the drainage system may be materially greater than the cost of lining of the canal to prevent water losses. In addition, if pumping is also is required to dispose of water collected in seepage drain, the lining of canal and the associated cost becomes the more important.

Lining of canals at the time of original construction itself is more advantageous than at a later stage because the size of associated structures, such as dams, reservoirs, pumping plants, canals and distributaries necessary to provide the given (designed) amount of water will also be reduced. This would mean considerable savings in construction cost, which would pay, in part, at least for the lining of the canal system. A possible reduction in right-of –way costs is another important factor in this regard. When the capacity of an unlined canal is required to be increased to meet a greater demand of water or to irrigate a larger area of land, installation of lining may offer an economical and practical solution to the problem provided the required increase in capacity is relatively small. The mitigation of seepage losses and improved hydraulic properties of hard surface linings may possibly provide the needed increase in capacity. For canals on which powerhouses are situated, there would be more water available for generating hydropower. Such a solution is of particularly importance when additional right-of-way for larger canal is either not available or available only at greater cost. Thus, to judge the economic viability of canal lining project, it is very important that any evaluation includes a careful estimation of land and water values in relation to the cost of lining and the associated structures. Presently, economic analysis is carried out ti compare the project conditions with and without lining. He benefits and costs associated with various alternatives and types of lining are considered and conservation of seepage water is normally taken to be the governing factor. Thus, in reaches of unlined canals, where seepage is negligible, lining is not justified from seepage consideration. On the other hand, in canal reaches, where significant quantity of water is lost through, lining may be economically justified from seepage consideration.

An alternative of lining may be to allow the seepage from canal to take place and to store the seepage water in sub- surface reservoir. The water so stored may then be pumped out during the period when surface water supplies fall short. In case this alternative is adopted, then ground water levels will have to be maintained at an economical depth by maintaining or balance between inflow into and our flow from the under ground reservoir. However, the feasibility of creating the underground reservoir depends upon the existence of good unconfined aquifers, quality of ground water, volume of water that can be stored and likely losses from it. Under favorable circumstances, the purpose of lining the canal can be considered economical only if the cost of water saved by lining is less than the cost of pumping the seepage water from the underground reservoir.

Evaluation of cost of water saved as a result of lining requires estimation of seepage losses from the unlined canals. The seepage losses from the existing unlined canals may be determined by direct field measurements or by analytical methods. In case of canals, in the planning stage, the seepage losses can be estimated by using the following relationship.

$$q_u = c\,k\,h$$

Where, q_u = seepage loss from unlined canals

c = co-efficient depending on the canal dimensions and boundary conditions.

k = permeability of sub- soil

h = difference in water levels of canal and drainage

Similarly, the seepage from lined canal, which is homogeneous and free from leaky joints, is given by:

$$Q_l = \frac{cpkh}{crt + p},$$

Where, $r = k/ k_1$ and

K = permeability of sub-soil

k_1 = permeability of lining

p = perimeter of canal

t = thickness of lining

h =head difference between water levels in canal and drainage

Therefore, the water saved by lining is given by;

$$q_u - q_l = c\,h\,k - \frac{cpkh}{crt + p},$$

$$= chk\left(1- \frac{p}{crt + p}\right),$$

Dividing Nr & Dn by r t, and after simplification, we get,

$$q_u - q_l = \frac{c2hk}{c + \frac{pk1}{tk}}$$

If the canal runs for, say r days in a year, then total volume of water saved is:

$$qs= R^* \frac{c2hk}{c + \frac{pk1}{tk}} {}^*24^*60^*60$$

If the cost of lining per year per meter length of canal is = S, then, cost per unit of saved water

$$Cs = \frac{s}{qs} = \frac{S(c + \frac{pk1)}{tk}}{86400Rc2hk}$$

Similarly the cost of ground water pumping depends upon the capital cost and maintenance cost of the well and its operational charges. The cost of pumping a 0.42 cumecs capacity well for various depth of ground water levels have been worked out by Sharma et. al. They have found the average cost of pumping as rs 0.09/cumecs of water. In case the cost of saved water as a result of lining is less than the cost of pumping water, the lining is economically justified; otherwise pumping ground water is a more economical alternative.

Chawla and Sharma have studied the above criteria for canal in Gomati-kalyani Doab. They have found the cost of saved water as a result of lining as Rs1.10/ cumec against the average cost of pumping as 0.09/cumecs. The lining of irrigation channel is this doab, has, therefore been not found economical.

4.8 TYPES OF LININGS

The various types of linings can be grouped broadly into the following two categories

1. Exposed surface linings
2. Buried membrane linings.

4.8.1EXPOSED HARD SURFACE LINING

These linings are of the type placed directly upon the subgrade of the canal and are exposed to wear, erosion and deterioration effect of the flowing water, operation and maintenance equipment and other hazards. Such linings should preferably have a hard and smooth surface. Tile exposed surface linings are constructed of cement concrete, mortar, precast concrete slabs, bricks or tiles, stones, asphaltic concrete, soil-cement and earth, etc.

4.8.1.1 Cement Concrete Lining

The in-situ cement concrete lining is one of the most conventional types of lining, which has successfully been used in India and other parts of the world. This type of lining can withstand higher flow velocities of upto 2.5m/sec because of its greater resistance to erosion and is therefore more preferable than any other type of lining. The reinforced cement concrete lining can withstand even much higher external water pressure but at a very high cost. Cement concrete lining eliminates weed growth and thereby improves flow characteristics and lasts long. Even the burrowing animals cannot penetrate concrete. As such provision of cement concrete lining reduces maintenance charges to a minimum.

The disadvantage of concrete lining is its susceptib1l1ty to developing frequent cracks due to temperature effects as well as drying, shrinkage and settlement of subgrade material. The alkaline water is also harmful to cement concrete lining.

Cement concrete linings can be placed by various methods. Longitudinally operated slip-forms supported on rails placed along both the berms of the canal are usually used where considerable lengths of large canals are to be lined. The equipment needed for the purpose is, however, highly merchandised and has never been used in India

Small canals are often lined by hand screeding and finishing. Where labour is cheap, hand-placing method proves to be economical. Better progress can be achieved by use of subgrade-guided slip forms where sufficient length of the canal has to be lined.

Proper control of the workab1l1ty and consistency is important as even small variations in slump will leave honeycombs on the under surface if concrete is too dry or too wet and moreover concrete will not stay on slopes. A slump of 4 cm is considered suiTable for concrete to be placed manually on slopes of the canal and of 5.0 to 6.5 cm for concrete slabs in the bed. Curing of lining is also very important. To ensure that lining does not get dry rapidly, the subgrade should be well moistened, immediately before placing concrete. Use of curing compounds may be considered, where water for curing is in scarcity.

Similarly use of air-entraining agents may be helpful in improving the quality and workability of concrete, with the same quantity of cement. Use of richer wearing coat laid simultaneously over a leaner base or partial replacement of cement with surkhi or flyash would affect economy to some extent. Surkhi makes concrete more impermeable, and salt-resistant, generates less heat and prolongs the life of lining.

Due to low flexural strength plain concrete lining is easily damaged in filling reaches. Even in well-consolidated fills some movement of soils takes place to cause cracking of concrete slabs. So in case of heavy filling or weak soils, additional thickness or even reinforcement may be provided. It is difficult to lay and compact concrete on side slopes and curing also poses some serious problem. The lining on side slopes is therefore, generally weaker than that in the bed. As such, the thickness of lining on the side slopes should be kept slightly more than that in the bed.

The lining should normally be placed first in the bed and then on the sides. However, under unfavourable site conditions even the sides may be lined first but then the lining should necessarily be supported on toe wall, to ensure its stab1l1ty or else the lining may get damaged. In India, cement-concrete lining has been provided in some channels like Nangal Hydel Channel and Sunder Nagar Hydel Channel, etc.

The seepage, by cement concrete lining, was reduced from 0.23 m/d to 0.04 m/d (which is about 83 %) as found by Deacon.1984. Similarly in Fordwah Sadiqia, in Pakistan, the seepage control by cement concrete lining was found to be 74 % (experimental results). In Idaho,USA, the effectiveness of seepage reduction by cement concrete lining was found to be 70 % (as per Jay Switart & Jack Haynes, Boise,Idaho).

According to Guy Fipps (Ph. D, P. E., Associate professor & extension Agri. Engineer, Dept. of Agri. Engg., Texas, A&M University, Texas), the experimental seepage loss rates with cement concrete lining with different canal dimensions were as follows:

Table 28 Showing relations between seepage rates with canal geometry

Sn	Canal type	Top width-ft (m)	Length-ft (m)	Seepage rate gal/ft²/day (m/day)	Remarks
1.	Concrete	19 (5.8)	2577 (775)	4.28 (0.21)	Seepage rate is dependent on top width of the canal
2.	Do	12 (3.6)	2583 (783)	2.12 (0.11)	
3.	Do	12.5 (3.8)	9525 (2886)	2.47 (0.12)	

In another study by USBR,(1963), Nofziger,D.L.(1979), for the influence of canal seepage on ground water in Lugert lake Irrigation area, Oklohama water Resources research institute, the seepage rate found was in the range of 0.06 – 3.22 gal/ft^2/day (i.e 0.0037 – 0.161 m^3/m^2/day) .

4.8.1.2 Shotcrete lining

This type of lining is constructed by applying a mortar, consisting of a thorough mixture of cement, sand and water, shot into place by means of compressed air (pneumatic pressure). The usual mix is one part of cement to 4.5 parts of sand and a little less water than the amount that would cause sloughing. Shotcrete lining can be easily placed over rough subgrade and no fine trimming of subgrade, precise alignment and close conformity with design dimensions are commonly required. The lining is, therefore, better suited for use on existing cuts where finishing to exact shape and slope would be expensive. The lining may be constructed with or without reinforcement (in the form of wire mesh or expanded metal). The reinforcement, if used, increases its useful life, specially when laid over earth subgrade.

The thickness of shotcrete lining is limited to 5.0 cm. Such linings are therefore, applied on smaller channels or where operational requirements are not severe. This thickness being small, it is difficult to control its uniformity and a few patches are left over where the thickness is less than the minimum required. Such patches constitute the areas of weakness where lining may give way due to external water pressure

Equipment units for this method of construction are relatively small and mobile.

However, skilled labour is required to operate the equipment and so shotcrete lining is not generally economical for large lining projects. It has given excellent results in cases of small canals, parts of canals or canal reaches in weathered rocks and for the repair of canals. Since no coarse aggregates are included in the mix, the method requires greater proportions of cement than concrete lining which it is transported to the discharge nozzle under pressure. At the discharge end water introduced through a second hose is added to the mixture and the mortar is discharged under pressure. Shotcrete is usually applied to the canal surface by holding the nozzle about one metre away from and normal to the surface. The method plugs the joints and fissures properly and prevents leakage considerably.

4.8.1.3 Pre-cast Concrete Lining

Precast concrete has been used extensively in canal lining works for all sizes of canals but the trend is declining fast in areas where labour is expensive. The main advantage of precast concrete lining is that it is possible to exercise a close and continuous quality control over the selection, proportioning of concrete materials, mixing, compaction and curing operations. When the lining work is going on. The precast slabs are more compact and impervious. The precast lining has smaller thickness and smoother surface than the in-situ lining or any other type of lining. The facilities of construction of concrete slabs and their storage at a suitable site close to the site of works are additional advantages of precast concrete lining. The slabs are laid on compacted subgrade and joints have to be sealed to prevent leakage. As such considerable handwork is required for laying this type of lining. Proper backfilling and careful tamping under and around each section is of utmost importance to prevent breakage from minor movements and uneven settlement of the subgrade.

Tongue and groove joints are often provided along the edges. The joints are sealed with mortar or bituminous mastic. The slabs laid with continuous joints sealed with bitumen provide a slightly flexible lining that may adjust itself to minor movements of the subgrade. Thus the joints grouted with bitumen have the advantage of flexibility and need no curing. However, the joints are the weakest points where lining Is susceptible to damage due to excessive hydrostatic pressure and limited thickness of the slabs. Precast concrete linings are subject to deterioration on sharp curves also. To overcome weaknesses, the bottom sections of the lining are sometimes cast in-place and slabs are placed on canal slopes. This type of lining is especially suitable for use on side slopes and over weaker soils. Lining of canals with precast concrete slabs requires a large labour force and is competitive with other types of lining only when labour is cheap or for small canal size jobs and repairs where maintenance forces can be utilized.

The precast slabs are generally manufactured both by hand casting and by machine depending on the requirements and availability of the equipment using well graded aggregates (1:3:6 concrete). The slabs are cured as usual for24 hours in air and thereafter under water. After curing is complete, the slabs are transported to the site of work for use. For manual handling the slabs should be cast in 50 cm x 25 cm x 5 cm size (weighing about 16 kgs each). Slabs cast individually in moulds should preferably be compacted properly using a vibrating Table.

4.8.1.4 Brick (or Tile) Lining

This type of lining was first used on Haveli Canal. Next it was used on a portion of Thal Canal (both in West Pakistan) and thereafter in India on Sarda Canal, the Bhakra Canal and the Rajasthan Canal and so on. Brick or tile lining is economical and is always preferred for lining long lengths of canals in the plains. A considerable saving in the first cost is an important consideration in favour of this type of lining. In plains, stone and sand have to be transported over long distance for concrete lining, whereas for brick lining, bricks can be burnt almost at site from the abundance of clay available in the vicinity of the canal. Also this involves low consumption of cement and can be laid by skilled manual labour without the use of any machinery. The advantages of brick lining in comparison to concrete lining are that their maintenance cost is low, have almost equal permeability and are safe against cracking. The individual tiles or bricks have large number of joints in which hair cracks can appear but this hardly cause any damage to the work as a whole. To increase the impermeability and strength of the lining, two layers of bricks or tiles with a sandwiched layer of mortar are provided. Although their use is confined to sides from stability considerations then use is confined only to the sides.

Brick or tile lining is laid manually. The subgrade should be properly dressed and moistened before laying the lower layer of bricks or tiles over a layer of mortar. This lower layer of bricks or tiles should be wetted thoroughly before laying plaster on it. Next day the fine cracks which appear on the surface of plaster should be widened and repaired. After treating the cracks the plaster should be cured for a week. Bricks or tiles should be laid over another layer of plaster. The joints between the bricks should be filled properly. The composite lining is then cured for three to four weeks.

On bed, single tile lining can be laid in the following sequence:

(i). 9mm thick 1:5 cement mortar on the bed.

(ii). 30 x 15 x 5 cm thick tiles laid in 1:5 cement mortar.

On sides, double tile lining with sandwiched plaster can be laid in the following sequence:

(i). 9 mm thick 1:5 cement mortar on sub grade.

(ii). 30 x 15 x 5 cm thick tiles laid in 1:5 cement mortar.

(iii). 16 mm thick 1:3 cement mortar.

(iv). 30 x 15 x 5 cm thick tiles laid in 1:3 cement mortar and over the mortar 6 mm thick 1: 3 cement mortar layer.

4.8.1.5 Stone Lining

Stone lining has been employed in areas where suitable materials such as sandstone or basalt are available in abundance. This type of lining is cheaper than concrete lining. The construction of stone lining is, however, relatively slow and the cost of labour is the major expense since stones are placed by hand.

Seepage losses are very high if the stones are not mortared properly. Non-mortared stone lining may prove advantageous only where erosion control is the main reason for lining such as on steep slopes. Such lining is not suitable for canals in the filling. Stone masonry has little flexural strength and so even the slightest settlement of the sub grade causes distress and the lining fails due to development of cracks.

In India, stone lining has been used in Karnataka. Maharashtra and Andhra Pradesh. In Chambal Areas, large slabs upto 30 cm thickness of a sedimentary rock is abundantly available. These slabs when split down to 2 cm thick slabs may be used for stone lining. However, the main problem in using this type of material for canal lining is the high temperature and coefficient of expansion Causing cracks to develop at the joints. if these are not taken care of properly. In Andhra Pradesh15cm to 23cm thick random rubble masonry in cement mortar (1:6 to 1:8) with 2 cm thick cement plaster (1:4 to 1:6) has been used successfully.

4.8.1.6 Asphaltic Concrete Lining

Asphalt is a petroleum product, which when mixed with sand and gravel. is used as a lining material in much the same way as cement. Asphaltic concrete lining is cheaper than cement concrete lining and may be a suitable substitute for it especially when the quality of aggregate is not good for cement concrete but is suiTable for asphaltic concrete. Thus the overall advantage in the use of asphaltic concrete for canal lining is dependent on a considerable price differential between asphalt and cement in favour of the former; and the suitability of local aggregate to asphaltic concrete. Asphaltic concrete lining has an edge over the cement concrete lining because of its better adjustment to sub grade changes and the possibility to use even slightly poorer quality aggregate.

The life of asphaltic concrete lining may range between 10 to 20 years. Other disadvantages of asphaltic concrete lining are the maximum permissible velocity limitation to 1.5m/sec. Danger of weed growth, poor resistance to external hydrostatic pressure and the danger of sliding during hot weather. To prevent weed growth sub grade sterilization therefore, becomes an integral part of the lining operation.

The hot-mixed asphaltic concrete is a carefully controlled mixture of asphalt, cement and graded aggregate, which is prepared placed and compacted at a high temperature. Asphaltic concrete lining is well adapted to smaller canals where placement can be accomplished by using sub grade guided slip forms similar to those used for cement concrete lining. The method is economical to achieve the desired degree of compaction and also a uniform high density of asphaltic mixture. The initial cost of placing the hot-mixed asphaltic concrete lining is generally more than that for cement concrete lining

The cold-mixed asphaltic concrete is very much similar to the hot-mixed type. The only difference being that in this case well graded aggregate and asphalt are mixed and compacted in place at ordinary temperature. However, curing of cold mixes is essential for which favorable weather and extra time are needed. Although the process of mixing and placing cold-mixed asphaltic concrete lining is very simple. The lining is not adequately resistant to erosion and hence is not much durable.

4.8.1.7 Soil-cement Lining

Soil-cement lining. as the name implies. is constructed with a mixture of portland cement. Natural soil and water all of which hardens to a concrete-like material. Soil-cement offers possibilities for use as a canal lining material in localities where the climate is mild and where the sub grade soils or those adjacent to the canal are of a sandy nature and other suitable materials are not readily available. The durability and the water tightness of the soil-cement lining is essentially dependent on the soils to be used. If the soil is poorly graded or lacking in fines, the cement content should be higher, which obviously increases the cost of construction. So when the soils excavated from the canal is not suitable soils available within a reasonable distance may be investigated and in some cases even importing soils from a distant source may be found more economical than using the local soils. Thus most of the local soils can be considered fit for use as a lining material. Laboratory tests indicate that for best results soils for this purpose should be well graded with a maximum size of 20 mm and contain between 10 and 35 percent fines. passing the Indian Standard Sieve No.8.

The soil-cement lining is not weather-resistant and its life is comparatively short and the maintenance charges are relatively high. It does not even permit velocities higher than those in an unlined canal and its merit lies only in the reduction of seepage losses and prevention of water logging in the adjoining areas. So the soil-cement lining may not be used in the new canals where high flow velocities are proposed to reduce the excavation cost or even in the existing canals to increase their water-carrying capacity. The use of this type of lining is limited only to the existing canals where the primary purpose of lining is the reduction in seepage losses. Infact, soil-cement lining is a low cost lining, which sometimes effects considerable saving as compared with cement concrete lining. It is considered fit for minor canals with low velocities.

For the construction of soil-cement lining two general methods are in vogue (1) Dry-mix method and (ii) Plastic-mix method. The dry-mix soil-cement lining also known as standard soil-cement lining or the compacted soil-cement lining is commonly mixed in place and compacted to its maximum density keeping the moisture content of the mix at about the optimum. Lining thickness commonly applied are 7.5 to 15 cm. Mixing in place with travelling machines may give satisfactory results on slopes not steeper than 1: 4. However, for economic reasons the side slopes of irrigation canals are normally much steeper. Therefore. mixing in place as well as compaction has all to be done manually. Dry-mix soil-cement compaction should be completed within an hour after the mix is spread. Necessary field and laboratory tests should be carried out side by side to exercise a better control on moisture content and compaction so as to achieve the desired maximum density. After the compaction is complete curing must start immediately. Proper curing is just as important with soil-cememt as it is with cement concrete. Improper or no curing may result in excessive shrinkage, cracking, reduced durability, increased permeability and lower strength. If the soil cement lining is kept at or near saturation change in volume is minimised and shrinkage cracks eliminated. So the canal should be filled with water as soon as practicable. Joints are not provided in this case.

Plastic soil-cement lining is laid with soil-cement mixture in plastic form. Plastic soil-cement has higher water and cement contents than dry-mix soil cement and a consistency comparable to that of cement concrete used for slip form lining. The soil is mixed with cement and water in a mixer travelling along the canal or in a stationary plant. The mix is then poured by hand or by slip form on to the sub grade to produce lining similar to cement concrete lining. Expansion and contraction joints similar to those in cement concrete linings are provided in plastic soil-cement lining. Properly manufactured and applied plastic soil-cement may approach cement-concrete in self-serviceability, if conditions of exposure are not very severe.

4.8.1.8 Earth Lining

Earth is undoubtedly one of the most universally used materials for reducing seepage losses from irrigation channels. It has been used in the form of a silt layer deposited in the flowing channel; it can be cast loosely on the canal sub grade surface to provide a more impermeable barrier over permeable strata; and it can be compacted in place to increase its density and impermeability. Now, with the advancement of soil-mechanics and improvement of earth-moving equipment and techniques, the construction of earth linings has advanced to provide one of the most common types of linings. In some countries earth linings are surpassed by concrete linings only.

The lining of an irrigation channel using natural or processed soils as lining material is termed as earth lining. This type of lining may prove economical if suitable earth materials are available locally within a reasonable distance. Soils selected for lining purposes should be impermeable and non-erodible and should not crack or disintegrate under the weathering action. In this regard, gravel-sand-clay mixture is considered a suiTable material for lining even large canal sections because the material has low permeability, high stability and good resistance to erosion. The stability and impermeability of the available soils may be improved by mixing soils with bentonite, asphalt emulsions, resins, chemicals, cement, lime and petrochemicals etc. However, the use of chemically stabilized soils for canal linings is still in an experimental stage. Secondly, the stabilization of soils would make lining more expensive.

Earth lining is most suited to canals passing through sandy or gravelly materials where it reduces high seepage losses immediately. This type of lining can be used beneficially to prevent seepage in the filling reaches of the canal where other exposed surface linings may prove not only expensive but may also develop cracks due to sub grade settlement. In situations where water logging conditions are created adjacent to the canal passing through the pervious stratum overlain by a top impervious layer, the top soil may be used to line the canal and seal off the seepage most effectively. Earth linings may also be used in combination with hard surface linings; for example earth lining in the bed and brick or concrete lining on side slopes.

Earth linings are susceptible to damage due to erosion, weed growth, weathering and cracking on drying. It is, therefore, desirable to provide earth linings in canals, which have sTable sections, are free from weed growth and erosion and are continuously running

Earth linings may be classified as (i) Thin compacted earth lining (ii) Thick compacted earth lining (iii) Loosely placed earth lining (iv) Stabilized soil lining and (v) Bentonite soil lining.

(i) Thin compacted earth lining

A thin compacted earth lining has a 15-30 cm thick layer of cohesive soils thoroughly compacted and protected by a 15-30 cm thick cover of coarse soil or gravel. The thickness of the lining and the cover may vary with the type of soils used, velocity of flow, and other conditions. Clayey gravels may be used without cover if flow velocities are' not high. But for lining using silty soils of low permeability, a cover is a necessity to resist erosion and protect lining. The use of thin compacted earth lining is very much limited because of the risk of severe damage from erosion. The use is confined to straight reaches of continuously running stable canals free from the problem of weed growth. The maintenance cost being high, the overall cost of a thin compacted earth lining is more than that of a thick compacted one.

(ii) Thick compacted earth lining

A thick compacted earth lining is most economical, if suitable soils are available in sufficient quantity within reasonable distance and if the canal is large enough to permit the use of heavy earth moving equipment. The lining will be the cheapest, if soils obtained from the excavation of the canal are found suitable for use. Since lining is placed at optimum moisture content, the existing moisture content of the soils hauled for lining will also largely govern the cost of lining. If the soil is too dry water will have to be added and if it is too wet it will be spread for drying.

A thick compacted earth lining is constructed of selected soils both the bottom and side slopes being compacted in successive horizontal layers not more than 15 cm thick after compaction. The thickness of lining normal to the slope may vaxy between 60 and 90 cm depending upon the size of the canal section. The bottom lining is commonly 30 to 60 cm thick. The performance of such linings is generally better than that of other types of earth linings.

In case of canals subjected to frequent wetting and drying fat clays can be used only when the lining is protected by gravel-sand cover. As already stated gravel-sand-clay mixtures are most suited to earth linings. However, it is usually economical to mix coarse sub grade soils with fine soils hauled from outside to make an impervious, stable and blended lining. To compensate for the loss thorough mixing in the field, fines may be added slightly in excess to make the mixture suitable for the lining.

(iii) Loosely placed earth lining

This type of lining consists essentially of a loose uncompacted earth blanket of selected clayey soils dumped into the canal and spread over the bed and sides of the canal so as to provide an earth lining about 30 cm in thickness. Seepage can often be reduced to an acceptable degree provided the soils used are sufficiently fine and impermeable in the loose state and also adequately stable to resist erosion. Although the serviceable life of loosely placed earth lining is relatively short. it may be advantageous in certain cases where the first cost is required to be low. However. it is subjected to erosion and scour and hence is not very much durable. Loosely placed earth lining has a limited use and is good enough to check seepage as a temporary measure.

(iv) Stabilized soil lining

If available soils are below standard requirements for the slope stability, erosion resistance and water tightness, their natural deficiencies can be improved upon by treating them with small quantities of certain substances like specially treated resins, asphalts, chemicals, petrochemicals, cement and swelling clays etc. The stabilized, earth lining is very costly and is yet in the experimental stage.

(v) Bentonite soil lining

Out of all types of earth linings, bentonite lining has found the maximum use due to its high impermeability. Bentonite is a natural earth material characterized by high water absorption and swelling properties. The material becomes impervious on swelling and is therefore, very useful to control seepage from canals. It is very cheap also. if it can be obtained from local deposits at low cost. In India, Bentonite is available in Kashmir. Rajasthan and Bihar.

The three methods generally employed for lining the canal with bentonite are (I) Bentonite-water mixture. (ii) Bentonite-soil mixture and (iii) Bentonite membrane lining. In the first method, a pond is made in the canal with the help of temporary bunds. In this pond both the bentonite and pumped water are added and thin lump-free bentonite slurry is produced using special dispersing agent, and necessary mixing arrangement. The slurry is then allowed to stand in the pool for about two days to flow into the leaky holes and thus to plug the soil pores. This method is very much effective in highly permeable materials. The second method is recommended for sandy soils. The soil is mixed in place with 5-25% bentonite (percentage being predetermined in the laboratory) to form 5-10 cm thick finished lining. A protective cover is also needed, if the velocities are excessive to erode the lining. As regards the third method a 3-5 cm thick bentonite membrane is laid over the sub grade soils. This membrane is protected by a 15-30 cm thick soil cover or by a layer of bricks or tiles in cement mortar. This type of lining is actually a buried membrane type lining and is suitable for continuously running canals.

4.8.2 Buried Membrane Lining

A buried membrane lining consists of a thin and impervious water barrier covered by a protective layer. Hot applied or sprayed-in-place asphalts, prefabricated asphaltic materials. Plastic films, synthetic rubber, bentonite and other types of clay have been found to effectively control seepage over a considerable period of time when covered. The need to provide a protective cover became apparent after a few trials, which showed that the exposed membranes have little resistance to various field hazards. The protective layer saves the membrane from exposure damage by turbulent water, maintenance equipment and animals. Generally earth and gravel are used as a covering material. These linings can be provided immediately after completion of excavation or even later

However, in case of such linings, the permissible water velocity is low and the life of lining is uncertain.

The commonly used buried membrane linings are:

1. Sprayed-in-place asphaltic membrane lining

2. Prefabricated asphaltic membrane lining

3. Plastic film and synthetic rubber membrane linings and

4. Bentonite and clay membrane linings

4.8.2.1 Sprayed-in-place Asphaltic Membrane Lining

It is composed of a special high - softening - point asphalt sprayed in-situ at a high temperature (I 750 C - 2100 C) on a prepared sub grade to form 5-8 mm thick waterproof barrier. It is protected from damages by a layer of earth and gravel. It provides an effective and cheap means to control seepage and can be laid satisfactorily even in cold and wet weather. However, it requires skilled labour and a proper organisation for work.

This type of lining has been used extensively and to date there have been no reports of aging of asphalt. All failures, although very few in number, have been due to too thin a membrane, penetration by weeds and rupture due to movement of the covering material.

4.8.2.2 Prefabricated Asphaltic Membrane Lining

Membranes of this category are ready-made and include all thin asphalt-coated felts, fibre glass mats, or asbestos etc. This type of lining is used in smaller channels or in short reaches of large canals where the use of spray-in-place lining is costlier on account of the requirement of special equipment and skilled personnel. For its fabrication all that is required is the selection of an adequately watertight, durable and low cost material. These membranes are relatively thin and light and there is no difficulty in their transportation, storage and handling. The membranes have a thickness of about 3-6 mm and are made up in rolls of standard size.

Construction procedure is similar to that used in the placement of spray-in-place lining I.e. the lining is placed on a prepared sub grade and is covered by a protective layer. All joints of the membrane are usually overlapped at least 5 cm. Adhesives used are hot asphalt cements.

4.8.2.3 Plastic film and Synthetic Rubber Membrane Linings

Extensive use is being made of a variety of plastic and some rubber prefabricated membranes. The most commonly used materials are plasticized polyvinyl chloride (PVC), and polyethylene (PE) and butyl rubber. In recent years the puncture resistance of polyethylene has been improved considerably. Yet of these three materials polyethylene remains the most susceptible to sun damage. Considering both performance and cost polyethylene may be the most economical material for buried flexible membrane canal lining.

The plastic film and synthetic rubber membranes can be manufactured in any size. Being light, these can be transported and handled easily. Synthetic rubber has been used in canal lining and has given excellent results. Although these membranes are highly durable, they undergo mechanical damage when exposed. As such the membrane linings should be covered with earth or gravel material as soon as possible to prevent early deterioration due to wind damage, sun exposure and temperature effects. Similarly, when these membrane linings are extended to the sides.

The combination lining is suitable for sandy reaches of the canal, which are in regime and have acquired working stability and where the ground water Table is below the canal bed. However, this type of lining is not good in situations where weed growth is a problem because of the likely damage to the flexible lining by weed roots. Similarly, where there is a possibility of cattle crossing the canal. a suitable cover of gravel and sand should be provided to protect the membrane lining from getting damaged. If Kanker or any other sharp material is present over the sub grade, a layer of sand of sufficient thickness should be provided below the membrane lining.

The membrane linings should be seamless and free from pinholes, streaks, tears and foreign matter. To produce water tightness at least 15 cm of the film should be anchored into the rigid lining and at least a 7.5 cm overlap be provided at the joints. The overlap joints may be sealed properly using either some adhesive tapes or heat sealing.

4.8.2.4 Bentonite and Clay Membrane Lining

Bentonite is a natural clay-like substance distinguished from other clays by its extreme fineness, highly absorbent power and the property of swelling in water. High quality bentonite contains unto 90 percent colloidal-size particles and a high water-sealing power. As such, it is a very useful material for controlling seepage from canals if available locally at low cost. It is used by spreading as a membrane 3-5 cm thick over the canal sub grade and covering it with a 15-20 cm thick protective blanket of stable earth or gravel.

For laying the membrane lining, finely ground bentonites are best suited. If a good distribution of particle size is obtained even the coarse-grained bentonite may be equally satisfactory. Although for comparable results, a greater quantity of material is required. Actually the quantity of material required to achieve the same reduction in seepage depends upon the swelling property and water absorption capacity of the material.

4.8.2.5 Part Lining

Part lining of the canal is sometimes suggested to reduce the cost of lining. However the studies carried out at Indian Institute of Technology. Kanpur has indicated that for shallow canal (B/H > 9) and deep water table conditions. The bottom lining reduces seepage upto to 50%. For deeper channels with deep water table conditions, lining on the sides is more effective. For shallow water table conditions, electrical analogy experiments conducted at U.P.Irrigation Research Institute. Roorkee indicated that even a small open area is good enough to defeat the purpose of lining. The seepage losses go as high as 97 percent of what they would be without any lining. Thus a part lining or damaged lining of a canal means no lining. Part lining of a canal with shallow water table conditions is therefore, not economical and advisable from seepage considerations.

4.9 GENERAL DESIGN CONSIDERATIONS

4.9.1 EXPOSED SURFACE LININGS

Exposed surface linings may further be classified as (i) Hard surface linings and (ii) Earth linings. The design considerations for these two categories are therefore, given separately.

4.9.1.1 Hard Surface Linings

Since the cost of hard surface linings is usually high. A section with the least perimeter for a given area is most economical. Although a semi-circular section satisfies this requirement, it is not practical because the top portions of the sides become too steep. The steepest satisfactory slope for most of the canals from both the construction and maintenance viewpoints is 1.5: 1. Steeper slopes may be used on small canals where the soils remain stable. The limitations to steepness of hard surface linings are due to slippage of lining and soil stability. This slippage may be caused by insufficient friction between the lining and the sub grade and also by the external hydrostatic pressure i.e. draw down.

Canals provided with hard surface linings are usually designed with a finished bed width to water depth ratio (B/D) of 1/2. Smaller canals may have a ratio B/D of 1. However. Channels with larger discharge may have much higher B/D ratio of20 or even more depending on the permissible depth and available slope.

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Adequate freeboard in a hard surface lined canal depends on the size of the canal conditions of flow,. curvature of alignment, wind and wave action, increase in flow resulting from error at diversion, variation in the friction coefficient, and accumulation of silt and the method of operation. The normal freeboard for hard surface linings ranges from 15 cm for small canals to over 60 cm for larger ones. The height of the canal bank above the top of the lining usually ranges from 30 to 60 cm depending on the size of the canal and the local conditions.

(i) Sub grade

A primary pre-requisite to the success of the hard surface linings is a firm foundation in order to reduce the amount of cracking and the danger of failure due to settlement of the sub grade. Natural in place soils of low density should therefore be thoroughly compacted or removed and replaced with suitable material. Clays, because of their expansion qualities when wet, are usually a hazard to hard surface linings and should therefore be avoided or treated suitably. The treatments usually given to expansive clays are overloading, removal and replacement with gravel and chemical treatment with lime. Where the cost of any of these treatments is prohibitive. Change of alignment may be the best solution.

Gypsum soil is another hazard to hard surface linings. Water in contact with gypsum will dissolve salts in the sub grade soil and in time create cavities to cause serious damages to the lining and the canal. Solutions to this problem include making the lining waterproof by applying a cement-plaster coating over the existing lining or placing a well-compacted layer of selected clay material under the lining.

The weed growth may also be a potential hazard to some of the hard surface linings. Weeds may penetrate the lining and. when dead leave openings through which water may leak. Treatment of the sub grade with a soil sterllant is advisable when such linings are to be placed in areas infested with heavy weed growth.

(ii) Embankments

For most hard surface linings the canal embankments must be compacted at least to the height of the lining. The top width of the embankment at this height varies with the size and location of the canal, type of lining and other pertinent factors. Usually. it varies from 0.6 to 1.2 m for canals of capacity unto $3m^3$/sec and from 2.0 to 2.5m for larger canals. Loose material is then placed over and outside the compacted embankment to provide space for roads and stability to the embankment. The unsuitable material from beneath the compacted embankment should be removed and compaction completed to 95% of the laboratory maximum density at optimum moisture.

(iii) Drainage

Occasionally, it may be necessary to construct a hard surface lined canal in an area where the groundwater is likely to rise above the bottom of lining. In such situations suitable pressure release arrangements (as discussed later) may be provided to relieve any hydrostatic pressure that may cause uplift of the lining when the canal is empty.

(iv) Water Velocities

Usually velocities in a lined canal should not exceed 2.5m/sec to avoid the possibility of lifting the lining. A mathematical check using a Manning's n, which is 0.003 less than the design n used for the lining, is also recommended to ensure that the depth of flow does not approach the critical depth closely enough to develop standing waves. Reaches most likely to develop these waves are those in which the canal bottom is raised above theoretical grade. At the point of maximum upward tolerance the depth should be greater than the critical depth when computed with the reduced value of n.

(v) Roughness Coefficient

In a given channel the rate of flow is inversely proportional to the roughness of the surface. An appropriate value of the rugosity coefficient n, should therefore, be taken in consideration of the nature of finished surface of the lining for its design with the help of Manning's formula.

(vi) Silt Deposits

Bed load and fine sand can be prevented from entering a canal but not the suspended silt. In unfavorable situations the silt may settle down in the canal where its removal would be costly. The minimum velocity, which prevents silting, is called the critical velocity. A deeper canal requires higher velocity to prevent silting. The studies carried out by

Kennedy for canals in the Punjab found that the canal with a 0.0005 slope is safe from silting at flow depths unto 2.21m and that the canal with a 0.0002 slope is safe from silting only to a depth of 1.16 m.

4.9.1.2 Earth Linings

Cross-Section - If the canal cuts a pervious as well as impervious soil strata, lining of the impervious part is not necessary. Side slopes in earth-lined canals are 1.5.1 or flatter, depending on canal size and materials available for lining, as well as the type of lining to be used. If highly plastic soils are to be used, it is advisable to use slopes of 2: 1 or flatter because of loss in stability when these soils become saturated. The bed width and water depth ratio is usually about three for small canals and eight or even higher for large canals. The minimum freeboard should be provided as already discussed above. Alternate wetting and drying cycles are serious hazards to most types of compacted earth linings. They reduce the soil density of the compacted layers and thus lessen the effectiveness of the lining as a water barrier.

The care should be taken for other factors such as;

(i) Sub grade

The sub grade treatment depends upon the sub grade material. Where sub grade consists of fine - grained soil, it is ploughed and compacted. In case of sands and sandy gravels, no sub grade treatment is required. If the sub grade contains open voids, as in case of gravel and fractured rocks, it may be necessary to over-excavate and place a sand-gravel filter layer before placing the lining to avoid piping.

(ii) Erosion

Erosion protection of earth lining is necessary. Linings constructed of silty and sandy materials with little coarse gravel are susceptible to scour. If these are to be used, the cost of reducing the velocity by use of a larger section, as compared with the cost of maintaining a smaller section with its higher velocity and protecting the lining with a gravel cover, should be evaluated.

(iii) Density

For placing compacted earth linings, rigid control of soil density and optimum moisture is required. A density at least 95% of the laboratory maximum will normally provide adequate stability and impermeability. Several in-place density tests should be taken during construction to check the quality of work. The material should be compacted till the desired density is obtained. Similarly, a check on the permeability should also be exercised by carrying out laboratory tests on samples taken from the lining. In addition, a few field permeability tests should also be made. These in place tests are important particularly in the beginning of the lining job to ensure if the construction procedures are producing the desired results.

(iv) Velocities

The permissible velocities for different earth materials may vary from 0.3 to 1.3 m/sec, large curvatures in the canal are generally avoided or else the outer bank may get damaged due to scour. The value of Manning's n is taken as 0.025 or 0.020 for canals having discharge less than 3 m3/sec. For larger canals, this value is taken as 0.0225 or 0.020.

(v) Seepage

Seepage losses through thick compacted earth linings and loose earth linings range from 0.03 to 0.28 m^3 /sec/l0^6 m^2 and from 0.18 to 0.53 m^3 /sec/l0^6 m^2 respectively. The observed seepage losses through the loosely placed earth linings range between 1.32 and 1.66 percent of the canal discharge per kilometer.

4.9.2 BURLED MEMBRANE LINING

In order that erosion may not damage the membrane or sliding, the channel section must be completely stable and resist the scouring effect of flowing water. A bed width to water depth ratio of about 4: 1 in most of the materials is usually sufficient to overcome erosion. As regards the sliding of banks, no particular side slope will satisfy all sub grades and cover types. However, a side slope of 2: 1 has been found satisfactory in most of the cases. Even a flatter slope may be required, if the cover is composed of relatively unstable material such as uniformly graded sands, fine gravels or silty sands. The other considerable aspects are as follows:

(i) Sub grade

If properly placed the buried membranes are almost completely watertight. Their durability depends primarily on the proper sub grade treatment and the adequacy of the cover material to protect them from damage. The canal section must be excavated to accommodate the required water prism plus the cover material. The native soil sub grade should be disturbed as little as possible. After necessary excavation the sub grade surface should be made smooth and firm so that it may facilitate the laying of the membrane of uniform thickness and may provide a satisfactory membrane support. If the sub grade is composed of rough, irregular, angular or fractured rock and gravel etc. the sub grade surface should be made smooth with fine sand or soil padding. Sterilization may also be necessary to prevent vegetation from penetrating the membrane lining

Protective Cover - Since earth excavated from the canal section, is usually the least costly cover material. it is most frequently used. The thickness of the covering layer depends on the erosion resistance of the material and the local conditions such as type of cleaning equipment, amount and type of animal traffic and localised scour particularly at curves and structures. When the cover material is clayey gravel or some equally erosion resistant material, a minimum depth of cover equal to 1/12 of water depth plus 25 cm is recommended. In case of fine-grained and non-cohesive material a greater total thickness is required and gravel protection should be provided.

Rapid draw down of water surface will tend to cause the cover to slide down the slope. Therefore rapid water fluctuations should be avoided otherwise the slope will have to be fattened or the cover material should be selected so as to be free draining without loss of fines. In such cases the thickness of the cover may be increased. The stability of the cover may be improved by compaction also.

(ii) Velocity

When designing a buried membrane lining, the flow velocities should not be allowed to exceed the permissible ones. The velocity is usually somewhat less than that in an unlined canal of soil similar to the cover material. In case of earth covers scour is generally a hazard to the membrane. The cover material should therefore be compacted to maximum density.

4.10 PRECONSTRUCTION INVESTIGATIONS

The investigations necessary to decide the need of lining in a certain area include

(i). The type and permeability of the subgrade in different reaches of the canal.

(ii). Assessment of seepage losses in pervious reaches.

(iii). Water-table conditions and

(iv). The extent of area likely to get waterlogged.

The soil investigations should include the type of soil by taking bore logs 30-50 m deep (or upto impervious layer if encountered earlier) spaced at about a kilometre for larger canals. Where soil strata are variable, intermediate boreholes may be located to define the soil profile as best as possible. If the soil stratum continues to be pervious for large depth, as indicated by a few deep borings, the stratum may be assumed as extending to infinity for seepage computations. Soil tests, in addition to usual classification tests, should include tests to determine expansive nature of subgrade material and chemical tests to guard against the presence of any possible deleterious substances, which may adversely affect the lining material. Sulphates of sodium and magnesium are known to be the worst enemies of concrete and brickwork. Similarly, total soluble salts if present more than 0.25 percent by weight of soil are harmful to the lining material. Suitable remedial measures should therefore be adopted in such problematic reaches. Field permeability of the strata below canal bed should be determined at every kilometre along the canal centre line. In order to determine the overall permeability of the strata below canal bed, pump out tests should be conducted in representative soil strata.

The factors governing the seepage losses and the methods for their determination under different site conditions have all been dealt with separately in the article 12.3 on 'Seepage Losses'. To assess the likely seepage losses from the channel cross-sections upto governing drainage on either side of the channel should be taken at every kilometer.

All bore holes, shallow or deep, made for the soil investigations should be used for measuring the position of water Table in the area. The lowest and highest positions of water Table in various reaches should be known, preferably for several years, to provide more realistic limits of water table fluctuations.

Thus, after having completed the above fieldwork, a longitudinal section of the canal showing bore logs and the water table positions (lowest and highest) should be prepared for detailed study and for framing the proposals. Similarly, all cross-sections showing the strata charts of bore-holes, water table position and water levels in the drainages should also be prepared to assess the seepage losses from the canal and to mark the area likely to get waterlogged as a result thereof.

The availability of materials for canal lining, such as aggregates and sand for cement concrete lining, soil suitable for brick tiles, bentonite soils suitable for earth linings etc. should also be investigated.

4.11 SELECTION OF TYPE OF LINING

Although canal linings are very simple structures from an engineering point of view, the fact that normally large investments of labour and material are involved necessitates a very careful selection of the type of lining. So once the necessity of the lining of canal is decided, sincere efforts should be made to select a type of lining that fits best into the given conditions.

The various factors governing the selection of the type of lining are discussed below, the sequence being necessarily not in order of their importance

4.11.1 SOIL PROPERTIES

Concrete and some other rigid type linings when constructed on subgrades containing swelling clays or gypsum are likely to get damaged. A more flexible type of lining, such as thick compacted earth lining or a buried membrane lining, would serve better in such soils. For a hard surface lining it is often advantageous to remove the unsuitable soils, present in short reaches to be crossed to a certain depth by over-excavation and replace it with sand or some other suitable material. Also, a minor change in the canal alignment, so as to by pass areas with unsuitable soils, may sometimes provide a more economical solution to the problem.

If sufficient amounts of sand and gravel are available in the areas nearby, cement concrete or soil cement lining may be adopted. Similarly, if soils are fit for compaction, a compacted earth lining should be favoured. In case the available soils can neither be used as aggregate nor they are found suitable for compaction but may provide a good cover material, a membrane lining may be considered keeping in view their resistance to erosion

4.11.2 TOPOGRAPHY

Hard surface lined canals can better follow contour lines on a hillside, whereas earth linings and buried membranes are normally best suited for slightly or non-sloping land. This is mainly because of the difference in the permissible flow velocities.

4.11.3 LAND VALUE

In urban and some other areas where the land value is quite high, installation of buried pipe systems or use of hard surface lined canals with steep side slopes is favoured. In such areas it would be highly uneconomical to provide a buried membrane lining which needs side slopes of 3: 1.

4.11.4 OPERATION AND MAINTENANCE

If the operation of the canal requires frequent running and closing or causes frequent water level changes, a hard surface lining will perform the best. In case of earth linings or earth-covered membrane linings such conditions would speed up the deterioration process quite fast and the maintenance costs would go very high. As regards weed control small repairs and silt removal etc. the latter types of linings have very little advantage over the unlined canals. If the hand labour is expensive, the higher maintenance cost of earth or membrane linings in comparison to most hard surface linings may even exceed the difference of capital or installation cost.

4.11.5 WATER TIGHTNESS

If the value of water is high, the aim should be to mitigate the seepage losses to the minimum possible value. In such areas a relatively watertight type of lining should be adopted. Probably the most impermeable lining is thin plastic, asphalt or rubber sheeting, placed under a normal concrete lining. The additional cost for such a sub lining of some membrane material will be quite justified because of the additional water saved

4.12 DURABILITY OF LINING

The durability of linings depends on the type of lining, the quality of construction materials used, the quality and accuracy of construction, canal operation and maintenance etc. Properly constructed and maintained cement concrete linings may have a service life of at least 40 to 50 years. The life expectancy of thin exposed membrane may be shorter than two years, but still may be economically feasible as a temporary lining. Similarly, compaction of natural soils in unlined canals may also be useful to prevent or rather reduce seepage temporarily. Its effectiveness may last for only one irrigation season. However, by repeating the treatment during the next off-season, a satisfactory solution of seepage reduction may be obtained.

Since the benefit-cost calculations essentially require the durability period of the lining. The latter should be determined carefully. Performance of lined canals in the nearby projects may provide valuable data in this regard.

4.12.1 AVAILABILITY OF CONSTRUCTION MATERIALS

Generally, the most economical lining is the one, which makes the best use of locally available materials. So for economic reasons, it is essential that the material used to construct the lining is available at site or within the reasonable distances from the canal. Stone or tile linings are feasible only with the existence of stone or clay at site.

The extent of utilizing off-site materials depends largely on transport facilities. If both cement and aggregates have to be transported long distances to the job site, serious consideration should be given to prefabrication, or a lining other than cement concrete should be employed. In sandy soils, soil-cement-lining requiring only the procurement of cement may be a cheap and suitable lining.

4.12.2 AVAILABILITY OF LABOUR AND MACHINERY

Some linings are more suitable for hand labour and others, like cement-concrete, for machine installation. The choice, therefore, is often governed by the relative supply of labour and machinery. In areas with surplus manual labour and poverty it is a socio-political necessity to utilize the labour potential to the maximum. Stone and brick tile linings are common examples of highly labor-intensive types. Even compacted earth linings may be economically carried out by hand labour when aided by simple implements and animal power. However, thick compacted earth linings, thickness exceeding 112mm require compaction equipment and machinery. The requirement of prompt and quick completion of the lining to obtain early benefits calls for the introduction of some machine-placing techniques.

The types of lining and their effectiveness in seepage control found on different countries are given in Tables (29,30,31,32) below:

Table 29. Seepage losses from unlined and lined canals in different countries

Sn	Country	Canal type		Seepage Rate	Remarks.
		Unlined	Lined		
1.(a)	India-Punjab		(i) Bk.lined, Suman Br., 4 month old	0.06 m/day	Seepage losses from canals older than 4 years are comparable to losses from unlined canals
			(ii) Mudki Dys. 15 kms, 5 yrs old	0.29 m/day	
			(iii) Muktshar Dys. 6yrs old	0.49 m/day	
			(iv) W/cs (24)	-	
(b)	Periyar Vaiga - Tamilnadu	Main canal	-	29.7 %	
		Large Dys.	-	44.6 %	
		Med. Dys.	-	66.6 %	
		Small canal	-	75 %	
3.	Nebraska, 1986,USA				
		i) Farewell main canal		0.17 m/day	Before lining
				0.08 m/day	After lining
		(ii) Franklin canal		0.30 m/d	Before lining
				0.14 m/day	After lining
		(iii) Meeker canal		0.34 m/day	Before lining
				0.10 m/day	After lining

4.	Sri Lanka	Kadulla IS	0.13 m/day	Unlined, ponding method
			0.07 m/day	Lined
5.	Pakistan, Fordwah sadiqia	(i) Geomembrane covered with cast in-situ concrete	98 %	
		(ii) Concrete only	74 %	
		(iii) Geomembrane under soil cover	Fail	
		(iv) Geomembrane over bed only	49 %	
		(v) Concrete fill mattress over geomembrane	94 %	
		(vi) Bricks over geomembrane	97 %	
6.(a)	China, Tarim-1, Project	(i) Concrete slab with plastic film (311kms)	0.149 m/day	0.18mm polyethylene plastic films
		(ii) Plastic film with earth, grass, cobbles (466 kms)	0.253 m/day	
		(iii) Conc. slab only	0.307 m/day	
		(iv) Pebbles with mortar	0.361 m/day	

(b)	Annual seepage losses in Tarim –1, before and after lining	(i) Yarkand Oasis	787 Mil.m^3	Before lining
			251 Mil.m^3	After Lining
		(ii) Weigan Oasis	587 Mil.m^3	Before lining
			155 Mil.m^3	After Lining
The effectiveness of canal lining was 70 % and ground water table was dropped from 0.5m to 1.0m. Saline lands were reclaimed				
7.	Pakistan- Seepage values	(i) In unlined canals seepage losses assumed normally	8 cusecs/Mil sq. ft.	
		(ii) Estimates of average losses up to out lets	20 – 25 % of head discharge	
8.	USA, Seepage losses	Seepage rate of soil groups (Idaho)		
(a)	Idaho	(i) Clayey	0.07 m/day	All results are Ponding test results.
		(ii) Silty	0.23 m/day	
		(iii) Loamy	0.29 m/day	
		(iv) Sandy	0.48 m/day	
(b)	Utah	(i) The seepage losses from unlined canals ranged from 5 – 42 % of total seasonal flow	Average loss was 17.4 % of Head discharge	These values were obtained from the study of 20 canal systems in Utah (1977)
		(ii) Operational wastage	0 – 12 % of Head discharge	

Similarly the test results for seepage found at Punjab Irrigation Research Institute, Amritsar, were applied in U.G. Irrigation Modernization Project. The test results are tabulated in Table 30 below:

Table 30. Test results of different linings

Sn	Lining Type	Stabilised seepage rate in cusecs/ mil.sq. M of WP
1.	Unlined canal	3.13
2.	Cement: lime: Surkhi (1:5:12) mortar sandwiched between two layers of 30*15*5 cms tiles	0.038
3.	Cement: Sand (1:3) mortar sandwiched between two layers of 30*15*5 cms tiles	0.0082
4.	100 mm thick concrete of Cement: Sand: Ballast (1:3:6) proportion	0.0061
5.	100 mm thick concrete of Cement: Lime: Surkhi: Brick ballast (1:5:12:24) proportion	0.119

Source: Lining of Irrigation Canals, The Concrete Association of India.

Types of lining and their characteristics: (Reference: D.B.Kraatz, Irrigation canal lining, FAO, 1977)

The effectiveness of the exposed hard surface lining and buried membranes lining for controlling seepage losses with respect to their thickness and working condition is given in Table 31 below.

Table 31:Comparision of exposed hard surface and buried membrane lining

Sn	Types of lining and thickness	Durability/service life (yrs)	Water losses cumecs/ Mil.sq.m	Notes
1	Hard Surface Lining			

(a)	Portland cement concrete unreinforced, 50mm – 100mm thickness depending on canal capacity. Reinforcement not used except when soil conditions are dubious (e.g. on swelling clays)	Unto 50yrs	Between 0–0.35 if properly constructed and maintained. Seepage up to unlined rate if constructed poor	SuiTable for all sizes of canals, all topographic al, climatical and operational conditions. Firm sub-soil required, susceptible to damage by swelling clays membrane underlay needed on gypsiferos soils
(b)	Pre-cast concrete blocks500mm*250mm*70m m,typical weight 21 kgs/block	About the same as above, if properly maintained	If joints are well sealed, about, 0.35, virtually 0, if sound membrane under lay used	Advantageo us when concrete lining is suiTable, factory pre-casting is more economical. Membrane underlay ensures

				lower water loss and is essential on gypsiferous soils.
©	Brick and stone: (i) bks.300mm*150mm*50mm laid on 10mm mortar bed with 20mm plaster cover	May be as high as cement concrete lining if properly constructed and maintained	Bks. With cement plaster, seepage around 0.35,stone negligible with good membrane. Up to unlined seepage without membrane.	Labour intensive method, availability of cheap construction materials at or near the site is essential. Not practical if labour cost is high.
2.	Burried membrane	Depends largely on erosion resistance of cover material maintenance weed hazards, breaching etc borrowing		Suitability of excavated soil as cover material is important. Heater and spray equipment must move
(a)	Sprayed in situ, asphalt, 5-8mm thick		From almost 0-0.7	
(b)	Pre-fabricated asphaltic membrane		0.9	
©	Polyethylene 0.2-0.3mm thick		0.7	
(d)	Polyvinyl chloride 0.2-0.3 mm thick		0.9	

(e)	Synthetic rubber 0.8mm thick	animals) and operation (draw down). Records show serviceable life of 15 years but rubber membrane is likely to last more	0.35	along canal. Skilled personnel are required. Easily transported and placed materials but slippage if cover material draw downs is likely to be a problem,

Note: The actual seepage value in all cases is very much dependent on the standard of workmanship. Unless there is a guarantee of exceptionally high standards being realized, assume the greatest seepage in the given for design.

Table 32: Seepage losses values for different lining type.

Sn	Type of lining	Seepage losses	Remarks
1.	(a) Reinforced conc.lin	The value of seepage ranged from 0.03-0.32 $m^3/s/Mm^2$	Based on the results of seepage measurements done by USBR in various projects in USA
	(b) Unreinf or P.C.C lining.	0.25 – 2.93 $m^3/s/Mm^2$	
	© Cement conc. Lining in Lower Bhawani canal in (Tamilnadu)	0.72 $m^3/s/Mm^2$	Field measurements done by Inflow – Out flow method.
2.	Shot Crete Lining	0.11 $m^3/s/Mm^2$	USBR – observation in various projects

3.	Brick lining	Bks. Lin. With sand witched layer of cement plaster is equally impermeable as cem. Conc. lining.	-
	(i) Bks. Lining in Sarda Power Canal (field observation0	$0.27*10^{-3}$ cumecs/m length of unlined canal	Reduction in seepage was 44 %. But the laboratory results show that the bricks permeability value was of the order of 8*10-6, which show that the seepage reduction would be 70 %, the effective field permeability of lining in the field was found much higher due to cracks developed in lining
	(ii) Lower Ganga Canal (field observation)	Average losses from brick lined section is $1.084*10^{-4}$ cumecs/ m length of canal and $1.61*10^{-4}$ cumecs/m length of unlined canal section	Reduction in seepage losses is 33%
4.	Effect of the leaking joints in lining	Even 5% leak areas leads to seepage losses of the order of 90% of those from unlined canals.	-

4.13 COST AND BENEFICIAL ASPECT

Cost of the lining has to be weighted against the obtainable benefits. Theoretically, the most economical solution should be adopted, regardless of its cost. However, in practice the financial resources of the project often determine the type of lining. Therefore a balance has to be struck and a solution commensurate with the project conditions should be adopted. Actually, it is more economical to line a large portion of the canal network with a less expensive type of lining rather than lining only a small portion with an expensive type lining.

4.14 SEEPAGE LOSSES FROM WATER COURSES:

It is estimated that in major irrigation projects about 45 percent of the water diverted for irrigation gets lost in transit in different links of conveyance network from the source to the farmers fields. Out of this 45 percent loss nearly half is lost in watercourses and field channels. Since huge quantity of water is lost through unlined watercourses and field channels, their improvement obviously is advantageous in the context of minimising the loss and saving the precious water. The watercourses capacities usually are fixed on the basis of the handling capacities of the farmers. They are generally of less than 28 lps (one cusec) capacity serving a group of farmers, but in Punjab & Sind water courses with capacities ranging from 3-5 cusecs were in the past. Accordingly the water distribution practice followed in a system, main and branch water courses run continuously or even intermittently for specified timings while the field channels normally run more intermittently to fulfil the irrigation requirement of the adjoining fields only. Any method selected and applied to improve the performance of watercourses depends upon the cost of the improvement against the benefit from the same.

Therefore, the major looser of water due seepage and others losses are the water courses, in comparison to other units of conveyance, which should be given due care for minimising the same. The commonly accepted figures for transit losses in the alluvial plains of Utter Pradesh and Punjab (India) are given in Table 33 below.

Table33: Seepage losses as % of head discharge (UP & PUNJAB).

Sn	Particulars	Percentage of seepage loss
1.	Losses from main canals and branches	17 % of H/D
2.	Losses from distributaries	8 % of H/D
3.	Losses from water courses	20 % of H/D
Total losses in transit		45 % of H/D

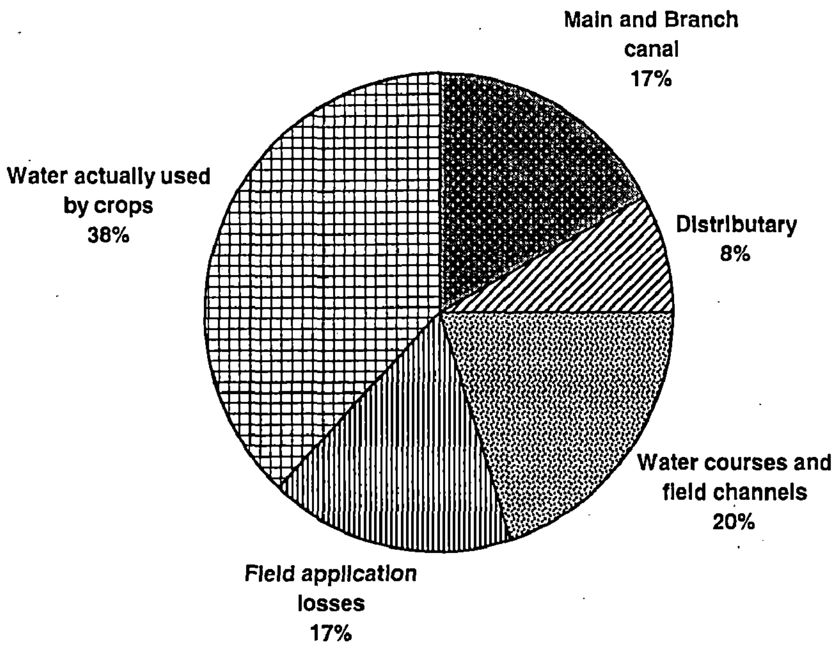


Fig.19: Showing % losses from different units of canal and application losses (commonly accepted values in Utter Pradesh and Punjab state of India)

Even allowing 20 % of this transit loss for evaporation, the loss due to seepage alone is as large as 36 % of the supply entering a canal head. The losses in the fields are further estimated to be approximately 30 % of the supply reaching the field (i.e. 16.5 % of the H/D). Thus only 38.5 % of the supply let into the canals by and large, is utilised by the crops.

Studies conducted by ICID/CWPC (1967), in unlined canals observed the loss of water as indicated in Table 34 below.

Table 34: Seepage losses as % of head discharge (ICID/CWPC).

Sn	Particulars	Percent loss
1.	Canals	15 % of H/D
2.	Distributaries	7 % H/D
3.	Water courses and field channels	22 % H/D
4.	Field application losses	27 % H/D
Total loss		71 % H/D

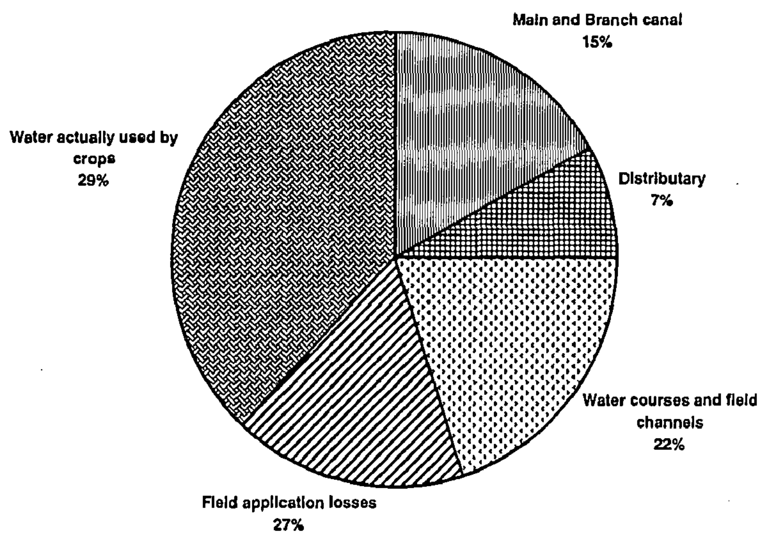


Fig.20: Showing % losses from different units of canals (ICID)

Similar studies done by Kennedy in unlined canals revealed the results as given in the Table 35 below.

Table 35: Seepage losses as % of head discharge (Kennedy).

Sn	Particulars	Percent loss
1.	Canals	20 % H/D
2.	Distributaries	6 % H/D
3.	Water courses and field channels	21 % H/D
4.	Field application losses	25 % H/D
Total loss		72 % H/D

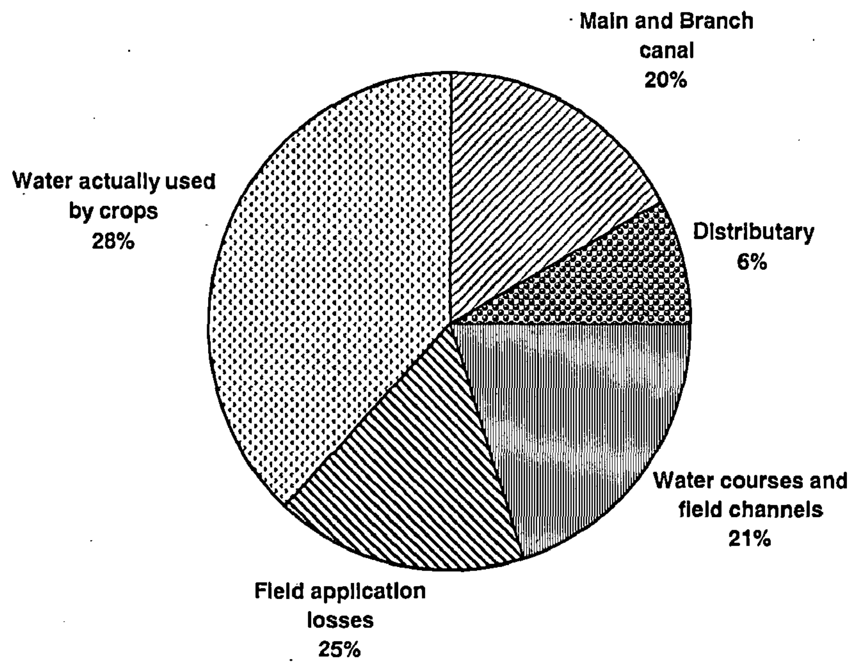


Fig.21: Showing % losses from different canal units according to Kennedy.

The accepted value of water loss from the unlined water course only is 20 - 22 % of the head discharge, which is quite a huge amount Moreover, the construction of the water courses are done by the users themselves, so obviously the required section would not be provided in the sense of saving their valuable agricultural lands and also being deprived of assessing the modern technology in application of irrigation water, the old traditional methods are still continuing resulting in either over use of water, misuse or even wastage of the water made available.

The comparison of the seepage losses obtained by Kennedy, ICID and the values of seepage adopted in Punjab and Utter pradesh for the main canal, branch canal and water course is presented in the graph (fig 22) below.

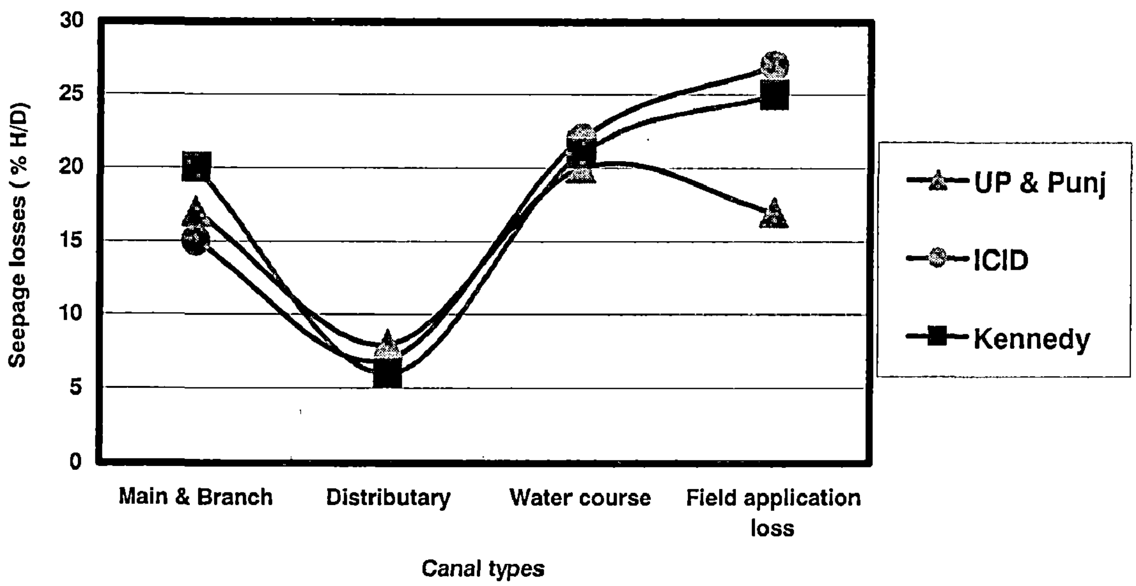


Fig. 22: Showing seepage value found by different studies

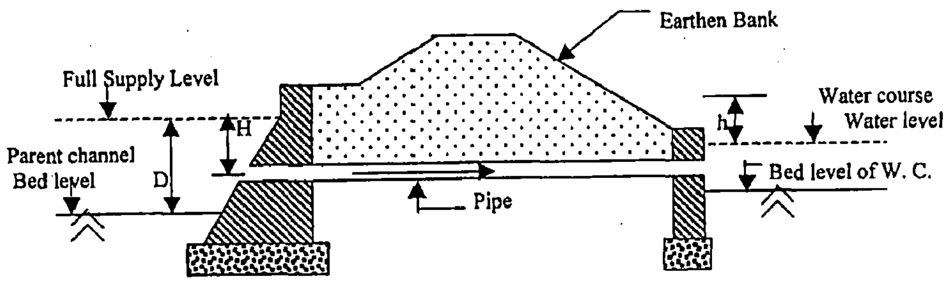
4.15 IRRIGATION OUTLET

4.15.1 FUNCTION OF AN OUTLET

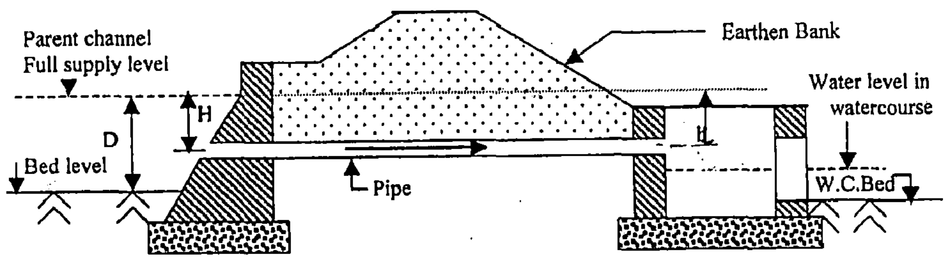
An outlet is a device provided at the head of watercourse to control flow of water from a canal to the watercourse. It also provides a means for measuring the quantity of water delivered in the watercourse. It plays a vital role in distributing water equitably and efficiently and the proper functioning of the distribution system is dependent on the performance of the outlet structures in accordance with design assumptions.

4.15.2.TYPE OF OUTLETS

Outlets may be divided into the following three categories:



Submerged Pipe Outlet



Pipe Outlet with Free fall

4.15.2.1 Modular Outlet

An outlet is termed as modular or rigid when the discharge through the same remains independent of water levels in the parent channel and watercourse within certain limits. Such an outlet would give fixed supply of water irrespective of the discharge in the channel. If the discharge in the channel is higher than designed, the excess water will reach at the tail and may go to waste. On the other hand if the discharge is lower, the outlets in head reaches will continue to take their prescribed share, resulting in shortage of water in the tail reaches. Since in practice it may be difficult to run a channel at all time with a constant discharge, the above limitations restrict the use of rigid modules mainly to the following cases:

1. Direct outlets on Branches, which are usually operated with fluctuations according to the availability of water.

2. Outlets just upstream of cross-regulator or raised crest falls where heading up may be necessary to feed the offtaking channel.

In view of the above limitations,utility of rigid modules and their complicated designs and construction they have not in common use of distribution system of UGC command.

4.15.2.2 Non-modular Outlet

Discharge through a non-modular outlet depends on the difference of water levels in the parent channel and the watercourse. Thus variation in any of the two would affect the discharge through such an outlet. The most common type of non-modular is a pipe outlet widely used in UGC system. The pipe is generally kept horizontal and at right angles to the direction of flow in the parent channel. The pipe outlets are ungated and run continuously so long as the channel runs. The discharge formula is

$$Q=CA(2gh)^{1/2}$$

Where Q is the discharge of the outlet is a constant depending on the length of pipe and coefficient of fluid friction in the pipe.

A is the area of internal section of pipe.

h is the difference in water levels in the parent channel and the watercourse.

The pipe outlet is provided with head and tail walls to safeguard it against tampering by the cultivators and to prevent any leakage of water along the outer periphery of the pipe. The axis of the pipe is kept 9 inches below the FSL in the Dy/Minor. In the case of Branches, the pipe is fixed at a depth depending upon the minimum water level with which a Branch may have to be run in rosters according to availability of water. No outlets are generally allowed in Main canal. Obviously the discharge through such outlets fixed on Branches would be much higher when the Branch is running with full design discharge.

In UGC system the following Table 36 of average discharge of pipe outlets on Dys/Minors has been approved as a ready reckoner for the field engineers.

Table:36 Discharge of pipe outlets in UGC system.

Ventage(diameter of circular pipe)		Unit	Average discharge for			
			Free overfall	Outlet with submerged outfall		
Inches	Cm.			0 to 20% lift areas	21 to 50% lift areas	Over 50% lift areas
1	2	3	4	5	6	7
6	15.0	Cusec	0.90	0.66	0.55	0.40
		Cumec	0.025	0.0185	0.0154	0.011
5	2.15	Cusec	0.68	0.50		
		Cumec	0.019	0.014		
4	10.0	Cusec	0.40	0.30	0.25	0.20
		Cumec	0.011	0.008	0.007	0.006
3	7.50	Cusec	0.20	0.15		
		Cumec	0.006	0.004		

The above Table applies to pipe lengths upto 18 feet. When the outlet length exceeds 18 feet, the next higher ventage is adopted. The Table is based on normal conditions of head over the axis of the pipe. The discharge through the pipe outlet varies with $(h)^{1/2}$ and may fluctuate considerably if the supplies in the canal are fluctuating.

The outlet size is selected for any command based on duty factor (outlet factor) for the crop to be irrigated and the intensity of irrigation proposed.

4.15.2.3 Merits and Demerits of Non-modular Outlet

(i) These are not easily adjustable, as it would require dismantling and reconstruction of the structure.

(ii) The submerged outlet can be converted into free fall and the discharge can be increased by the cultivators by letting the water drop into a sump from where it is lifted by the cultivators with the help of a pump or Persian wheel.

(iii) The discharge of the pipe outlet increases if a part length of pipe is removed by the cultivators or the pipe is lowered.

(iv) The discharge is also dependent on the condition of clearance of silt and weed growth in the watercourse. Badly maintained watercourse may cause rise in water level and make the outlet more submerged than in normal condition. Thus even with the same water level in the parent channel, the discharge in the watercourse may vary.

(v) The fluctuations in water level in the parent channel result in inequitable distribution of water in the command of the channel.

(vi) The non-modular pipe outlets draw less silt in the head reaches and thus more silt often gets deposited in the head reaches of a channel which impairs its discharging capacity.

Despite all the above aspects a pipe outlet is the most simple and popular outlet.

4.15..3 SEMI-MODULAR OUTLET

Semi-modular outlets also known as flexible outlets are those through which discharge is dependent on the water level in the parent channel but is independent of water level in the watercourse so long as the minimum working head required for its working is available. The important types of semi-modular outlets are described below:

(i) Pipe outlets discharging freely in the air

The discharge is proportional to $(h)^{1/2}$ where h is the head of water or the difference between water level in the parent channel and the axis of the pipe outlet. This condition is created artificially in some cases by dropping the water into a sump and then lifting it again.

Since the conditions of free fall into the air are limited, the pipe outlets do not operate as semi-modules. Moreover the discharge passing through the outlet is proportional to the discharge carried by the parent channel only within a limited range of setting of the outlet (h/d) which is about 0.2 in the case of lined channel and about 0.3 in the case of unlined channels. For other settings the discharge passing out will not be truly proportional. The distribution of silt is also not proportional in the case of pipe outlets. In view of these limitations it has been proposed to provide orifice type semi-modular outlets or open flume outlets in the Upper Ganga Irrigation Modernization Project.

(ii) Orifice Semi-modules

It consists of an orifice provided with a gradually expanding flume. The flow through the orifice being hyper-critical results in the formation of jump and thus making the discharge independent of the water level conditions in the watercourse. The most common type of orifice semi-modular outlet is the Adjustable Orifice Semi-module (AOSM) which is widely used in India and Pakistan. It is an improvement over Crump's Adjustable Proportional Module (APM) which was although truly proportional for discharge but did not draw proportional silt and therefore the parent channel suffered from silting.

The AOSM is very suitable for drawing proportional discharge in channels of UGIMP where two FSLs will be run, both in the parent channel and the watercourse, the Kharif FSL being higher than Rabi FSL. No adjustment will be required in the setting of the outlet within the range of Kharif and Rabi FSLs. The limitation is that from practical considerations the throat width of the orifice,Bt should not be kept less than 6 cm even if it so works out from the discharge formula and the height of the orifice,Y should be calculated corresponding to the Bt provided. For small discharges of less than 0.65 cusec or so Bt would work out to less than 6 cm. To keep Bt to the minimum of 6 cm,Y would work out less resulting in higher setting of the AOSM. Likewise Y should also not be less than 6 cm from practical considerations and if Y works out to be less than 6 cm from calculation, the AOSM would not be fully meeting the requirement of proportionality for Kharif and Rabi discharge. The AOSM is usually found to have a higher setting to meet the requirement of proportionality and hence does not draw its fair share of silt. However the advantage of proportionality should override the marginal drawback in drawing fair share of silt.

Discharge Formula:

Crump's formula for Adjustable Proportional Module (APM) also applies to it which is as below:

$$q = CBtY(2gHs)^{1/2}$$

In simplified form the formula in metric units is

$$q = 0.0403\ BtY(Hs)^{1/2}$$

where q is in litres per second and Bt, Y and Hs are in centimeters.

If Bt, Y and Hs are in meters,

C = 4.03 and we get q in cumecs.

When the orifice height and Bt are known for an outlet, the discharge is easily computable from a single gauge reading G showing the height of water level in the parent channel above the crest as shown in the figure and using the formula

$$q = 0.0403BtY(G-Y)^{1/2}$$

as Hs = G-Y

Since Bt and Y for a particular outlet are known, q can be computed for different values of G depending upon the likely water levels in the parent channel.

It is recommended to engrave and paint the gauge on the slanting surface of the u/s wing wall of the outlet in its straight portion, whose zero reading should correspond to the crest level of the outlet. On one side of the gauge, values of G should be engraved and painted at different levels while on the other side corresponding values of discharge should be painted in accordance with the computations made for each value of G in the office from the known values of C,Bt andY of the particular outlet. The discharge through the outlet can thus be read at site directly on the gauge in this type of outlet.

4.15.4 HYDRAULIC PROPERTIES OF OUTLET

As in the case of Crump's APM, this type of outlet is also instantaneously proportional when the bottom of the roof block (Hs) is at 0.3 of the full supply depth (D) of earthen parent channel. For lined parent channels in which channel index is about 8/3 proportionality is obtained when Hs/D = 1/2/8/3 = 0.2 approximately, i.e., when bottom of roof block (Hs) is at 0.2 of the full supply depth (D). Since Y is generally kept equal to Hs, the setting for proportionality (G/D) is 0.6 in an unlined channel and 0.4 in a lined channel. At this setting, the outlet does not draw its fair share of silt from the parent channel. To overcome this deficiency, it has been recommended by some authorities to fit a 90° bend pipe of suitable length at the mouth of the AOSM. The cross sectional area of the bend pipe is kept the same as that of the orifice and the mouth of the bend is kept at about 0.8D.

Flexibility (F) of any outlet is m/n*D/h

Where, m is outlet index.

n is channel index.

D is water depth in parent channel.

h is head working on the outlet.

For AOSMs fitted in earthen channels

$$m = 0.5$$

$$n = 1.667$$

Flexibility = 1/2D/5/3h = 3/10 D/h = 0.3 D/h = 0.3 D/Hs

When there is fall in the water level of parent channel, the proportional decrease in Hs is more than the proportional decrease in D. Therefore, flexibility of outlet increases and the outlet moves towards proportionality. Similarly when there is rise in the water level in the parent channel, the flexibility is reduced and the outlet moves towards rigidity.

4.15.4.1 Merits and Demerits

1. Susceptibility to tampering:

The structure of the outlet is very strong and has a long serviceable life. But cases of tampering with it are not infrequent. The roof block is sometimes raised bodily and refixed but such type of tampering is easily detected. A wooden plank is sometimes inserted at the downstream side of the roof block and covered with earth and grass, thus forming an airtight room in continuation of the roof block. This increases the discharge due to imperfect aeration of the jet.

2. Suitability and range of operation:

The outlet can work semi-modularly for all heads and with all working heads above the minimum modular head and for all discharges from 1 cusec to 5 cusec (28 l/sec to 150 l/sec), which is the discharge range generally required. These are eminently suited for head and middle reaches of distributaries and minors where sufficient working heads above minimum modular heads are available. In tail reaches where sufficient working heads are not available, these cannot be used.

3. Adjustability

The outlet is easily adjustable at a small cost either by raising or lowering the roof block or by dismantling one sidewall.

4. Control gates:

The structure operates without any control gate and hence is easy to install and keep in practical functioning.

5. Discharge observation:

The discharge of the outlet can be computed from a single gauge reading, which can be checked whenever any officer carries out inspection of the outlet.

6. Silt drawing capacity:

The outlet does not draw its fair share of silt when it is set to draw proportional discharge. With its setting at 0.6 it can draw 99.5% of its fair share. But with higher settings to attain proportionality the percentage drawl of silt reduces. With 0.8 setting it is capable of drawing 109.7% of its share of silt. Hence compared to other types of outlet AOSM can be considered more suitable from this aspect also

5.4.2 OPEN FLUME OUTLET

ɔen Flume Outlet (OFM) is also a semi-module. It is a weir with a throat constricted fficiently to ensure hyper-critical velocity. The length of the throat is such that the ntrolling section remains within it for all ranges of discharges within which the outlet s to operate. A gradual expansion is provided below the throat to obtain maximum covery of head. The sidewalls of the structure are built in brick masonary and top is of CC precast slab. To prevent tampering an iron base plate is fitted in the center of the ntrolling section in the gullet with two side plates which can be adjusted for distance by iding base bolts. The discharge formula adopted is:

$$Q = C\,B_t\,G^{3/2}$$

Where Q is litres/sec and G is height of FSL in canal above the crest of outlet.

For different throat widths Bt, the value of C is:

Bt	C
6-9 cm	0.0160
9-12 cm	0.0163
Over 12 cm	0.0166

In the case of Open Flume Outlet also the setting is high for small outlet discharges to meet the requirement of proportionality and fair share of silt is drawn only when the crest of the outlet is at bed level or close to it. Hence the OFM is more suitable for tail reaches of Dys or on minors. The proportional distribution for Rabi and Kharif FSLs for small discharges is also better in the tail reaches than in upper reaches of a Dys.

4.16 TAIL CLUSTER

The work constructed at the tail end of a channel for the distribution of supplies there is called tail cluster. As the name implies generally two or more outlets are clustered at the tail with aggregate discharge over 0.07 cumec and the side offtakes having equal angles with respect to the centerline of the distributary. The offtaking angles are 45°, 60°, 90° or straight in line with the channel alignment.

Tail cluster is thus a combination of two, three or four open flume outlets, so that the fluctuations in the distributary may effect them equally, the crest level of all the outlets is kept at the same level and proportionality is secured by adjusting throat width (Bt). Depth of water on the crest is kept 0.3m and value of C is 1.66 in the open flume discharge formula $Q = C\, Bt\, H^{3/2}$. The discharge formula of tail cluster thus simplifies to $Q = 1.66\, Bt\, H^{3/2}$. The angle of offtake and lower approach velocity effect in the side offtakes being not appreciable are ignored.

The tail clusters are useful in distributing the supply proportionately and in easily absorbing any excess that reaches the tail. The gullet width is widened by 20 cm at full supply level to facilitate passing down any excess supply reaching the tail without endangering safety of the structure and the canal reach upstream.

The low working head, 6 cm, required for the modular functioning of the tail outlets avoids undue raising of the full supply level in the distributary resulting in economy in the construction of the canal system.

4.17 O&M OF OUTLETS AND WATERCOURSES

Outlets are constructed maintained at Government cost on all irrigation channels. The outlets have to be physically checked for their correctness by the Sinchpal, Ziledar, DRO, JE, AE, EE and the quota for checking the outlets is at present based on the consideration that all outlets will be checked by different level of staff within a period of two years. Any outlets found tampered with should be repaired, corrected and restored to the original sanction. Tampering with Outlets is punishable under Section 70 of the NICD Act 1873.

The watercourses upto 5-8 ha command are to be lined at project cost under UGIMP and maintained by the Government. The field channels have to be constructed and maintained by the beneficiaries or at their cost by the Executive Engineer if the beneficiaries fail to do so.

The discharges of an outlet should be observed by Parshal Flume and checked with the design discharge at least once in 2 years. The effectiveness of lining in reducing the seepage losses must also be checked by observing the discharge at 3 or 4 important junctions of the lined watercourses and comparing it with the design where the seepage losses are assumed to be reduced from 8 cusec/mil sft. to 2 cusec/mil sft. of wetted perimeter. This would also help in deciding whether the lining of watercourses should be carried out at project cost in future time slices and whether the maintenance of lined watercourses could be entrusted to the beneficiaries/Farmer's Associations. The structures such as falls, siphons, culverts, distribution boxes etc should be checked and kept under proper repairs.

4.18 FIELD OBSERVATIONS AND STUDIES ON THE LOSSES AND LINING OF WATERCOURSES

Utter Pradesh Irrigation Branch circulation no. 1 on puddling of irrigation watercourses based on the observations in U. P. & Punjab about seepage. Some important observations were as follows:

1. Kennedy, an executive engineer, in Bari Doab canal irrigation works, Punjab found that average loss of water in water course was 21 percent of head discharge of canal or nearly 43 percent of the outlet head discharge.

2. Demptster, another engineer found the losses possibly over 30 percent of head discharge.

3. Observation on Chenab Canal on a representative watercourse with 5-cusec capacity (2 ft. bed width) with average length of 12000 rft. in a representative village having command area of 1712 acres with 8 main water courses and 4 branch water courses having aggregate length of 37,500 ft and field channels of length in total 584010 ft.was carried out. This gives an idea that over 100 miles of field channels were in a single village. In Chenab Canal main watercourses were equivalent to minors and branch water courses are equivalent to water courses (capacity nearly 0.60 cusecs). The loss quantum can very well be imagined in this channel network.

4. Attempts were also made to study the comparative losses on the said channels as: Wetted area of main watercourses = 12000*8 =96000.0 sq.ft. (running constantly) Wetted area of branch water courses = 37,500*4 =150,000.0 sq. ft. (running half of MWC). Wetted area of minor channels (field channels) =584010*2 = 1168020.0 sq. ft. (1/12 of them running always). The proportionate losses, based on wetted perimeter would be 96: 150/2: 1168 /12 or, 96: 75: 97 or roughly the losses is equal in each of the channels. As the main water course runs constantly and others intermittently the absorption in the minor channels would be more, which remains often dry.

5. Kennedy in his memorandum has also given the rate of absorption in different kinds of channel. He worked out the proportion of branch canals, constant running distributories, tatiled distributories and watercourses as: 45: 30: 17: 8.

This shows that the proportionate loss is maximum in watercourses, less in distributories and least in canals.In general the more the depth of water in canal the more is the absorption. So the results should have been more loss in branch canals, less in distribtories and least in the watercourses. Here in this case it is in the reverse order. So the reason behind it must be due to the lower velocities in the smaller channels and their greater rugosity, which increases the wetted area. This would be specially the case in the watercourses, which are so often irregular and eroded.

6. Another recent studies on losses in field channels, the losses in kachha guls maintained and kept in (unlined watercourses) during running period were observed and found as 4 percent per 100 m length (UGC). It was also observed that the loses in watercourses with poor maintenance is double of that properly good order.

7. Kennedy based on his observation predicted the loss figures, which were taken to be correct as Out of 100 cu. ft. entering the canal, 80 cu. ft. enters the distributory, 74 cu. ft. enters the watercourse,53 cu. ft in water courses.Again out of 53cu. ft 25 cu. ft. are dissipated by wasteful application and the rest 28 cu. ft. are actually utilised by the crops.

From this it is evident that the lining in watercourses will not stop the wasteful application (or excessive irrigation) but if all other loss could be controlled, the quantity of water provided in the irrigation fields would increase from 53 to 74 or nearly 40 percent. Similar estimation of Dempster (engineer) was 30 percent. Though from the practical point of view it would not be possible to control all the loss completely in watercourses but most practical estimate of losses reduction limit would be nearly 50 percent.

It is evident that the seepage is a complex problem and many seepage variables contribute for seepage process. The comparison of seepage losses found by different studies are as given in Table 37 below

Table 37: Comparison of % losses of H/D from different units of canal

Sn	Particulars	ICID (1967)	Kennedy (1890)	Adopted values in Utter Pradesh & Punjab (India)
		Percentages of losses as per Head Discharge		
1.	Main & Branch canals	15	20	17
2.	Distributaries	7	6	8
3.	Water Courses	22	21	20
4.	Field application losses	27	25	17
Total losses		71	72	62
5.	Water actually used by crops	29	28	38

It is to be noted that in average the seepage losses from the unlined canal network have a range of 60 – 70 % of the Head Discharge and the water actually used by the crops varies from 28 – 38 % of the Head Discharge only. Therefore, the seepage problem has to be looked through the Engineering, Social, Agricultural, Economic and Managerial aspects to obtain desirable solutions.

Khungar by analysing 8 years data from (1935 – 1943) in Chenab and Jhelum canals predicted the results as given in Table 38 below.

Table 38:Comparation of losses as percentage of head discharge for different canal units

Sn	Lower chenab canal	Total discharge at head-cusecs	Losses in main and branch-cusec	Losses in Dys.in cusec	Losses in water courses in cusec
1.	Lower Chanab Canal	6805	1128(16.5 %)	366 (5.4 %)	444 (6.4 %)
2.	Upper Chanab Canal	2324	162 (7 %)	131 (5.6 %)	139 (6 %)
3.	Lower Jhelum Canal	2375	340 (14.3 %)	136 (5.3 %)	154 (6.5 %)
4.	Upper Jhelum Canal	958	305 (31.8 %)	53 (5.5 %)	30 (7.3 %)

Similarly Blench in his observations on upper and lower Chenab canals gave the following results as shown in Table 39 below.

Table 39 : Comparation of losses as percentage of head discharge for different canal units

Sn	Name of Canal	Total estimated loss in cusecs	Losses in cusecs with percentage from			
			Main canal	Branch canal	Distributaries	Water courses
1.	Upper Chenab Canal	1170	563 48 %	40 3.5 %	275 23.5 %	292 25 %
2.	Lower Chenab Canal	2550	365 14 %	1196 47 %	552 21.5 %	437 17.5 %

The Table above also shows that there is a considerable amount of losses from watercourses.

4.19EVALUATION OF MODERNIZED WATER COURSES IN PILOT PROJECT OF UPPER GANGA CANAL MODERNIZATION PROJECT IN U.P (World Bank Aided)

During the first phase modernisation scheme under the above said project in (1984-1990),Bulandshahar and Hardnaganj distributaries including distribution main channel, all the minors and water courses were to be lined besides the rehabilitation and updating of water courses and out lets for proper distribution and better use of water. The AGP (WAPCOS –Govt. of India) performed the evaluation studies of the modernisation of water courses on both the distributary system and found as:

1. The proposal of reorganisation and regrouping of large watercourses and converting them into minors could not be finalised and executed in view of many related problems in the old established irrigation practice.

2. On Bulandshahar dy. System the average percentage seepage losses in unlined watercourses during kharif and Rabi were found to be 28 %. This is based on the analysis of observed data of 24 nos. of unlined watercourses in Kharif and 20 nos. in Rabi.

   On lined water courses of the above said dys., based on the analysis of 9 lined water courses, the average percentage loss found was 12 %. Based on the above data saving in seepage losses between unlined and lined wcs. is nearly 53 %. The percentage of lined length varied from 69 to 80 % in case of 4 out of 9 outlets and in others it is varying from 38 to 53 % while the suggested length of lining of water course were 50 to 60 %.

1. On Harduaganj distributary system, the average losses in unlined was, during Kharif have been assessed as 32 % and during Rabi as 28 %.

On the lined water courses based on the data of 29 observations during Kharif, the average loss found was 16 % and based on 9 observations, the average loss during Rabi was 14 %. The saving of water in this system has been nearly 50 % during Kharif and Rabi. Out of the 30 water courses lined, the lined length of 16 only ranged from 61 to 100 % while on 5 outlets it ranged from 14 to 38 % and for the remaining it varied from 45 to 60 %, but the recommended length of lining being 50 to 60 % depending upon conditions and layout of water courses.

2. It has also been observed that mild variation in permeability of soil through which the water course passes does not play important role in seepage as the fine silt carried by canal water gets deposited over the time, on inner surface of unlined water courses and make it less pervious in due course of time.

The variation in losses on unlined water courses on a particular channel in the same area normally depends on the quality of maintenance of watercourse, culverts and other structures and water management by farmers. Also the percentage of seepage losses on both distributaries on unlined water courses were found higher during wet Kharif period than during hot weather Kharif period or Rabi. This may be primarily due to slake demand and wastage of water.

Thus it could be summarised that although the modernisation works lead to substantial saving in seepage losses and satisfaction to the farmers but the advantages were not found as per expectation and could not be sustained over a period due to neglect in maintenance and misuse by farmers.

4.20 STUDIES BY WRDTC (U .O .R. J. N. Chakraborty) ON IMPROVEMENT OF WATER COURSE OF JANJOKHAR MINOR OF DABTHUA DISTRIBUTORY OF U. G. C. SYSTEM (U. P.)

1. On and average the watercourses conveyance efficiency was found to be 75 % in the field and the conveyance efficiency of minor to be 88 %. If the minor is also is lined, the seepage rate of lining could be controlled to 0.5 cumecs per million square meter, the conveyance efficiency of the minor will increase from 88 % to 98 %.

The following improvements in watercourses were considered.

1.cleaning and repair

2.earthen renovation and

3.complete channel lining

2. The first suggestion is least costly and has the least potential to save water while the last one is the costliest and has maximum potential to save water. What ever the method is followed either in single or in combination the optimal objective should be that the return from saved water should be maximum.

3. The most conventional type of lining of watercourse is brick lining. Discharge capacity being low, rectangular sections is preferred to trapezoidal sections. As an alternative the use of black LDPE film in buried condition of9 400 gauge (100 micron) with cover of 30 – 40 cm of sand has been tried in various distributaries in Punjab.

   The values of seepage of above lined sections were found ranging from 0.13 to 0.475 cms/$10^6$$m^2$ for bk. Lining and 0.6 to 0.7 cms/10^6 m^2 for LDPE film buried lining. Life of above two lining is assumed as 20 yrs. and 10 yrs. respectively.

4. Earthen renovation involves the reconstruction of channels according to proper specification and based on hydraulic conditions. Compaction of new banks is to be achieved at OMC to achieve dry density of 1.6 gms / cm^3. Life of the new constructed channels are to be assumed 8 years and the maintenance cost @ 10 % annually and the seepage may be assumed to be of the range of 3.6 cms/ 10^6 m^2 of wetted area.

5. Cleaning and repair includes plugging of holes to stop visible leakage, raising of bank to stop over topping, strengthening of thin banks to prevent washouts, improving deteriorated junction areas to prevent leaks and breaches, smoothening of channel bottom fluctuations to reduce dead storage, removing

silt from the bed and so on. It was observed that the seepage rate varied from 4 cms/ 10^6 m^2 to 7 cms/$10^6 m^2$ of the wetted area.

Therefore the improvement alternative for water courses may be lining few meters of head reach, earthen renovation in next few meters and regular cleaning and maintenance in the remaining part including the water course structures which may improve the conveyance efficiency of the water course from 75 % to 90 %.

6. Studies made on five outlets of a minor and the results were found as the annual cost of brick lining, lining with LDPE, earth renovation per metre length is estimated as Rs.17.91, Rs. 14.43, Rs 6.09 respectively. The cost per metre of cleaning and repair in each year will be Rs. 1.34. The reduction in losses by brick lining, LDEP lining, earthen renovation and cleaning and repairing will be 97%, 96 %, 78 %, 67%. Reduction in loss per unit of annual cost of brick lining and LDPE buried lining respectively is 1.06 cms / Rs and 1.29 cms / Rs. This indicates that LDPE with earth cover may be more economical.

4.21 TYPES OF LOSSES IN WATER COURSES

The different types of losses in watercourses are;

4.21.1 STEADY STATE LOSSES

(i). Seepage into bed and banks

(ii). Visible losses through and over the banks

(iii). Evaporation losses

4.21.2 TRANSIT LOSSES

(i). Initial seepage into dry banks in excess of normal long term seepage rates (ii). Dead storages in bed and banks

(iii). Short-term leakages as breaches, outlet breaks

4.21.3 WASTAGES

(i). Purposeful wastage due lack of need

(ii). Malicious wastage.

The steady state losses in kachha water courses has been observed as 20 – 30 cusecs per million sq. ft. of wetted area. During first 24 hrs running, after usual 7- day closure, losses have been found to be as high as 50 – 100 cusecs per million sq. ft. depending upon the soil nature and seasonal temperature. In a lined water course the losses on first 24 hrs running and after a 7 day closer were observed to be between 4 to 8 cusecs per million sq. ft. of wetted area and the steady state losses dropped to about 3 –6 per million sq. ft.. The perimeter of the kachha watercourse is about 1.5 to 2.0 times that of a lined one for the same discharge. Hence saving in loss is admirable.

4.22 MEASURES FOR REDUCTION OF LOSS

1. There was a practice in 19^{th} century on watercourses in Punjab that if farmers did not take care for proper maintenance during a crop season, his supplies were cut off.

2. It has also been observed during recent studies on Pakistan canal system that cleaning and compaction of unlined water courses give best returns on investments in the view of substantial reduction in losses, specially if the water course is thoroughly cleaned of vegetation growth and well compacted after proper clearance.

3. The most common and cheapest method tried in Punjab and Sind canals to reduce the seepage was mud plastering the watercourses and lining puddled clay for

canals passing through sandy soils. The thickness of puddling was 3" and a cover of 3" to 6" good soil was put over it to keep the puddled clay moist.

4. Another method of lining with 12"*6"*3" sun dried bricks, but this also needed proper joining and regular maintenance. The maintenance of water courses and field channels was the primary responsibilities of farmers and the British engineers also instead of intervening left the farmers decide themselves to take the suitable method they felt necessary in sandy soils.

4.23 MODERNISATION OF WATER COURSE AND FIELD CHANNELS

There can be many objectives in modernising the watercourses. The main objectives may be as;

1. Equitable distribution of water
2. Improvement in command
3. Reduction in filling time
4. Increase in supply to the tail end cultivators
5. Better regulation of water courses
6. Reduction in local water logging
7. Less maintenance

The seepage losses go on increasing in the unlined watercourses as the delivery point from the outlet increases. This indicates not only the loss of water but also creates an inequitable distribution among the users because the warabandi system, presently, in use in most of the systems, does not take into account the progressive loss of water due seepage. Therefore one of the main purposes of lining watercourse was to achieve social objective of equitable distribution of water on major surface irrigation systems by minimising the seepage losses through them. Among the several causes of losses from the watercourses, some of them may be as:

1. Properties of soil forming the canal and surrounding area
2. Rodent holes in canal banks
3. Weedy and grassy channels
4. Poor maintenance
5. Excess supply of water
6. Poor operating procedures
7. Excess supply of water
8. Inherent construction defects (Compaction not proper)
9. No involvement of beneficiaries in preparation of operation and scheduling
10. Lack of extension education and training
11. Traditional method of irrigation practice.

4.24 BENEFITS OF MODERNISATION

Many benefits can be assessed from the modernization of water courses, some of them can be mentioned as follows.

1. Increase in command
2. Increased achievement in equitable distribution

3. Increase in farmers co-operation at out level

Lining of water courses has provided the opportunity for equitable distribution of water within the farmers, fulfilling the objective of efficient and proper management of water. Traditionally the benefited were the farmers having their lands near the outlet head or in the middle of the chalk. This situation was true because of the water lost in frequent breaches and cuts by the head users the tail users generally got deprived of water which in turn frusted the tail enders about their efforts. But in case of lined watercourses all shareholders (farmers) are assured for their share.

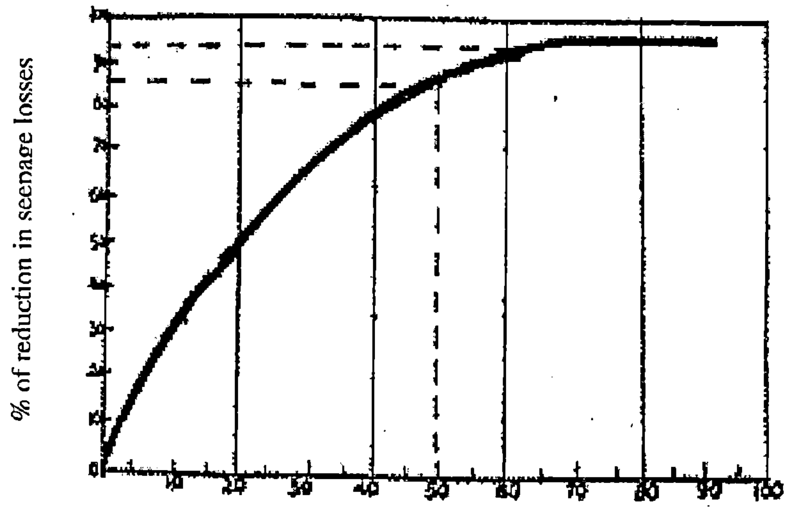
An evaluation study performed in Haryana for the lining of watercourses has concluded as:

1. Tail ender beneficiaries were most benefited in comparison to those in the middle or near at head.

2. Due to the bridging of the depressions, flatter slopes availability by lining in the water course there has been an over all improvement in the command as well as saving in human energy and cost involved in lifting waters to irrigate higher lands.

3. A substantial increase in irrigation intensities on lined watercourses as well as increase in irrigable area by 15 to 25 percent.

4. The lining 100 percent length of watercourses is not desirable because the benefits derived were not matching with cost and a cut off point is there beyond, which if lining is done the benefits will decline sharply. About 50 percent-lined lengths would lead to the reduction of 85 percent seepage losses. A curve is developed on the above concept and shows that 60 percent lined length give about 94 percent reduction in seepage losses, as shown in fig.23 below.



% Length of water course lined

Fig. 23: Showing relation between reduction in seepage losses and length of water course lined

5. S.P.Malhotra, Engineer-in chief (lining) Haryana introduced the concept of feet hours considering that the head reaches were required to run for longer periods than middle and tail reaches during 7 day running programme. He concluded that the lining of about 50 percent length of watercourse was equivalent to the lining of about 85 percent feet hours. In other words, 50 percent-lined lengths would lead to the reduction of 85 percent seepage losses. It may be seen from the curve developed on the above concept that 60 percent-lined lengths give about 94 percent reduction in seepage.

It was concluded that lined length should be between 50 to 60 percent. This may impose fewer burdens to the users to pay back the cost of lining, but in practice the cost is divided among the shareholders equally irrespective of the length of lining. From further studies carried in Hissar District developed a curve of increase in irrigated area verses lined length of watercourses. The curve shows that 50 to 60 percent length of lining gave 5 to 6 percent increases in irrigated area. For achieving the desired increased by 25 percent the length to be lined had to be about 85 percent or more as shown in Fig 24 below.

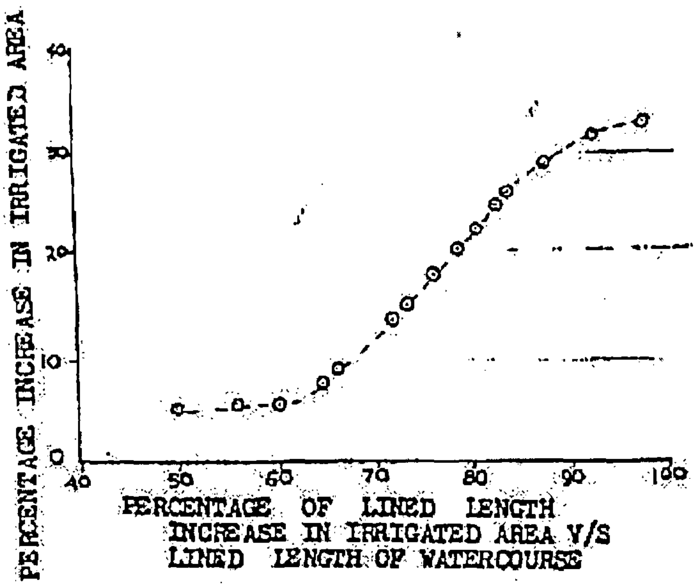


Fig. 24

In normal cases the area near the tail of main and branch water courses are at higher levels and cannot be fed by unlined water courses, the lining permits flatter slopes bringing higher areas in command. This is achieved by lining about 80 percent.

With the above view Punjab has taken a well-planned programme since 1970 for lining of the water courses (with the aid of World bank aided projects) and have made extensive appropriate efforts in reducing loses in irrigated command.

CHAPTER –5

MAINTENANCE OF CANAL NETWORK

CHAPTER- 5

MAINTENANCE OF THE NETWORK

5.1 GENERAL

Most of the irrigation projects, though are constructed with much experience and equipped with latest technology, the benefit derived from them is still unsatisfactory. In spite of the massive investment and skilled technical personnel involvement, the irrigation systems could not have proved exemplary achievements. The reasons behind it may be numerous for the unsatisfactory performances such as

1. Poor organizational structures, either government/ public/private
2. Inadequate involvement of the water users, their co- response towards the project, irrigation staffs and vice versa
3. Lack of funding for operation and maintenance programme
4. Lack of well planned O&M programme
5. Inadequate approach to available technology
6. Inadequate training to irrigation staffs and users
7. Perception development is more prestigious than maintenance
8. New system requires minimum maintenance.

The system care-take or the maintenance thus needed to keep

1. Conveyance and delivery system to be in good condition for better water management/ distribution and retain operational efficiency

2. More efficiently deliver water in equitable and reliable manner to outlets to ensure the increase productivity

3. Conservation of precious water resources because economically viable and reliable sites are shrinking and new sites with complex problems are available incurring intensive investments.

In connection of irrigation system maintenance, the National Water Policy, 1987,GOI, says 'structures and systems created through massive investment should be properly maintained in good health. Appropriate annual provision should be made for this purpose in the budget'. Similarly in USA, the system policy says to ensure proper maintenance or upkeep says ' The USBR provides and retains certain overview and review functions throughout the project project life and usually retains the ownership in perpetuity to attain intended benefit and protect federal benefit'.

5.2 TYPES OF MAINTENANCE / MAINTENANCE CONCEPT

Maintenance should refer to operations performed in preserving system and facilities in good or near original form without increasing their capital cost. Repairs are essential part of maintenance (ie capability of the system should be maintained by repairs). The maintenance differs in nature according to the situation evolved and may be categorized as:

1. Normal or routine maintenance

2. Emergency maintenance

3. Essential structural maintenance

4. Deferred maintenance

5. Catch up maintenance

6. Preventive maintenance

7. Rehabilitation / Restoration works

8. Modernization (remodeling)

9. Diagnostic walk through maintenance survey

10. Special repair

5.2.1 NORMAL OR ROUTINE MAINTENANCE

This covers the usual annual repair works such as weed removal from canal bank, rain cuts and service road repair and oiling and greasing of gates etc. The activities are to be done rather than should be done every year. Percentile allocation of annual budget (of total budget) should be arranged for system maintenance and repair budget for annual repair.

5.2.2 EMERGENCY MAINTENANCE

The repair works done in urgency under unusual condition conditions, required for the safety of the works of functional. Such types of maintenance works cannot be postponed but should be executed immediately.

5.2.3 ESSENTIAL STRUCTURAL MAINTENANCE

The necessary structural maintenance carried specially for flow measuring devices and regulatory structures, flumes, current meter fitted stations etc. such maintenance will help in acquiring the condition of canal carrying capacity which in tern assists in flow monitoring.

Maintenance carried out for the accumulated bulk of routine maintenance. In such case inspection of the system is very necessary so that repair works be prioritize accordingly.

5.2.5 CATCH UP MAINTENANCE

Repair works done taking care of deferred maintenance for regarding the hydraulic efficiency of the system.

4.2.6 PREVENTIVE MAINTENANCE

Essential minor repairs done to avoid probable major expensive problems in future in future (i.e. repair works done foreseeing would be mishap in future).

4.2.7 REHABILITATION OR RESTORATION

When the system does not respond to the desired or designed objective, then rehabilitation is done. It may also be said as the renovation of existing system or ageing structures. If perfect preventive maintenance has been taken up, the aging structures are needed to restore.

4.2.8 MODERNIZATION OR REMODELING

The upgrading and improving existing system for enhanced technical, social and economic objective achievements is called modernization where as some additions or changes made to any structures is called remodeling.

4.2.9 DIAGNOSTIC 'WALK THROUGH' MAINTENANCE SURVEY

Field survey done by walking along the canals by 2-.3 experienced persons in a group. The broad record of maintenance is prepared. The need to rectify the deficiencies are studied and prioritized. More inspection record, cost estimation, request or order for maintenance to rectify deficiencies is decided.

4.2.10 SPECIAL REPAIRS

This is the case of unforeseen mishap due which large collapse of lining, canal breaches, washing away of structures, flooding the near by area causing huge damage to agriculture. In such cases, repair works are done from reserve O & M budget. In India, CE possesses some reserved funds for O & M. If it is not sufficient, it can be drawn from the Governor's contingency budget and later on could be approved by the State Parliament Assembly.

5.3 MAINTENANCE OF EARTHEN DAMS/HIGH EMBANKMENT CANALS

For maintaining the earthen dams or high embankment canals, the following considerations should be taken into care:

1. Rate of rise of reservoir level should be slow in infant stages:
   Full reservoir level should not be allowed to achieve during first three years of filling because settlement of foundation and embankment is gradual. Phreatic line should get properly established and regulation should provide for the above.

2. D/S toe of the earthen dam should be kept clean of vegetation specially in lowest 1/3 height.

3. Filter toe be provided on d/s slope to contain phreatic lines within dam section (filter toe is provided when dam height is more than 3 m. If d/ s face is moist or sweating (filters may have been chocked), relaying of filter is done but for relaying reservoir should be lowered (i.e. no relaying without lowering reservoir).

4. If water oozing from d/ s toe is dirty or silty (i.e. fine silty materials from dam/embankment section is being washed away, such locations immediately are loaded with proper filter and ensure that seepage water is clear.

5. Due to heavy uplift pressure on d/s ground outside the toe, formation of boils be on and off with fine materials coming out with water ultimately causing piping. In such cases a ring bond is created around the boils and observe it if water coming after the bond creation is clear, no problem but if the water coming is again dirty/ muddy then treatment should be done. In such cases construct 3" dia. pipe relief wells with network of longitudinal drains.

6. If breach of the dam is apprehended, the district administration should be informed (magistrate, police etc.), the villagers residing d/s side should also be informed, assistance from district administration should be sought for. If breach occurs, the first duty / action to be taken is to control the property and life and inform everybody possible (i.e. district administration, police, public offices etc.), control out flow of water from the canal, immediate measures to save the structures, plan for emergency repairs and prepare technical examination report.

5.4 MAINTENANCE OF LINED CANAL / LINING

While maintaining the lined canals, the points to be considered are:

1. A logbook of thorough and regular inspection is prepared and the damages are identified. The damages identification should be performed in different canal conditions such as canal running partly or fully closed.

2. Proper drainage of banks:

   Sufficient catch drains should be provided and clean regularly to keep operative (i.e. quick discharge of drain flow should take place). The bank cross-slopes be maintained and no water towards the lining should occur (i.e. top x-slope outwards towards the outer bank).

3. Removal of weeds:

The weeds are to be removed clearly. They may assist in seepage promotion, create obstruction to flow and reduce the available free board.

4. Repair to cracks in lining joints:

The joints should be properly raked and repaired by cement mortar or bitumen.

5. **Repair to cavities (behind lining):**

Sometimes cavities are formed behind lining due sub-grade settlement or water movement. If the activities formed in the sub grade are large in sizes, then a mixture of sand with shingle should be poured to make it tight. For smaller cavities sand filling will be sufficient.

6. Leakage at the toe of the bank:

Thorough examination for the cavity 150m u/s as well as d/s from the leaking point should be done. If the sand grouting is not effective then treat the cavity with cement sand slurry of 1:8 or 1:5. Even then if leakages still continuous, then the cement sand slurry of 1:1 ratio is applied.

7. Leakage through works (structures):

More probably leakages from the x-drainage works are accepted. In such cases suitable initial treatment would be the sand grouting and if not found effective, then apply the cement slurry of ratio 1:2 or 1:8 as per the site conditions.

8. Repair to damage slab:

Up to the depth of 1.5m of water (if canal water depth is more than this, then the water level should be lowered) slabs are repaired by ring bond creation under water, wooden sleeper loaded by empty cement bag filled with sand. In such underwater repair case, a cement ratio of 1:2:4 is used. More advantage is the use of quick setting cement or water repellent cement mixture of higher ratio.

9. Erosion of outer slopes:

The outer slopes are protected by growing grasses (or turfing). Grazing should be prohibited on the slopes. Trees should not be allowed as the long roots of the trees may help create the water path or when they dry create a clear drainage path.

5.5USBR PROCEDURES FOR OPERATION, MAINTENANCE AND MANAGEMENT OF IRRIGATION SYSTEMS

Though the irrigation sector uses about 80% of the world's fresh water supply, the efficiency rate of use is about 38 %, which in fact is very low. The factors behind being very many, or site specific, cannot be generalized to all conditions. Even with the long experience in irrigation distribution network planning and operation, there has always seen an indication of inefficiency and ineffectiveness in use. The procedures and concepts proved successful, since long used by USBR are to be considered as guidelines for better operations and maintenance.

5.6 INTEGRATION OF O& M ACTIVITIES IN PLANNING, DESIGN AND CONSTRUCTION PHASES OF THE SYSTEM

Suitable operational procedures should be included in planning, design and construction process of any irrigation system to obtain desired output. Personnel experienced in O&M procedures should be involved in the planning process to provide practical input specially regarding O & M cost estimate, compared to similar projects and condition would be useful and reliable input. Evaluation of O & M cost budget be made with timely changes. Drainage requirements be determined and provided. Users involvement in O & M be examined and planned for. O&M personnel should have an opportunity to review design and plans from operational point of view.

A good process is to have operational personnel on site during construction to input into the process from O&M viewpoint. This may provide an excellent opportunity to write required O&M Manuals (Regulation and Operating orders and instructions). This may also provide proper background for transfer of distribution facilities to users organization for operation and maintenance and also in pre- transfer examination to determine the adequacy of the system for operation and formal transfer processes.

5.7 ORGANISATION AND RESPONSIBILITIES

The USBR is the primary agency for planning, construction, operation and maintenance and overall watch and assistance to Irrigation Districts. The specific roles and responsibilities of various O&M offices in Bureau are as follows:

1. Commissioner's office (Bureau wide)
   - Formulates O&M policy for Bureau

2. Engineering and Research center (Bureau wide)
   - Provides technical assistance to other offices
   - Develops training programmes and assists training
   - Develops technical standards
   - Provide periodic review of facilities
   - Review plan, design reports etc. related to O&M facilities and infrastructures

3. Regional office (region wide)
   - Direct responsibilities for all O&M activities
   - Provide technical assistance and training to projects and Irrigation Districts
   - Periodic review of facilities
   - Provide O&M input to regional activities
   - Fulfillment of contractual obligation- efficient water use and care of facilities

4. Project offices (Project wise)
    - Direct O&M facilities retained for operation by Bureau
    - Provide technical assistance and training to Irrigation Districts
    - Periodic and annual review of facilities
    - Efficient water use, repayment and care of facilities

Irrigation districts are a non- profit entity, organized under state laws operate many facilities constructed and generated by USBR. Irrigation Districts consists of Board of Directors (3,5or 7 members), who formulate policy for O&M facilities, provide guidelines for Directors. Each Board member is a water user and is selected by water users; thus, policy formulation is controlled directly by Water Users.

Each director serves as a prescribed term at the end of which they are re-elected or replaced and they are not paid any salary. Boards of Directors hire a Manager who is responsible for day to day operational and who hires most other staffs. The USBR provides and retains certain overview and review functions throughout the project life and usually retains ownership in perpetuity, to attain intended benefits and protect Federal investment.

5.8 OPERATION

Written regulations and instructions are essential to the effective operation of an irrigation system. Without written and approved instructions, essential procedures are easily forgotten or never known by operational personnel, resulting in pre-mature breakdowns, use of improper procedures, unsafe practices and discontinuity in operations, specially during changes of personnel.

The purpose of operation of an irrigation system is to deliver water in a specific quantity at a proper place and time for development of land resources and assure increased yields in the large command. The purpose can be accomplished by proper and timely regular measurements of water in transit through the system including farm outlets. Water measurement is more important in shortage situation and for equitable distribution among large numbers of users. For precise and adequate measurements modern devices should be introduced during rehabilitation and modernization.

An established good communication system is another very important factor for safe and efficient operation of an irrigation system. Reliable and quick communication can aid greatly in scheduling routine and handling emergency problems. This may include telephones, mobile radios and all weather roads.

The operation of an irrigation system to assure equity, adequacy and reliability in water distribution in large areas among very large number of users is likely a very complex process and need professional managers and trained staffs who are very adept in managing the systems for operation use on experiences and "guts". The installation and use of automation techniques and equipment on newly planned water system will conserve water and more effectively routing through the system but need to be thought over on availability for skilled operational and maintenance personnel.

For rotational running system of irrigation channels to feed large command areas on major irrigation systems, the water should be used in an economical way, maintaining good regime of channels, minimizing seepage and percolation to irrigated lands and also generating flagging demands for operational use of available water as well as a good approach for equitable distribution of water.

5.9 MAINTENANCE

A main objective of irrigation system should be to attain a high level of O&M and maintain it on the sustained basis. One of the most reliable ways to reach this objective is through the use of a Periodic Review of O&M of the system, the most important objective of this review is to evaluate, discuss and identify deficiencies in OMM of the system. This review should be done periodically on an interval of 4-5 years, by some one from outside the organization of the project and who is really experienced in such system O&M and evaluation. The purpose of this is to attain an unbiased evaluation of the past system operation, maintenance and management activities. Factual data should , however, be available to the reviewers. A report is needed describing the findings of reviews including deficiencies in O&M, on priority. Responsible parties should also develop a schedule for correction of the problems. This has been very effective Bureau programme and in many cases it provides excellent history of O&M and continuity and creditability.

Availability and use of suitable equipments are quite often extremely useful for timely and proper maintenance, which, also provide quick services and cost effective as well.

The number and type of personal required efficiently operating and maintaining an irrigation system varies with country philosophy, crops grown and type of system. With the development of useful equipments and the strength of personnel can be controlled and substantial important requirements can be fulfilled by seasonal workers which has been the practice on all major works for regulation requirements. Maintenance of equipments and facilities is obviously one of the most important and critical aspects related to efficient delivery of water and maintenance cost may account for at least 50% cost of total O&M budget as per experience by USBR.

Procedures for maintenance of irrigation system facilities are often complex and unique to on site conditions. Past experiences are certainly, extremely useful but new methods should also be developed through "O&M Bulletin" and training of personnel in maintenance conducted by the real field experienced professionals. There was a moral and practice to endeavor double use of earth works on repair of channels and desilting operations, which was really the need for cost and all other considerations. Dilution in professional capabilities and administrative control has faded the well-established experienced based practices.

Vegetative control is another important aspect of maintenance of irrigation system specially unlined channels, suitably grown plants help in stability on slops but uncontrolled plantation and vegetation growth is a cause of serious trouble and constant nuisance to channels and embankments. With the expansion of various departments and activities this very important aspect is being neglected. Lack of O&M budget is the real problem but growing carelessness in personnel and neglect of control at the level of senior professionals, is the main cause of poor maintenance standards on these aspects. Only few decade back the maintenance standard of Ganga canal in UP, India was an example for canal professionals not from India but even from abroad but this has been allowed to decay to unexpected poor levels in a short span of time simply by continuing practices of neglect at various levels and mainly manned by inexperienced and non-committed professionals and personnel deferring the most essential maintenance requirements and attending only to major repairs.

In establishing a new irrigation system, it is often a good idea for experienced O&M personnel to write the first sets of codes and procedures for the operating and maintaining entity. As operation continues the rules and instructions can be modified to more closely suit the actual conditions. This is really surprising that with the expansion of professional levels and units, even the major structures like Barrages on mighty rivers and constructed out of large capital are operated for long period without specific approved 'Regulation standing orders' by Chief Engineers who are an experienced senior professional competent to do so. This is really not a healthy trend looking from administrative and professional accountability and responsibilities.

5.10 TRAINING

Training of field personnel responsible for operation and maintenance of an irrigation system is often one of the most important but neglected aspects. Often day to day work interest and pressures priority over training needs and unless it is scheduled and followed through on, it often is delayed and never takes place. In USBR workshops, seminars, water users' meetings and study tours provide training through technical session conducted by experienced and knowledgeable professionals with in depth knowledge of such other systems.

5.11 SAFETY

Safety and loss prevention should be a high priority item for all major systems and it should be documented and structured programme. A lost time accident can very costly to an organization in terms of both economic and social and emotional stress. USBR has successfully implemented safety programmes in many districts in which all employees receive monetary benefits or other related facilities.

CHAPTER –6

OPERATION OF THE DISTRIBUTION NETWORK

CHAPTER- 6

OPERATION OF THE DISTRIBUTION NETWORK

6.1 GENERAL

The system design should always follow the bottom up procedure for reliable canal operations and give beneficial output as planned. The considerations require for designing the system for planned operation are:

1. Some flexibility for rainfall occurrences should be provided in the irrigation systems operation in order to achieve the desired efficiency specially for the area where water scarcity is probable.

2. The system should be able to respond quickly to sudden fall in demand without wasting much water into the drainage system.

3. The soil –water plant relationship is a critical consideration in on farm development. In this case the advice from agricultural department is most needed in regulating supplies to the crops at various stages.

4. There should be enough controlling points like x-regulators coupled with escapes on the main canal and its main distribution system. This aspect will enable the distribution system to function properly even if irrigation is practiced under rotation system.

5. Maintenance of proper levels of main canal upstream of the control points is most important for water management.

6. Measuring devices at various control points, both for gauging the depth of flow and rate of flow are an absolute necessity. A simple gauge is enough to monitor the stage of flow. If the operation is to be provided for demand based delivery or limited delivery, flow-measuring devices are required at each delivery point. Flow measuring devices are also needed in selected reaches to

monitor seepage losses in the canals. Very often oftakes are calibrated to provide information on the rate of flow. Similarly drop structures on a distributory are the best suited for calibrating the rate of flow based on the depth of flow over the structure.

6.2 WATER LEVEL CONTROL

The control to canal water level is very important and the acceptable limits in canal water level variations should not be much. The basic important reasons for water level control are:

1. Keep area under command by gravity flow.

2. Canal protection against deterioration.

3. Canal safety.

4. Flow control at off takes.

The water level in the canal, if drops too fast the canal interior slope may get deteriorate due to sudden draw- down condition and the canal the canal lining if any may slip. It is therefore important to keep the water level in between the maximum, which is designed for safety region and a minimum, which is required to supply the land by gravity. Generally these levels correspond to full supply level and half supply level, which correspond to 0.75 full supply depth.

It is to be noted that it is impossible to supply water from the head works to exactly suit the consumptive demand and also accommodate for seepage and evaporation losses on the way. After a few years of system performance the extra quantity of water to be released at head works can be computed to ensure that the lowest off-take is adequately supplied. Operation of the canal mainly consists of:

1. Preparation of seasonal and annual operational plan

This is similar to the Rabi irrigation conferences that the district collector and engineers and agricultural officers in fixing and identifying the area to be given for Rabi crop by rotation etc.

2. Authorising opening and closing of canals and announce depending upon the seasonal river flow etc. It can also be said as water budget planning.

3. These are communicated in details to the scheme staff for working out details of the delivery schedules.

4. Monitoring the operational activities of the field staffs.

5. Taking corrective action on the basis of the field data monitored during the irrigation season.

6. Monitoring water levels and flows in main canals and the water delivery to all the off takes from the main canal.

7. To issue instructions from time to time to alter gate openings to achieve planned delivery of flows in response to rain fall in emergencies.

The operation of the whole system should be in harmony to obtain a desirable output. The detailed operation plan for weir/barrage up to the minor turnout including field channel turnout should be prepared to have efficient system operation plays a vital role in system performance as well as in water management. The operation includes not only the distribution network but also the weirs/barrages as well.

6.3 OPERATION AND REGULATION AT BARRAGES/ WEIRS

The main structure is the head works for acquiring water from the steam/ river for irrigation, so the first phase of operation starts from the weir/ barrage.

1. Pond level to be maintained.

2. Make non-monsoon flow close to head regulator.

3. Fair distribution of flood discharge along barrage.

4. Avoid parallel flows.

5. Deep scour and formation of shoals be minimized.

6. Minimum entry of sediment.

7. Keep hydraulic jump up to the toe of glacies.

8. Avoid high intensity of flow in deep scour zone.

9. Washing of shoal formation.

10. No leakage down the gate.

11. Constant discharge in the canal.

12. Adequate safety measures.

6.3.1 OPERATION OF UNLINED CANAL

In operation of unlined canals the following aspects should be taken into consideration:

1. Review of durability and adequacy of engineering infra structures in the system.

   Since the main and branch canals are the carrier system it should have more flexibility in accommodating on the way additional inflows (inlets) such as drains (urban/natural) and rain water during monsoon running coupled with safety structures such as escapes. More care should be given during rain in canal operation. In Upper Ganga Canal (capacity 10,500 cusecs), the practice of head gate operation is followed as if:

- Appearance of rain at foothill, canal discharge, reduced to 8500 cusecs.
- Rain at head reach, canal discharge, reduced to 6500 cusecs.
- Rain is continuous near head, and then the head gate is operated according to the rainfall extent.

Rainfall in inches	Gate height reduced @ (12feet is for 10,500 cusecs)
2	9'
3	8'
4	7'
5	6'
Above	Close

2. Study of regime of main canal and distribution canal:

   For the main and branch canals hydraulic survey (for efficiency) should be done to confirm the health of the canal. The water distribution in equitable manner should also be conformed for distributing channels.

3. Control of sediment entry into the main canal and judicious self-clearance of silt from the distribution channels.

4. Study of regime disturbance and canal capability.

   During monsoon period the canal should contain safe limit of sediment load. The sediment load present in the canal should regularly be monitored for better operation. As per UGC, the coarser sediment load in the canal should not increase more than 500 ppm whereas finer sediment load for the same condition may be up to 30,000 ppm.

5. Sudden downpour in any area:

   If heavy rainfall occurs in the area (either in catchment or command), then the responsibilities of operational staffs are:

   - Immediate reduction in the head
   - Open escapes on u/s
   - Open channels closed in roaster
   - Inform d/s regulation point to handle the discharge
   - Inform local district administration if breach is accepted

8. Gradual opening and closing of canals;

   For proper functioning and safety of canals, they should not be opened/ closed suddenly. In case, if sudden closure is unavoidable, x-regulators should be used for ponding water. The normal safe rate of opening / closing practiced in UGC is 12 inches/hr.

9. Observation of discharge:

   The discharge should be monitored at gauged stations or control points so that the correct carrying capacity of canal is maintained. A good communication system helps much in discharge monitoring.

10. Frequent annual closures, 2-3 weeks for inspection / repairs.

6.3.2 OPERATION OF LINED CANALS

The following points should be considered while operating the lined canals:

1. Rate of lowering and raising the water level.

   In normal cases prescribed rate of lowering and raising should be followed, where as in emergency closure due to unseen accident, high flashy floods with excessive sediment, the help of the regulators either to divert the water to the canal or for short term duration ponding would be essential.

2. During heavy continuous rains, rate of lowering is kept at 50% of the normal lowering rate to avoid any hydrostatic pressure behind lining.

3. For emptying the canal up to the bed level for inspection and repairs, regulators are opened. In high water reaches the water level is reduced by battery of tube wells.

4. If two parallel canals, with a common bank and on e is lined and another is unlined is to be operated, then is such cases, as far as possible both the canals should be run at a time. Nevertheless, if to run both canals is not possible or the discharge is less, then run preferably the lined canal.

6.4OPERATIONAL GUIDE LINES FOR RUNNING OF DISTRIBUTARY CHANNELS

1. Distributaries perforce run in turn or system of rotation.

2. Condition of water demands varies with geographical positions, soil types, crop varieties, previous rainfall etc. In the large com and area, there may arise a variation of 2-3 weeks in water demand so this advantage of demand variation (time variation) may be taken into account t for preparing roaster plan.

3. Accurate knowledge of water availability for supply and all the local conditions affecting the demand should be known. Only the senior person (probably the SE) will be capable of knowing but the sub-ordinate (probably EE) should be kept well informed accordingly.

4. In tight roaster farmers normally draw 20- 30 % more water (lowering bed and increasing head) so that tail supply reduces. It should be recovered by running the channels with 10 % more than allocated supply and the extra water needed

may be made good by shorter running and larger closure period. The other useful alternative is to run the distributary fort-nightly instead of weekly.

5. Two golden rules in art of irrigation by rotation running are;
    - Run channels in proportion to the state demand but avoid running them at all unless unless the additional demand towards tail is minimum 50 %.
    - Close channels as soon as demand is satisfied o preserve the channels in state of good regime and control wastage by seepage.

6. For equitable distribution of water legitimate duty are lawful, confirming and to established rule:
    - Distributaries run with full discharge s they are designed for from head to tail.
    - Distributaries are in proper state of clearance from head to tail.
    - They should run on suitable system of roaster.
    - Outlets are in proper order and made untemperable.

7. Longer the canal are run, more silt will be deposited and moral is never run the channels longer than is necessary for satisfying demands.

8. A closure is an excellent thing for good regime assurance, prevent wastage by seepage and percolation, and stimulate flagging demands.

9. Some channels are troublesome/ problematic. ie with few days of running may be silted. In such case vanes may be introduced at the head, technical suitability of x-section may be checked as;

   b/d = 3, for minor channels up to 20 cusecs
   = 5, for distributary channel up to 50 cusecs
   = 8, for branch channels up to 250 cusecs

For channels up to 300 cusecs, the ratio of b/d with respect slope is given by empirical formula as below and this practice is followed in Sarda Canal,UP.

$D = \sqrt{b}$, for slope of 0.56 ft/mile

$= 0.94\sqrt{b}$, for slope of 0.64 ft/ mile

$= 0.86\sqrt{b}$, for slope of 0.8 to 1.2 ft/mile

6.5 MINOR CANAL OPERATIONS AND WATER COURSES

The minor canals should always get its designed share to feed the water courses at required or adequate quantity so that each farmer gets his crops irrigated with sufficient water to meet the evapo-transpiration of the crops. The tail cluster gauge readings can be the good measure of monitoring the proper of the discharge.

6.6 PROPER SCHEDULING OF OPERATION

The primary objective of efficient management of an irrigation system is the ensured water distribution in adequate quantity/adequacy of water delivery and at proper time (timeliness) throughout the command of a channel or the system as a whole. The development of a suitable canal water delivery scheduling is therefore is the basic need to meet the crop water requirement of the crops in command.

Irrigation scheduling is the process used in making decision for (i) when to irrigate the crops and (ii) how much of water is to be applied. The purpose of scheduling is to optimize the production, conserve the water resulting the improvement in the system performance as well as keep the irrigation system sustainable, For preparing a good schedule for irrigation, the knowledge of (i) moisture holding capacity of soil (ii) current available soil moisture content (iii) crop water use or evapotranspiration (Eto) (iv) crop-sensitivity to moisture stress at current growth stage (v) irrigation and effective rain fall received (vi) available water supply and (vii) time span it takes to irrigate a particular field are essential. The crops plant in the command may generally be of diversified nature and the agricultural activities carried by farmers may also differ due various constraints within the command. Moreover, the water needs of the crops vary with the development stage and the general practice is to deliver water as per average requirement of crop-water, which in actual case do not commensurate. Moreover the nature of soil, water-holding capacity are also very essential elements which generally are overlooked. Therefore, irrigation scheduling requires good knowledge of crops water requirements and soil water characteristics that determine when to irrigate the crops and how much water is to be applied to the crops to meet the requirements of the crops adequately. The skill and knowledge of the farmers, in most of the cases, determine the effectiveness of irrigation scheduling at farm level.

The farmers can apply water accurately to their fields only when the water supply/delivery is timely and in adequate quantity. Poor management in water supply and the inadequacies in the irrigation system itself results the unreliable and inadequate water supply to the farmers fields. This may bring frustration to any attempts (modernization/remodeling) made for accurate crop water need irrigation scheduling among the system managers and the farmers.

Efficient irrigation scheduling should result the improvement in crop yields, water saving and intern increase the availability of water resources (saved quantities) with positive impact on quality of soil and ground water.

According to Chambers (1983), irrigation scheduling is a means of conserving water, which helps in making decision on allocation of quantity and timing of water supply commensurate with crop needs. It is one of the key activities that has the potential to improve performance of the system, specially its productivity, equity and stability.

Nowadays , researches have made available many methodologies and techniques useful for proper irrigation scheduling. The available methodologies are (i) crop – water requirement estimation method (Doorenbos and Pruitt, 1977) (ii) soil water depletion procedures (iii) water stress indicators (iv) water and crop yield functional relationships and others.

Though these methods for irrigation scheduling are available but in practice their applications are far below the expectations of irrigation developers particularly in developing countries. The reasons behind may be that the irrigation systems are complex in nature because each of the irrigation system ahs its own physical conditional characteristics, climatic events, design criteria, institutional arrangement, resources availability, water rights, operational rules and socio- cultural practices and these characteristics are mostly interactive in nature. The introduction of any new procedures or technique and the degree of its success largely depend upon these (above said) system characteristics (Vaidhyanathan and Janagarajan,1988). There are wide variations between developed abd develop-ing countries in terms of these characteristics and therefore modern scheduling procedure is still in inception level in most of the developing countries.

There are many constraints for preparing the scheduling for water distribution. These constraints are: (i) localized policy of irrigation (distribution not based on crop-water requirement) (ii) water allocation strategy / practice (duty based supply –timeliness not met) (iii) water distribution strategy / practice (adequacy and reliability- not met) (iv) infrastructures, canal and flow control system (system deficiencies or inadequacies).

The usual practice followed in India is to run the canals in a pre- determined rotational scheduling of 1in 2, 1 in 3, 2 in 4 and so on which means canal run for one week and remains closed for other week (one week on and one week off), one week on and two weeks off, two weeks on and two weeks off respectively. This would have been fixed earlier on the basis of some knowledge of soils and crops but with the changes in cropping patterns and introduction of high yield varieties crops it has to be modified in order to suit the irrigation scheduling requirements of different crops. Sometimes water is more than required and the farmers have no option but to use/ apply it and many times, specially, at peak demand period, there falls a shortage of water and crops yields are reduced. The crop water requirement for any crop is very less in the beginning and goes on increasing till it reaches a peak value and then decreases and diminishes afterwards. The some trend should be followed/ adopted in applying the water. The scheduling should be such prepared (planned) to meet the growth-stage wise crop-water demand of the crops.

The localized system of distribution practice in Andhra Pradesh, Tamilnadu, Karnataka etc. for paddy growing areas, where when once the command area is registered under wet (command area is localized as wet for water intensive crops such as paddy, sugarcane, banana) and irrigated dry (for crops like ground nut, onion, cotton etc.), the farmers are free to decide the crops (choice of crops). This local system of water distribution hinders in preparing scheduling in two ways as:

1. The localization policy permits farmers freely to make the crop choices, even though it is authorized for a particular crop (as command area is registered/ recorded as wet or irrigated dry in the revenue department). Farmers grow more than one crop in a diversified manner according to their family need, local expertise and market fluctuations.

2. In this localization policy, when land once is classified and recorded it remains as such for ever in the revenue records and is eligible to draw water from the system legally. No special permission is necessary season after season and thus it confirms permanency in irrigation. Thus by the way of confirming rights for water along with land, gives the farmers a notion that they acquire the riparian rights on the use of water and they try to seek the legal remedies whenever changes are introduced in the interest of better water arrangement.

Localization policy, therefore, gives little or scope for government agency for revising the crop policy or the existing operational procedures.

The water allocation strategy and use of irrigation water is more or less supply based in northern alluvial plains of India where in south part the allocation is generally demand based. The seasonal and in-seasonal water supply depends on the resources available (water resource at the source), crop seasons, priorities for water allocations prevailing in the particular location of the system. The senior official (CE, SE, EE or who ever is) designated to decide the water allocation allows the water share of any channel as per the duty specified in design at heads of the main / branch distributary canal for command area under these canals, but in general, the crop seasons are planned with monsoon for the Kharif season and for Rabi the farmers are totally dependent on irrigation water where available. The situation may arise with uncertain monsoon whether the supply for any seasons would match with the cropping season not affecting the crops yields. So there arises some uncertainty in deciding the proper water allocation and delivery where as the farmers like to have the timely supply of water with proper share. Thus, the 'timeliness dimension' is very complex in the case of irrigation scheduling in the system where the crop season is monsoon based and the source is non-snow fed one or the storage system.

Though the system managers while preparing the scheduling, under these conditions, make assumptions regarding the extent of crop area, land preparing timings and transplantation of crops etc, but in general it do not coincide with the actual field practices (as the farmers perform the agricultural activities on their own perception and tradition) which requires a revision in the scheduling. There is no in-built feed back system (mechanism) to revise the schedule on a real-time basis.

In Argentina, on the on the basis of field studies, it was found that the water delivery was very much mismatched with the water actually required as shown in Figure 25 below. The probable reasons were insufficient data collection, processing and dissemination in combination with shortage of staff, little contact with or feedback from the field (especially from the tertiary level), and insufficient water measurement capability, malfunctioning of structures, commitment of the service providers and so on. Except in the month of July the supply is not matching with the demand but is always more, resulting much wastage of water. This shows that the if efficient water management could be practiced tremendous volume of water can be saved for further use but needs additional operational requirements (money, skilled manpower etc).

Instead of emphasizing to the creation of new systems if bit more care and time be devoted to the proper operation and flow monitoring, the existing systems would give much more advantageous for engineers and planners. This needs more number of trained operational personnel and improved physical facilities. The scheduling of Rama Gill Canal is also an evident that the planners and engineers do give less care for operation of systems.

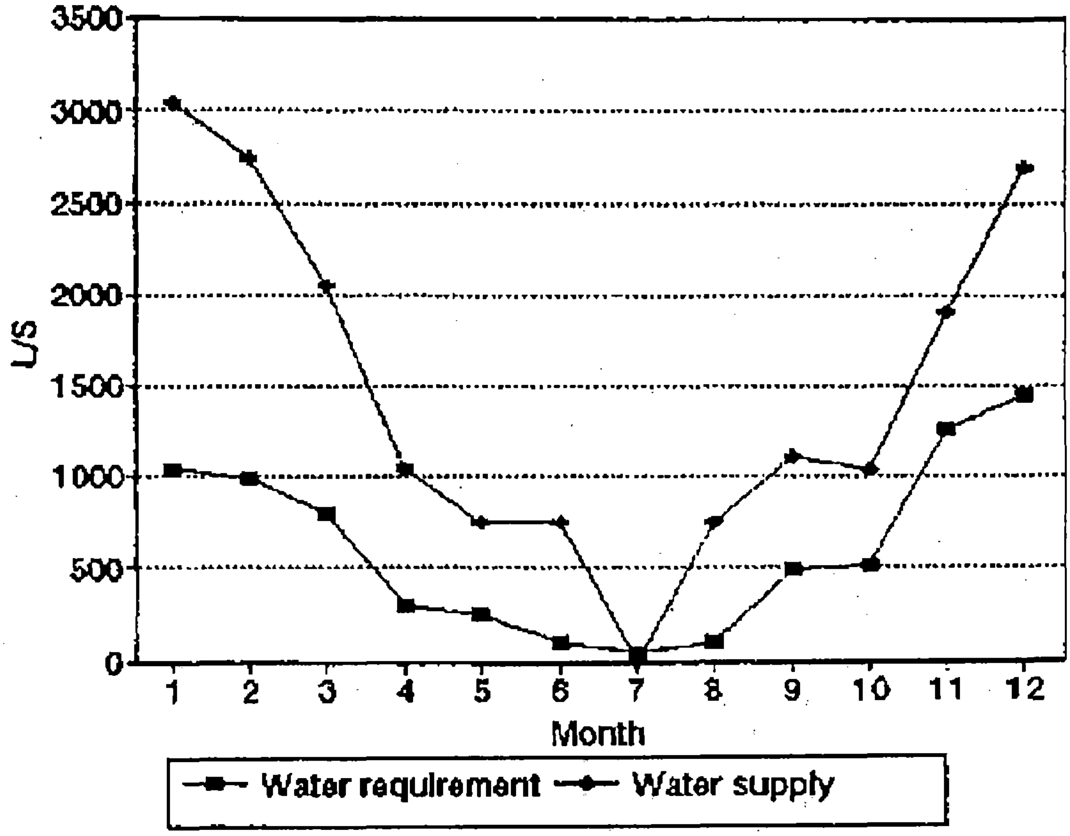


Fig. 25: Water requirement and water supply (irrigation)

(1994), Martiz Gill Secondary canal (Rama Gill), Argentina, SA

Government agency and farmers, jointly manage many irrigation systems in India. The water distribution responsibility up to the outlet head is in the hands of government agency where as the beneficiaries take over the distribution responsibility below the outlet. The water is distributed for different parts of the canal network according to the duty assigned and the land below outlet is to be irrigated in tern of one after the other from head to tail with mutual consent among the farmers. The practice followed by the farmers works satisfactorily as long as there is adequate water but is very difficult during scarcities, leaving tail enders suffer. Therefore the 'systematic scheduling' is the time demand necessity. For this the water balance concept is also necessary as shown in Figure 26 below.

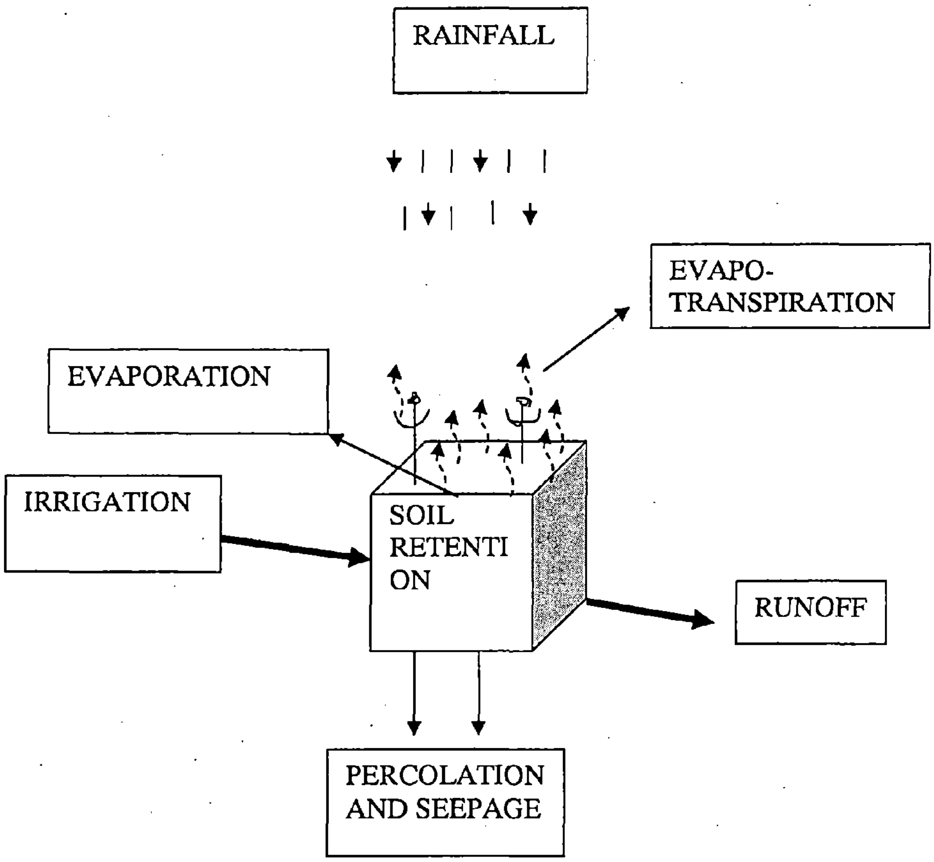


Fig.26: Water balance schematic diagram

For proper scheduling, the crop water requirement should be known properly, which will help in making decision in making schedules. The crop water requirement may be calculated as,

$$CWR = ET + AL + SR,$$

Where, CWR = Crop water requirement
ET = Evapotranspiration
AL = Application loses
SL = Special requirement

Since part of the water requirement may be met by the rainfall and moisture already present in the soil profile within the root zone. The rest of the water is to be supplemented by irrigation. The irrigation requirement can be calculated by

$$IR = CWR - (ER+S),$$

Where, IR = Irrigation requirement

ER = Effective rainfall

S = Contribution of soil moisture

It has been noticed, in many irrigation systems, that the main system scheduling done by the irrigation agency and the on-farm scheduling practiced by the farmers do not match in terms of ' time of operation' (Santhi, 1994). The example for this situation can be taken from The Sathanur I P in Tamilnadu where the distributary canal are scheduled to be operated for a duration varying from 5-7 days according to the size of the command where as the farm schedule is prepared on weekly basis (7 days) specifying timings for individual farmers (with the assistance of agricultural department). This suggests that a systematic scheduling based either on bottom-up or top-down approach on a service agreement basis is very important for field implementation. This has been tried on a small scale on Thindal area of Lower Bhawani I P in Tamilnadu through a farmers association with the assistance of irrigation community organizers (ICOs) and it has been found to work well till today. The main objective focused is on the adequate delivery or utilization to meet the crop needs.

Field experiment conducted in Tamilnadu Agricultural University, Coimbatore, in the rice crops revealed that loss of water by evapotranspiration and deep percolation was adequate to obtain maximum crop yield. Irrigation water applied in excess of this limit did not show any significant increase in yield. Irrigation to half the water lost though saved 50 % of water; reduced the crop yields drastically. Applying 5 – 7 cms of water per week was sufficient for satisfactory yields.

Rice Rsearch Institute, Cuttack, Orrisa, found that 40 – 50 % of water applied to rice can be saved by simple procedures without affecting the yields. Seepage losses were found 5times more per hectare in 1 ha field than in 25 ha block.

The rate of water applied should be equal to the infiltration capacity of the soil and exceeding than this capacity will cause (i) erosion (ii) wastage (iii) overland flow even before the root zone of the soil is filled.

Soil more than 20 % clay develop good puddle. Field studies conducted under water management project revealed that 14 – 20 % of irrigation water can be saved by puddling without improved puddlers. The percolation rate was 5 mm / day. (Krishan B. singh, retd director, Institute of Agricultural Management, UP).

The highest saving in water occurred when loamy soil was compacted to a bulk density of 1.84 gm / cm3 , (initial 1.65 gm/cm3). Such a practice saved 50 cu.meter of water and there was no reduction in yield.

Due to the reduction in hydraulic conductivity, drainage from a puddle soil may be 1000 times slower than that from the granulated soil (Ghildyal 1978).The compaction also reduces the seepage substantially as given in Table 40.

Table: 40 Reduction in density and hydraulic conductivity by compaction

Sn	Particulars	Bulk density, gm/cc	Hydraulic conductivity, (x 10-4)	Remarks
1	Puddling	1.73	0.45	Pande et. al. 1973, Research done for water requirement in rice
2	Compaction	1.68	0.48	

From several field studies it was found that the next irrigation is needed when the soil has lost the 60 % of the available soil moisture in the root zone.

Farmer prefer doing agricultural activities / operation at their personal and managerial convenience depending on the availability of input/credit/ labor etc. it has also been seen that farmers prefer to complete their cultural agricultural operations at a lower cost as such they try to use their own labour and minimize the hired labour which might cause delay in completion of the agricultural activities. Hence the planned schedule could not be implemented effectively i.e. to maintain timeliness in water scheduling is very difficult.

The design as well as the operation of the distribution network in practice is based on the average duty. But with the inadequate or insufficient in built structures for water conveyance control, distribution control and application control structures as well as for monitoring the delivery for the adequacy, timeliness and dependable scheduling is facing difficulties for the efficient distribution management. For efficient scheduling, following considerations should be taken into account.

1. The localized system of water distribution in practice since long permits farmers to grow more than one crop (though it is permitted for a single crop-as paddy) as per their choices. The diversified cropping pattern (rice and non-rice crops) with differing growth stages (crop water need also being different) with variable area covered under same sluice/ outlet results in wasteful, in efficient and uneconomic use of irrigation water. This may cause the loss of production as well as loss of water. Without the appropriate control system and measuring devices in-built in the distribution system efficient scheduling could not be achieved. So localized system of delivery should be discouraged.

2. The water being the resource exogenous to the farmers is to be distributed fairly among them under any outlet command and in proportion to their land holding. Such attempt is called 'turn scheduling' of water in the out command which is also called as 'warabandi'.wara means turn and bandi means fixation. So warabandi is the fixation of turns for supply water on equitable basis in a rotational running of the canal system for the cultivators with appropriate quantities at appropriate time meeting the crop water requirement with adjustment in conveyance loses and travel time among the beneficiaries.

3. Since the warabandi is the planned system of equitable water distribution by terns specifying day, time and duration of supply for each cultivator under a outlet command, so the, preparation of scheduling should be based on the consideration of water availability at the source, the cropping pattern of the area, the crop water requirements, the soil conditions and the farm distribution

efficiencies. Equitable, adequate, dependable and timeliness supply of water is the objective of proper scheduling through warabandi. The scheduling is said to be successful if required water is available at the outlet and a complete and functional network of field channels with properly in-built and in sufficient number of conveyance control, grade control, distribution control and application structures are also available.

4. The field channels should be able to carry the required or the designed discharge at the time of peak water demand of irrigation interval inclusive of conveyance losses so that the demand of the farmers can be judged (monitored) down stream of regulation as minor wise, distrbutary wise and so on.

5. The scheduling of terns to individual farmer should be such that he should get the exact volume of water required to the proportion of his land in the outlet command, in unit time (generally in hours as 168*area /total area under an outlet).

6. As far as possible, the scheduling (warabandi tern) allocation should synthesize with the start of the cropping season, crop planning, and end of the cropping season as well as with the area allocated for irrigation.

In case of jointly managed systems, the water scheduling should be dictated /controlled by the beneficiaries d/s of the outlet command. ie there should be the service agreement between the agency and the beneficiaries. The actual distribution of water at field level is the product of a number of circumstantial causes.

First of all, irrigation scheduling which follows the soil-water balance closely requires varying irrigation intervals and/or varying irrigation applications. In order to accommodate such schedules, coordinated operation of the regulatory and measurement structures are necessary. Combined with hydraulically unstable canal systems with structures cumbersome to operate, the often poorly trained field staff is confronted with an impossible operational task. Furthermore, in many cases the real cropping patterns differ from the ones assumed in the irrigation scheduling, creating uneven distribution. Moreover, the field staffs often live in and originate from the area they have to serve. Their loyalty (genuine or bought) lies primarily with the local farmers concerned and less with the office in town. Therefore, when they are confronted with shortages of water, they will distribute the water at their discretion, on the basis of their experience, ignoring official irrigation scheduling instructions. Finally, the field staff also might ignore these instructions when after many years of experience they have learned how to better accommodate the various groups of farmers by taking into account local conditions such as soil differences and topography than by strictly following the official irrigation schedules. Similarly, water might be distributed differently from irrigation scheduling on the basis of negotiations, power relations or traditional rights.

Under such circumstances, distribution and measurement of water expressed in litres per second, become irrelevant. Real measures of water flows will be 'too much', 'too little' or 'sufficient'. From studies, research and field observations, it becomes clear that this discrepancy is apparent in a large number of irrigation projects (e.g., IIMI, 1987 and 1989, World Bank 1990, Horst 1996, Van der Zaag 1992, etc.). Clearly, the assumptions on design and irrigation scheduling to deliver water through irrigation systems in predetermined quantified flows in litres per second may have no bearing on operational reality, where water flows are qualified from a different perception.

7. The present design and operation procedure of irrigation systems are generally duty based. Scheduling has to be done with suitable interventions like introducing crop water requirement concepts, allowing for losses in the network and using measuring devices.

8. The participation of the farmers is very necessary to efficient implementation of scheduling. The active participation of the beneficiaries should be sought by the agency to the maximum extent possible for secured and sustainable maintenance. The organization will help for flexible scheduling as well as resolve the conflicts on water sharing, maintenance of on-farm distribution network, and adoption of water management practices through self-disciplinary action, which ultimately results in higher performance of the

system or the increased efficiency. But there is a need to develop the capacity of the farmers (through associations) and officials alike in the concept of crop -water requirement and water saving methods for efficient utilization of water.

9. It is the fact that in most of the developing countries, the irrigation systems are lagging behind in terms of equipment and data bases. Meteorological stations on representative sites of the commands, moisture-measuring equipments, measuring devices along the canal network, controllable distribution networks and communication facilities are necessary to obtain timely and reliable data. A good data base system has to be maintained to improve the operation through good information.

10. The system design, allocation and distribution procedures are made with certain assumptions and approximations. The delivery schedule prepared on such assumptions and approximations may not hold good in field implementation. There is thus a need to build a feed back mechanism in the system procedures to obtain the right field in formations through interactions with farmers and make corrections on a real time basis. In this connection, Abernethy (1985), reviewing six years' research into system operations on the Kaudulla scheme in Sri Lanka, identified the following issues as key factors influencing the performance of the scheme

    - Inadequate utilization of wet season rainfall, leading to restricted cropping opportunities in the following dry season;
    - Lack of feedback about actual field water status, leading to inappropriate responses resulting in ineffective water releases, or crop yield losses;
    - Poor operational practices, with only limited knowledge of actual water distribution achievements and little guidance for field staff;
    - Little use of data collected in decision-making.

11. The efficient distribution system should fulfill three important aspects as (a) to ensure a regular and adequate supply of water at outlet head by proper operation and maintenance of the canal network (b) the construction of the

field channels required below the outlet up to the individual land holdings (c) strict enforcement of scheduling (warabandi) system to ensure justifiable and equitable distribution of water among the beneficiaries.

12. The ultimate objective is to increase the production in proportion to the efficient water distribution and application in the fields with minimum losses so that environmental and soil degradation would not occur. The maximum production per unit of water should be the monitoring basis for economic returns in terms of best water utilization.

Bandaragoda (1996) suggests that the introduction of irrigation scheduling will have to be preceded by a change in the attitudes, policies, awareness and the institutional framework of irrigation management. This change will not occur easily or quickly. A strong vested interest among influential individuals to keep the existing institutional arrangements intact is the greatest obstacle to change. Yet, alternative strategies need to be developed for introducing new technologies to replace or modify the traditional water delivery systems, which are crumbling under the stress of changing socio-economic conditions. These strategies should ensure that the benefits of new technologies of water delivery and irrigation scheduling reach the more disadvantaged groups among the water users.

Burt (1996) states in his presentation of some guidelines for establishing irrigation policies, that 'agencies should be cognizant of the fact that their responsibility is to provide a service, not to dictate schedules. The only way this concept of service can work is if the water delivery system is broken down into levels of service'. He states that when project staff wholeheartedly adopts the concept of service, amazing agronomic and social improvements can be made.

The irrigation system is very complex in nature consisting of many sub sections, which are the unavoidable integral part of the system as shown in the schematic diagram below and each sub-component has great contribution to the system to be successful in practice and should be looked in coordinated approach with equal weightage.

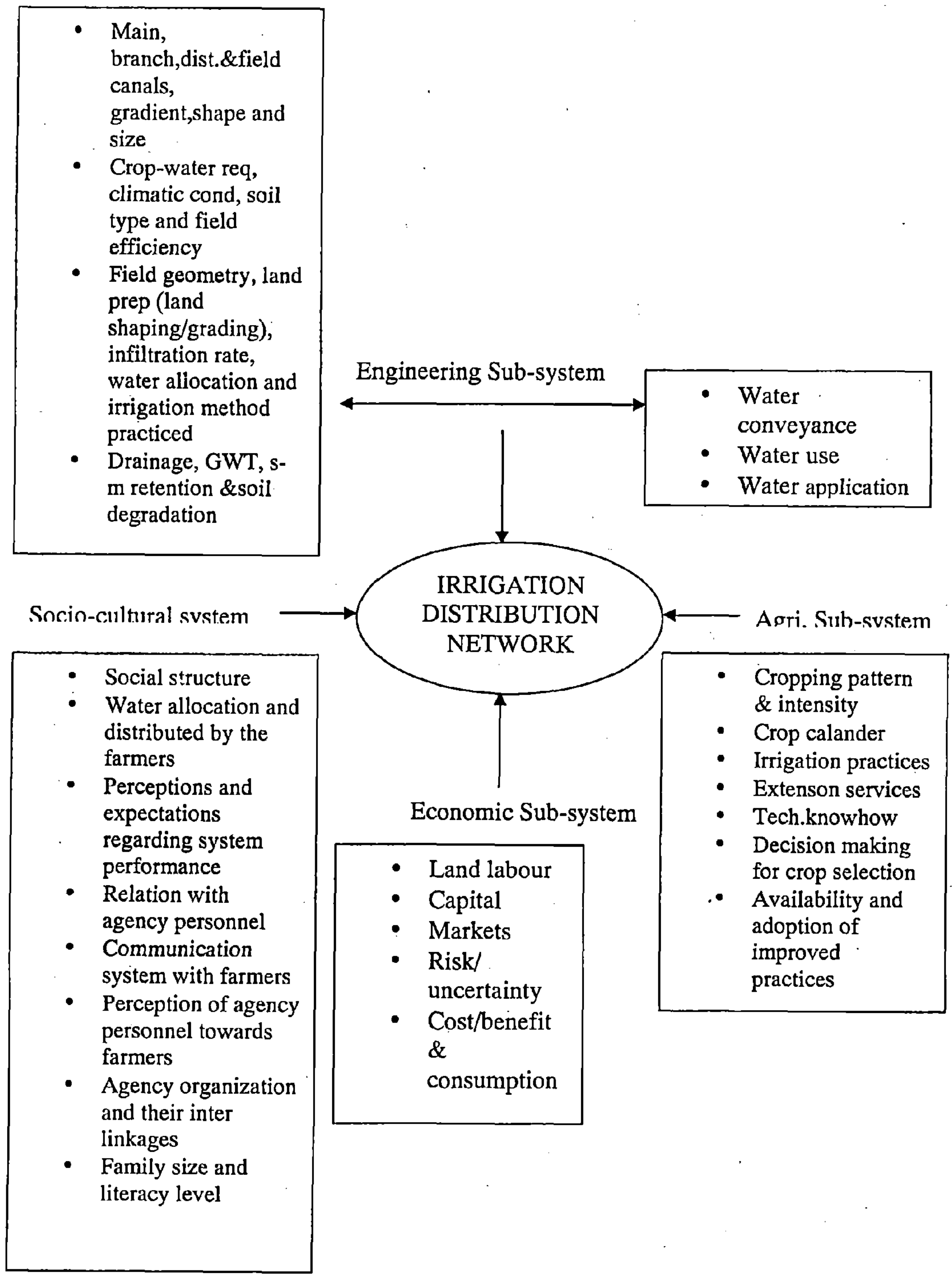


Fig. 27: Schematic diagram of sub-system components

CHAPTER –7

DISCUSSIONS

CHAPTER- 7

DISCUSSIONS

The competitive demand of water used multi-sectorally is increasing tremendously day by day with the process of developments in all parts of the world. The availability of fresh water is only 1 % of the total available in nature, which is also not evenly distributed over the world but differs in space and time. The irrigation sector, being the principal user of 80 % of that fresh water available for producing required food for the growing world population, is yet not satisfied to command the land required; resulting the unsatisfactory outcome from the irrigated agricultures and that too is lost partly. The reasons behind, may either be the over use of water in limited lands or the age-old practices of irrigating land by allowing water to flow from higher lands to lower ones is still continuing and the conceptual change of the water user could not be synchronized with the modern trends of developments in the use of water and the management of it scientifically. These causes have resulted reduction in yields, degradation in land quality, wastage of water itself, loss of investments and time, no or very less input to national treasury. The responsibilities, duties and morals are either lagging or not properly made known to the irrigation service providers and users. This also gives a notion that the irrigation professionals with much experience and confidence give more emphasis to the creation of the new systems rather than to maintain, operate and manage the old systems for seepage minimization. Though the expansion of professional expert fields are confined to specific areas, even then the precise expertism of the concerned fields in not being integrated in the creation of the system. The co-ordination, proper communication, past experiences and would be problems are to be discussed openly within the related departments and a combined effort to make the system efficient, effective, sustainable is essential.

The most viable phase of the system is the utilization phase, which includes the beneficiaries at large. The time bound technology transfer with respect to the irrigated agricultural developments to the users is a massive task to be performed on a large scale and in continuation is still lagging behind in most of the developing countries in the world. Without knowing the process and procedures of proper utilization of water made available, the expectations of achievements would never be fulfilled. The human nature is very difficult to change or adjust according to the time need basis because learning by doing would be the best process of teaching but requires large investments and is one of the key points to give the required exposure to the users about the water use management and increase production with respect to the unit of water used. However this is a time taking and tedious process for which professionals with patience, commitments, and confidence as well as with persuasive quality for motivating, problems identification and providing suitable solutions should be assigned for the task.

The responsibilities transfer to the users with proper motivation and capability build up is the base line of system sustainability. The vision about the user is still not gaining due height in the perception of the planners and designers, so is either neglected or least cared for. Their importance of the users for the project, their cooperation, grievances and suitable feed backs should be incorporated and corrected to make them assured that the responsible agency listens to their problems and reacts timely, makes them self –motivated for working as a co-partner and serve as public police for every betterment of the system with ownness feelings towards it.

A substantial amount of valuable water goes wastage during transportation as a flow to the sub-surface reservoir or to the sub-surface drains as seepage and other losses till it reaches to the farmers' fields. The irrigation projects, though are created with massive investments and past experiences of the professionals along with the use of advance technology in construction with high standards of quality control, still the seepage problems are unavoidable. The seepage problem may be considered as site specific or the project specific rather than generalized one because the nature and extend of seepage varies from place to place. The seepage problem has not only the engineering dimensions but also has the equally important social, economical, agricultural, environmental, political and other dimensions which still are not addressed with due weight. The physical ground features on the other hand are to be studied in depth well in time and the system to be created is to be structured on the real data base analysis wisely and carefully in each steps of development so that the system would work to its maximum efficiency in good health without the problem of water logging and soil salinization.

The initial important phase of the system is the planning period, which if goes wrong shall never be able to satisfy the aspirations and desires of the public but shall be a burden rather than an achievement. In past, most of the projects designed were based on certain approximations and assumptions as the real field data were not available or if available were not sufficient for proper predictions, so the results, in real fields differ at large. The soil properties, the seasonal ground water table fluctuation data are basically the most important parameters for planning the network avoiding canal network routing through seepage prone zones to minimize seepage losses. These less cared parameters in planning have resulted complex problems in many irrigation systems in most of the developing countries, which later on, have caused a huge investment, time and stress on planners and designers for deficiencies rectifications. This sometimes is blamed as the professional failures or the shortsightedness in the planning. Moreover, in the past planners and designers never cared for the operational and maintenance problems during planning phase without which the real benefit from the system cannot be derived. The pre- determined mode of canal operation, roles, responsibilities and rights of WUA as well as of ID (irrigation department) officials should carefully be addressed in planning phase, which generally is lagging. The structural and operational safety in case of emergencies or some unavoidable circumstances is also the considerable factor. The inclusion of O&M experienced personnel in planning would help much by the input of knowledge gained regarding O&M. Moreover the O&M experienced personnel should be provided with the opportunity of reviewing the planning and design from the operational point of view and incorporate the past lessons learnt so that the deficiencies could be rectified in time. The involvement of O&M personnel at site during construction also helps provide beneficial input to works executed from O&M perspective which in turn would help much more for writing the site specific operational and maintenance rules and regulations or even the O&M manuals based on real data. The irrigation water management is the essential component in the distribution system. The on-farm development networks including drainage have to be constructed to the required level so that the water may not go wastage. The effective use of water be made known to the users according to their cropping pattern and cropping intensities with respect to the local soil conditions. Agricultural extension education plays vital roles in water savings. The field demonstrations in pilot forms stressing that the limited water use (only as required) would not effect the production with other usual inputs and this would make farmers aware of the importance of water use and also bring a successful conceptual change. Proper communication and technology transfer may include the media advertisement, study or observation tours, action research programmes and farmer-to-farmer interactions of successful projects to transfer the practical know-how of using water in efficient manner and also the ill consequences of over use. The incorporation of all these facts in planning stage would emerge the project as an economically viable one at the matured stage.

The design and construction should provide an economical, safe and hydraulically efficient channel section. The savings in water should get the priorities with operational ease as well. The design should prefer the use of available local materials for providing environmentally acceptable, technically robust and hydraulically efficient sections. Sufficient numbers of essential structures at required intervals coupled with the structural safety arrangements are the pre requisite of sustainability. The construction techniques, technology used should not get any relaxation in workmanship and quality control throughout the project Provision for sufficient control points (diversion/measuring structures) would be required for water management which would also help in reducing water loss though initially extra cost is incurred but may prove economical in time span. The earthen (unlined) channel section should get compacted to get the dry density of 1.6 – 1.8gm cm3. The proper compaction may reduce seepage to the considerable extent (approx. 5- 10 %). The compaction if done at OMC level would provide the best results and if the compaction is done above the OMC, the effect of compaction decreases. The phreatic lines should be checked properly in case of filled sections for structural safety. If the channels are bound to run through pervious media and in filling, where lining is uneconomical, provision of core may probably be the best solution, but economical viability of every alternative to be analysed is the engineering moral.

The proper assessment of the water availability at the source is very important before deciding for the preparation of operational plans. On the basis of the source reliability only, the water requirement in the command can be concluded. In the old projects, the water supply was duty based but the modern trend is to deliver the water as per the crop water requirement of the command. The supply should always fulfill the required demand of the crops grown in the fields for which certain fixed mode of operation as well as approved rules and regulations for operational procedures are necessary. In the absence of approved instructions in writing, essential procedures are easily forgotten or never known by operational personnel specially during the change which results pre- mature break down, use of improper procedures, unsafe practices and even discontinuity in operation. The adequacy, equity, timeliness and reliability are the objectives of irrigation water supply to the farmers which when could not be met with would result the misbehaving with the system such as water pilferation or even anarchism in water use where social justice could not be maintained. For such situation not to occur frequently, the operational procedures should be guided by preparation of seasonal operational plans, opening and closing canal rules, monitoring of operation and issue instructions for better operation of the canals in emergencies and heavy downpours. The seepage minimization is another aspect of operation which needs proper monitoring of the flows for quantity assessment at each diversion points as well as the in built good communication system within the network. The safety of the distribution system during operation should be given due care.

The proper scheduling has direct relation to the irrigation water input to the lands. The soil moisture content, the type of crops and their pattern in the command are the pre-requisites studies to be to be performed before finalising the scheduling operation. The scheduling should be based on the mode of operation as continuous running, on demand basis or on rotational basis. The rotation basis or the warabandi is the process of supplying water at certain time intervals of one, two or even three weeks as per the availability of water, extent of command area and the nature of the crops in the command. The objective of scheduling is to finalise and fix as how much to irrigate (i.e. how much of water is to be applied to the crop land), when to irrigate (frequency of irrigation) and how long to irrigate (time duration) to meet the desired crop water requirement without wastage of water resulting increase in production. This task when performed by irrigation department/agency only in the past showed that the adequacy, timeliness, equity and reliability in water supply was not met or was very poor. The reason is that the whole operation up to the farm outlet was in the control of irrigational department and there was no involvement of the farmers in water distribution. The farmers who are at or near the head reaches draw more water by any means creating scarcities in the lower reaches. The farmer who is socially strong enough would draw more water neglecting the others turns, making them sufferers who cannot provoke any words against him. Therefore, farmers involvement in water distribution scheduling is felt must in order to share the available water in proportion, maintaining social justice as well as for raising their voices for any unjustifiable activities found in water distribution collectively through water users associations within the periphery of their approved roles, responsibilities and rights. The importance of water to the crops and both the over use and the under use has detrimental effects to crop as well as to soils should be made clear both to the water users (farmers) and the suppliers (irrigation staffs) through trainings needed. Without knowing the importance of water saving and its beneficial effects to crops, the water saving concept cannot be practicalised and with this knowledge only the operational persons can perform their duty effectively and the farmers will remain alert for water misuse.

Maintenance of the network is very essential to its sustainability as well as to draw the desired output from the system created. Regular and essential structural maintenance are very important in order to keep the system in good health. Thorough investigations of the system at certain intervals is very necessary and the records of investigation (deficiencies identified) should be maintained and on this basis priority based maintenance works are to be carried out as per the maintenance fund available and push on further for the required funds to the concerned authorities for those deficiencies to be rectified in order to upkeep the system to its optimal efficiency level and preserve it from deteriorations. In most of the developing countries, though the irrigation systems created are technically sound, the utilization part always is week. Among many causes, the most important one can be said the lack of proper knowledge of conservation of the source and the preservation of the system.

The old concept of construction works is more prestigious than maintenance works among the professionals was also an obstacle and quite often the maintenance of many old systems was not much cared by them. The time has changed and today the utilization part is the most viable because the created system if could not be utilized in proper and sustainable way, the whole objective of production increase by input of water would not be justified and even the partial return of the investment could not be thought of. Therefore, the new concept to be applied is " Maintenance should not be neglected and O&M experienced, committed and competent senior personnel should be deployed for" to extract the real benefit from the system for long time, serving farmers to their satisfaction and recovery of the investment through production boost.

The irrigation system/ distribution network consists of several sub-components called as "Sub-systems" which are (i) Engineering (ii) Agricultural (iii) Economic and (iv) Socioeconomic. All these sub – systems when perform harmonically, then only the project or the distribution network will attain its targeted achievements and failure of either of the ones leads to the dis-satisfactory output. This draws the needs of a multi-disciplinary team approach with required field expertism having committment and dedication towards the system.

The hundred percent control of seepage in practical is rather impossible and from the practical point of view and even if around fifty percent can be controlled would reveal a satisfactory achievement. The weightage loss of (i) engineering is 45% (conveyance), (ii) users 25% (in avg.). If only 50% of the lost water can be saved (would be equal to 35%), about double of the area could have been commanded. This gives the notion that the new integrated approach should give more emphasis on maintenance, operation and management aspects of the system together with the required capability build up of the water users to gain more sustainable output from all sub-components.

CHAPTER –8

CONCLUSIONS

CHAPTER - 8

CONCLUSIONS

The measures more relevant to control seepage losses in the irrigation system are listed as follows.

1.Measures to be taken during planning stage of the system

(i) Detailing of alignment and layout of the canal network
(ii) Detailed examinations and explorations of type of soil
(iii) Examination and assessment of ground water table (GWT) in the command
(iv) Adequate input of experience of similar projects on operation and maintenance
(v) Requirements of proper management

2. Measures to be taken during design stage of the system

(i) Simple and detailed design of the system to suit the local conditions
(ii) Emphasis on the use of locally available materials
(iii) Adequate input of experience of similar system of operation and maintenance
(iv) Simple and bold designs using the local materials

3. Measures to be taken during construction stage of the system

(i) Strict and effective control on quality
(ii) Control on cost and time as far as possible for avoiding cost overrun
(iii) Special stress on excellent quality on seepage control measures such as lining, puddling etc
(iv) Thorough, proper and required maintenance before the commissioning of the system.

4. Measures to be taken during operation and maintenance of the system

(i) Formulation of proper rules, codes and regulations for the operation and maintenance system including input of experience of other similar systems

(ii) Strict monitoring should be carried out to review and improve the system performance

(iii) Periodic review of operation and maintenance (O & M) for quick and timely removal of deficiencies

(iv) Thorough examinations and maintenance of the seepage control measures used in the system such as lining of water course, maintenance of water course, removal of vegetation and water weeds etc

(v) Measurements and assessment of losses in different parts of the system

(vi) Participation and motivation of farmers (users) to avoid the losses by awakening and training

(vii) Suitable scheduling and rostering of distribution channel based on experience, creating scarcity conditions in water use by the users and minimizing the losses through proper outlets.

Other measures

1. Motivation of farmers to make the proper use of the water and keeping the water courses clean and free of vegetations.
2. Lining of watercourses in 50 – 60 % of the length
3. Lining of distributary channels in the selected seepage vulnerable reaches
4. Lining to be applied should be well designed; effective and long durable use,requiring minimum maintenance.

REFERENCES

1. Abernethy, C.L. " Irrigation Water Management at Kaudulla, Sri Lanka: A review of Measurements made and a proposal for new Management Methods". Hydraulics Research, Wallingford. Report No70, 1978 to 1983.
2. ASCE," Journal of Hydraulic Engineering", Vol. 117, No. 1-3, 5-6, Jan.- June 1991.
3. Bottrall, A "Improving Canal Management - The Role of Evaluation and Action Research ", 1981.
4. Bouwer Herman,"Theoretical Aspects of Seepage form Open Channels", ASCE journal of Hydraulic division, Vol.91, No.Hy.9, May 1965.
5. Campus Team, Cairo ARE, Fort Collins, Colorado USA,"Keyes Egypt Water Use & Management Project, Problem Identification Training Manual for On farm System" , USA, Vol. I Sept. 1980, 1981.
6. CBIP ,"Journal of Irrigation and Power", 1962 & 1968.
7. CBIP&IGG, National workshop on " Role of Geo-synthetics in Water Resources Projects", 20 – 24 Jan.1992.Proceedings Publication No. 232, March 1993.
8. CBIP, "Engineering with Geo-synthetics", Compilation of two proceedings held at Gauwahati and Hyderabad,, Oct.1995.
9. CBIP, "Manual on canal linings", Technical Paper No.14, Sept.1975.
10. CBIP, "Symposium on canal linings " Publication no.82, 1967
11. Challa Satya Narayan Murty, "Water Resources Engineering, Principles and Practices"2nd. Edition, New Age International Publishers.
12. Chaw V.T "Open Channel Hydraulics", McGraw-Hill Book Co. Inc., New York, 1973.
13. Colorado State University,"Improving Irrigation Water Management on farms", Annual technical Report, 1979.
14. Ellis L.D, "Irrigation Manual".
15. Ernest F. Barter & Horace Williams King "Handbook of Hydraulics for the solution of Hydraulic Engineering problems", Mc-Graw-Hill Book Company.
16. FAO, " Irrigation Water Management Training Manual" No 4, Irrigation Scheduling, Paper No. 4.
17. FAO, "Crop water requirements" FAO Irrigation and Drainage Paper 24. FAO, Rome, 1977.
18. FAO, "Design and optimization of Irrigation Distribution Network", Irrigation and drainage paper No. 44, FAO. 44.
19. FAO, "Irrigation Water Delivery Models", Water Paper 2, FAO 2.
20. FAO, "Organisation, Operation and Maintenance of Irrigation Schemes", Irrigation and Drainage Paper. No.40.FAO.Rome, 1986.
21. FAO, "Yield response to water" FAO Irrigation and Drainage Paper 33. FAO, Rome, 1977.
22. FAO/RAP, "Modernisation of Irrigation Schemes, Past Experiences and future Options", Water Report 12, 1997, Rap Publication 1997/22.

23. Garde and Chawla,"Seepage from Trapezoidal Canals", Journal of Hydraulic Division, ASCE, Vol.96, No. Hy.6, June 1970.
24. Gideon Peri & Gaylord V. Skogerboe," Evaluation and improvement of Irrigation System", Water Management Resaerch Project, Colorado State University, Tchnical report no.49 A, 49C,May 1979.
25. Goyal M. C, Prof.WRDTC & J. N. Chakrobarty E.E (Agri), West Bengal.
26. Harr, M.E., Ground Water and Seepage, McGraw-Hill Book Co. Inc., New York, 1972.
27. ICID – CIID,"The Watsave Scenario", Dec. 1997,
28. ICID _CIID, "Water for Food and Rural Development, Country Position papers", Sept.2000.
29. ICID, "Controlling Seepage Losses from Irrigation Canals", World Wide Survey, 1967.
30. ICID, "Design Practices of Irrigation Canals", 1972.
31. IGG&CBIP, "Use of Geo-textiles in Water Resource Projects", Case Studies- Vol.I, Pub.No.225, New Delhi, June 1992.
32. IS Code 10430,"Guidelines for Design of canal/ Watercourse", 1982.
33. IS Code 10646 "Pre-cast concrete lining", 1983.
34. IS Code 3878 "Cement Concrete Lining", 1973.
35. Keyes Conrad G., Jr. and Ward Tim J "Development and Management Aspects of Irrigation and drainage Systems", Edited by, Published by ASCE, 1985.
36. Kinori B.Z.," Manual of Surface Drainage Engineering", Vol. I, Elsevier Publication Company, 1970.
37. Kraatz D. B," Irrigation Canal Lining 2", Irrigation and Drainage Paper No.2, FAO.
38. Malhotra G. P, C.Engg (lining), Haryana State Minor Irrigation (Tubewell) Chandigarh, "Modernization of Canal Water Courses in Haryana", Ford Foundation, 1970.
39. Nawaliwala, B N Key Note Address in All India Seminar on Water Logging & Drainage, IE (U), Roorkee, 1990.
40. Nofziger, D. L, Bureau of Reclamation, " The influence of Canal seepage on Ground Water in Lugert Lake Irrigation, Oklohama water Resource Institute"1979.
41. Planning Commission, GOI,"Pilot Studies on Water Use Efficiency for UGC" (UP),WAPCOS, Feb.2003.
42. Rohit Goyal and Abote Tadesse Wolde Kirkos.Thesis on "Seepage from canals founded on finite pervious soil with asymmetric drainages" 1984July & 1993 Sept. respectively.
43. Satish S and Sunder A, "Peoples participation in Irrigation Management", Common Wealth Publishers, New Delhi, 1990.
44. Sharma, H.D., and Chawla, A. S., "Manual of canal Lining", Tech.Report No. 14, CBIP, New Delhi, 1975.
45. SMO ,"Water Resources Situation in Pakistan", Challenges & Future, , Unpublished data.

46. Swamee,P.K., Mishra, G.C., Chahar,B.R., "Design of Minimum Water Losses Canal Sections",2001.
47. The Concrete Association of India "The linings of Irrigation Canals", 1960.
48. Third congress of Irrigation and Drainage Transactions, vol. II, 1967.
49. Thiruvenkataswamy K.R (S Engg.), Agricultural Engineering, Tirunelveli, Tamilnadu. Paper on "Design of Field channels- On farm Development".
50. Thomas J Trout & W Doral Kemper," Water Course Improvement Manual", Water Management Research Institute, Colorado State University, 1980.
51. USBR Technical Bulletin No. 1203.
52. USBR,"Linings of canals"
53. V.K.R. V. Rao, "Impact of Irrigation, Studies of Canal, Well, Tank Irrigation in Karnataka", Himalayan Publishing House, Bombay 1979.
54. Water Management Forum, Gandhi Nagar "Seminar on Irrigation Water Management", 1992.
55. Zimmerman J.D.," Irrigation", John Wiley and Sons, Inc., New York-London-sydney.