CHAPTER IX.

ANALYTICAL APPROACH TOWARDS DEVISING ANTI-WATER-LOGGING MEASURES.

9.0 Before devising suitable measures to solve the menacing problem of water logging in the State, it will not be out of place to state briefly the conditions which bring about rise of water table and consequent water logging. Now main factors which cause these conditions are :

(A) Percolation from rainfall and flooding.

(B) Seepage from canals and high intensity of irrigation

(C) Blocked drainages and absence of proper drainage system.

(D) Abandonment of percolation wells.

(E) Subterranean Obstructions.

(F) Soil characteristics leading to poor natural drainage of the subsoil.

9.1 A single or a combination of measures may have to be used for lowering water table in an area. It all depends upon the tract or the area to be dealt with. Each case will require a close study of the geological conditions, the position of sources and sinks, the Constitution of the soil, the quality of the under ground water and the existence of clay bands and their position. Taking the measures generally and on a broad basis, the storm water drains of proper dimensions and design to dispose off quickly the rain water, appear very essential. The large tract of lands, once supposed to have been permanently ruined by over-irrigation, are with the help of proper drainage, now being successfully brought back under cultivation and their fertility restored. Equally important is the prevention of in-undation of the area from the floods. Adequate water ways under roads, canals, their branches and distributaries, have to be provided. As far as possible, rivers should be utilized for draining out excessive water. Sandy areas are amenable to drains effectively. Where tube-wells are to be installed for anti-waterlogging measures, due importance should be given to the clay layer in the underground. Large diameter shallow tube wells should be installed in the upper strata for lowering the water table, as deep tube wells have little effect on the water table level. Lining of canals should be done as far as practicable to check the heavy amount of seepage there-from. These aspects have been separately dealt with as below:-

(A) PERCOLATION FROM RAINFALL

(i) Recharge-Precipitation Relationship.

This case is by far the most important as it covers the bulk of agricultural lands which usually lie between two natural drainages viz. rivers, better known as Doabs. The rise of water table in all such cases is largely conditioned by the effective recharge i.e. the balance between the infiltration due to rainfall and return flow from irrigation and the discharge towards natural drainage.

In a previous chapter, the average rate of rise of water table has been determined by fitting in regression lines both for June and October separately and then by differentiating the algebraic relationship. This is the one way, when the effect of rainfall alone has been considered. The second method takes into effect the effect of irrigation as well. In case of Ludhiana Division of the Sirhind Canal Circle and other canal Divisions, it has been statistically determined that "14.47 inches of rainfall can be dealt with by natural agencies without causing rise of water table". In case of Jandiala Division of the Upper Bari Doab Canal Circle, the figure is 14 inches. As a result of detailed statistical analysis carried out for a number of years, the average recharge for various Doabs in Punjab (I) when correlated with rainfall for the year gave the following relation

$$R = 2.5 (P-16)^{\frac{1}{2}}$$

Where R = Recharge during the year expressed in inches.

P = annual precipitation in inches.

Following examples have been worked out to determine the goodness of fit.

The average annual rainfall at the selected stations based on 60 years average is

Amritsar (Upper Bari Doab Tract)		23.54 inches.
Jullundur (Bist Doab Tract)	xx.	27.91 inches
Karnal (Cis-Sutlej Tract)		22.85 inches

(a) BIST DOAB

$$R = 2.5 (27.91 - 16)^{\frac{1}{2}}$$

$$= 2.5 (11.91)^{\frac{1}{2}} = 2.5 \times 3.45$$

$$= 8.60$$

This is against 8.52 inches (0.71 ft. upto 1958 figures) as calculated by Regression Line Method.

(b) UPPER BARI DOAB

$$R = 2.5 (23.54 - 16)^{\frac{1}{2}}$$

$$= 2.5 (7.54)^{\frac{1}{2}} \qquad = 2.5 \times 2.75 = 6.875$$

This is against 0.56 ft. or about 6.72 inches for October levels (upto 1958 figures).

(b) CIS SUTLEJ DOAB

$R = 2.5 \; (22.85 - 16)^{\frac{1}{2}} \qquad = 2.5 \times (6.85)^{\frac{1}{2}}$

$= 2.5 \times 2.6 \quad = 6.50$

This is against 0.54 ft. or 6.48 inches for October levels (upto 1958 figures) as calculated for Karnal Division of the Western Yamuna Canal Circle.

The above relation is an average result and variations are possible when there is considerable departure in geology and hydrology. For finding the recharge in the case of heavily irrigated areas, P has to be suitably increased by adding to the rainfall, the deep percolation from total depth of irrigations during the year taking into account the consumptive use of this irrigation water.

(B) SEEPAGE FROM CANALS AND HIGH INTENSITY OF IRRIGATION.

A detailed study of seepage losses both from lined and unlined canals has been made and finds mention in Chapter VIII of the thesis. A new method was previously developed in the Research Institute (69) to determine the seepage from the canals in waterlogged areas. This method depends upon the determination of the angle θ_1 which the outer most stream line of subsoil flow makes with the vertical and the measurement of velocity v of the subsoil flow by an electrical method. The total flow across any section of the canal can then be obtained by the integration of a mathematical expression involving the two variables θ_1 and v. The theory is worked out as below. When the water table is below 12 ft. the method is not applicable due to practical difficulties.

Let the middle point of the surface of water in the canal be the origin for purposes of calculation. Taking x-axis in the direction of flow and the axis of y in the vertically downward direction, it is clear that any element of volume of water that percolates downwards will trace a path in the plane $z = $ constant. Obviously, the central stream line is taken to be directed vertically downwards and the inclination of other stream lines increases with the increasing value of x. Taking the inclination θ of a stream line to the vertical as proportional to the first power of the x-co-ordinate, we put -

$$\theta = x.f(y)$$

writing $f(y) = 1/b$, for the plane $y = h$

$$\theta = x/b$$

The velocity in the case of steady viscous flow is directly proportional to the forces producing it. If V_o is the vertically downward velocity along the y-axis at the point (o,h,z_1), the velocity at the corresponding point on another stream line inclined at an angle θ with the vertical would be $V_o \cos \theta$.

Velocity at any point $(x,y,z) = V_o \cos \theta = V_o \cos x/b$

The downward flux of water through an element of area x enclosed by unit length of the canal would be :

$$V_o \cos x/b \,\delta x. \cos x/b = V_o \cos^2 x/b \,\delta x.$$

Hence the total flux, F, per unit length of the canal equals:

$$2V_o \int_0^{d_1} \cos^2 x/b \; dx$$

where $x = d_1$, gives the point of observation of velocity of the outermost stream line. Then the flux

$$F = 2V_o \int_0^{d_1} \cos^2 x/b \quad dx$$

$$F = V_o \int_0^{d_1} \left(1 + \cos \frac{2x}{b} \right) b \quad dx$$

$$= V_o \left\{ d_1 + \frac{b}{2} \sin \frac{2 d_1}{b} \right\}$$

V_o and b are determined from experimental data.

Let the velocity of the point of observation on the outermost stream line be v and if θ_1 (a particular value of θ) is its inclination to the vertical, then

$V_o \cos \theta_1 = v$

and $\theta_1 = d_1/b$

or $V_o = v/\cos \theta_1$

and $b = d_1/\theta_1$

Substituting the values of V_o and b in above relation, we have:

$$F = \frac{v}{\cos\theta_1} \left(d_1 + \frac{d_1}{2\,\theta_1} \text{Sing } 2\,\theta_1 \right.$$

$$= vd_1{}^{k} \frac{1}{\cos \theta_1} + \frac{\sin \theta_1}{\theta_1}$$

It follows from the above expression that the flux of water per unit length of the canal can be calculated from a knowledge of θ_1 and v.

EXAMPLE

The values of the seepage losses at three sites on the Jhang Branch calculated according to this theory are given below as an illustration of the use of the method.

(i) R.D. 3,337.

$v = 0.128$ ft./hour

$d_1 = 67.0$ ft.

$\theta_1 = 0.785$ radians.

$F = 2.21 \times 10^{-3}$ cusecs per foot length of the canal.

$= 15.8$ cusecs per million sq. ft. of wetted surface.

(ii) R.D. 7,280

$v = 0.0643$ ft/hour

$d_1 = 73.6$ ft.

$\theta_1 = 1.138$ radians.

$F = 1.68 \times 10^{-3}$ cusecs per foot length of the canal.

$= 11.5$ cusecs per million sq. ft. of wetted surface.

(iii) R.D. 12,160

$v = 0.088$ ft./hour.

$d_1 = 75.0$ ft.

$\theta_1 = 1.017$ radians

$F = 2.01 \times 10^{-3}$ cusecs per foot length of the canal.

$= 12.8$ cusecs per million sq. ft. of wetted surface.

The above relationship thus gives a higher value of seepage than the usually accepted value of 8 cusecs per million square feet of wetted surface and the theoretically determined value of 6 cusecs.

(C) SURFACE DRAINAGE.

Development of modern civilisation resulting in a net work of railways, roads, embankments and canals running across the country and expansion of inhabitations has encroached very seriously on the natural run off over the ground surface. At most of the places, the original courses of the streams under the railways, roads, and canals have been closed and new courses given. This does not work satisfactorily because it takes quite an appreciable time for the streams to adjust to the new courses. In the meanwhile considerable heading up of water occurs, flooding takes place and waterlogging is caused. Again the openings provided for the run-off have been inadequate. The floods of 1947, 1950, 1952, 1955 1960 and 1962 in the Punjab have definitely shown the inadequacy of these openings. Besides opening of the old blocked drains, new storm water drains should be constructed to drain off the area quickly.

The rivers are the natural drainages of the country. The first effort should be to take the artificial drainage channel to the nearby river. For instance, waterlogging in Ludhiana and Ferozepur Districts could be eradicated by conducting run-off to drop into the Sutlej river. If in certain cases, the requisite slope is not available, it can be secured by slightly changing the alignment of the drainage channel. It should be possible in most of the cases to secure a proper drainage of the area by utilising the river as a sink. Similarly on Yamuna, Ravi and Beas Rivers, proper outfall sites are available and more sites can be found and storm water diverted on to it.

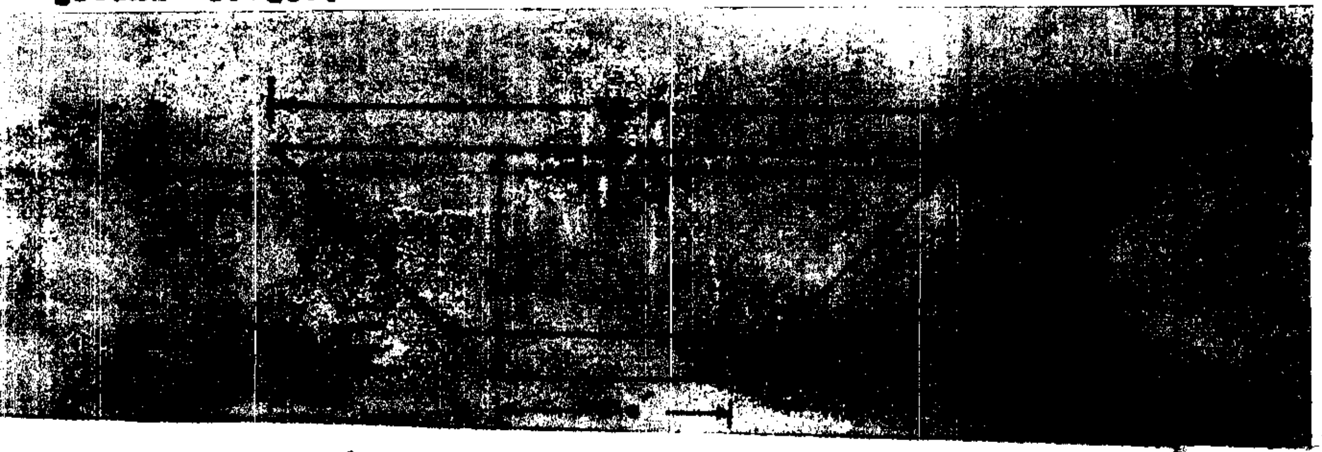
(i) DESIGN AND SPACING OF SHALLOW OPEN DRAINS AS ANTI-WATER LOGGING MEASURES.

In an area of high water table where subsoil water has nearly come to surface, a shallow open drain is an effective measure to lower it to limits considered safe and desirable for growing certain types of crops. Interception of ground water flowing laterally from a source which may be outside the affected area is the common problem. The variables involved are depth, length and size of the drain and their location relative to the problem area and source of seepage. The purpose is to investigate and the design a shallow open type of drain, where there is a source of seepage at some finite distance from the projected location of the drain.

The design of such a drain has been worked out with the help of Darcy's law and Chezy's Formula for uniform flow and explained by way of an example. In the analysis of the equations, following assumptions have been made.

(1) Capillary flow is negligible.
(2) Open shallow drain intercepts all the flow.
(3) Seepage flow is uniform in entire length of the drain.

Let us assume that water table in a certain tract is at least 3.5 ft. below the natural surface level. Selecting a drain of usual trapezoidal shape having bed width and depth equal to 5 ft. and side slope 1:1 and hydraulic slope as 1 : 1000 , the spacing of the drain can be calculated by Darcy's Law and Chezy Formula for uniform velocity, keeping the water table 3.5 ft. lower than the ground surface.



No by Darcy's Law, the flow of ground water is governed by the equation :

$$V = Ki$$

Where V = Darcy's Discharge velocity.
K = Permeability coefficient.
i = Hydraulic Gradient

Now assuming the depth of flow in the drain to be 1 ft. we have

$$v = K \frac{hf}{R}$$

Where h_f is the fall of water surface up to the drain and R is the spacing of drains

Again assume a
value of K = 0.32
h_f = 0.50 ft.

$$\therefore \quad V = \frac{0.32 \times 0.50}{R}$$

Now flow in the drain from both sides for a length of one foot is given by the equation

$$q = 2 \,(\, a \times v \,)$$

where a = mean area of flow

Hence $q = \dfrac{2\,(\,1.75 \times 1\,)\,(\,0.32 \times 0.50\,)}{R}$

$$= \frac{0.56}{R}$$

Again assuming that the length of the plot parallel to the drain is L,

$\therefore$ total seepage into the drain $= \dfrac{0.56\,L}{R}$

The channel capacity to pass this much discharge will be worked out from Chezy Formula as below

$$V = C\sqrt{mi}$$

where V = velocity of uniform flow in the drain

C = Chezy' constant

m = hydraulic mean radius

and i = energy gradient of flow

Value of C will be found out by Mannings' Formula as below

$$C = \frac{1.486}{N}\,(m)^{1/6}$$

Now $m = A/P = \dfrac{6}{7.83}$

$\therefore \quad C = \frac{1.486}{N} \left\{ \frac{6}{7.83} \right\}^{1/6}$

Taken N $= 0.025$

Hence $C = \frac{1.486}{0.025} \left\{ \frac{6}{7.83} \right\}^{1/6}$

$= 59.44 \times 0.95$

$= 56.47$

$= 57$ (say)

$\therefore \quad V = 57 \sqrt{mi}$

$= 57 \left(\frac{1}{(1305)}\right)^{\frac{1}{2}\,1/2} \cancel{\left\{ \frac{1}{1000} \right\}^{\frac{1}{2}}}$

$= 57 / 36.4$

$\therefore \quad Q = A \times V$

$= \frac{6 \times 57}{36.4} = 9.4$ cusecs.

Now $Q = \frac{0.56}{R} L = 9.4$

Now take L $= 3{,}000$ ft.

$\therefore \quad R = \frac{0.56 \times 3000}{9.4}$

$= 179$ ft.

$= 180$ ft. (say)

$\therefore$ Spacing of the drain $= 360$ ft.

Hence No. of Drains $= \frac{3{,}000}{360} + 1 = 8 + 1.$

$= 9$ (say).

Open surface drains can provide a suitable solution when the formation is shallow with top soil being sandy or sandy loam, underlain by hard pan as compared to clayey formations under similar situations. In the latter case, only the underground or sub-surface drains will be more suitable as surface drains will be un-economical and waste too much of land because of closer spacing.

(11) SPACING OF SUB SURFACE DRAINS.

This can be worked out in a simple form by applying Darcy's law and the Continuity Equation, assuming the natural drains to go down to an impermeable stratum underneath.

With usual notations

$$q = kh \frac{\partial h}{\partial x}$$

and $\frac{\partial q}{\partial x} = R$

Combining the above two and putting at $x = 0$, $h = h_o$ and at $x = \frac{L}{2}$, $\frac{\partial h}{\partial x} = 0$

we get

$$h^2 - h_o^2 = \frac{-1}{k} \left(R x^2 - RLx \right)$$

Where R is the effective recharge and L is the spacing between the drains. This gives a parabolic profile.

If H is the maximum head midway between the drains, we get,

$$H^2 - h_o^2 = \frac{RL^2}{4k}$$

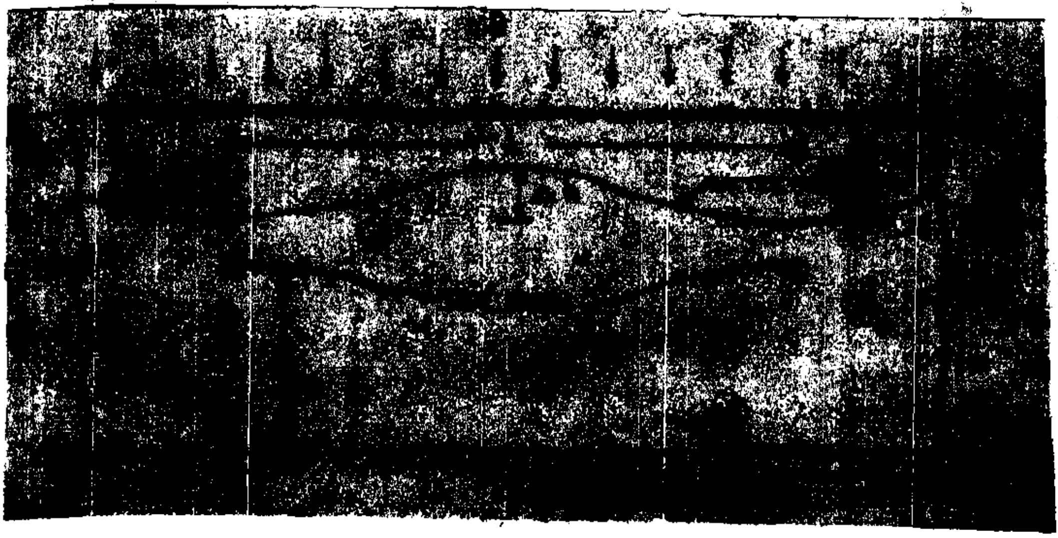
Now total discharge in each drain per unit length = R x L = Q

$$\therefore \quad L = 4k \left(\frac{H^2 - h_o^2}{Q} \right)$$

The size of the subsurface drain can be obtained in the usual way for the required Q and the available slope of the drain.

Taking into account the curvature of streamlines, Hammad(70) improved the above equation by solving the Laplacian Equation for two dimensional flow using Schwartz Christoffel Theorem. According to him, discharge to the drains per foot length is given by

$$Q = \frac{2\Pi k (h)}{\log_e (1 + L/r)} \; *$$



than L/2)

(iii) INTERCEPTING DRAINS AND FEEDER WELLS

When waterlogging is due to general building up of water table from seepage of canals supplemented by recharge due to rainfall and irrigation etc., the intercepting drains along embankment reaches sometime give substantial relief when the aquifer underneath is shallow and near the top soil. This device has been successfully used at many places and especially in the United Punjab on Upper and Lower Chenab Canal areas. It was found that the distance of these drains as 1,000 ft. from the canal was generally successful but this would normally depend on several factors like the drainage capacity and thickness of the quifer formation, and difference of head between canal full supply level and the water table.

When faced with deep aquifer formations, the intercepting drains cannot prevent the general building up of water table. A line

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* Where r = radius of the tile.

of feeder wells parallel to the canal would be more appropriate in this case. The problem is how to decide the distance of this line from the canal so that the canal seepage does not increase. It would also be necessary to determine suitable distance between the feeder wells themselves in the proposed line. Field experiments carried out on Ganga Canal feeder wells showed that under conditions when the canal is neither in digging nor in filling, the distance of feeder wells can be safely taken as 500 ft. It can be taken somewhere around 1,000 ft. for canals under heavy embankments.

(D) ABANDONMENT OF PERCOLATION WELLS.

With the advent of canal irrigation, a large number of percolation wells have gone out of use. Records show that there are at present 42,553 percolation wells in the districts of Ferozepur, Ludhiana, Hoshiarpur and Jullundur out of which 36,604 are in working condition and the rest 5,949 in non working condition. In the whole of the State, excluding the Erstwhile Pepsu State, number of abandoned wells is 26,000 according to " Season and Crop Report of the Punjab Government - 1957 ". Taking on an average 0.1 cs. discharge of each well, at least 2,600 cusecs have remained unpumped from the underground reservoir all these years. This amount would have gone a long way in lowering the watertable and removing water logging in the State.

When the quality of water is good and water bearing formations extend to larger depths, it will be advisable to sink a large number of shallow tube wells which besides augmenting irrigation supplies, help a lot towards lowering of watertable to limits considered safe for growing of crops. Before embarking on such a project, it is, however, essential to explore the subsoil strata for sufficient depth below the natural surface. In short, the following information would be desirable.

(i) What amount of water is there in the sub-strata and its quality.

(ii) How quickly it can part with the water.

(iii) How much lowering the watertable would be affected.

(iv) How this water is to be disposed of in case it is good and when it is bad.

Such tests in the field have been made in Amritsar and Ludhiana Districts recently by the Research Institute. Borings near Amritsar showed that the strata underneath the surface upto a depth of 100 feet was mostly composed of good sand except in the top 7 feet. This proved to be a good feature for installing tubewells. After that, four tubewells of 6" diameter have been installed to various depths such as 30,50 and 100 feet below the surface and their effect on lowering the water table studied. It has been shown that the effect of lowering water table by a tube well taken say for instance to a depth of 50 feet, does not extend beyond 500 feet. The effect is more pronounced upto 250 feet. It is thus observed that for effective lowering of the water table with the help of tubewells, these may have to be placed about 1000 feet apart.

In the Ferozepur district, in Sidhwan bet area, field tests showed that an impervious clay layer exists at a depth varying from 30 ft. to 50 ft. and the thickness of the clay layer in certain cases is 15 to 20 feet. The results of geological investigations have shown that the area is not at all suitable for installing shallow tube wells.

The necessity of underground exploration before taking up anti-waterlogging measures cannot be over emphasized. When the water bearing formations extend to larger depths, the development of the basin between two drainages in regard to maintenance of the water table at lower elevations is better worked out by tube-well pumping which besides affecting lowering of water table will be beneficial for the extension of irrigation. This has been analytically determined with the help of Darcy's Law and the equation of Continuity as below:-

According to the Darcy's equation, the flow at any section between the gallery and drainage is given by

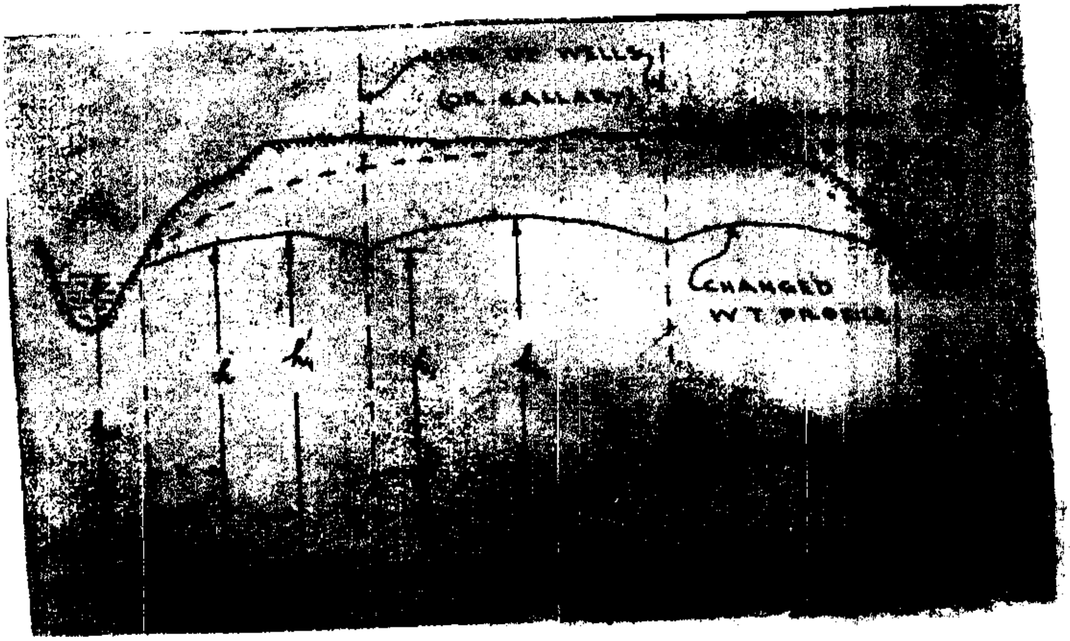
$$q = -kh\frac{\partial h}{\partial x} \qquad \ldots\ldots\ldots (9.1)$$

and the equation of continuity gives

$$\frac{\partial q}{\partial x} = R \qquad \ldots\ldots\ldots (9.2)$$

$$\text{or} \quad \int dq = R\int dx \qquad \ldots\ldots\ldots (9.3)$$

$$\text{and} \quad q = Rx + C_1$$



Combining Eqs (9.1) and (9.3) and integrating, we get

$$\int q\,dx = -k\int h\,dh = \int Rx\,dx + \int C_1\,dx$$

$$\text{or} \qquad -\frac{kh^2}{2} = \frac{Rx^2}{2} + C_1x + C_2$$

which gives the water table profile as

$$h^2 = -\frac{1}{k}\left\{ Rx^2 + 2C_1x + 2C_2 \right\} \ldots\ldots\ldots\ldots\ldots (9.4)$$

Wherein C_1 and C_2 are constants governed by the boundary conditions.

Applying the boundary conditions(when $x = 0$, $h = h_o$ and at $x = A$, $h = h_1$) the constants can be evaluated as

$$C_1 = k \frac{h_o^2 - h_1^2}{2A} - \frac{RA}{2} \text{ and } C_2 = \frac{kh_o^2}{2}$$

and the water table profile is given by

$$h^2 = h_o^2\left(1 - \frac{x}{A}\right) - \frac{R}{k}\left(x^2 - xA\right) + \frac{h_1^2}{A}x \quad ..(9.5)$$

Here, the distance x_1 from the drainage for the maximum head h_1 between the gallery and drainage can be found by differentiating equation (9.5), equating to zero and substituting x_1 for x.

$$2h\frac{\partial h}{\partial x} = -\frac{h_o^2}{A} - \frac{R}{A}(2x_1 - A) + \frac{h_1^2}{A} = 0$$

or $$x_1 = \frac{k}{2R}\left(\frac{h_1^2 - h_o^2}{A}\right) + A/2 \quad (9.6)$$

The recharge to the strip close to the drainage upto a distance x_1 will flow to the drainage and the corresponding maximum head h_1 can be obtained by applying boundary conditions to eq. (9.4) wherein at $x = x_1$, $\frac{\partial h}{\partial x} = 0$, $h = h_1$ and at $x = 0$ $h = h_o$ and finding values of constants i.e.

$$C_1 = -\frac{R\,x_1}{2} \text{ and } C_2 = \frac{kh_o^2}{2}$$

Thus $h_1 2 = h_o^2 + R/k\ x_1^2$ (9.7)

Similarly, the ground water profile between the two galleries is obtained by again applying the boundary conditions to equation (9.4). Taking the origin at the gallery line instead of drainage line (at $x = 0$, $h = h_1$ and at $x = (L/2-A), \frac{h}{x} = 0$) gives

$$C_1 = R (L/2-A) \text{ and } C_2 = -\frac{kh_1^{2}}{2}$$

Thus $$h^2 - h_1^2 = - 1/K \left\{ Rx^2 - R (L - 2A) x \right\} \quad (9.8)$$

At the centre of the drainage basin i.e. at $x = (L/2-A)$, $h = h_2$, equation (9.8) reduces to

$$h_2^2 = h_1^2 + R/K (L/2-A)^2 \quad \ldots\ldots\ldots (9.9)$$

From the above analysis it is easy to locate the position of the galleries i.e., the line of wells, and the head against which pumping is required for economically lowering the water table profile to the desired level.

EXAMPLE

Let us take the case of waterlogged tract of land in the Upper Bari Doab Canal Circle, 16,000 ft. wide, lying between two drainages of infinite length. Assume that the soil is homogeneous having a coefficient of permeability equal to 24 ft. per day. It is desired to provide the most economical drainage measures by tube well pumping. Further assume that the maximum ground elevation of the water table in the centre is 175 ft. above the impermeable base and on the sides upto 4,000 ft. the average country elevation is 172 ft. Taking that the maximas of the depressed water table profile should be 7 ft. below the ground surface so that the effect of waterlogging is eliminated within the root zone, the allowable safe elevations of water in the centre and the sides are respectively 168 ft. and 165 ft. Again take the water level in the drainages to be 160 ft.

Now rate of recharge in the Upper Bari Doab Canal Tract (vide page 95) is equal to 6.875 inches in 6 months, as most of the annual precipitation is received during the Monsoon months (May to October).

This gives an average daily a recharge

$$R = \frac{6.875}{180} = 0.04 \text{" approx.}$$

$$\text{Now } R/k = \frac{0.04}{24 \times 12} = \frac{1}{7200}$$

Substituting the known values of the variables in equations (9.6) , (9.7) and (9.9), we have

$$x_1 = \frac{A}{2} + 3600 \left(\frac{h_1^2 - 160^2}{A} \right) \quad \ldots\ldots\ldots (9.6A)$$

$$h_1^2 = 160^2 + \frac{x_1^2}{7200} \quad \ldots\ldots\ldots (.7A)$$

$$h_2^2 = h_1^2 + \left(\frac{8000 - A}{7200} \right)^2 \quad \ldots\ldots\ldots (9.9A)$$

From equation (9.7A), x_1 = 3420 ft(say 3400) when h_1 = 165 ft and (9.9 A)we have h_1 = 164 and A = 4900 (Approximately).

Thus the suitable distance of the gallery from the drainage is 4900 ft. and 164 ft. above the impermeable base. This will mean that the flow to the drainage on either side will be from a strip of land 3400 ft. wide, leaving the recharge to the galleries over a width of $\frac{16000 - 6800}{2} = \frac{9200}{2}$ ft.or 4600 ft. per gallery

(E) SUBTERRANEAN OBSTRUCTIONS.

The relation of the observed rise of watertable in the various canal irrigated tracts to the intensity of irrigation and rainfall has already been investigated theoretically as well as by the method of statistical analysis. The general conclusions drawn from this study indicate that a large proportion of the increased volume of ground water must be arrtibuted to percolation of water from the surface of the soil. A general rise of the water-table results until such time as a dynamic equilibrium is established in which theflow of the ground water as relieved by natural or artifical surface drainage and evaporation from the soil, can cope with the volume of water continually added. It is found that with an infinitely deep sub-soil of uniform permeability, the possibility of establishing an equilibrium condition of flow for an estimated percolation load depends largely on possible depth of the subsoil stream. In order that any prediction shall be possible of the equilibrium profile of a water-table beneath an irrigated tract, it is necessary to estimate the possible depth of flow in the sub-soil.

Usually the breat thickness coupled with enormous width an uniform character of the alluvium forms the subsoil of the plan. Engineers have bored down through layers of mud, sand and clay for nearly 500 ft. at Calcutta and 1,000 feet at Lucknow without coming to solid rock bottom. Later on Geodetic Surveyors(71) deduced its depth to about 6,500 feet but this estimate is considered too low by Geologists. Mr. R.D.Oldham of the Geological Survey of India concluded that the maximum depth of through is 15,000 feet at the feet of Sivalik Hills. Later on Mr S.G. Burnard of the Survey of India Department, speculated it likely to be 20 miles.

Had it been also so in the case of Punjab, the problem of water-logging might have not arisen at all. The sub-stratum in the Punjab is believed to be intruded by ranges of impervious rocks which prove a direct check to the flow of sub-terranean water and thus curve of hydraulic gradient is disturbed. A narrow ridge near Delhi, which is really a northern continuation of the Aravali Mountain system, dips under the plains. It is further said to have underlain the North-Eastern section of the Sutlej-Jumna Doab. It may be further observed that geodetic investigations have revealed below the Punjab rivers alluvium, the existence of a continuous ridge which after traversing this Doab runs parallel to the Himalayas through the Bist and other Doabs, right from Delhi to the salt range. The visible parts of the range represent the Shahkot, Sangla and the Kirana Hills in Pakistan (West Punjab). (Fig. 9.1).

It,is, therefore, necessary that series of traverses at right angles to this ridge of Aravali system be taken and the exact sub-surface topography be plotted.

The first problem taken up by the Irrigation Research Laboratory in 1926 was the determination of the depth of sub-mak alluvium of Rachna Doab. Mr. Wilsdon, the then Scientific Research Officer, carried out gravity survey with the help of Etovos Torsion Balance. This survey was found useful in understanding the problem of waterlogging in that Doab and devising measures to check that. Many methods have come to limelight since then. Etoves Torsion Balance become obsolete as back as in 1939 and has been replaced by gravimeter. The whole survey is thus expedited and is undisputedly more accurate. Developments in the science of seismology have given rise to a much better method. Seismic surveys, though expensive, are more reliable and instructive. Various methods in vogue for sub-surface surveys can be enumerated as below:-

(1) Gravimetric Method.

(2) Seismic Method.

(3) Electrical Resistivity Method.

(4) Magnetic Method.

A peculiar feature, however, in the hydrographic system of the Punjab State is that northern half of the State is water-logged and southern half is in the grip of severe draught. The difference in the water depth from the surface in the two halves may be easily more than 100 feet. This has been the subject of investigation since the establishment of the Institute. Recently it was taken up by the Geophysics Department which carried out seismic observations, but so far there has been no indication of a definite ridge underneath. Whatever the cause of this peculiar system may be, it is a fact that the two areas present a very strong contrast as to the water table conditions. Excepting for Indo-Gangetic drainage system of rivers, there is no other river worth naming. The ground slope may also be in the reverse direction. This subject has to be further studied. There would be a big drop in water table contours also because the ground surface does not drop so suddenly. With a view to eradicate high water table, big drop may be utilised and should be considered as a very valuable feature. This will have a double effect to remove water logging from the northern part and remove draught from the southern part of the Punjab as well as from Rajasthan. The ground water removed from the northern part of the Punjab should be utilised in filling the underground reservoir to a reasonable depth in the lower part. If the natural surface drop for the free water is not available, the underground drop can be effectively used by bringing this water through a channel and leaving this into large ponds. It can be to a certain depth as to give some drop in the bed slope of the channel bringing water. The absorption in sub soil would be small as compared to the channel flow but its cumulative effect would be great as this would be a continuous process.

(F) <u>SOIL CHARACTERISTICS:</u>

It has been found that a few years after irrigation has been introduced to an area, the salts begin to appear at the surface at places where there were none before. Thus with irrigation, alkali appears to spring up denovo and where salt patches already existed, these spread rapidly with artificial irrigation.

On a modest estimate it may be stated that total area of saline and alkali lands in India is10 million acres. The damage to land appears to be very great in Punjab and Uttar Pradesh and about 80% of the total damaged area lies in these two States. In the Punjab before the advent of canal irrigation, the Thur (Saline) Land occupies only a small area of the State but with the introduction of canal irrigation, there has been wide spread increase in thur area. To estimate damage to canal irrigated lands in the Punjab, a regular Thur Girdawari was started and a reasonably accurate record is being kept since 1927. These Thur Girdawaries are made both by the Civil as well as by the Irrigation Departments according to their own basis of assessment. According to the Civil Department instructions, an area is reported Thur when damage to the land is indicated by a crop which is less than 25% of normal yield. According to the Irrigation Branch standard, however, the land which is 20% damaged by thur is classed as Thur or Kallar Land. The thur area in 1943-44 in united Punjab in selected estates alone stood at 26 lakh acres which is quite high. The total thur land in whole of the State was, however, considerably more.

In Punjab (I) after Partition, a regular record of thur Girdawaries has been kept in the Institute and it has been shown that every year, thur is on the increase. The total thur within the Irrigation boundary on the various canal systems is about five lakh acres (Table 9.1). Outside the Irrigation boundary although the records are not very accurate, yet it shows enormous area affected by thur.

Since the problem of Thur is very serious in the Punjab on account of its rapid spread, it has been tackled also on a proper scientific basis. As early as 1935-40, methods for the reclamation of thur land were evolved and applied to the field(72) The carrying out of soil survey in such salt affected areas and the survey for each Irrigation Project before it was taken up, was considered as an essential feature. Soil surveys of 57,200 acres of Chag Darkhana Block of Haveli Project (1932-33), 26,86,000 acres of Thal Project (1939-42), 10,00,000 acres in Lyallpur district (1941-43), 1,67,200 acres of Jalalpur Pumping Project (1943-45) and 64,800 acres of Crown Waste Land on Rangpur Canal (1944), were made in the pre-partition period. These were continued after 1947 as well and an area of 1,71,200 acres of culturable waste land in Karnal District (1948-49).

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Statement Showing Division-wise areas affected by Thur from 1952-53 to 1962-63.

(In Acres).

Name of Division.	Culturable commanded area.	1952-53	1953-54	1954-55	1955-56	1956-57	1957-58	1958-59	1959-60	1960-61	1961-62	1962-63
Delhi Division.	351513	57387	67328	69008	68389	68389	69558	72059	72564	38924	36999	34520
Karnal Division.	237114	28090	28791	28793	27993	27969	27969	27969	27961	66590	66590	67758
Hariana Division.	417125	15369	15657	15677	15681	15677	15849	16568	17083	18319	18319	18319
Rohtak Division.	351612	20500	14895	15051	13481	13539	13539	13534	13534	15908	15873	16471
Hissar Division.	513523	1964	10749	10773	10980	10560	13085	12563	13208	19685	12099	12184
Pehowa Division.	-	-	4216	4216	2325	2325	22238	22747	22747	22747	20304	23147
Bhakra Main Line.	165937	-	-	-	-	4181	4265	4413	4413	4500	4586	4600
Tohana Division.	378505	-	-	-	6901	5700	4923	6404	4409	4634	8221	7936
Fatehbad Division.	615672	4950	1312	4308	2489	950	950	950	638	638	638	458
Rupar Division.	140297	242	256	245	194	1750	422	783	1190	2679	2679	2683
Bhatinda Division.	846772	3980	5429	6786	6952	7071	7264	10659	11007	12650	12581	11936
Abohar Division.	654935	3618	3919	11099	11099	11099	11159	11129	11129	11129	11129	11746
Ferozepur Division.	729527	16348	17513	10687	10913	10850	12473	12857	12857	13952	16627	16748
Eastern Division.	369173	93739	99211	79879	53960	53967	53967	53967	51125	53436	53047	53505
Sidhwan Division.	430641	85482	67493	72121	75689	75868	75868	75868	91804	89691	89070	43148
Madhopur Division.	18947	-	-	-	7808	6536	23401	24801	23911	23787	23787	23787
Majitha Division.	404285	71166	81677	89860	89443	77188	82946	30299	79411	80066	79964	79964
Jandiala Division.	618339	10527	8178	9604	8786	8668	10714	12059	[illegible]	[illegible]	13900	[illegible]

33,04,200 acres of Punjab Bhakra Project (1949-52), 1,20,000 acres of Gang Canal in Bikaner - Bhakra Rajasthan Canal Project (1951 - 52), 12,68,458 acres of Madhya Bharat (1952),23,77,411 acres of Pepsu Bhakra (1954-56) and 10,00,000 acres of old areas on Sirhind Canal Circle (1955-57) were surveyed. The grid used was 400 acres in some cases and 600 or 1000 in others. Based on the information obtained from these soil surveys, schemes for the reclamation of the damaged areas were planned and executed.

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