SEEPAGE AND DRAINAGE

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INTRODUCTION

Canals continue to be major conveyance system for delivering water for irrigation in the alluvial plains of India. But loss of water due to seepage from unlined irrigation canals constitutes a substantial percentage of the usable water. By the time the water reaches the field, it has been estimated that the seepage losses are of the order of 45 percent of the water supplied at the head of the canal (CBIP, Technical Report No.14, 1975). According to the India Standard (IS:9452,1980) the loss of water by seepage from unlined canals in India generally varies from 0.3 to 7.0m^3 per second per 10^6 m^2. The transit losses are more accentuated in alluvial canals. It has been estimated (CBIP,Report No.14, 1975) that if the seepage loss is prevented, about six million hectares of additional area could be irrigated easily. The seepage losses from a canal may lead to water logging and soil salanisation. Canals in alluvium are lined for water conservation and prevention of water logging. Depending on the lining material seepage from a lined canal occurs at a reduced rate. Various research organisations and many investigators have carried out experimental and analytical studies on seepage and drainage since independence for solving the problems due to seepage. In this chapter the contributions made by various investigator and research organisations in India in the study of seepage from canals have been focused.

The process of seepage from a canal starts as soon as water is filled in it. As the time elapses, in the first stage, the soil layers around the canal get saturated . The saturated front, in the next stage, moves slowly downwards and after a certain period of time, it reaches the water table below the bed of the canal. During this downward propagation of seepage from the canal into the flow domain beneath the canal, the seepage water is used for the saturation of the wetted zone, where the pores were previously filled with air. After reaching the water table only part of the infiltrating water is stored within the extending saturated zone where as the remaining part recharges the ground water. It may be noted that seepage rate from the canal is not the recharge rate at the water table at all time. With wetting front position some where between the canal bed and initial water table position at very large depth and for initially dry soil, the seepage rate varies in time, but the recharge rate is constant and zero. If the water content behind the wetting front is close to saturation, recharge rate rises abruptly from zero to the prevailing seepage rate at the time the saturation front encounters the table.

The seepage loss from an unlined canal depends on the depth of water in the canal. depth to water table in the vicinity of the canal measured from the water surface in the canal, width of the canal at the water surface, side slope of the canal, distance

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of the governing drainage, and coefficient of permeability of the porous medium. In addition, flow velocity, soil and water temperature, atmospheric pressure and stratification of the underlying soil also affect the seepage rate.In case the canal is lined besides the above mentioned factors seepage loss depends on the permeability and thickness of the lining material. Initially the seepage losses are high due to steep gradients, but as the sub-soil becomes saturated, the gradients flatten and ultimately stabilise if the channel is continuously running. The discharge given by the theoretical formulae mostly corresponds to steady state conditions which are difficult to attain in practice due to fluctuations of water in the canal and the water-table. Thus except for cases of canals where steady condition can be obtained early as for instance in soils of high permeability with main drainage located close to the canal, the discharge as computed from theoretical formulae may be poor estimate of the likely losses and only serve to indicate the order of seepage losses for deciding the necessity or otherwise of the lining.

Of the various factors which influence seepage loss from a canal the very important are the boundary conditions of the flow domain and permeability of the medium. Only after a correct assessment of the coefficient of permeability and boundary conditions, the seepage loss can be estimated either by numerical method or by analytical technique. In order to avoid the difficult task of estimating the insitu coefficient of permeability and the prevailing subsurface boundary conditions, experimental techniques like ponding method and inflow and out flow method have been used for estimation of seepage loss. In recent years, tracer technique has been used to estimate seepage from canal because of its comparatively easy operation in respect to other experimental method.

Analytical Method

Steady state seepage from a canal when the water table is at large depth has been analysed by a number of investigators for various boundary condition. For solving the seepage problem hodograph method and conformal mapping technique are applied. Garg and Chawla(1970) have derived analytical solution for seepage from a canal influenced by drainage boundary. Zhukovsky function has been used to map the curve linear phreatic lines to straight line boundaries and conformal mapping technique has been used for finding the nondimensional seepage loss from the canal and locating the phreatic lines. The study has been applied to Ganga Canal, Hardoi Canal Lower Ganga Canal and Sarada Sahayak Feeder Channel.

Lining of canals is an accepted practice to reduce seepage losses. However the large construction cost sometimes precludes the lining of many minor and small channels. Also many existing unlined channels and water courses require heavy financial outlay if they are to be lined completely. The canal bed can be lined by artificial sealants or by bentonite clay in which case the losses occurring through the canal bed can be reduced. A study of seepage from partially lined trapezoidal canal in a homogeneous isotropic porous medium of large depth has been carried out using inversion of hodograph and Schwarz Christoffel transformation by Subramanya et.al(1975). The two cases studied are: (1) seepage from canals whose sides are lined but bottom unlined; and (2) seepage from canals whose bottom is lined but sides unlined. It is found that for every side slope of the canal there is a particular aspect ratio(bottom width to depth of water in the canal) at which the sides lining or bottom lining results in the same reduction of seepage. For canals having an aspect ratio more than this, bottom lining is more effective and for a lesser aspect ratio, sides lining will be more effective. For a canal having an aspect ratio of 9 and a side slope of 2.5.1, a 50% reduction in seepage is ensured by sealing the bottom. The loci of the phreatic lines, resulting in the aforementioned two cases, are also studied. From the study it is found that if the canal is completely lined but cracks develop in the bed, the seepage is very vulnerable to width of the cracks.

Garg and Chawala (CBIP, Technical Report No.14, 1975) have extended the analysis of seepage from unlined canal to estimate seepage from a lined canal. The expression for computation of seepage from a lined canal which has been derived by Garg and Chawla is: q=cPkh /(crt+P) in which q is the seepage rate from unit length of the canal, P is the wetted perimeter of the canal, k is the permeability of the subsoil material, $r=k/k_1$ where k_1 is the permeability of the lining, and c is a function of canal geometry and location of drainage boundary which has been given by Garg and Chawla. An analytical solution has been found for the problem of seepage flow from an unlined trapezoidal canal taking into account the general anisotropic behaviour of the porous medium (Reddy and Basu, 1976). Since a canal in an anisotropic medium transforms into one with unequal slopes in an equivalent isotropic porous medium, the solution has been given for the problem of seepage flow from an unsymmetrical trapezoidal canal. The method of inversion of hodograph has been made use of and expression for the seepage loss and locations of the phreatic lines have been obtained. Numerical results have been presented for the equivalent isotropic flow domain. Using the transformation formulae given, the actual discharge and location of the phreatic lines in anisotropic medium can be obtained. The nonsymmetry of trapezoidal canals of side slopes less than one has considerable influence on quantity of seepage.

Seepage from an unsymmetrical triangular canal in a porous medium of infinite depth has been analysed by inversion of hodograph and conformal mapping (Reddy,etal.1976). Using the analysis the seepage from a triangular canal in an anisotropic medium can be computed. From the study it is found that direction of the principal permeability controls the loci of the phreatic lines.

An analytical solution has been obtained with the help of conformal mapping for the problem of steady seepage from a canal to drainage boundaries located symmetrically on either side of the canal in homogeneous and isotropic medium of finite depth (Sharma,and Chawala,1979). Equation have been given to determine the seepage losses from the canal and the locus of the phreatic lines. The solutions of the equations have been presented in the form of dimensionless curves to facilitate computation. The analysis indicates that seepage losses from the canal increase with an increase in the bed width and depth of the saturated thickness of the porous medium, and decrease with an increase in the drainage distance. The seepage discharge is greater for vertical drainage than for horizontal drainage. The analysis also indicates that the phreatic surface rises with an increase of the bed width ,an increase in the drainage distance, and a raising of the lower impermeable boundary. For a shallow impervious boundary,the phreatic surface near the drainage tends to a straight line.

Seepage from a triangular canal in a porous medium exhibiting high degree of anisotropy has been analysed by Achrya (1980) using hodograph and method of inversion.

A canal in such domain when transformed to a fictitious isotropic domain one of canal banks is transformed to an over hanging equipontential boundary. From the study it is found that for a degree of anisotropy more than 10 the two phreatic lines orient themselves in the direction of stratification and become parallel away from the canal. Seepage loss increases with increase in the degree of anisotropy.

Seepage from depression storage in an arid region has been estimated using a technological functions (Rao,1981). Using discrete kernel approach a mathematical model for study of interaction of large depression storage and aquifer has been developed. The model has been applied to estimate seepage losses from nineteen inter connected depressions in Rajasthan near Surathagarh for the known water level in the depressions at different times. Using method of fragments, and conformal mapping seepage loss from a canal in a two layered soil system under confined flow condition has been found by Mishra and Mahapatra(1983). The effect on seepage loss because of removal of top soil, whose permeability is 1/10 of the permeability of soil in the underlying layer has been studied. For (b/D) < 0.1 and (d/D) > 0.01 where b is the bottom width of the canal and D is the thickness of the underlying sand layer and d is the thickness of the over lying semi pervious layer, seepage loss from the canal is almost doubled when half of the top soil is removed. The effect of excavation on seepage loss is prominent for canal with small bed width.

Hussain (1986) presented numerical analysis of two dimensional steady state unconfined seepage through partially lined channels. The channels are either lined at base only and sides unlined or sides only lined and base unlined. The soil is considered to be homogeneous and isotropic while the sub soil is either impermeable (condition B) or highly permeable (condition A). The parameters governing seepage are the depth of water in the channel,the base width of the of the channel, the position of water table and the position of sub soil layer. The side slope of the channel is kept constant at 1H:1V. The condition A is more active state of seepage than condition B. There is a marginal effect of position of water table on the percentage reduction in discharge for both cases of lining for condition B while for condition A the percentage reduction in seepage is found to increase with the lowering of the water table for base only lined case and decrease for sides only lined case. The lowering of the impermeable layer increased the percentage reduction in seepage for both cases of lining for condition B while lowering of the permeable layer decreased the percentage reduction in seepage condition A. For H_w/W_b less than 0.4 for a set of other parameters the base lining only of the channel was found to be more effective in reducing seepage while for H_w/W_b greater than 0.4 sides lining was found to be more effective for condition A. It is also observed that the percentage reduction in seepage due to lining is not linearly related to the percentage of the total wetted perimeter lined. The analysis is done with the help of a computer program based on finite element method.

A study on interference of two parallel canals, seepage from which is not governed by the water table position, has been carried out by Bhargava et.al(1987). The study is based on analytical solution of one dimensional Boussinesq's equation. From the study it is found that for two parallel canals which are not hydraulically connected with aquifer, their interference relates to evolution of water table only. In case of two identical parallel canals, it has been found that in the beginning of recharge, two distinct water mounds are formed below the centre of each canal. With lapse of time, the points of maximum rise move towards each other; but they do not move beyond the respective recharging strip. With further lapse of time, a stagnant zone gets created between the canals, and the region between the two parallel canals takes the shape of a plateau. It has been found for the case of unequal parallel canals that, sometime after the onset of recharge, only one point of maximum rise under the larger canal is established.

Using Zhukovsky's function and Schwarz-Christoffel conformal mapping technique, unconfined seepage from a river of large width has been analysed for a steady state condition by Mishra and Seth (1988). Seepage quantities occurring through the bed and bank of the river have been estimated separately. The reach trans- missivity constant for a river with large width has been determined. It is found that if the distance between the river bank and the observation well is more than half of the saturated thickness of the aquifer below the river bed the reach transmissivity constant is independent of drawdown at the observation well. The reach transmissivity constant dependents on the depth of water in the river bed and the distance of the observation well from the river bank. The seepage loss from the river at any time is product of the reach transmissivity constant and the difference in water level in the river and at the observation well at the time of observation.

The study of unsteady seepage from two parallel canals, when the water table is located at shallow depth below the bed of the canals, has been carried out for equal and unequal canals which run continuously (Bhargava,1988). The study has been extended for the case in which one of the canals runs intermittently. It has been found that in case of two continuously running parallel canals, the reduction in seepage from one canal due to interference of the other is zero in the beginning of seepage. The interference increases with time, attains a maximum value, and then decreases. The decrease in interference is monotonic at large time. The interference of parallel canals is found to decrease with increase in the spacing between the canals. For unequal parallel canals, the interference of bigger canal on smaller canal is more than that of the smaller canal on the bigger one. If one of the parallel canals runs intermittently, it is found that the reduction in seepage from the continuously running canal, due to interference of the intermittently running canal, starts from zero, increases from cycle to cycle, reaches a maximum value, and then decreases. Also, the intermittently running canal in the parallel canal system acts as a drain during its closure period after a few cycles of running. It has been seen that in case of two continuously running equal parallel canals a stagnant zone is formed between the canals with lapse of time.

Study of seepage losses from large depression storage has been analysed by Bhar and Mishra (1988) considering the variation in water spread area due to occurrence of seepage losses from the depression. The model predicts the ground water evolution and the water level in the depression with time. The time at which some of the depressions loose all the stored water has been found. It is estimated that seepage rate from the depression storage after seven months of filling is one third of initial seepage rate.

An analytical solution for estimating seepage from a canal embedded in a porous medium of finite.depth under lain by a highly permeable layer has been derived using Zhukovsky's function and conformal mapping for any position of water table above the highly permeable layer by Mishra,and Chandra (1988). The depth of water in the canal, bottom width of the canal, and width of canal at the water surface have been preserved in the analysis. For small depth of water in the canal the seepage loss has been compared with that given by Aravin. Also the results have been compared with those of Hammad for a case in which the difference in potentials at the canal surface and in the aquifer at large distance from the canal is small. The locus of phreatic line has been determined .The phreatic lines merge with the water table at finite distance from the canal because of the presence of the highly permeable layer at finite depth.

The function of a natural drainage channel has been studied using a mathematical model by Bhargava et.al(1989). The time of activation of a drainage channel which runs parallel to two continuously running ridge canals has been predicted. The return flow entering to the drainage channel at different times after its activation has been quantified. The evolution of water table prior to and after the activation of the drainage channel has been predicted. It is found that the time of activation depends on the ,aquifer parameters, seepage rate from the canals, distance of the drainage channel from the canals, and the elevation of the drainage channel. If a drainage channel is located nearer to the canal, it receives return flow at higher a rate. The water table between two continuously running canals is marginally affected by the presence of the drainage channel.

Mathematical model for seepage studies from two parallel canals one of which is situated on a high ridge and the other at a much lower elevation has been carried out by Bhargava et.al.(1990). The combined evolution of water table due to seepage from the ridge canal and valley canal has been obtained. The study also predicts the time variant seepage from the valley canal.

Experimental Method

Currently accepted methods for direct measurement of seepage losses from existing canals are the ponding, inflow-outflow and seepage meter. In addition .there are special methods such as tracer technique, electrical logging or resistivity measurement, piezometric survey and remote sensing.

U.P Irrigation Research Institute (1963) has conducted systematic laboratory study for predicting seepage loss from canal bed lined with bentonite clay with or without tiles. Lining of canals is considered an essential feature of an irrigation project as it not only minimises the loss of water but also affects economy in the use of land. Seepage control with conventional linings (e.g. cement concrete, masonry, asphaltic concrete, lime concrete, pre cast concrete and R.C.C) is found to be prohibitive because of economic point view. There has been a need for a low cost canal lining which should be consistent with the requirements of a good lining viz.,economy, imperviousness, hydraulic efficiency, durability and structural stability. Bentonite is available in abundance in Rajasthan, Bihar, and Kashmir. A study on benonite found in Bihar for its use as a lining material has been conducted simultaneously by U.P.I.R.I. and Bihar Institute of Hydraulic Research Institute. It was aimed to use this bentonite as a material for lining of the Gandak Canal in Eastern U.P. Bentonite was mixed with soil from the then proposed Gandak Canal in 5,10,15,20 and 30 percent by weight and the bentonite soil mixes were laid in 10cm thick in the permeability cylinder. The experiment was conducted under 6.096 m head. For 0, 5 10 ,15, 20, and 30 percent of bentonite by weight the seepage loss were found to be 11.10, 9.95, 6.25, 2.36, 1.20, and 0.70 cusec/10^6 s ft. Seepage through various types of tile linings was determined with the help of seepage tank .The results indicated that 10 cm thick bentonite soil mix of Gandak soil with 20 percent un activated Bihar bentonite gives the seepage comparable to tile lining with cement plaster. The only direct method of doubtless reliability for computation of seepage is to isolate the suspected section of the canal and to determine the rate of disappearance of the impounded water. However this method is not easily practicable and often may not be desirable due to continuous irrigation requirements. The Indian standard code of practice(IS: 9452 Part-I, 1980) for measurement of seepage losses from canals by ponding method was finalised in January 1980. The ponding and inflow-outflow methods are applicable regardless of canal or soil conditions.

According to the Indian Standard for determining seepage losses by ponding method a reach of the channel is isolated by constructing temporary bunds or by bulkheads on existing control structure. The method has been applied to canal with discharge capacity of about 150 m^3 per second. Length of the pond should be large enough so that the area of the end bunds is a small percentage of the total wetted area. The suggested length of the pond is about 100 times the bed width of the canal. Gravity flow or pumping may be used to fill the test pond depending on the conditions that prevail at the site and the size of the canal. The evaporation losses from the pond surface may be significant as compared to seepage losses from lined canal. In order to apply corrections due to evaporation, an evaporation pan is used for measuring the evaporation rate during the ponding test. The rate of fall of the water surface within a few hours after the initial readings of the gauges shall provide an indication of loss rate. Seepage losses may be computed from the observation recorded after the steady state condition has been achieved. In the computation of seepage loss the effect of variable head is not considered.

According to the Indian Standard (IS:9452,Part II,1980), for determining seepage losses by inflow-outflow method, the quantities of water that flow into and out of a canal reach are measured and the difference of the water quantities flowing into and out of the canal reach is attributed to seepage. Evaporation from the from the canal water surface and precipitation are taken into consideration in the computation. The selection of the site is governed by the availability of the measuring device at the site of inflow and outflow measurement. The standard devices which are preferred are: standing wave flumes, V notches, rectangular notches and measuring devices should be independent of submergence effect. In the absence of such facilities the canal discharges at the two sections can be measured by current meter(IS:1192-1959). The length of a reach should be such that the loss from the reach is of higher order compared to the accuracy of the measuring devices.

Maharastra Engineering Research Institute (1980) has conducted study on measurement of seepage loss from lined canal by inflow and outflow method. Discharge was measured by current meter and using standing wave flumes where ever available. The seepage losses are found to vary from 2.22 to 2.91 cumec per $10^6 m^2$ of the canal wetted surface.

Estimation of seepage from Janjokar minor, and Dabthua distributory has been made by Sing(1983) by different methods. The disharge of the minor is .421 cumecs and that of the distributory is 2.24 cumecs. Ground water in the study area occurs under shallow water table conditions. The seepage losses computed by inflow and outflow method from Janjokar minor and from Dabthua distributory at chainage 10km and at chainage 16.5 km are 2.12 1.17 and 2.14 m^3 per second per $10^6 m^2$ respectively. The inflow and the out flow have been quantified by area velocity method.

Estimation of seepage loss by inflow-outflow method using current meters has been made for the Ferozepur Feeder, a large capacity (design discharge =316 cumec) double tile lined channel in the Punjab (Dhillon et al,1986).The channel was commissioned in 1958. The average seepage flow from a reach of length 9.144 km is found to be 2.70 ± 1.0 cumec per $10^6 m^2$ of wetted surface area (0.23 ± 0.09 m/day). This seepage loss rate is inclusive of evaporation loss from the channel surface which is 0.01m/day.

Plastics, manufactured as low density and high density polyethylene (LDPE/HDPE), for controlling seepage through earthen structure, has been in use for canals in India since 1951. The Punjab and Gujarat states were the first to use this type of lining during 1959 to 1962 followed by other states subsequently. U.P.Irrigation Research Institute (1989) has undertaken a study on seepage losses from experimental irrigation channels and existing irrigation field channels under the following condition: i) unlined channels, ii) with hard surface lining ,iii) with LDPE film lining with varying thickness and earth cover over it, iv) with LDPE film lining covered with hard surface lining such as brick lining, cement concrete tiles lining and compressed clay tile lining. The seepage losses has been found using ponding method. The seepage loss from an unlined reach of Nanu Minor of Harduanganj distributory in Aligarh is found to be 1.139 m^3 per second per $10^6 m^2$. The reach has average width of 1.37m ,its side slope is 1:1 ,average water depth is 0.4m and the discharge is 0.396m^3 per second. The seepage loss from a lined reach of this distributory is found to be 0.295 m^3 per sec per 10^6 m^2 . The radius of the lined canal section is 0.46m, average water depth in it is 0.678m thickness of film is 100 micron and the mortar used is 1:4. Thus a 74.10 percent of seepage reduction is possible through lining by LDPE.

Attempts have been made to determine seepage losses in an indirect way by measuring the velocity of seepage flow in the neighbourhood of the canal. Midha (1937) and others tried to develop a method using the measured velocities of seepage flow. The velocities were determined measuring the transit time of a tracer. They also obtained the formula $q = v_r d\ (\sec\theta + \sin\theta/\theta)$ where v_r is the measured velocity of seepage flow, d is the distance of the observation point from the central line of the canal , θ is the angle the stream line makes with the vertical at the point of measurement.

A method for estimation of seepage rate from the filtration velocity of seepage flow measured by radio tracer point dilution technique and then using Numerov's theoretical analysis of laterally spreading seepage from unlined canal has been given by Krishnamurthy and Rao(1969). A practical application of the procedure to estimate seepage losses from Ganga canal near Roorkee has been described. The seepage loss computed is 2.2 m^3 per day per one meter length of the canal.

Singh et al have determined seepage losses from lined part of main Ganga canal and Deoband branch of Ganga canal by radio active dilution technique(1990). Tritiated water was injected into a number of bore holes located on a line perpendicular to the canal axis. After a lapse of twenty minutes first sample is collected and there after samples were collected at regular interval up to 10 days. The samples were put in plastic containers with air tight lid. The estimation of tritium was done using liquid scintillation counter LSS-34. Natural log of the counting rate versus time was plotted to find the filtration velocity. The slope of the phreatic line was found from observation of water level in the bore hole. Assuming that the hydraulic gradient is given by the slope of the phreatic line the hydraulic conductivity of the soil has been estimated which has been used to compute the seepage loss from canal using analytical method of Numerov, and method of Garg and Chawala.

There is a need for compilation and study in respect of thefollowing aspects of seepage and drainage:

i) Seepage losses from canal running in peninsular India;

ii) Computation of seepage considering the unsaturated flow in the initial stage of seepage flow;

iii) Seepage from intermittently running canal;

iv) Details of water logged area caused due to water logging;

v) Induced seepage due to augmentation tube wells;and

vi) Method for reducing seepage from existing canals.

REFERENCES

Acharya,B.B.(1980) Seepage from a canal in anisotropic porous medium. M.E.thesis submitted to WRDTC, Univ.of Roorkee.

Bhar,A.K. and G.C.Mishra (1988).Interaction of large depression storage with an aquifer. Proceding, International Symposium on Artificial Recharge of Ground Water, (ASCE Symposium) California , U.S.A

Bhargava, D.N., G.C.Mishra, and Satish Chandra (1987).Evolution of water table due to seepage from to parallel canals. International Symposium on Groundwater Monitoring and Management 23-28 March, Dresden, GDR.

Bhargava, D.N., G.C.Mishra, and Satish Chandra(1989). Effect of drainage channel on evoulation of water table due to recharge from two parallel canals. International workshop on appropriate methodologies for development and management of groundwater resources in developing countries, National Geophysical Research Institute, Hyderabad, India.

Bhargava, D.N., G.C.Mishra, and Satish Chandra (1990). Mathematical model for seepage studies from parallel canals. Irrigation and Power Journal .V. 47, No.4, pp 71-84.

Dhilon,G.S. ,T.C. Paul,and S.K.Sayal(1986). Measurement of seepage losses from large canal by current metering. 53rd Annual R and D Session ,CBIP,pp 319-327.

Hussain K. S.(1986) .Seepage through partially lined channels. M.Ethesis submitted in Dept.of Civil Engg., IIT, Kanpur.

Indian Standard Code of Practice for Measurement of Seepage Losses from Canals(1980).IS:9452 (Part I)

Indian Standard Code of Practice for Measurement of Seepage Losses from Canals(1980).IS:9452 (Part II)

Indian Standard Code of Practice for Velocity Area Measurement of Flow of Water in Open Channel (1959).IS:1192.

Midha,D.C. et al.(1937) A new method of determining seepage from canals in areas of high water table Research publication, Vol.V, No.7, Punjab Irrigation Reasearch Institute, Lahore.

Mishra, G.C., and B.Mohapatra (1984). Effect of excavation of top soil on seepage loss from a canal in a two layred porous medium. Journal of The Institution of Engineers (India).V.64, PT CI3.

Mishra, G.C., and Satish Chandra (1988). Reach transmissivity for a canal embedded in a porous medium underlain by a highly permeable layer. 54th R and D Session ,CBIP, Proceedinggs, Vol.VI,pp 98-103.

Mishra,G.C.,and S.M.Seth (1989). Recharge from a river of large width to a shallow water table aquifer. Ground Water, Vol.26 , No.4,pp 439-444.

Manual on Canal Linings (1975). Tecnical Report No.14, Research scheme applied to river valley projects, Central Board of Irrigation and Power, New Delhi.

MERI (1980). Canal Losses in Lined and Unlined- Prototype Observation. Annual Review 1980, CBIP, p 28.

Rao,N.B.(1981). Interaction of large depression storage and an aquifer. M.E.Thesis Dept.of Hydrology, Roorkee University.

Sharma,H.D.,and A.S.Chawla(1979). Canal seepage with boundary at finite depth. Journal of the Hydraulics Division, ASCE, Vol.105,No.HY7, pp 877-897.

Singh Indramani T.(1983). A study on economics of canal lining with special reference to Salwa Distributary. M.E. thesis WRDTC, Roorkee University.

Singh,B.P.,N.Seshadri,Satish Chandra and Bhishm Kumar (1990). Ganga Canal seepage studies by nuclear technique. Hydrology Journal of IAH.Vol.XIII,No.4,pp198-212.

Siva Reddy, A., G.C.Mishra, and K. Seetharamiah (1976). Seepage from a triangular canal. Journal of the Institution of Engineers(India) V.56,CI.6,pp.219-223.

Siva Reddy, A., and U. Basu (1976). Seepage from trapezodial canal in anisotropic soil. Journal of the Irrigation and Drainage Division, ASCE, IR3. pp 349-361.

Subramanya K., M. R. Madhav, and G.C.Mishra (1973). Studies on seepage from canals with partial lining. Journal of the Hydraulic Div.,ASCE, V.HY 12, pp.2333-2351.

U.P Irrigation Research Institute (1963). Use of bentonite for Gandak Canal lining. T.M.No.33-R.R.(G-62).

U.P Irrigation Research Institute (1989). Annual Review 1989.