A MEANDERING STREAM, AQUIFER AND WELL INTERACTION

A DISSERTATION

submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
WATER RESOURCES DEVELOPMENT

By
ANDY IKHVAN

WATER RESOURCES DEVELOPMENT TRAINING CENTRE
UNIVERSITY OF ROORKEE
ROORKEE-247 667 (INDIA)
November 2000

CANDIDATE'S DECLARATION

I hereby certify that the work, which is being presented in this dissertation entitled " *A Meandering Stream, Aquifer And Well Interaction* " in partial fulfillment of the requirement for the award of the Degree of Master of Engineering in Water Resources Development (Civil) submitted in the Department of Water Resources Development Training Center of the University, is an authentic record of my own work carried out during a period from July 2000 to November 2000 under the supervision of ***Dr. G. C. Mishra***, Professor, Water Resources Development Training Center, University of Roorkee, Roorkee, Uttaranchal. India.

The matter embodied in this dissertation has not been submitted by me for award of any other degree.

Andy

December 3, 2000 **(Andy Ikhvan)**

Trainee Officer

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

G. C. Mishra

December 3, 2000 **(Dr. G.C. Mishra)**

Professor, WRDTC
University of Roorkee
Uttaranchal, India

ACKNOWLEDGEMENTS

I have got privilege to express my deep sense of gratitude to **Dr. G.C. Mishra,** Professor, WRDTC University of Roorkee, Roorkee for his continued guidance and supervision. I also acknowledge with thanks, the advice and inspiration that I received from other faculty members of Water Resources Development Training Center during this study.

I am very much grateful to the Ministry of Public Works, Directorate General of Water Resources Development, Indonesia, which gave much appreciated for me to avail this opportunity of doing higher study in Water Resources Development at the WRDTC, University of Roorkee.

Thank are also due to Mrs. Sunita Devi, computer incharge, librarian WRDTC and all of colleagues for their help and inspiration towards the improvement of this dissertation.

At last, but not least, I express my gratitude to my brothers and especially to my respected father and mother for their encouragement and keeping my moral always high.

Roorkee, December 3, 2000

(ANDY IKHVAN)

CONTENTS

SYNOPSIS

In the area of modern hydrological and hydro-geological investigation, the Aquifer - Stream - Well Interference has got an important place. Spatial and temporal variations of groundwater and surface water interaction are important for studying, estimating and forecasting ground water and surface water resources.

A stream comprising boundary of flow domain is often encountered in regional groundwater flow modeling. When a stream fully penetrates an aquifer and has considerable stream discharge, the stream is to be treated as a boundary of prescribed head. In such case, the region on each side of the stream behaves independently. However, a situation is rarely seen where a stream completely penetrates an aquifer. In case of partially penetrating stream with considerable stream discharge in comparison to the seepage losses besides treating the stream as specific head boundary, the exchange of flow between the stream and the aquifer has to be introduced through boundary while modeling the groundwater flow. The recharge from a stream to an aquifer is proportional to a difference between the level of water in the stream and in the aquifer in the vicinity of stream. The coefficient of proportionality is recognized as reach transmissivity, which depends on shape of stream cross section besides the aquifer parameters.

In this study, interaction among a partially penetrating meandering stream, pumping wells and homogeneous aquifer has been studied. The recharge from the stream during passage of a flood and the base flow after recession of the flood wave have been quantified. The advantageous location of well to cause induce recharge has been identified.

CHAPTER-I
INTRODUCTION

1.1 GENERAL

A stream, comprising a boundary of flow is often encountered in regional groundwater flow modeling. When a stream reach cuts right through to the base of an aquifer, it conforms to the Dirichelt type of boundary. A fully penetrating stream reach with large discharge as compared to the influent or effluent seepage can be conveniently treated as a boundary of prescribed head. In such a case the region on each side of the stream would behave independently. However, a situation is rarely seen where a stream completely penetrates an aquifer.

In case of a partially penetrating stream with considerable stream discharge, besides treating the stream as a prescribed head boundary, the exchange of flow between the stream and aquifer has to be introduced through the boundary nodes while modeling the groundwater flow (Rushton and Redshaw, 1978). The recharge from a stream to an aquifer is proportional to a difference in the level of water in the stream and in the aquifer in the vicinity of the stream (Bouwer, 1969). The coefficient of proportionality recognized as reach transmissivity depends on the streambed characteristic and shape of stream cross-section (Morel Seytoux, 1964 ; Bouwer, 1969). The water level in the aquifer depends on all the abstractions and recharges including recharge from the stream. Such an implicit and complex stream - aquifer interaction problem has been analyzed by Morel - Seytoux and Daly (1975) who have used reach transmissivity and discrete kernel theory for finding an expression for recharge. Numerical methods and electrical analogue can handle the non-homogeneous and anisotrophic nature of soil besides the various complex boundaries.

Few authors have dealt with the computation of rise in water table due to recharge from water bodies. Hantush (1967) has derived an expression for rise in water table height due to recharge from a basin of finite length and width. If the dimension of length is increased to a very large value, the solution will correspond to rise in water table due to recharge from a stream. However, the solution involves numerical integration. Shestakov (1965) has tabulated special function for calculating water table rise due to recharge from a strip source using numerical method for integration. Glover (1974) has analyzed the evaluation of water table due to recharge from a line source, but has not taken the width of recharge body into consideration.

Hantush and Glover have assumed that there is no hydraulic connection between the recharging water bodies and the aquifer. Morel-Seytoux and Daly (1975) have developed stream aquifer interaction model in which the stream has hydraulic connection with the aquifer.

It has been often assumed for a stream which is hydraulically connected with the aquifer, that the exchange flow rate is linearly dependent on the potential difference between the aquifer and the stream (Aravin and Numerov, 1965, Herbert, 1970, Morel-Seytoux, 1975, Besbes et al., 1978, Flug et al., 1980). There has been evidence that the process can be very non-linear (Dillon, 1983,1984, Rushton and Redshaw, 1972). As it is difficult to determine the exact non-linear relationship, the linear relationship is still in vouge.

1.2 THE SCOPE OF THE PRESENT STUDY

In the present study, using the linear relationship governing the exchange of flow between a stream and an aquifer proposed by Herbert, the basic solution given by Hantush for predicting water level rise in an aquifer due to constant recharge from a rectangular stream reach, and the discrete kernel approach proposed by Morel-Seytoux that converts an integral equation to an algebraic equation, the recharge from a meandering stream, which is hydraulically connected with the aquifer, has been found consequent to passage of a flood wave in the stream. The method described in the thesis is very general. The effect of pumping the aquifer has been included in the stream aquifer interaction study.

CHAPTER- II
REVIEW OF LITERATURE

2.1 METHOD OF ASSESSMENT OF WATER RECHARGE

The literature on steady recharge from stream and its impact on ground water regime has been well documented by Bouwer, 1969 ; Glover, 1970; Harr, 1962 ; Kovacs, 1981 ; Muscat , 1940; Schestacov, 1965. In the current study literature review has been made only for stream, well and aquifer interaction in which the stream has hydraulic connection with the aquifer.

The recharge from i^{th} reach of a stream could be expressed in the form (Morel –Seytoux et al. , 1973, 1975).

$$Q_i = \Gamma_i \left(S_i - \sigma_i \right) \qquad \text{………..2.1.1}$$

where :

Γ_i = the reach transmissivity of i^{th} reach of the stream,

σ_i = the draw down to the water level in the stream measured from a high datum,

S_i = the draw down in the aquifer in the vicinity of reach measured from the same datum.

A positive value of Q_i means the flow is taking place from the stream to the aquifer. Under a steady – state regime, a simple application of potential theory for saturated flow leads to the formula (Morel – Seytoux et al. 1979)

$$\Gamma_i = \frac{T\, L_i \left(0.5\, Wp + m\right)}{m\left(4b + 0.5m\right)} \qquad \text{….2.1.2}$$

where :

Wp = wetted perimeter,

m = thickness of the aquifer below the stream,

b = width of the stream,

Li = length of i^{th} stream reach, and

T = aquifer transmissivity.

Equation 2.1.1 has been applied to transient condition on the basis that a transient system could be well represented as a continuous succession of steady states.

Methods of calculating the hydraulic river resistance also have been proposed by Aravin and Numerov (1965), Streltsova (1974) and Herbert (1970). Because of the difficulty in determining the actual nonlinear relationship, it is common practice to use a linear relationship. The constant of proportionality in the linear relationship has been designed as reach transmissivity or river resistance.

According to Herbert the linear relationship between the exchange flow rate and the potential difference between the river and the aquifer underneath is given by:

$$Qi = \frac{\pi \; Li \; k \; (hr - ho)}{\ln\left(\frac{0.5 \; m}{r}\right)} \qquad \ldots\ldots.2.1.3$$

in which:

Li = length of i^{th} stream reach,

k = coefficient of permeability of the aquifer material,

hr = potential at the river perimeter,

ho = potential in the aquifer at a point under the river,

m = thickness of the aquifer as shown as figure 2.3, and

r = radius of the semicircular river cross section.

2.2. ASSESSEMENT OF WATER RECHARGED BY BASIN METHOD

Schematic section and plan view of a spreading basin and the groundwater abstraction structures are shown in figure 2.1. Water is recharged through the basin during a certain period of time. The groundwater is withdrawn through abstraction wells such as shown in the figure. Continuous monitoring of ground water level is done at an observation well. It is requred to find the quantity of groundwater recharged through the basin and its distribution in space and time using groundwater level data.

Hantush (1967) developed the following approximate analytical expression for the rise and fall of the water table in an infinite unconfined aquifer in response to uniform percolation from a rectangular spreading basin in absence of pumping well :

$$h^2 = h_0^{\,2} + \left(\frac{w\bar{h}t}{2\phi}\right)\left\{ F\left[\frac{a+X}{2\sqrt{\left(\frac{k\bar{h}t}{\phi}\right)}};\frac{b+Y}{2\sqrt{\left(\frac{k\bar{h}t}{\phi}\right)}}\right] + F\left[\frac{a-X}{2\sqrt{\left(\frac{k\bar{h}t}{\phi}\right)}};\frac{b+Y}{2\sqrt{\left(\frac{k\bar{h}t}{\phi}\right)}}\right]\right.$$

$$\left. + F\left[\frac{a+X}{2\sqrt{\left(\frac{k\bar{h}t}{\phi}\right)}};\frac{b-Y}{2\sqrt{\left(\frac{k\bar{h}t}{\phi}\right)}}\right] + F\left[\frac{a-X}{2\sqrt{\left(\frac{k\bar{h}t}{\phi}\right)}};\frac{b-Y}{2\sqrt{\left(\frac{k\bar{h}t}{\phi}\right)}}\right]\right\} \quad \ldots\ldots.2.2.1$$

$$F(p,q) = \int_0^1 erf\left(\frac{p}{\sqrt{z}}\right) erf\left(\frac{q}{\sqrt{z}}\right) dz$$

$$= \int_{-1}^{1} erf\left(\frac{p}{\sqrt{0.5+0.5\,v}}\right) erf\left(\frac{q}{\sqrt{0.5+0.5\,v}}\right) 0.5\, dv$$

$$erf\,(X) = \frac{2}{\sqrt{\pi}}\int_0^X e^{-u^2}\, du$$

Alternatly equation 2.2.1 can be written as:

$$h^2 = ho^2 + \left(\frac{w\,\bar{h}\,t}{2\,\phi}\right)\left[f(X,Y,t)\right] \qquad \text{..........2.2.2}$$

in which:

$\bar{h}$ = weighted mean of the depth of saturation during the period of flow,

w = constant rate of percolation,

ϕ = storage coefficient of the aquifer,

k = coefficient of permeability,

2a,2b = dimension of the rectangular strip in X and Y direction, and

t = time measured since the onset of recharge ie the percolated water joins the water table.

$$f(X,Y,t) =$$

$$\int_{-1}^{1} \operatorname{erf}\left(\frac{a+X}{2\sqrt{(k\bar{h}\,t/\phi)}\,(0.5+0.5V)}\right)\operatorname{erf}\left(\frac{b+Y}{2\sqrt{(k\bar{h}\,t/\phi)}(0.5+0.5V)}\right)\frac{dV}{2}$$

$$+\int_{-1}^{1} \operatorname{erf}\left(\frac{a-X}{2\sqrt{(k\bar{h}\,t/\phi)}\,(0.5+0.5\,V)}\right)\operatorname{erf}\left(\frac{b+Y}{2\sqrt{(k\bar{h}\,t/\phi)}(0.5+0.5\,V)}\right)\frac{dV}{2}$$

$$+\int_{-1}^{1} \operatorname{erf}\left(\frac{a+X}{2\sqrt{(k\bar{h}\,t/\phi)}\,(0.5+0.5\,V)}\right)\operatorname{erf}\left(\frac{b-Y}{2\sqrt{(k\bar{h}\,t/\phi)}(0.5+0.5\,V)}\right)\frac{dV}{2}$$

$$+\int_{-1}^{1} \operatorname{erf}\left(\frac{a-X}{2\sqrt{(k\bar{h}\,t/\phi)}\,(0.5+0.5\,V)}\right)\operatorname{erf}\left(\frac{b-Y}{2\sqrt{(k\bar{h}\,t/\phi)}(0.5+0.5\,V)}\right)\frac{dV}{2}$$

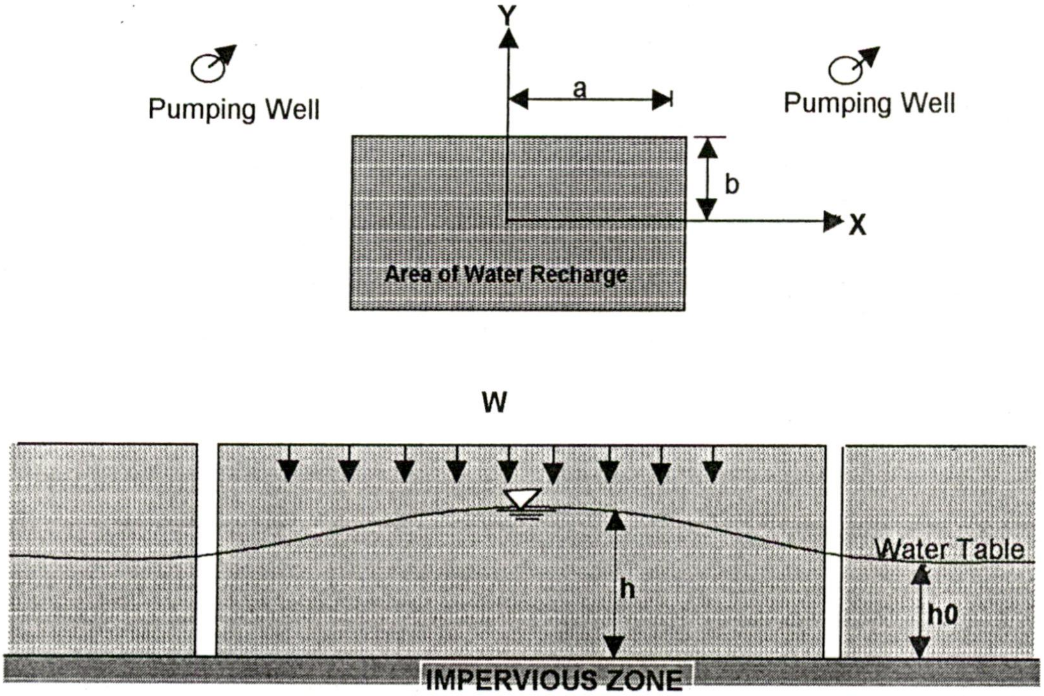


FIGURE 2.1 SCHEMATIC PLAN AND SECTION OF SPREADING BASIN

The rise in water table height, S (X,Y,t) is given by:

$S(X,Y,t) = h - h_0$

and the average water level height $\bar{h}$ is given by

$$\bar{h} = \frac{h + ho}{2}$$

substitution of $\bar{h}$ into equation 2.2.2 gives:

$$h^2 - ho^2 = \left[\frac{w\,(h + ho)\ t}{4\ \phi} \right] f\,(X, Y, t)$$

$$h - ho = \left(\frac{w\ t}{4\ \phi} \right) f\ (X, Y, t)$$

$$S\,(X, Y, t) = \left(\frac{w\ t}{4\ \phi} \right) f\ (X, Y, t) \qquad \text{.........2.2.3}$$

Equation 2. 2. 3 gives the rise of water table due to recharge at w unit rate. For continuous recharge at a unit rate (w = 1 unit), the water table rise is given by:

$$S(X, Y, t) = \left(\frac{t}{4\phi}\right) f(X, Y, t) = K(X, Y, t) \quad \text{.........2.2.4}$$

If recharge takes place for one unit time, and no recharge after that, the rise at the end of n^{th} unit time step at i^{th} stream reach i.e at (Xi , Yi) due to recharge at j^{th} stream reach i.e. at (Xj , Yj) is given by:

$$\delta_R(i, j, n) = K(i, j, n) - K(i, j, n-1) \quad \text{.....................2.2.5.}$$

For first unit time step (n = 1)

$$\delta_R(i, j, 1) = K(i, j, 1)$$

If the recharge varies with time, the rise of water table at i^{th} reach due to recharge from all reaches at the end of n^{th} unit time step is given by:

$$S_R(i, n) = \sum_{j=1}^{R} \sum_{\gamma=1}^{n} Q_R(j, \gamma)\, \delta_R(i, j, n-\gamma+1) \quad \text{............2.2.6}$$

where :

$Q_R(j, \gamma)$ = Recharge rate at j^{th} stream reach during γ^{th} unit time step.

$\delta_R(I, j, m)$ = Discrete Kernel coefficient of drawdown due to unit pulse recharge at J^{th} reach during 1^{st} unit time step

2.3 . ASSESSEMENT OF FALL OF WATER TABLE DUE TO PUMPING WELLS

Similar to rise of water table due to recharge,fall of water table at i th stream reach at the end of n^{th} unit time step due to pumping at J_1^{th} well is given by :

$$S_P(i,n) = \sum_{J_1=1}^{N} \sum_{\gamma=1}^{n} Q_p(J_1, \gamma)\, \delta_P(i, J_1, n-\gamma+1) \qquad \text{........2. 3.1}$$

where:

$Q_P(J_1, \gamma)$ = Pumping rate at J_1^{th} well during γ^{th} unit time step.

$\delta_P(I, J_1, m)$ = Discrete kernel coefficient of drawdown at m^{th} unit time step due to unit pulse pumping at J_1^{th} well during the first unit time step.

N = Total number of pumping wells.

The discrete pumping kernel is given by:

$$\delta_P(i, J_1, m) = \frac{1}{4\pi T}\left[E_1\left(\frac{r_{i,J_1}^2\,\phi}{4Tm}\right) - E_1\left(\frac{r_{i,J_1}^2\,\phi}{4T(m-1)}\right)\right] \qquad \text{.......2.3.2}$$

where :

$E_1(Z)$ = an exponential integral $= \int_Z^{\infty} \frac{e^{-U}}{U}\, dU$

$r_{I,J1}$ = distance of I^{th} stream reach from J_1^{th} pumping well,

T = Transmissivity of the aquifer, and

ϕ = storage coefficient.

2.4 COUPLING OF GROUNDWATER AND STREAM FLOW

Cooper and Rorabaugh (1963) have studied flow into and out of an aquifer of finite length as shown in figure 2.2 in response to changes in the stream stage. They solved one dimensional Boussinesq's equation under the condition:

$H(x, 0) = 0 \qquad 0 \le x \le L$

$$\frac{\partial H(L,t)}{\partial x} = 0 \qquad t \ge 0 \qquad \text{.............2 . 4 . 1}$$

and

$$H\ (0,t) = \begin{cases} N H_0\ e^{-\delta t}\ (1 - \cos \omega t) & 0 \le t \le \tau \\ 0 & t \ge \tau \end{cases} \qquad \text{..........}\ 2.4.2$$

where τ = the duration of the flood wave,

$$\omega = \frac{2\pi}{\tau}$$

$$\delta = \omega \cot \frac{\omega\, tc}{2}$$

tc = the time of the flood crest, and

$$N = \frac{e^{\delta\, tc}}{1 - \cos \omega\, tc}$$

From the literature survey it is found that no analysis has been done for meandering stream. The discrete kernel approach suggested by Morel-Seytoux can be extended to quantify the stream aquifer interaction consequent to passage of a flood wave in a meandering stream.

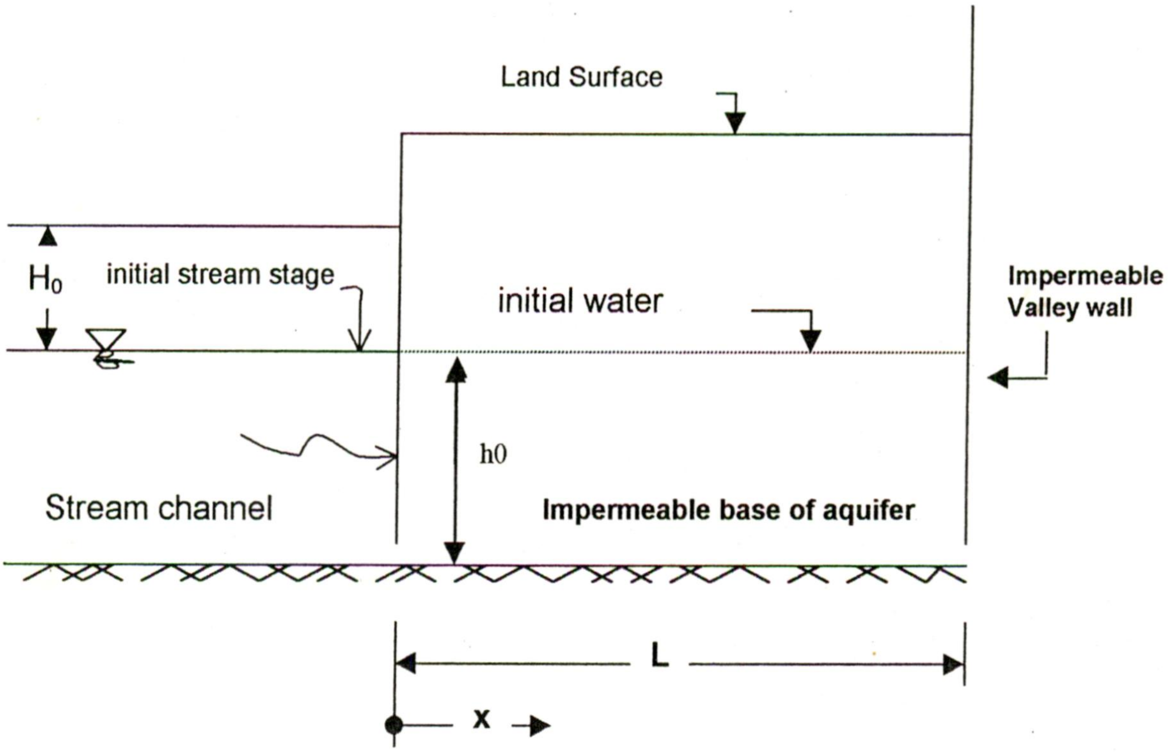


Figure 2 . 2 Defination Sketch For Stream - Aquifer Coupling

2.5 DETERMINATION OF THE COEFFICIENT OF REACH TRANSMISSIVITY (Γ_i)

A river must not be represented as a known ground water potential applied to the appropriate network nodes unless it cuts right through to the base of the aquifer and has a flow rate greater than the quantity flowing through the aquifer. In practice, many rivers only partially penetrate the aquifer, yet the transfer of water to or from the aquifer can have a significant effect on the flow in the river.

Herbert (1970) considers the case of a partially penetrating river which is small compared to the thickness of the aquifer. The overall flow within the aquifer is represented by the finite-difference mesh and therefore the nodal points effectively represent conditions at half the aquifer depth, as shown in figure 2.3.

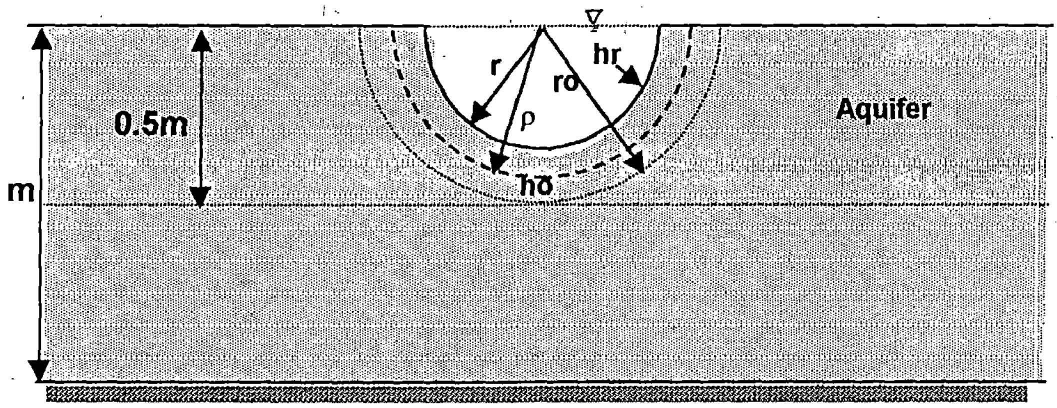


FIGURE 2.3. : REPRESENTATION OF PARTIALLY PENETRATING RIVER

According to Darcy's Law, velocity along radial direction ρ is given by:

$$V_\rho = -k \frac{\partial h}{\partial \rho} \qquad \text{..........2.5.1}$$

Under steady state condition the flow from the river perimeter across a semicircular arc of radius ρ per metre length of the river is:

$$q_r = q_\rho = A V \rho$$

$$q_r = -\pi \, \rho \, k \frac{\partial h}{\partial \rho}$$

$$q_r \frac{\partial \rho}{\rho} = -\pi \, k \, \partial h$$

Integrating

$$q_r \ln \rho = -\pi \, k \, h + C$$

At $\rho = r$, h =the hydraulic head along the river perimeter = h_r.

Hence, $C = \pi \, k \, h_r + q_r \ln r$

Substituting C ,

$$q_r \ln \rho = -\pi \, k \, h + \pi \, k \, h_r + q_r \ln r$$

or

$$q_r \ln \frac{\rho}{r} = \pi \, k \left(h_r - h\right)$$

At $\rho = r_0$, $h = h_0$.

Hence $q_r \ln \frac{r_o}{r} = \pi \, k \left(h_r - h_0\right)$

$$q_r = \frac{\pi \, k}{\ln \frac{r_o}{r}} \left(h_r - h_0\right)$$

r_0 is taken to be half of the aquifer depth. Hence,

$$q_r = \frac{\pi \, k}{\ln \frac{0.5 \, m}{r}} (h_r - h_0)$$

or

$$q_r = \Gamma_i \, \left(h_r - h_0\right) \qquad \text{........ 2.5.4}$$

Hence, the reach transmissivity of the i^{th} reach under which m is depth of aquifer, is given by :

$$\Gamma_i = \frac{\pi k}{\ln \frac{0.5m}{r}} \qquad \text{......... 2.5.5}$$

Morel-Seytoux has also derived an expression of reach transmissivity as described below. Consider an effluent stream, which receives water from the aquifer as shown in figure 2.4.

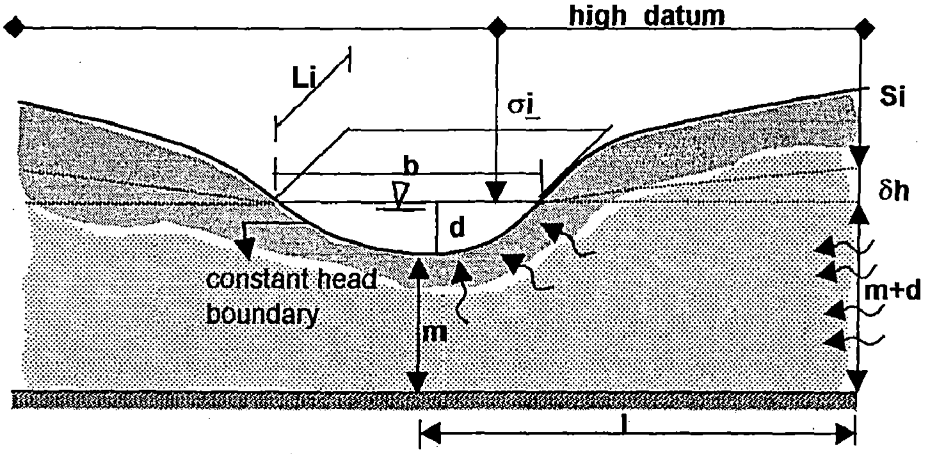


FIGURE 2.4. EFFLUENT STREAM

Area through which flow is taking place at distance L in i^{th} reach is:

$$A = [2(m + d + \delta h)]Li$$

The average area is:

$$\overline{A} = \left[\frac{Wp}{2} + (m + d + \delta h)\right] Li$$

The gradient is:

$$i = \frac{\delta h}{l}$$

where, the average length of flow path is given by:

$$\bar{l} = \frac{l + m + (l - \frac{b}{2})}{2} = l + \frac{m}{2} - \frac{b}{4}$$

The average velocity is:

$$\bar{v} = k \frac{\delta h}{l + \frac{m}{2} - \frac{b}{4}}$$

The rate of seepage to the stream (conversely recharge to the aquifer) per unit length of the stream at i^{th} reach is:

$$Qi = \bar{A}\ \bar{v}$$

$$= \left[\frac{Wp}{2} + (m + d + \delta h) \right] \frac{k\ \delta h}{l + \frac{m}{2} + \frac{b}{4}}$$

$$= \frac{T}{m} \frac{\left[\frac{Wp}{2} + (m + d + \delta h) \right]}{l + \frac{m}{2} - \frac{b}{4}} (\sigma i - Si) \qquad \text{........ 2.5.6}$$

Simplifying equation 2.5.6 becomes:

$$Qi = \Gamma_i\ (\sigma_i - S_i)$$

The terms d, δh, and b/4 are very small compared to m, the thickness of aquifer, therefore, the reach transmissivity (Γ_i) is expressed as:

$$\Gamma_i = \frac{T\left(\frac{Wp}{2} + m\right)}{m\left(l + \frac{m}{2}\right)} \qquad \text{.......2.5.7}$$

where:

Wp = wetted perimeter,

m = thickness of the aquifer,

l = distance of the observation point from centre of the stream (l = 4b),

T = transmissifity.

2.6 MATHEMATICAL DESCRIPTION OF A FLOOD WAVE

For detailed analysis of wave motion we need a mathematical language for describing waves. Transverse waves on a stream during wave motion in each reach, labeled by its equilibrium position at X, is diplaced some distance Y in the transverse direction. The value of Y depends on which reach of the stream is being described (that is, on X) and also on the time t. Thus the function Y = f (X,t), once it is known, constitutes a complete description of the motion, such a function is called a wave function.

Stream stage rise at particular reach during passage of flood wave had been given by Cooper and Rorabaugh. The equation, which describes the flood stage is,

$$\sigma_i(t) = \sigma_0 \, N(1-\cos\omega t)\, e^{-\partial t} \qquad \text{.........2.6.1}$$

The time required for the wave disturbance to travel from X = 0 to some point X to the right of the origin is given by X/V, where V is wave velocity. The transverse motion of a point at X at time t is the same as the transverse motion of a point at X = 0 at an earlier time t - X/V. Thus the displacement of a point at X at time t is obtained simply by replacing t in equation 2. 6. 1 by (t - (X/V)), and we find:

$$\sigma_i\left(t-\frac{X}{V}\right) = \sigma_0 \, N\left[1-\cos\omega\left(t-\frac{X}{V}\right)\right] e^{-\partial\left(t-\frac{X}{V}\right)} \qquad \text{.........2.6.2}$$

in which, as per figure 2.5.

$$\partial = \omega \operatorname{cotg}\left(\frac{\omega\, tc}{2}\right)$$

$$\omega = \frac{2\pi}{td}$$

$$N = \frac{e^{\partial\, tc}}{1 - \cos \omega\, tc}$$

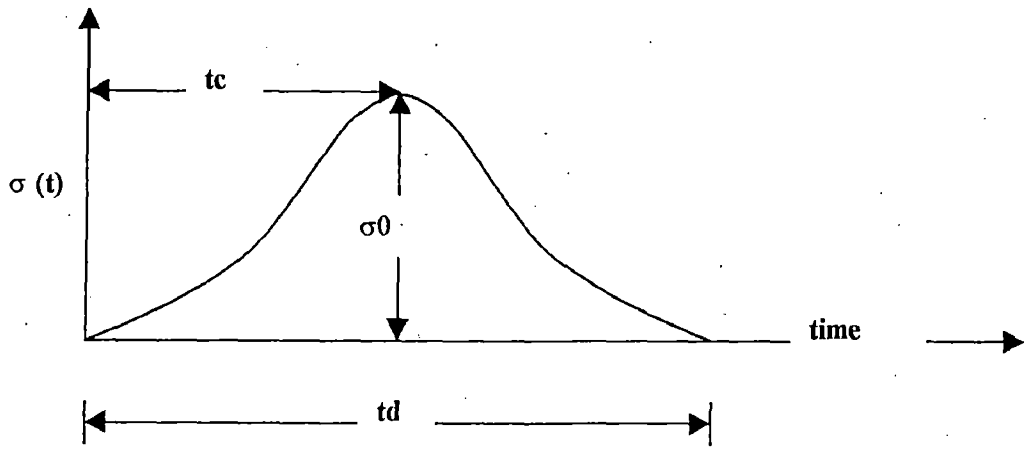


FIGURE 2.5.

The flood stage is measured at the begining time t_0 at a particular point in down stream. Same flood wave has passed through an upstream point at an earlier time. The passage of the flood wave along the stream is shown in Fig. 2.6.

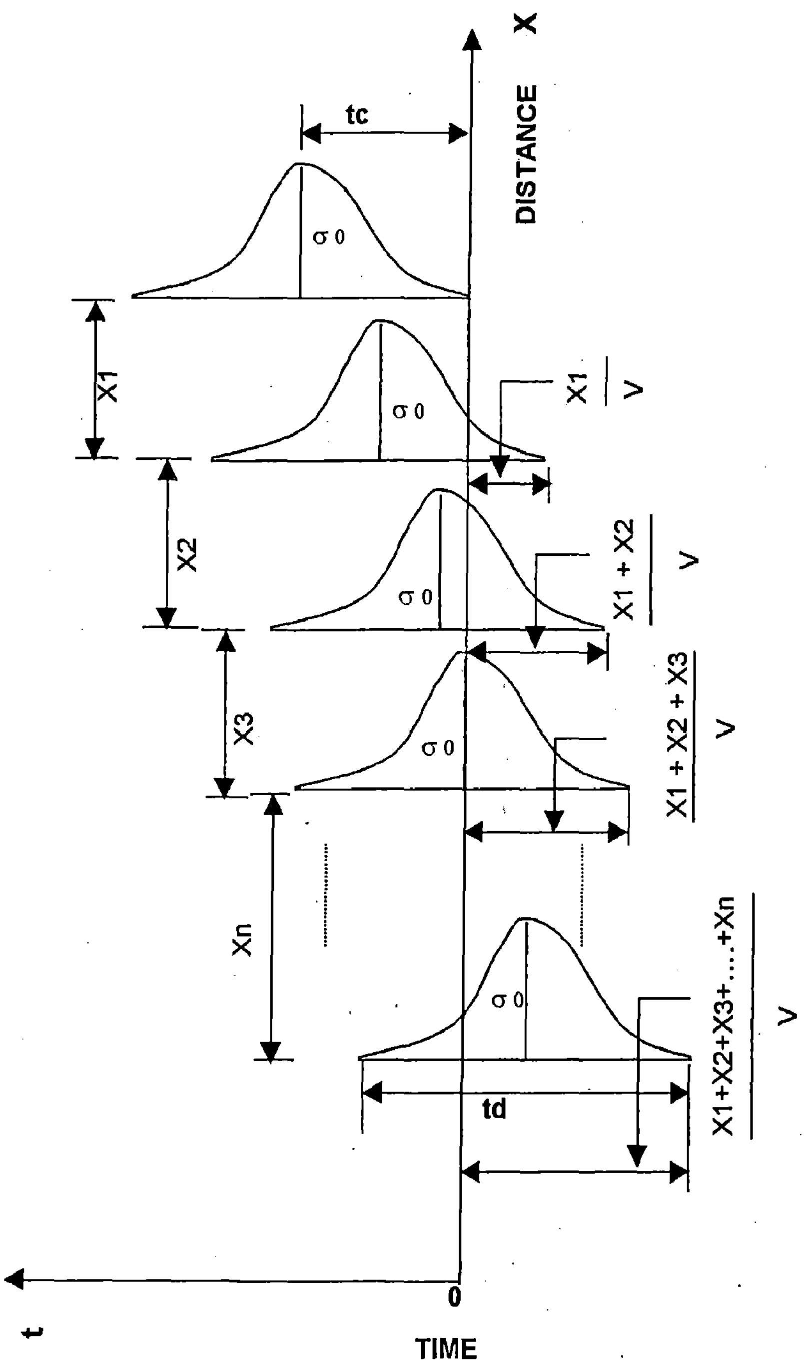


FIGURE 2.6: FLOOD HYDROGRAPH ALONG A STREAM

G10533.

CHAPTER - III

ANALYSIS

3. 1. PROBLEM DEFINITION

Hydrologic modeling of a meandering stream, well and aquifer interaction, the stream having hydraulic connection with the underlying aquifer can be solved by discretising the meandering stream into a number of small reaches in form of rectangular basin treating river reach as a recharge or discharge well.

The area of each small reach ($j = 1, 2, 3, \ldots, R$) can be conserved while representing the stream by a number of continuous rectangular basin. To apply Hantus Solution conveniently, the basins are chosen such that sides of rectangular basin are either parallel to x-axis or y-axis. Let the coordinates of the centre of area of the basin are (x_1, y_1), (x_2, y_2), ..., (x_n, y_n), as shown in figure 3.1.

At a particular time, the stages are different at different reaches. If the stage is falling in one reach, it may be rising in a downstream reach. Due to percolation the water level in the aquifer rises. Due to pumping the water level falls. The water level beneath a reach is governed by recharge from all reaches that has occurred since the time of stream stage rise and pumping from the aquifer. The recharge from a stream is linearly proportional to the difference in stream stage in the reach and water level position in the aquifer under the particular reach.

The flow in the stream and in the aquifer is unsteady. The stream stage rises during passage of a flood wave.

3.2 METHODOLOGY

The following assumptions are made in the analysis:

1. The aquifer overlies on an impermeable horizontal bed.
2. The flow in the aquifer is in horizontal direction and one-dimensional Boussinesq's equation is adopted.
3. Velocity of the flood wave is assumed same along the stream and attenuation of wave is neglected during passage of the flood wave.
4. At large distance from the river, the difference in piezometric surface and stream stage is negligible.
5. The hydraulic properties of the aquifer remain constant with respect to time and space.
6. The flow from the stream reaches is vertically downwards until it reaches the water table.
7. Dupuit's assumptions are valid.
8. The time span is divided by uniform time step. Within each time step the recharge from the stream is constant, but it varies from step to step.

A linear relationship of the recharge rate entering in an aquifer with potential difference that has been postulated and verified by Morel - Seytoux (1975) is of the form:

$$Q_R(i,n) = \Gamma_i \left[S(i,n) - \sigma(i,n) \right] \qquad \text{..........3. 2. 1}$$

where :

Γ_i = Transmissivity of i^{th} river reach.

$S(i,n)$ = Depth to water level rise in the aquifer measured from a high datum at i^{th} reach during n^{th} time step.

$\sigma(i,n)$ = Depth to water level in the stream measured from same datum at i^{th} reach at n^{th} time step.

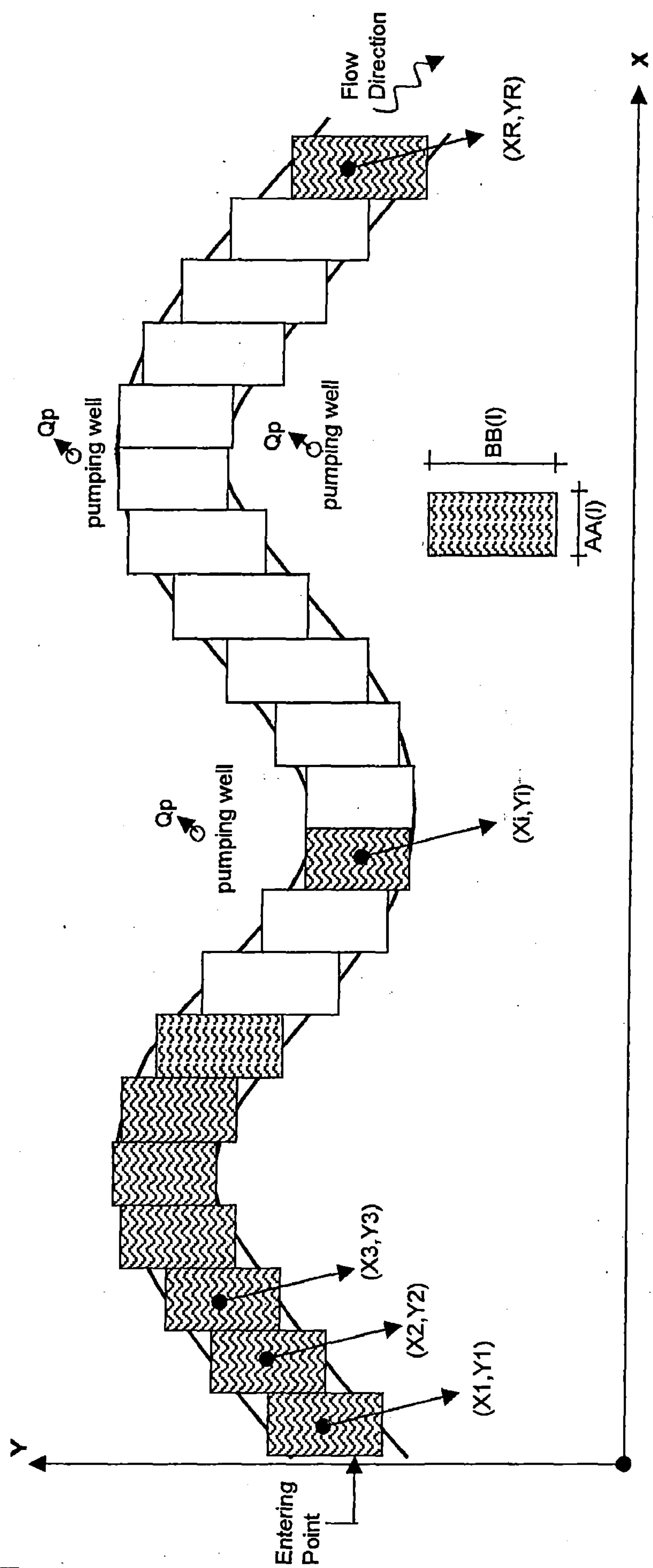


Figure : 3 . 1 Discretisation of meandering stream by a number of rectangular basins

Draw down of water table due to both recharge from the stream and pumping from the aquifer in the vicinity of the stream, at i^{th} reach at the end n^{th} unit time period is given by:

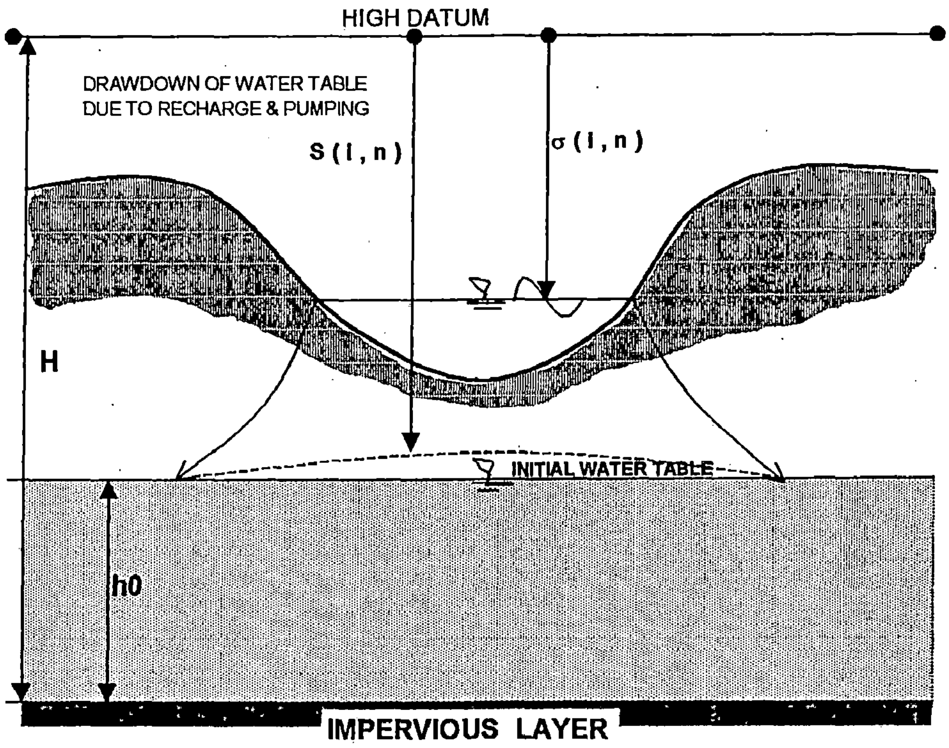


FIGURE 3 . 2 SCHEMATIC SECTION OF A STREAM HYDRAUCALLY CONNECTED TO THE AQUIFER

$$S(i,n) = H - h0 - S_R(i,n) + S_P(i,n)$$

$$= H - h0 - \sum_{j=1}^{R} \sum_{\gamma=1}^{n} Q_R(j,\gamma)\, \delta_R(i,j,n-\gamma+1)$$

$$+ \sum_{J_1=1}^{N} \sum_{\gamma=1}^{n} Q_P(J_1,\gamma)\, \delta_P(i,J_1,n-\gamma+1) \quad ....3.2.2$$

The recharge from the i^{th} reach is given, by the linear relation

$$Q_R(i,n) = \Gamma_i\,[\,S(i,n) - \sigma(i,n)\,]$$

or

$$\frac{Q_R(i,n)}{\Gamma_i} = S(i,n) - \sigma(i,n) \qquad \text{.................3.2.3}$$

Substituting S (i, n) into equation 3 . 2. 3

$$\frac{Q_R(i,n)}{\Gamma_i} = H - h0 - \sum_{j=1}^{R}\sum_{\gamma=1}^{n} Q_R(j,\gamma)\ \delta_R(i,j,n-\gamma+1)$$

$$+ \sum_{J_1=1}^{N}\sum_{\gamma=1}^{n} Q_P(J_1,\gamma)\ \delta_P(i,J_1,n-\gamma+1) - \sigma(i,n) \qquad \text{..........3.2.4}$$

Splitting the temporal summation of stream recharge into two parts (one part includes summation up to $(n-1)^{th}$ step, the other part includes only the n^{th} step, we write

$$\frac{Q_R(i,n)}{\Gamma_i} = H - h0 - \sum_{j=1}^{R}\sum_{\gamma=1}^{n-1} Q_R(j,\gamma)\ \delta_R(i,j,n-\gamma+1)$$

$$- \sum_{j=1}^{R} Q_R(j,n)\ \delta_R(i,j,1)$$

$$+ \sum_{J_1=1}^{N}\sum_{\gamma=1}^{n} Q_P(J_1,\gamma)\ \delta_P(i,J_1,n-\gamma+1) - \sigma(i,n)$$

$$\text{..........3.2.5}$$

Collecting the recharge term from I th reach during n th time step,

$$\frac{Q_R(i,n)}{\Gamma_i} + Q_R(i,n)\,\delta_R(i,i,1) + \sum_{\substack{j=1\\ j\neq 1}}^{R} Q_R(j,n)\,\delta_R(i,j,1)$$

$$= H - h0 - \sum_{j=1}^{R}\sum_{\gamma=1}^{n-1} Q_R(j,\gamma)\ \delta_R(i,j,n-\gamma+1)$$

$$+ \sum_{J_1=1}^{N}\sum_{\gamma=1}^{n} Q_P(J_1,\gamma)\ \delta_P(i,J_1,n-\gamma+1) - \sigma(i,n) \qquad \text{.........3.2.6}$$

Rearranging equation 3. 2. 6

$$Q_R(i,n)\left[\frac{1}{\Gamma_i} + \delta_R(i,i,1)\right] + \sum_{\substack{j=1 \\ j\neq i}}^{R} Q_R(j,n)\,\delta_R(i,j,1)$$

$$= H - h0 - \sum_{j=1}^{R}\sum_{\gamma=1}^{n-1} Q_R(j,\gamma)\,\delta_R(i,j,n-\gamma+1)$$

$$+ \sum_{J_1=1}^{N}\sum_{\gamma=1}^{n} Q_P(J_1,\gamma)\,\delta_P(i,J_1,n-\gamma+1) - \sigma(i,n) \qquad \text{..........3.2.7}$$

For i = 1

$$Q_R(1,n)\left[\frac{1}{\Gamma_1} + \delta_R(1,1,1)\right] + Q_R(2,n)\,\delta_R(1,2,1)$$

$$+ Q_R(3,n)\,\delta_R(1,3,1)$$

$$+ Q_R(4,n)\,\delta_R(1,4,1)$$

$$\vdots$$

$$+ Q_R(R,n)\,\delta_R(1,R,1)$$

$$= H - h0 - \sum_{j=1}^{R}\sum_{\gamma=1}^{n-1} Q_R(j,\gamma)\,\delta_R(1,j,n-\gamma+1)$$

$$+ \sum_{J_1=1}^{N}\sum_{\gamma=1}^{n} Q_P(J_1,\gamma)\,\delta_P(1,J_1,n-\gamma+1) - \sigma(1,n)$$

<u>For i = 2</u>

$$
\begin{aligned}
Q_R(1,n)\,\delta_R(2,1,1) \; &+ Q_R(2,n)\left[\frac{1}{\Gamma_2} + \delta_R(2,2,1)\right] \\
&+ Q_R(3,n)\,\delta_R(2,3,1) \\
&+ Q_R(4,n)\,\delta_R(2,4,1) \\
&\quad \vdots \\
&+ Q_R(R,n)\,\delta_R(2,R,1)
\end{aligned}
$$

$$
= H - h0 - \sum_{j-1}^{R} \sum_{\gamma-1}^{n-1} Q_R(j,\gamma)\,\delta_R(2,j,n-\gamma+1)
$$

$$
+ \sum_{J_1=1}^{N} \sum_{\gamma=1}^{n} Q_P(J_1,\gamma)\,\delta_P(2,J_1,n-\gamma+1) - \sigma(2,n)
$$

<u>For i = R</u>

$$
\begin{aligned}
Q_R(1,n)\,\delta_R(R,1,1) \; &+ Q_R(2,n)\,\delta_R(R,2,1) \\
&+ Q_R(3,n)\,\delta_R(R,3,1) \\
&\quad \vdots \\
&+ Q_R(R,n)\left[\frac{1}{\Gamma_R} + \delta_R(R,R,1)\right]
\end{aligned}
$$

$$
= H - h0 - \sum_{j=1}^{R} \sum_{\gamma=1}^{n-1} Q_R(j,\gamma)\,\delta_R(R,j,n-\gamma+1)
$$

$$
+ \sum_{J_1=1}^{N} \sum_{\gamma=1}^{n} Q_P(J_1,\gamma)\,\delta_P(R,J_1,n-\gamma+1) - \sigma(R,n)
$$

The set of R number of equations represented by equation 3. 2. 7 can be written in the following matrix form:

$[A].[B] = [C]$ 3. 2. 8

in which

$$[C]=\begin{bmatrix} H - h0 - \sum_{j=1}^{R}\sum_{\gamma=1}^{n-1} Q_R(j,\gamma)\,\delta_R(1, j, n-\gamma+1) \\ + \sum_{J_1=1}^{N}\sum_{\gamma=1}^{n} Q_P(J_1,\gamma)\,\delta_P(1, J_1, n-\gamma+1) - \sigma(1, n) \\ \\ H - h0 - \sum_{j=1}^{R}\sum_{\gamma=1}^{n-1} Q_R(j,\gamma)\,\delta_R(2, j, n-\gamma+1) \\ + \sum_{J_1=1}^{N}\sum_{\gamma=1}^{n} Q_P(J_1,\gamma)\,\delta_P(2, J_1, n-\gamma+1) - \sigma(2, n) \\ \vdots \\ \vdots \\ H - h0 - \sum_{j=1}^{R}\sum_{\gamma=1}^{n-1} Q_R(j,\gamma)\,\delta_R(R, j, n-\gamma+1) \\ + \sum_{J_1=1}^{N}\sum_{\gamma=1}^{n} Q_P(J_1,\gamma)\,\delta_P(R, J_1, n-\gamma+1) - \sigma(R, n) \end{bmatrix}$$

$$[A]=\begin{bmatrix} \frac{1}{\Gamma_1}+\partial_R(1,1,1) & \partial_R(1,2,1) & \partial_R(1,3,1) & \cdots & \partial_R(1,R,1) \\ \partial_R(2,1,1) & \frac{1}{\Gamma_2}+\partial_R(2,2,1) & \partial_R(2,3,1) & \cdots & \partial_R(2,R,1) \\ \partial_R(3,1,1) & \partial_R(3,2,1) & \frac{1}{\Gamma_3}+\partial_R(3,3,1) & \cdots & \partial_R(3,R,1) \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \partial_R(R,1,1) & \partial_R(R,2,1) & \partial_R(R,3,1) & \cdots & \frac{1}{\Gamma_R}+\partial_R(R,R,1) \end{bmatrix}$$

$$[B] = \begin{bmatrix} Q_R(1,n) \\ Q_R(2,n) \\ Q_R(3,n) \\ . \\ . \\ . \\ Q_R(R,n) \end{bmatrix}$$

Hence,

$$[B] = [A]^{-1}\,[C]$$

and $Q_R\,(j\,,\,n\,)$ can be solved in succession starting from time step 1.

CHAPTER-IV

RESULT AND DISCUSSION

For estimating recharge from a meandering stream consequent to passage of a flood wave, a meandering stream with known geometry was considered. The different well location and meandering stream considered for calculation of recharge, is shown in figure 4.1. Only one meander has been considered for obtaining the result. However the analysis presented is valid for a stream that may have several meanders.

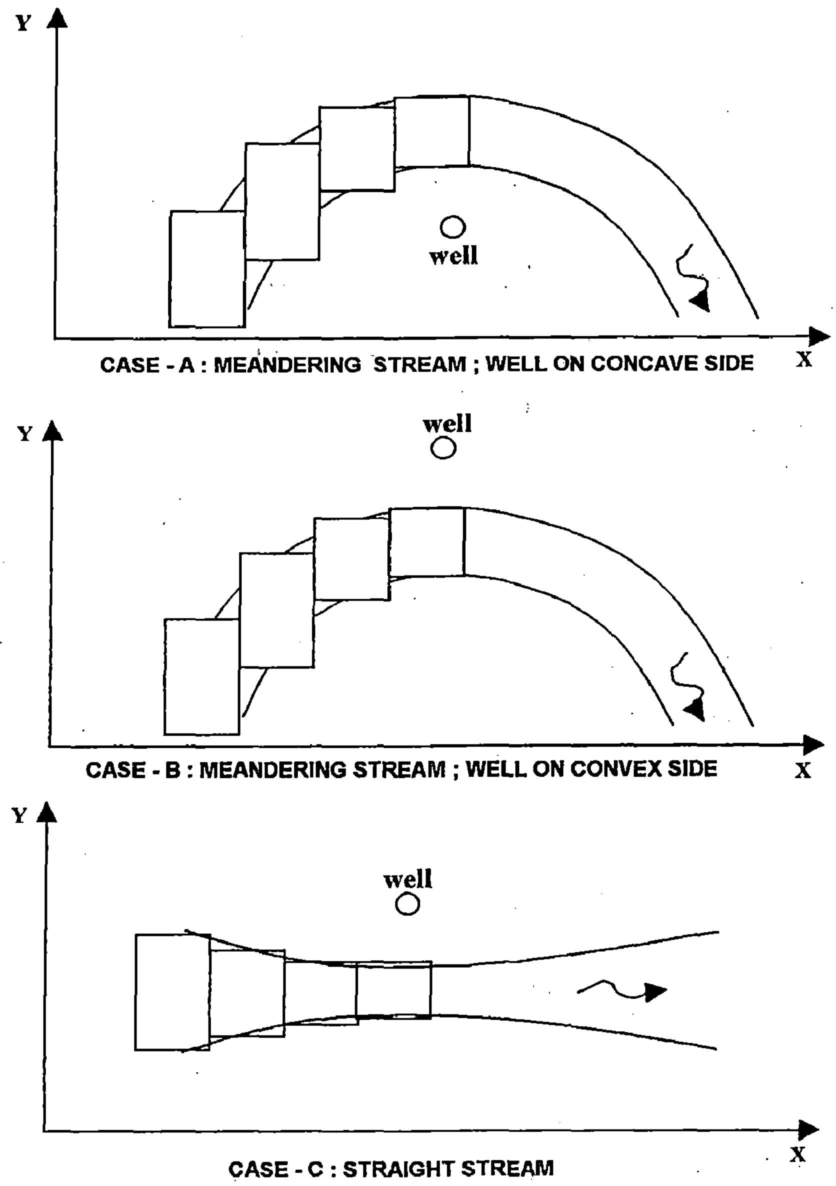


FIGURE - 4.1. DIFFERENT GEOMETRY AND WELL LOCATION

The result presented pertains to the following data:

1. Aquifer Parameters.
   a. Transmissivity = 300. M^2/day
   b. Storage Coefficient $\phi = 0.01$
2. Flood wave Parameter.
   a. Maximum stage rise, σ_0 = 3 m.
   b. Time to peak , Tc = 4 days.
   c. Duration of flood wave = 7 days.
   d. Period of computation = 10 days.

The stream is divided into 8 reaches. For the known width and length of the recharge basin, the discrete kernel coefficients were generated. Only one well is assumed to operate near the stream. The discrete pumping kernels for draw down under each reach were generated accordingly. The input data for obtaining the results are given in Appendix 1.

The stages in each reach corresponding to the flood wave are presented in Appendix 2. It may be seen that when the flood wave is receding, the stage is rising in down stream reaches. Therefore at a particular time the draw downs to the stream stages from a high datum are different and varies with time.

An initial 2 meter depth of water was assumed to prevail in all reaches before onset of stream stage rise. The initial water table was assumed to lie at the depth 100 meter from the high datum. Because of this initial potential difference recharge takes place even without occurrence of a flood. The recharge occurring from the stream for such condition that is no change in the stream stage and no pumping is presented in table 1A and table 1B, The temporal variations of cumulative volume of flow recharged from a meandering stream and straight stream are shown in figures 4.2. The volume of water recharged when pumping takes place and there is no flood wave and no potential difference, is presented in table 2A, 2B and 2C and the variation of cumulative recharge with time is presented in figure 4.3, which represents induced recharge in the absence of flood wave. It may be seen that the induced recharge for a meandering stream is maximum when a pump operates on the concave side of the meander. If the pump operates on the convex side the induced recharge is minimum. For a straight stream the induced recharge is bounded by these two limits. But when a flood wave passes the meandering's influence on induced recharge becomes insignificant as the recharge from the stream due to stage rise predominates.

The temporal variation of recharge from the 8 reaches with time when a flood wave passes and there is no pumping, is presented in Table 3 and in Figure 4.4. The initial variations corresponds to the variation in stream stage ie. the flood wave. Recharge from the stream to aquifer continues up to 5^{th} day during passage of flood. The cumulative recharge decrease because of effluent seepage due to lowering of stream stage. The latter part of the graph corresponds to recharge taking place due to potential difference between the stream and the aquifer, because a 2 meter depth of water is assumed to prevail in all reaches after passage of flood wave. In Figure 4.5 the recharge when both flood wave passes and pumping well is operated. The recharge would depend on the location of the pumping well. The recharge from a straight stream is also shown in the figure. It may be seen that the recharge is minimum for straight channel and location if well has no influence compared to the case when there is no flood wave. The numerical results for these cases are given in Table 4.

Tabel 1: Total Volume of Water Recharged Without Passage of a Flood Wave

(When Pumping Well is not operated)

A : *Recharge from A Meandering Stream*

Reach No.	Recharge Rate (M3/Day) Time (Days)										Total Volume (M3)
	1	2	3	4	5	6	7	8	9	10	
1	0.1010	0.0692	0.0577	0.0516	0.0477	0.0450	0.0430	0.0414	0.0401	0.0390	0.53562
2	0.0672	0.0351	0.0265	0.0227	0.0205	0.0190	0.0179	0.0171	0.0164	0.0159	0.25836
3	0.0712	0.0383	0.0295	0.0256	0.0233	0.0217	0.0206	0.0198	0.0191	0.0185	0.28751
4	0.0666	0.0347	0.0263	0.0226	0.0205	0.0191	0.0180	0.0172	0.0166	0.0160	0.25766
5	0.0663	0.0345	0.0262	0.0225	0.0203	0.0189	0.0179	0.0171	0.0164	0.0159	0.25598
6	0.0701	0.0376	0.0289	0.0250	0.0227	0.0212	0.0201	0.0193	0.0186	0.0180	0.28139
7	0.0654	0.0340	0.0255	0.0217	0.0196	0.0181	0.0171	0.0163	0.0156	0.0151	0.24818
8	0.0958	0.0649	0.0537	0.0478	0.0440	0.0413	0.0393	0.0378	0.0365	0.0354	0.49657
Total Volume (M3) =	0.60367	0.34833	0.27428	0.23933	0.2185	0.20436	0.19393	0.18582	0.17925	0.1738	2.62127
Cumulativ eVolume (m3)	**0.604**	**0.952**	**1.226**	**1.466**	**1.684**	**1.888**	**2.082**	**2.268**	**2.447**	**2.621**	

B : *Recharge From A Straight Stream*

Reach No.	Recharge Rate (M3/Day) Time (Days)										Total Volume (M3)
	1	2	3	4	5	6	7	8	9	10	
1	0.09055	0.06475	0.05564	0.05066	0.04742	0.04509	0.0433	0.0419	0.04077	0.03981	0.51994
2	0.04235	0.02287	0.01759	0.01507	0.01354	0.01248	0.0117	0.0110	0.01052	0.01006	0.16720
3	0.06214	0.03406	0.02655	0.02309	0.02105	0.01968	0.0187	0.0179	0.01730	0.01679	0.25725
4	0.06728	0.03555	0.02719	0.02339	0.02118	0.01970	0.0186	0.0178	0.01712	0.01657	0.26439
5	0.06697	0.03538	0.02704	0.02325	0.02104	0.01956	0.0185	0.0177	0.01699	0.01644	0.26282
6	0.06122	0.03348	0.02604	0.02260	0.02057	0.01921	0.0182	0.0175	0.01684	0.01634	0.25197
7	0.04155	0.02242	0.01721	0.01472	0.01321	0.01217	0.0114	0.0108	0.01024	0.00979	0.16345
8	0.08664	0.06153	0.05261	0.04773	0.04455	0.04226	0.0405	0.0391	0.03799	0.03704	0.48998
Total Volume (M3) =	0.5187	0.31004	0.24987	0.22051	0.20256	0.19015	0.18091	0.17365	0.16777	0.16284	2.377
Cumulativ eVolume (m3)	**0.519**	**0.829**	**1.079**	**1.299**	**1.502**	**1.692**	**1.873**	**2.046**	**2.214**	**2.377**	

Table 2 : Total Volume of Water Recharged Without Passage of a Flood Wave

(When Pumping Well Is operated)

A :*Recharge Of A Meandering Stream (location of pump concave side)*

Reach No.	Recharge Rate (M3/Day) Time (Days) 1	2	3	4	5	6	7	8	9	10	Total Volume (M3)
1	0.0011	0.0029	0.0037	0.0041	0.0044	0.0046	0.0047	0.0048	0.0049	0.0049	0.03991
2	0.0036	0.0061	0.0067	0.0070	0.0071	0.0072	0.0072	0.0072	0.0072	0.0073	0.06660
3	0.0069	0.0095	0.0101	0.0102	0.0103	0.0104	0.0104	0.0104	0.0104	0.0104	0.09901
4	0.0142	0.0171	0.0177	0.0180	0.0181	0.0182	0.0182	0.0183	0.0183	0.0184	0.17630
5	0.0138	0.0169	0.0176	0.0178	0.0179	0.0180	0.0181	0.0181	0.0182	0.0182	0.17464
6	0.0058	0.0088	0.0095	0.0097	0.0098	0.0098	0.0099	0.0099	0.0099	0.0099	0.09287
7	0.0018	0.0050	0.0057	0.0060	0.0062	0.0063	0.0063	0.0064	0.0064	0.0064	0.05642
8	-0.0042	-0.0013	-0.0002	0.0003	0.0007	0.0009	0.0010	0.0012	0.0013	0.0013	0.00088
Total Volume (M3) =	0.04296	0.06499	0.07073	0.0731	0.07437	0.07519	0.07576	0.07619	0.07653	0.07681	0.70663
Cumulativ eVolume (m3)	**0.043**	**0.108**	**0.179**	**0.252**	**0.326**	**0.401**	**0.477**	**0.553**	**0.630**	**0.707**	

B :*Recharge Of A Meandering Stream (location of pump convex side)*

Reach No.	Recharge Rate (M3/Day) Time (Days) 1	2	3	4	5	6	7	8	9	10	Total Volume (M3)
1	0.0002	0.0004	0.0007	0.0009	0.0011	0.0012	0.0013	0.0014	0.0015	0.00152	0.01009
2	-0.0012	0.0001	0.0007	0.0010	0.0012	0.0014	0.0015	0.0016	0.0017	0.00171	0.00957
3	0.0015	0.0049	0.0061	0.0067	0.0071	0.0073	0.0075	0.0076	0.0077	0.00781	0.06414
4	0.0164	0.0210	0.0225	0.0232	0.0237	0.0241	0.0243	0.0246	0.0247	0.0249	0.22940
5	0.0161	0.0208	0.0223	0.0231	0.0236	0.0239	0.0242	0.0244	0.0246	0.02477	0.22772
6	0.0003	0.0042	0.0055	0.0061	0.0065	0.0068	0.0070	0.0071	0.0072	0.00732	0.05800
7	-0.0031	-0.0011	-0.0003	0.0001	0.0003	0.0005	0.0006	0.0007	0.0008	0.00088	-0.00061
8	-0.0051	-0.0038	-0.0032	-0.0029	-0.0027	-0.0025	-0.0024	-0.0022	-0.0021	-0.00206	-0.02893
Total Volume (M3) =	0.02503	0.04643	0.05414	0.05819	0.06081	0.06263	0.06406	0.06516	0.06608	0.06685	0.56938
Cumulativ eVolume (m3)	**0.025**	**0.071**	**0.126**	**0.184**	**0.245**	**0.307**	**0.371**	**0.436**	**0.503**	**0.569**	

C : *Recharge Of A Straight Stream*

Reach No.	Recharge Rate (M3/Day) Time (Days) 1	2	3	4	5	6	7	8	9	10	Total Volume (M3)
1	0.00038	0.00140	0.00198	0.00235	0.00261	0.00280	0.0030	0.0031	0.00319	0.00328	0.02403
2	0.00056	0.00207	0.00258	0.00282	0.00295	0.00304	0.0031	0.0032	0.00318	0.00320	0.02665
3	0.00448	0.00720	0.00801	0.00838	0.00858	0.00872	0.0088	0.0089	0.00893	0.00897	0.08096
4	0.01580	0.01946	0.02050	0.02099	0.02128	0.02149	0.0217	0.0218	0.02191	0.02201	0.20689
5	0.01550	0.01928	0.02035	0.02084	0.02114	0.02136	0.0215	0.0217	0.02178	0.02188	0.20531
6	0.00357	0.00663	0.00750	0.00789	0.00811	0.00825	0.0084	0.0084	0.00847	0.00851	0.07570
7	-0.00025	0.00161	0.00220	0.00247	0.00263	0.00273	0.0028	0.0029	0.00290	0.00293	0.02288
8	-0.00353	-0.00182	-0.00104	-0.00057	-0.00026	-0.00003	0.0001	0.0003	0.00040	0.00050	-0.00593
Total Volume (M3) =	0.03651	0.05583	0.06208	0.06517	0.06704	0.06836	0.06934	0.07012	0.07076	0.07128	0.63649
Cumulativ eVolume (m3)	**0.037**	**0.092**	**0.154**	**0.220**	**0.287**	**0.355**	**0.424**	**0.494**	**0.565**	**0.636**	

Tabel 3: Total Volume of Water Recharged During Passage of a Flood Wave

(When Pumping Well is not operated)

A : *Recharge From A Meandering Stream*

Reach No.	Recharge Rate (M3/Day) Time (Days)										Total Volume (M3)
	1	2	3	4	5	6	7	8	9	10	
1	0.1172	0.1285	0.1584	0.1551	0.1001	0.0242	-0.0014	0.0181	0.0248	0.0280	0.75290
2	0.0781	0.0732	0.0872	0.0786	0.0387	-0.0085	-0.0168	0.0026	0.0078	0.0099	0.35083
3	0.0828	0.0791	0.0950	0.0869	0.0450	-0.0055	-0.0152	0.0047	0.0101	0.0123	0.39511
4	0.0774	0.0729	0.0872	0.0789	0.0392	-0.0080	-0.0164	0.0029	0.0081	0.0102	0.35245
5	0.0771	0.0727	0.0870	0.0788	0.0391	-0.0081	-0.0165	0.0028	0.0080	0.0101	0.35076
6	0.0815	0.0783	0.0943	0.0864	0.0447	-0.0059	-0.0158	0.0042	0.0096	0.0118	0.38895
7	0.0761	0.0719	0.0861	0.0778	0.0381	-0.0092	-0.0178	0.0017	0.0070	0.0091	0.34065
8	0.1116	0.1237	0.1540	0.1514	0.0971	0.0212	-0.0052	0.0144	0.0212	0,0244	0.71387
Total Volume (M3) =	0.70161	0.7002	0.84904	0.79371	0.44199	0.00028	-0.10487	0.05128	0.09664	0.11564	3.64552
Cumulativ eVolume (m3)	**0.702**	**1.402**	**2.251**	**3.045**	**3.487**	**3.487**	**3.382**	**3.433**	**3.530**	**3.646**	

B : *Recharge From A Straight Stream*

Reach No.	Recharge Rate (M3/Day) Time (Days)										Total Volume (M3)
	1	2	3	4	5	6	7	8	9	10	
1	0.10504	0.11834	0.14780	0.14762	0.10040	0.03241	0.0075	0.0227	0.02784	0.03024	0.73991
2	0.04917	0.04700	0.05631	0.05131	0.02630	-0.00390	-0.0100	0.0014	0.00445	0.00569	0.22769
3	0.07216	0.06961	0.08384	0.07718	0.04104	-0.00301	-0.0120	0.0047	0.00934	0.01126	0.35418
4	0.07816	0.07400	0.08863	0.08052	0.04072	-0.00689	-0.0157	0.0033	0.00847	0.01057	0.36185
5	0.07784	0.07380	0.08847	0.08040	0.04062	-0.00699	-0.0158	0.0032	0.00834	0.01044	0.36029
6	0.07118	0.06895	0.08327	0.07673	0.04069	-0.00337	-0.0125	0.0043	0.00887	0.01080	0.34889
7	0.04831	0.04648	0.05589	0.05102	0.02609	-0.00412	-0.0104	0.0011	0.00416	0.00542	0.22396
8	0.10086	0.11469	0.14447	0.14479	0.09806	0.03011	0.0046	0.0199	0.02504	0.02745	0.70994
Total Volume (M3) =	0.60272	0.61287	0.74868	0.70957	0.41392	0.03424	-0.06423	0.06056	0.09651	0.11187	3.32671
Cumulativ eVolume (m3)	**0.603**	**1.216**	**1.964**	**2.674**	**3.088**	**3.122**	**3.058**	**3.118**	**3.215**	**3.327**	

Table 4 : Total Volume of Water Recharged During Passage of a Flood Wave

(When Pumping Well is operated)

A :Recharge Of A Meandering Stream (location of pump concave side)

Reach No.	Recharge Rate (M3/Day)										Total Volume (M3)
	Time (Days)										
	1	2	3	4	5	6	7	8	9	10	
1	0.0172	0.0622	0.1044	0.1076	0.0568	-0.0163	-0.0397	-0.0186	-0.0104	-0.0062	0.25720
2	0.0145	0.0443	0.0674	0.0629	0.0253	-0.0204	-0.0275	-0.0073	-0.0014	0.0013	0.15911
3	0.0184	0.0503	0.0755	0.0716	0.0321	-0.0168	-0.0254	-0.0047	0.0014	0.0042	0.20660
4	0.0250	0.0553	0.0786	0.0742	0.0368	-0.0089	-0.0162	0.0040	0.0099	0.0125	0.27111
5	0.0246	0.0550	0.0784	0.0741	0.0367	-0.0090	-0.0163	0.0039	0.0097	0.0124	0.26941
6	0.0172	0.0495	0.0748	0.0710	0.0317	-0.0172	-0.0260	-0.0052	0.0009	0.0037	0.20045
7	0.0125	0.0429	0.0663	0.0621	0.0247	-0.0211	-0.0285	-0.0082	-0.0022	0.0005	0.14890
8	0.0116	0.0574	0.1001	0.1040	0.0538	-0.0192	-0.0435	-0.0222	-0.0141	-0.0098	0.21817
Total Volume (M3) =	0.14093	0.41685	0.6455	0.62749	0.29786	-0.12889	-0.22305	-0.05833	-0.00607	0.01866	1.73095
Cumulativ eVolume (m3)	0.141	0.558	1.203	1.831	2.129	2.000	1.777	1.718	1.712	1.731	

B :Recharge Of A Meandering Stream (location of pump convex side)

Reach No.	Recharge Rate (M3/Day)										Total Volume (M3)
	Time (Days)										
	1	2	3	4	5	6	7	8	9	10	
1	0.0163	0.0598	0.1014	0.1044	0.0535	-0.0196	-0.04305	-0.0220	-0.0138	-0.0096	0.22741
2	0.0096	0.0382	0.0614	0.0570	0.0195	-0.0262	-0.03321	-0.0130	-0.0069	-0.0042	0.10207
3	0.0130	0.0457	0.0715	0.0680	0.0288	-0.0199	-0.02830	-0.0075	-0.0012	0.0016	0.17169
4	0.0272	0.0591	0.0833	0.0795	0.0424	-0.0030	-0.01005	0.0103	0.0163	0.0191	0.32418
5	0.0269	0.0589	0.0831	0.0794	0.0423	-0.0031	-0.01022	0.0101	0.0162	0.0189	0.32249
6	0.0116	0.0448	0.0709	0.0675	0.0284	-0.0203	-0.02889	-0.0080	-0.0018	0.0011	0.16558
7	0.0076	0.0369	0.0603	0.0561	0.0188	-0.0268	-0.03419	-0.0138	-0.0078	-0.0051	0.09188
8	0.0107	0.0550	0.0971	0.1008	0.0505	-0.0226	-0.04686	-0.0256	-0.0174	-0.0132	0.18834
Total Volume (M3) =	0.12299	0.3983	0.6289	0.61258	0.28426	-0.14142	-0.23477	-0.06939	-0.01652	0.00871	1.59364
Cumulativ eVolume (m3)	0.123	0.521	1.150	1.763	2.047	1.906	1.671	1.601	1.585	1.594	

C : Recharge Of A Straight Stream

Reach No.	Recharge Rate (M3/Day)										Total Volume (M3)
	Time (Days)										
	1	2	3	4	5	6	7	8	9	10	
1	0.01486	0.05499	0.09415	0.09931	0.05559	-0.00988	-0.0329	-0.0161	-0.00975	-0.00630	0.24399
2	0.00738	0.02620	0.04130	0.03906	0.01571	-0.01333	-0.0186	-0.0065	-0.00289	-0.00117	0.08716
3	0.01451	0.04276	0.06529	0.06246	0.02857	-0.01397	-0.0219	-0.0043	0.00097	0.00343	0.17788
4	0.02669	0.05791	0.08194	0.07812	0.04082	-0.00509	-0.0126	0.0073	0.01325	0.01601	0.30435
5	0.02636	0.05770	0.08178	0.07799	0.04072	-0.00519	-0.0128	0.0072	0.01312	0.01588	0.30278
6	0.01353	0.04209	0.06473	0.06202	0.02822	-0.01433	-0.0224	-0.0048	0.00050	0.00297	0.17259
7	0.00652	0.02567	0.04088	0.03876	0.01550	-0.01356	-0.0189	-0.0068	-0.00317	-0.00145	0.08339
8	0.01068	0.05133	0.09082	0.09648	0.05325	-0.01218	-0.0358	-0.0190	-0.01255	-0.00908	0.21401
Total Volume (M3) =	0.12053	0.35865	0.56089	0.5542	0.27838	-0.08753	-0.17578	-0.04296	-0.00052	0.02029	1.58615
Cumulativ eVolume (m3)	0.121	0.479	1.040	1.594	1.873	1.785	1.609	1.566	1.566	1.586	

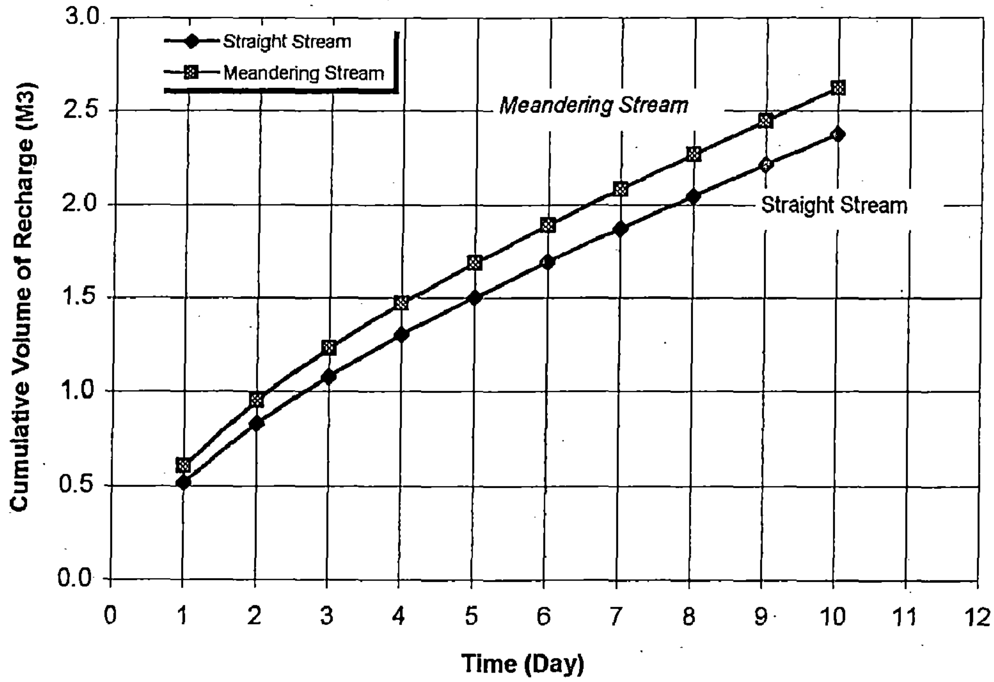


Figure 4.2 : Cumulative Volume of Recharge due to Initial Potential Difference VS Time

(When Pumping Well is not Operated and No flood Wave)

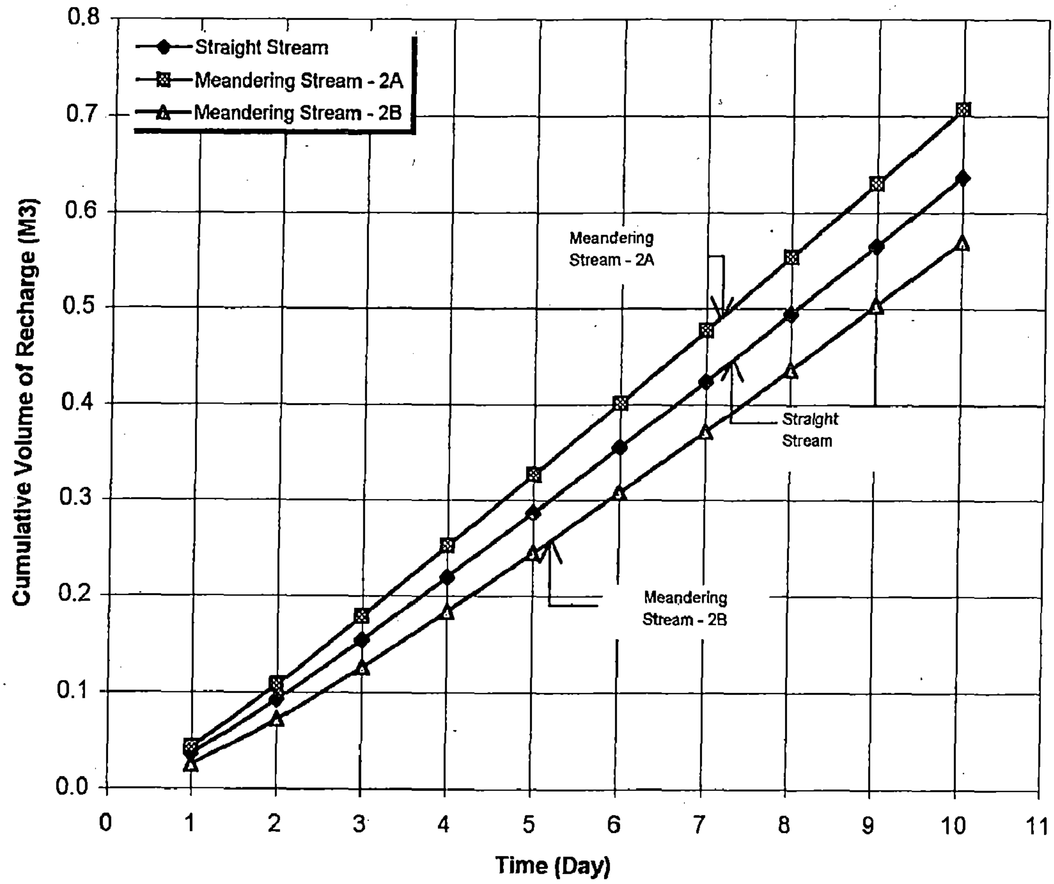


Figure 4.3 : Cumulative Volume of Recharge VS Time

(When Pumping Well is Operated, No Flood Wave and No Initial Potential Difference)

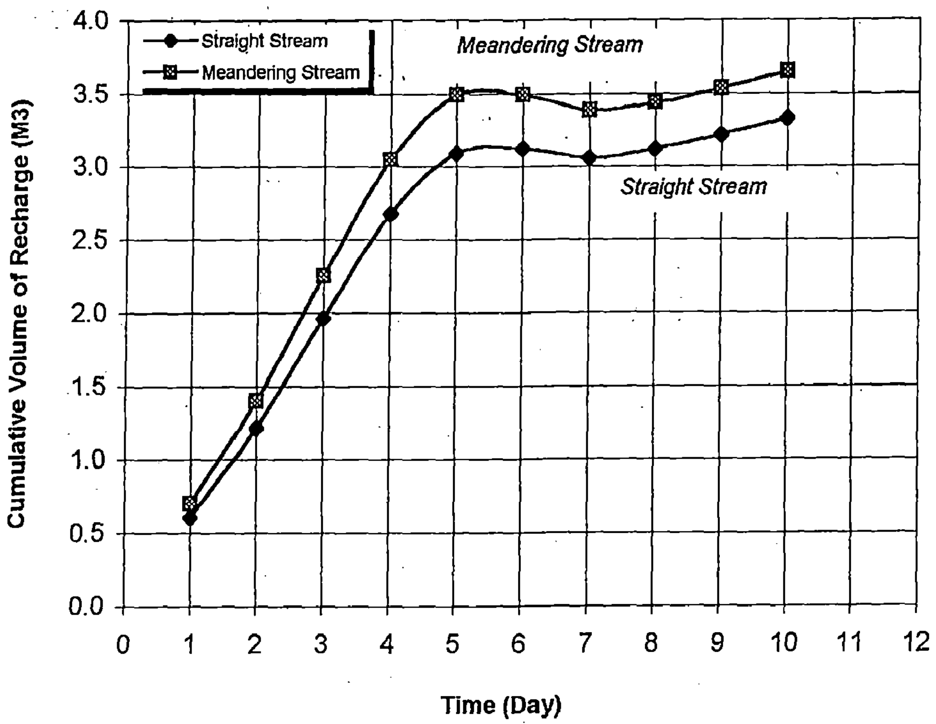


Figure 4.4: Cumulative Volume of Recharge due to Flood WaveVS Time

(When Pumping Well is not Operated and Initial Potential Difference Prevails)

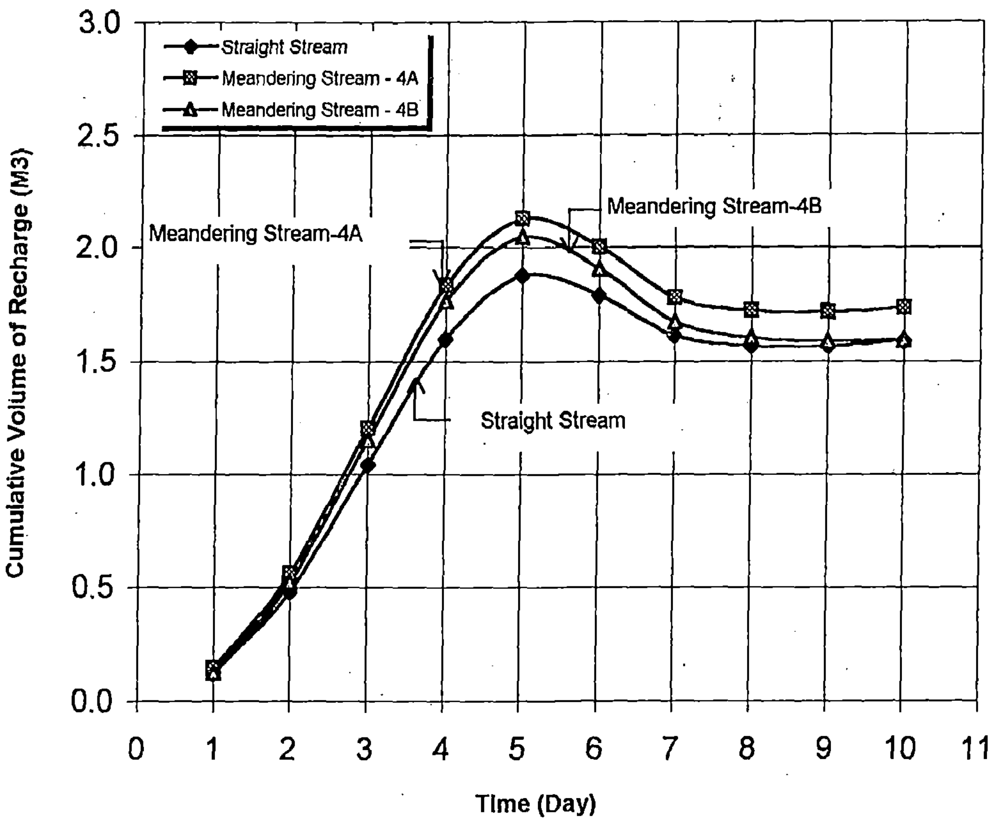


Figure 4.5 : Cumulative Volume of Recharge VS Time

(When Pumping Well is Operated and Flood Wave Passage)

CHAPTER-V
CONCLUSION

A methodology using Hantush method and discrete kernel approach of Morel-Seytoux has been developed to study behavior among a partially penetrating meandering stream, a homogenous aquifer and pumping wells interaction. The unsteady recharge during passage of a flood from a meandering stream to an aquifer that has hydraulic connection has been quantified. The analytical solution is tractable for numerical calculation. The solution has been obtained using unit response function coefficients.

It is found that cumulative volume of water recharged at a given time in case of meandering stream is more than that from a straight stream, even though areas of recharge for both stream are same. During no flood period the induced recharge depends on location of the well near the meandering stream as compared to straight stream. From examination of the result, it is found that induced recharge due to pumping near a straight stream is greater than the induced recharge due to pumping in a well which is located at the convex side of a meandering stream in absence of a flood wave.

A meandering stream always recharges more water to an aquifer compared to a straight stream.

The model presented is a general one and can be used for any type of variation in stream stage and for any geometry of stream.

APPENDIX – 1: DATA INPUT OF EACH CASE

DATA INPUT-1A

Meandering Stream-Well Interference
Without Considering Flood Wave And Pumping

Data of Pumping Wells

- Number of Pumping Well = 3
- Coordinate of Pumping Wells

Xp	Yp	Pumping rate (M^3/Day)
300.	200.	0.
500.	600.	0.
700.	200.	0.

Water surface depth on the stream = 2. M

Parameter of Aquifer

- Transmissivity = 300. M^2/Day
- Storage Coefficient ϕ = **0.01**
- Thickness of Aquifer $h0$ = 50. M
- Depth of Impervious Zone from High Datum = 150. M

Data of Flood Wave passing through the stream

- Height maximum of flood σ_0 = 0. M
- Time of concentration (Tc) = 0 Day
- Time of duration = 0 Day
- Period of time =10 Day

Data of Reaches

Number of reaches = 8 reaches
Coordinate and Characteristic of each reach

Reach	X-Reach	Y- Reach	AA(I)	BB(I)	Slope	N-Manning
1	150.	185.	100.	175.	0.0001	0.020
2	250.	325.	100.	150.	0.0001	0.020
3	350.	415.	100.	110.	0.0001	0.020
4	450.	445.	100.	100.	0.0001	0.020
5	550.	445.	100.	100.	0.0001	0.020
6	650.	415.	100.	110.	0.0001	0.020
7	750.	325.				
100.	150.	0.0001	0.020			
8	850.	185.	100.	175.	0.0001	0.020

Entering Point 150. 15.

Depth of riverbed measured from same datum = 100. M

DATA INPUT-1B

Straight Stream-Well Interference
Without Considering Flood Wave And Pumping

Data of Pumping Wells

- Number of Pumping Well = 3
- Coordinate of Pumping Wells

Xp	Yp	Pumping rate (M^3/Day)
300.	200.	0.
500.	600.	0.
700.	200.	0.

Water surface depth on the stream = 2. M

Parameter of Aquifer

- Transmissivity = 300. M^2/Day
- Storage Coefficient ϕ = **0.01**
- Thickness of Aquifer h0 = 50. M
- Depth of Impervious Zone from High Datum = 150. M

Data of Flood Wave passing through the stream

- Height maximum of flood σ_0 = 0. M
- Time of concentration (Tc) = 0 Day
- Time of duration = 0 Day
- Period of time =10 Day

Data of Reaches

Number of reaches = 8 reaches
Coordinate and Characteristic of each reach

Reach	X-Reach	Y- Reach	AA(I)	BB(I)	Slope	N-Manning
1	150.	450.	100.	175.	0.0001	0.020
2	250.	450.	100.	150.	0.0001	0.020
3	350.	450.	100.	110.	0.0001	0.020
4	450.	450.	100.	100.	0.0001	0.020
5	550.	450.	100.	100.	0.0001	0.020
6	650.	450.	100.	110.	0.0001	0.020
7	750.	450.	100.	150.	0.0001	0.020
8	850.	450.	100.	175.	0.0001	0.020

Entering Point 50. 450.

Depth of riverbed measured from same datum = 100. M

DATA INPUT-3A

Meandering Stream-Well Interference
Without Pumping And Considering Flood Wave

Data of Pumping Wells

- Number of Pumping Well = 3
- Coordinate of Pumping Wells

Xp	Yp	Pumping rate (M^3/Day)
300.	200.	0.
500.	600.	0.
700.	200.	0.

Water surface depth on the stream = 2. M

Parameter of Aquifer

- Transmissivity = 300. M^2/Day
- Storage Coefficient ϕ = **0.01**
- Thickness of Aquifer h0 = 50. M
- Depth of Impervious Zone from High Datum = 150. M

Data of Flood Wave passing through the stream

- Height maximum of flood σ_0 = 3. M
- Time of concentration (Tc) = 4 Day
- Time of duration = 7 Day
- Period of time =10 Day

Data of Reaches

Number of reaches = 8 reaches
Coordinate and Characteristic of each reach

Reach	X-Reach	Y- Reach	AA(I)	BB(I)	Slope	N-Manning
1	150.	185.	100.	175.	0.0001	0.020
2	250.	325.	100.	150.	0.0001	0.020
3	350.	415.	100.	110.	0.0001	0.020
4	450.	445.	100.	100.	0.0001	0.020
5	550.	445.	100.	100.	0.0001	0.020
6	650.	415.	100.	110.	0.0001	0.020
7	750.	325.	100.	150.	0.0001	0.020
8	850.	185.	100.	175.	0.0001	0.020

Entering Point 150. 15.

Depth of riverbed measured from same datum = 100. M

DATA INPUT-3B

Straight Stream-Well Interference
Without Considering Pumping And Considering Flood Wave

Data of Pumping Wells

- Number of Pumping Well = 3
- Coordinate of Pumping Wells

Xp	Yp	Pumping rate (M^3/Day)
300.	200.	0.
500.	600.	0.
700.	200.	0.

Water surface depth on the stream = 2. M

Parameter of Aquifer

- Transmissivity = 300. M^2/Day
- Storage Coefficient ϕ = **0.01**
- Thickness of Aquifer h0 = 50. M
- Depth of Impervious Zone from High Datum = 150. M

Data of Flood Wave passing through the stream

- Height maximum of flood σ_0 = 3. M
- Time of concentration (Tc) = 4 Day
- Time of duration = 7 Day
- Period of time =10 Day

Data of Reaches

Number of reaches = 8 reaches
Coordinate and Characteristic of each reach

Reach	X-Reach	Y- Reach	AA(I)	BB(I)	Slope	N-Manning
1	150.	450.	100.	175.	0.0001	0.020
2	250.	450.	100.	150.	0.0001	0.020
3	350.	450.	100.	110.	0.0001	0.020
4	450.	450.	100.	100.	0.0001	0.020
5	550.	450.	100.	100.	0.0001	0.020
6	650.	450.	100.	110.	0.0001	0.020
7	750.	450.	100.	150.	0.0001	0.020
8	850.	450.	100.	175.	0.0001	0.020

Entering Point 50. 450.

Depth of riverbed measured from same datum = 100. M

DATA INPUT-2A

Meandering Stream -Well Interference (CASE-A)
Considering Pumping And Without Considering Flood Wave

Data of Pumping Wells

- Number of Pumping Well = 3
- Coordinate of Pumping Wells

Xp	Yp	Pumping rate (M^3/Day)
300.	200.	0.
500.	300.	1 000.
700.	200.	0.

Water surface depth on the stream = 2. M

Parameter of Aquifer

- Transmissivity = 300. M^2/Day
- Storage Coefficient ϕ = **0.01**
- Thickness of Aquifer h0 = 52. M
- Depth of Impervious Zone from High Datum = 150. M

Data of Flood Wave passing through the stream

- Height maximum of flood σ_0 = 0. M
- Time of concentration (Tc) = 0 Day
- Time of duration = 0 Day
- Period of time =10 Day

Data of Reaches

Number of reaches = 8 reaches
Coordinate and Characteristic of each reach

Reach	X-Reach	Y- Reach	AA(I)	BB(I)	Slope	N-Manning
1	150.	185.	100.	175.	0.0001	0.020
2	250.	325.	100.	150.	0.0001	0.020
3	350.	415.	100.	110.	0.0001	0.020
4	450.	445.	100.	100.	0.0001	0.020
5	550.	445.	100.	100.	0.0001	0.020
6	650.	415.	100.	110.	0.0001	0.020
7	750.	325.	100.	150.	0.0001	0.020
8	850.	185.	100.	175.	0.0001	0.020

Entering Point 150. 15.

Depth of riverbed measured from same datum = 100. M

DATA INPUT-2B

Meandering Stream-Well Interference (CASE-B)
Considering Pumping And Without Considering Flood Wave

Data of Pumping Wells

- Number of Pumping Well = 3
- Coordinate of Pumping Wells

Xp	Yp	Pumping rate (M^3/Day)
300.	200.	0.
500.	600.	1 000.
700.	200.	0.

Water surface depth on the stream = 2. M

Parameter of Aquifer

- Transmissivity = 300. M^2/Day
- Storage Coefficient ϕ = **0.01**
- Thickness of Aquifer h0 = 52. M
- Depth of Impervious Zone from High Datum = 150. M

Data of Flood Wave passing through the stream

- Height maximum of flood σ_0 = 0. M
- Time of concentration (Tc) = 0 Day
- Time of duration = 0 Day
- Period of time =10 Day

Data of Reaches

Number of reaches = 8 reaches
Coordinate and Characteristic of each reach

Reach	X-Reach	Y- Reach	AA(I)	BB(I)	Slope	N-Manning
1	150.	185.	100.	175.	0.0001	0.020
2	250.	325.	100.	150.	0.0001	0.020
3	350.	415.	100.	110.	0.0001	0.020
4	450.	445.	100.	100.	0.0001	0.020
5	550.	445.	100.	100.	0.0001	0.020
6	650.	415.	100.	110.	0.0001	0.020
7	750.	325.	100.	150.	0.0001	0.020
8	850.	185.	100.	175.	0.0001	0.020

Entering Point 150. 15.

Depth of riverbed measured from same datum = 100. M

DATA INPUT-2C

Straight Stream-Well Interference (CASE- C)
Considering Pumping And Without Considering Flood Wave

Data of Pumping Wells

- Number of Pumping Well = 3
- Coordinate of Pumping Wells

Xp	Yp	Pumping rate (M^3/Day)
300.	200.	0.
500.	300.	1000.
700.	200.	0.

Water surface depth on the stream = 2. M

Parameter of Aquifer

- Transmissivity = 300. M^2/Day
- Storage Coefficient ϕ = **0.01**
- Thickness of Aquifer h0 = 52. M
- Depth of Impervious Zone from High Datum = 150. M

Data of Flood Wave passing through the stream

- Height maximum of flood σ_0 = 0. M
- Time of concentration (Tc) = 0 Day
- Time of duration = 0 Day
- Period of time =10 Day

Data of Reaches

Number of reaches = 8 reaches
Coordinate and Characteristic of each reach

Reach	X-Reach	Y- Reach	AA(I)	BB(I)	Slope	N-Manning
1	150.	450.	100.	175.	0.0001	0.020
2	250.	450.	100.	150.	0.0001	0.020
3	350.	450.	100.	110.	0.0001	0.020
4	450.	450.	100.	100.	0.0001	0.020
5	550.	450.	100.	100.	0.0001	0.020
6	650.	450.	100.	110.	0.0001	0.020
7	750.	450.	100.	150.	0.0001	0.020
8	850.	450.	100.	175.	0.0001	0.020

Entering Point 50. 450.

Depth of riverbed measured from same datum = 100. M

DATA INPUT-4A

Meandering Stream -Well Interference (CASE-A) Considering Pumping Well And Flood Wave

Data of Pumping Wells

- Number of Pumping Well = 3
- Coordinate of Pumping Wells

Xp	Yp	Pumping rate (M^3/Day)
300.	200.	0.
500.	300.	1 000.
700.	200.	0.

Water surface depth on the stream = 2. M

Parameter of Aquifer

- Transmissivity = 300. M^2/Day
- Storage Coefficient ϕ = **0.01**
- Thickness of Aquifer h0 = 52. M
- Depth of Impervious Zone from High Datum = 150. M

Data of Flood Wave passing through the stream

- Height maximum of flood σ_0 = 3. M
- Time of concentration (Tc) = 4 Day
- Time of duration = 7 Day
- Period of time =10 Day

Data of Reaches

Number of reaches = 8 reaches
Coordinate and Characteristic of each reach

Reach	X-Reach	Y- Reach	AA(I)	BB(I)	Slope	N-Manning
1	150.	185.	100.	175.	0.0001	0.020
2	250.	325.	100.	150.	0.0001	0.020
3	350.	415.	100.	110.	0.0001	0.020
4	450.	445.	100.	100.	0.0001	0.020
5	550.	445.	100.	100.	0.0001	0.020
6	650.	415.	100.	110.	0.0001	0.020
7	750.	325.	100.	150.	0.0001	0.020
8	850.	185.	100.	175.	0.0001	0.020

Entering Point 150. 15.

Depth of riverbed measured from same datum = 100. M

DATA INPUT-4B

Meandering Stream-Well Interference (CASE-B) Considering Pumping Well And Flood Wave

Data of Pumping Wells

- Number of Pumping Well = 3
- Coordinate of Pumping Wells

Xp	Yp	Pumping rate (M^3/Day)
300.	200.	0.
500.	600.	1 000.
700.	200.	0.

Water surface depth on the stream = 2. M

Parameter of Aquifer

- Transmissivity = 300. M^2/Day
- Storage Coefficient ϕ = **0.01**
- Thickness of Aquifer h0 = 52. M
- Depth of Impervious Zone from High Datum = 150. M

Data of Flood Wave passing through the stream

- Height maximum of flood σ_0 = 3. M
- Time of concentration (Tc) = 4 Day
- Time of duration = 7 Day
- Period of time =10 Day

Data of Reaches

Number of reaches = 8 reaches
Coordinate and Characteristic of each reach

Reach	X-Reach	Y- Reach	AA(I)	BB(I)	Slope	N-Manning
1	150.	185.	100.	175.	0.0001	0.020
2	250.	325.	100.	150.	0.0001	0.020
3	350.	415.	100.	110.	0.0001	0.020
4	450.	445.	100.	100.	0.0001	0.020
5	550.	445.	100.	100.	0.0001	0.020
6	650.	415.	100.	110.	0.0001	0.020
7	750.	325.	100.	150.	0.0001	0.020
8	850.	185.	100.	175.	0.0001	0.020

Entering Point 150. 15.

Depth of riverbed measured from same datum = 100. M

DATA INPUT-4C

Straight Stream-Well Interference (CASE- C)
Considering Pumping Well And Flood Wave

Data of Pumping Wells

- Number of Pumping Well = 3
- Coordinate of Pumping Wells

Xp	Yp	Pumping rate (M^3/Day)
300.	200.	0.
500.	300.	1000.
700.	200.	0.

Water surface depth on the stream = 2. M

Parameter of Aquifer

- Transmissivity = 300. M^2/Day
- Storage Coefficient ϕ = **0.01**
- Thickness of Aquifer h0 = 50. M
- Depth of Impervious Zone from High Datum = 150. M

Data of Flood Wave passing through the stream

- Height maximum of flood σ_0 = 3. M
- Time of concentration (Tc) = 4 Day
- Time of duration = 7 Day
- Period of time =10 Day

Data of Reaches

Number of reaches = 8 reaches
Coordinate and Characteristic of each reach

Reach	X-Reach	Y- Reach	AA(I)	BB(I)	Slope	N-Manning
1	150.	450.	100.	175.	0.0001	0.020
2	250.	450.	100.	150.	0.0001	0.020
3	350.	450.	100.	110.	0.0001	0.020
4	450.	450.	100.	100.	0.0001	0.020
5	550.	450.	100.	100.	0.0001	0.020
6	650.	450.	100.	110.	0.0001	0.020
7	750.	450.	100.	150.	0.0001	0.020
8	850.	450.	100.	175.	0.0001	0.020

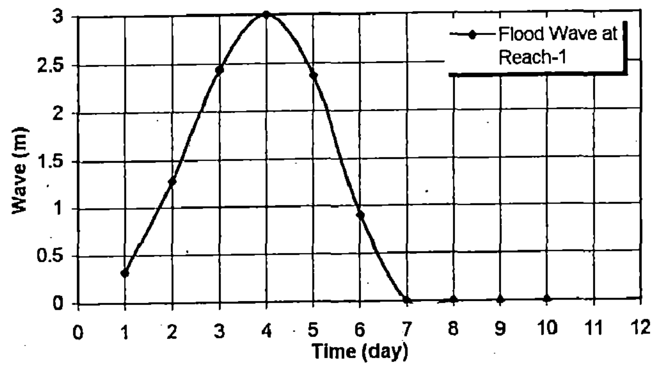
Entering Point 50. 450.

Depth of riverbed measured from same datum = 100. M

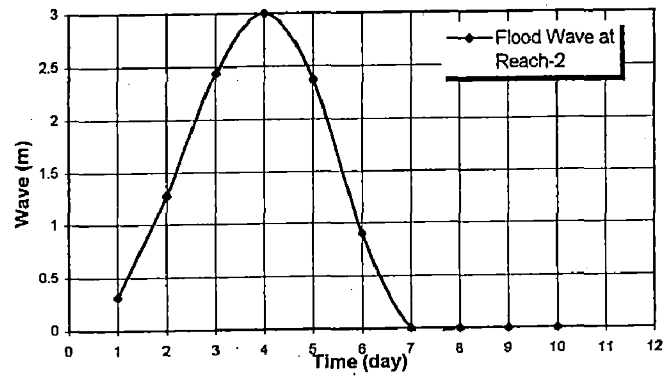
APPENDIX - 2 : FIGURE OF FLOOD WAVE

FLOOD WAVE PASSING INTO THE MEANDERING STREAM

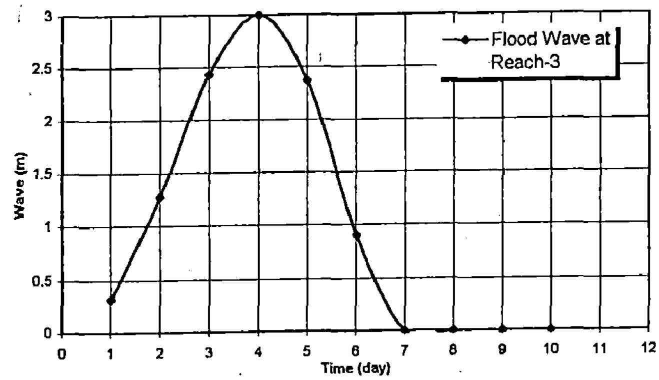
Reach-1	
Time (Hour)	Wave (M)
1	0.3202
2	1.27865
3	2.4425
4	3
5	2.37009
6	0.8977
7	0
8	0
9	0
10	0



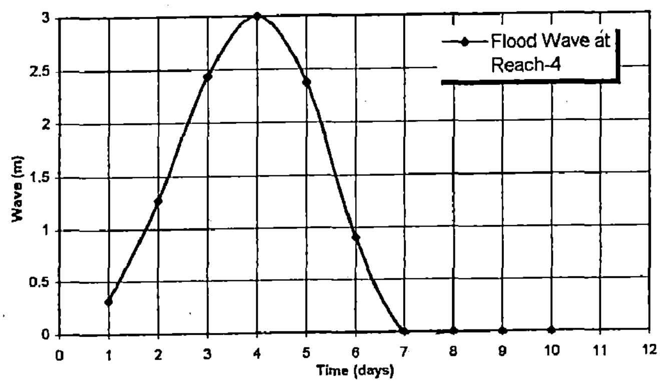
Reach-2	
Time (Hour)	Wave (M)
1	0.31902
2	1.27656
3	2.44072
4	2.99999
5	2.37224
6	0.90035
7	0.00001
8	0
9	0
10	0



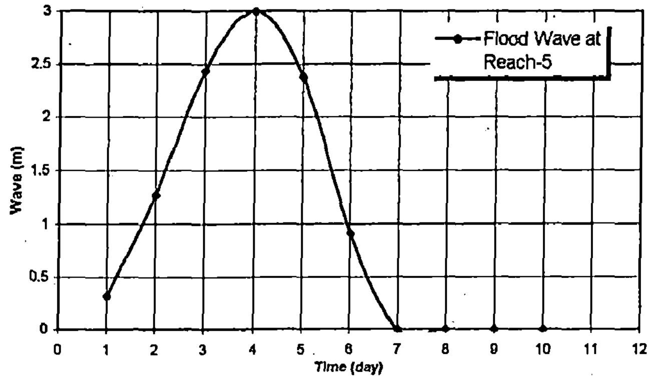
Reach-3	
Time (Hour)	Wave (M)
1	0.3181
2	1.27491
3	2.43931
4	2.99998
5	2.37393
6	0.90243
7	0.00003
8	0
9	0
10	0



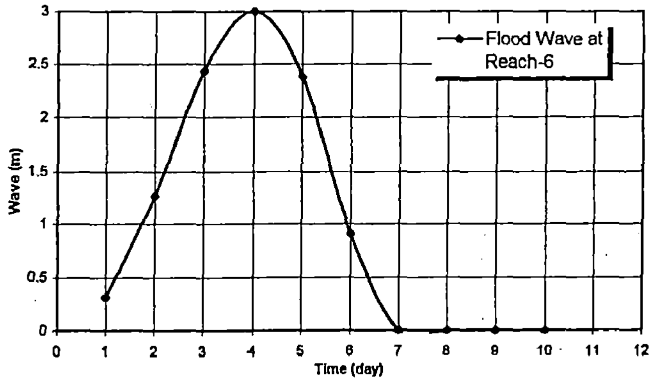
Reach-4	
Time (Hour)	Wave (M)
1	0.31737
2	1.27362
3	2.43821
4	2.99998
5	2.37525
6	0.90406
7	0.00004
8	0
9	0
10	0



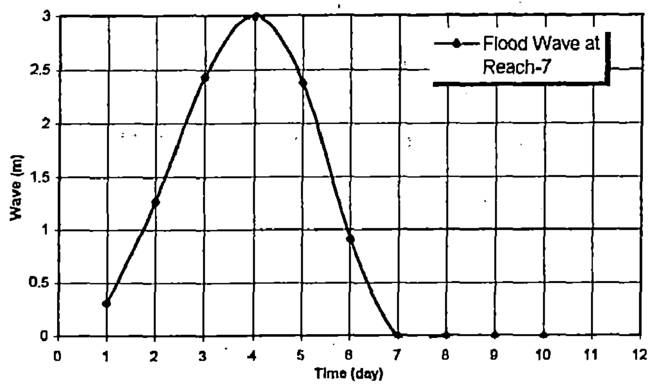
Reach-5	
Time (Hour)	Wave (M)
1	0.31668
2	1.27238
3	2.43716
4	2.99997
5	2.37651
6	0.90562
7	0.00006
8	0
9	0
10	0



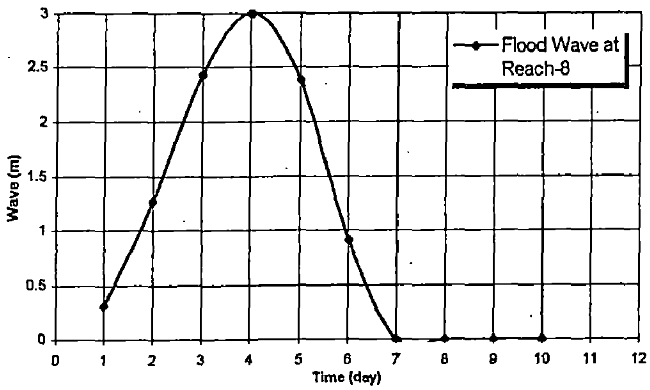
Reach-6	
Time (Hour)	Wave (M)
1	0.31596
2	1.2711
3	2.43606
4	2.99996
5	2.37783
6	0.90725
7	0.00008
8	0
9	0
10	0



Reach-7	
Time (Hour)	Wave (M)
1	0.31504
2	1.26945
3	2.43465
4	2.99994
5	2.37951
6	0.90933
7	0.00011
8	0
9	0
10	0



Reach-8	
Time (Hour)	Wave (M)
1	0.31387
2	1.26736
3	2.43285
4	2.99992
5	2.38164
6	0.91198
7	0.00015
8	0
9	0
10	0



APPENDIX - 3

COMPUTER PROGRAM

```
      DIMENSION GW(96),GX(96),DKERNEL(30,30,30),DPKER(5,30,30)
      DIMENSION XCORD(30),YCORD(30),AA(30),BB(30),DEPTHRB(30),
     1 SIGMA(30,30),DRAW(30,30),REACHT(30),PERIM(30),
     2 WAVE(30,30),DIST(30),SLOPE(30),VEL(30),TIMER(30),CMANING(30),
     3 XCORDP(10),YCORDP(10),QP(5),CC(30,30),AAAA(30,30),
     4 AAA(30,30),QR(30,30),RHS(30,30),RHS1(30),RHS2(30)
C     SIGMA=DEPTH TO WATER LEVEL IN THE STREAM FROM HIGH DATUM
C     DRAW= DEPTH TO WATER TABLE IN THE AQUIFER FROM THE HIGH DATUM
C     DEPTHRB=DEPTH TO RIVER BED

      open(3,status='old',file='GAUSS.DAT')
      open(1,status='old',file='ANDY9.DAT')
      open(2,status='new',file='andy9.out')

      READ(3,*) (gw(i),i=1,96)
      READ(3,*) (gx(i),i=1,96)

      READ(1,*)NWELL

      DO 101 I=1,NWELL
      READ(1,*)XCORDP(I),YCORDP(I),QP(I)
101   CONTINUE

C     CHECKING FROM BOUWER'S SOLUTION
C     T=2*5.333
C     A=10.
C     B=100.
C     PHI=0.15
C     NTIME=6
C     XX=0.
C     YY=0.

C     WRITE(2,*)T,PHI,XX,YY,NTIME,A,B
C     TIME=6.
C     CALL HANTUSH(T,PHI,GW,GX,XX,YY,TIME,A,B,RES)
C     RISE=0.2*RES
C     WRITE(2,*)RES,RISE

      PAI=3.14159265

      READ(1,*)WSDEPTH
      READ(1,*) T,PHI,THICK,DIMPS
      READ(1,*)HMAX,NTC,NDUR,NTIME
      READ(1,*)NREACH

      DO 5 I=1,NREACH
      READ (1,*) XCORD(I), YCORD(I), AA(I), BB(I),SLOPE(I),CMANING(I)
5     CONTINUE

      READ(1,*)XCORD(0),YCORD(0),DEPTHRB(1)
```

```
      AK=T/THICK
      SUM=0.

      DO 21 I=1,NREACH
      XX=XCORD(I)-XCORD(I-1)
      YY=YCORD(I)-YCORD(I-1)
      SUM=SUM+(XX**2+YY**2)**0.5
      DIST(I)=SUM
21    CONTINUE

      DO 22 I=1,NREACH
      WRITE(2,18)I,DIST(I)
22    CONTINUE

      DO 102 I=2,NREACH
      DEPTHRB(I)=DEPTHRB(I-1)+
     1          (SLOPE(I)+SLOPE(I-1))*0.5*(DIST(I)-DIST(I-1))
102   CONTINUE


      DO 103 I=1,NREACH
      SIGMA(I,0)=DEPTHRB(I)-WSDEPTH
103   CONTINUE

C
C     COMPUTATION OF REACH TRANSMISSIVITY
C

      DO 10 I=1,NREACH
      ADEPTHW=WSDEPTH+0.5*HMAX
      PERIM(I)=BB(I)+2.*ADEPTHW
      R=PERIM(I)/PAI
      SMALLM=DIMPS-DEPTHRB(I)+ADEPTHW
      REACHT(I)=AA(I)*PAI*AK/ALOG(0.5*SMALLM/R)
      IF(REACHT(I).LT.0)THEN
      SMALLE=DIMPS-DEPTHRB(I)
      REACHT(I)=AA(I)*T*(0.5*PERIM(I)+SMALLE) /
     1          (SMALLE*(4.*BB(I)+0.5*SMALLE))
      END IF
10    CONTINUE

      DO 20 I=1,NREACH
      WRITE(2,13)I,REACHT(I)
20    CONTINUE
      WRITE(2,*)'---------------------------'

C
C     COMPUTATION OF FLOOD WAVE AND SIGMA
C

      HYDRAD=BB(1)*ADEPTHW/PERIM(1)
      VEL(1)=HYDRAD**(2./3.)*SQRT(SLOPE(1))/CMANING(1)
      TIMER(1)=DIST(1)/(VEL(1)*3600.)

      DO 104 I=2,NREACH
      HYDRAD=BB(I)*ADEPTHW/PERIM(I)
      VEL(I)=HYDRAD**(2./3.)*SQRT(SLOPE(I))/CMANING(I)
```

```
      TIMER(I)=TIMER(I-1)+
   1            (DIST(I)-DIST(I-1))/(0.5*(VEL(I)+VEL(I-1))*3600.)
 104  CONTINUE

      W=2.*PAI/NDUR
      DEL=W/TAN(W*NTC/2.)
      AN=EXP(DEL*NTC)/(1.-COS(W*NTC))

      DO 400 J=1,NTIME
      AJ=J
      IF(J.GE.NDUR)GO TO 300
      WAVE(0,J)=HMAX*AN*(1.-COS(W*AJ))*EXP(-DEL*AJ)
      GO TO 400
 300  WAVE(0,N)=0.
 400  CONTINUE

C     WRITE(2,*)'WAVE AT ENTRY'
C     WRITE(2,*)(WAVE(0,J),J=1,NTIME)

      DO 700 J=1,NTIME
      AJ=J
      IF(TIMER(1).GE.AJ) GO TO 500
      IF((TIMER(1)+NDUR).LT.AJ) GO TO 500
      AJ1=AJ-TIMER(1)
      WAVE(1,J)=HMAX*AN*(1.-COS(W*AJ1))*EXP(-DEL*AJ1)
      GO TO 700
 500  WAVE(1,J)=0.
 700  CONTINUE
C     WRITE(2,*)'WAVE AT CENTRE OF FIRST NODE'
C     WRITE(2,*)(WAVE(1,J),J=1,NTIME)

      DO 8000 I=1,NREACH
      DO 7000 J=1,NTIME
      AJ=J
      IF(TIMER(I).GE.AJ) GO TO 5000
      IF((TIMER(I)+NDUR).LE.AJ) GO TO 5000
      AJ1=AJ-TIMER(I)
      WAVE(I,J)=HMAX*AN*(1.-COS(W*AJ1))*EXP(-DEL*AJ1)
      GO TO 7000
5000  WAVE(I,J)=0.
7000  CONTINUE
8000  CONTINUE

      WRITE(2,*)'WAVE AT CENTRE START FROM FIRST NODE'

      DO 106 I=1,NREACH
C     WRITE(2,*)'REACH NO=',I
C     WRITE(2,*)(WAVE(I,J),J=1,NTIME)

      DO 24 J=1,NTIME
      SIGMA(I,J)=SIGMA(I,0)-WAVE(I,J)
      WRITE(2,15)I,J,WAVE(I,J),I,J,SIGMA(I,J)
 24   CONTINUE
 106  CONTINUE
      WRITE(2,*)'------------------------'
```

```
C
C     COMPUTATION OF RECHARGE DISCRETE KERNEL
C

C     WRITE(2,*)'DISCRETE KERNEL'

      DO 30 I=1,NREACH
       A=0.5*AA(I)
       B=0.5*BB(I)

       DO 35 J=1,NREACH
        XX=XCORD(I)-XCORD(J)
       YY=YCORD(I)-YCORD(J)
        FIRST=0.

        DO 40 N=1,NTIME
        TIME=N
        CALL HANTUSH(T,PHI,GW,GX,XX,YY,TIME,A,B,RES)
        DKERNEL(I,J,N)=RES-FIRST
C      I=PERTURBATION POINT
C      J=OBSERVATION  POINT
       FIRST=RES
C      WRITE(2,16)I,J,N,DKERNEL(I,J,N)
40     CONTINUE
35     CONTINUE
30     CONTINUE


C
C     COMPUTATION OF PUMPING DISCRETE KERNEL
C

C     WRITE(2,*)'DISCRETE PUMPING KERNEL'

      BETA=T/PHI
      DO 107 I=1,NREACH
      DO 108 J=1,NWELL
      DISTRS=(XCORD(I)-XCORDP(J))**2+(YCORD(I)-YCORDP(J))**2
      TERM=DISTRS/(4.*BETA)
      FIRST=0.

      DO 109 N=1,NTIME
       AN=N
       U=TERM/AN
       CALL EXI(U,EXFN)
       DPKER(J,I,N)=(EXFN-FIRST)/(4.*PAI*T)
       FIRST=EXFN

C     WRITE(2,116)I,J,N,DPKER(J,I,N)
109   CONTINUE
108   CONTINUE
107   CONTINUE
```

```
C
C       COMPUTATION OF RECHARGE RATE FROM THE STREAM
C

        DO 201 I=1,NREACH
        DO 202 J=1,NREACH
        IF(I.EQ.J)THEN
        AAA(I,J)=1./REACHT(I)+DKERNEL(I,J,1)
        GO TO 202
        ENDIF
        AAA(I,J)=DKERNEL(J,I,1)
202     CONTINUE
201     CONTINUE

        DO 203 I=1,NREACH
        DO 204 J=1,NREACH
        CC(I,J)=AAA(I,J)
204     CONTINUE
203     CONTINUE

C       WRITE(2,*)'MATRIX ELEMENT'

        DO 205 I=1,NREACH
C       WRITE(2,*)(AAA(I,J),J=1,NREACH)
205     CONTINUE

        MMM=NREACH
        CALL MATIN (AAA,MMM)
C       WRITE(2,*)'MATRIX INVERSE'

        DO 206 I=1,NREACH
C       WRITE(2,*)(AAA(I,J),J=1,NREACH)
206     CONTINUE

C       WRITE(2,*)'CHECKING THE MATRIX INVERSION'
        KK=0
        DO 207 I=1,NREACH
        SUM=0
        KK=KK+1
        DO 208 J=1,NREACH
        SUM=SUM+CC(I,J)*AAA(J,I)
208     CONTINUE
        AAAA(I,KK)=SUM
207     CONTINUE

        DO 209 I=1,NREACH
C       WRITE(2,*)(AAAA(I,J),J=1,NREACH)
209     CONTINUE
```

```
C
C      COMPUTATION OF RECHARGE RATE FROM STREAM
C

C       FOR TIME STEP N=1

        DO 301 I=1,NREACH
        SUM1=0.
        DO 302 J1=1,NWELL
        SUM1=SUM1+QP(J1)*DPKER(J1,I,1)
302     CONTINUE
        RHS(I,1)=DIMPS-THICK+SUM1-SIGMA(I,1)
301     CONTINUE

        DO 303 I=1,NREACH
        SUM2=0.
        DO 304 J=1,NREACH
        SUM2=SUM2+AAA(I,J)*RHS(J,1)
304     CONTINUE
        QR(I,1)=SUM2
303     CONTINUE

C       FOR TIME STEP N=2,NTIME

        DO 333 N=2,NTIME

        DO 555 I=1,NREACH

        SUM1I=0.
        DO 305 J=1,NREACH
        DO 306 NGAMA=1,N-1
        SUM1I=SUM1I+QR(J,NGAMA)*DKERNEL(J,I,N-NGAMA+1)
306     CONTINUE
305     CONTINUE
        RHS1(I)=SUM1I

        SUM2QP=0.
        DO 307 J1=1,NWELL
        DO 308 NGAMA=1,N
        SUM2QP=SUM2QP+QP(J1)*DPKER(J1,I,N-NGAMA+1)
308     CONTINUE
307     CONTINUE

        RHS2(I)=SUM2QP

        RHS(I,N)=DIMPS-THICK-RHS1(I)+RHS2(I)-SIGMA(I,N)
555     CONTINUE

        DO 309 I=1,NREACH
        SUM3QR=0.
        DO 401 J=1,NREACH
        SUM3QR=SUM3QR+AAA(I,J)*RHS(J,N)
401     CONTINUE
        QR(I,N)=SUM3QR
309     CONTINUE

333     CONTINUE
```

```
C
C     COMPUTATION OF DRAWDOWN DUE TO RECHARGE AND PUMPING
C

      DO 403 I=1,NREACH
      DO 404 N=1,NTIME

      SUMQR=0.
      DO 405 J=1,NREACH
      DO 406 NGAMA=1,N
      SUMQR=SUMQR+QR(J,NGAMA)*DKERNEL(J,I,N-NGAMA+1)
406   CONTINUE
405   CONTINUE
      TERM1=SUMQR

      SUMQP=0.

      DO 407 J1=1,NWELL
      DO 408 NGAMA=1,N
      SUMQP=SUMQP+QP(J1)*DPKER(J1,I,N-NGAMA+1)
408   CONTINUE
407   CONTINUE

      TERM2=SUMQP
      DRAW(I,N)=DIMPS-THICK-TERM1+TERM2
404   CONTINUE
403   CONTINUE

      WRITE(2,*)'DRAWDOWN AND SIGMA'

      DO 501 I=1,NREACH
      DO 409 N=1,NTIME
      WRITE(2,110)I,N,DRAW(I,N),I,N,SIGMA(I,N)
409   CONTINUE
501   CONTINUE

C
C     CHEKING THE RESULT BY TWO EQUATION
C

      WRITE(2,*)'RECHARGE RATE AND CHEKING RESIDUE FROM TWO EQUATION'

      DO 502 I=1,NREACH
      DO 503 N=1,NTIME
      RESIDUE=(DRAW(I,N)-SIGMA(I,N))*REACHT(I)-QR(I,N)
      WRITE(2,220)I,N,QR(I,N),RESIDUE
503   CONTINUE
502   CONTINUE


13    FORMAT(2X,'REACHT(',I2,')=',F10.5)

15    FORMAT(2X,'WAVE(',I2,',''I2,')=',F10.5,5X,
     1 'SIGMA(',I2,',''I2,')=',F10.5)

16    FORMAT(2X,'DKERNEL(',I2,',',I2,',',I2,')=',F10.5)
```

```
18      FORMAT(2X,'DISTANCE(',I2,')=',F10.2)

116     FORMAT(2X,'DPKERNEL(',I2,',',I2,',',I2,')=',F10.5)

110     FORMAT(2X,'DRAWD(',I2,',',I2,')=',F10.5,5X,
      1 'SIGMA(',I2,',',I2,')=',F10.5)

220     FORMAT(2X,'QRATE(',I2,',',I2,')=',F10.5,5X,
      1 'RESIDUE=',F10.3)


        STOP
        END

        SUBROUTINE ERF(X,ERFX)
        XINDEX=X
        X1=X
        IF(X)4,5,5
4       X1=-X
5       CONTINUE
        IF(X1-15.)1,2,2
1       CONTINUE
        T=1.0/(1.0+0.3275911*X1)
        ERFX=1.0-(0.25482959*T-0.28449673*T**2+1.42141374*T**3-1.
      1 45315202*T**4+1.06140542*T**5)*EXP(-X1**2)
        GO TO3
2       ERFX=1.
3       CONTINUE
        IF(XINDEX)6,7,7
6       ERFX=-ERFX
7       CONTINUE
C       WRITE(2,52)X,ERFX
C52     FORMAT(2F10.5)
        RETURN
        END

        SUBROUTINE HANTUSH(T,PHI,GW,GX,XX,YY,TIME,A,B,RES)
        DIMENSION GW(96),GX(96)
        TERM5=2.*(T*TIME/PHI)**0.5
        TERM1=A+XX
        TERM2=B+YY
        TERM3=A-XX
        TERM4=B-YY
        TERM11=TERM1/TERM5
        TERM22=TERM2/TERM5
        TERM33=TERM3/TERM5
        TERM44=TERM4/TERM5
        SUM1=0.
        SUM2=0.
        SUM3=0.
        SUM4=0.

        DO 10 I=1,96
        V=GX(I)
        TERM=(0.5+0.5*V)**0.5
        X=TERM11/TERM
        CALL ERF(X,ERFX)
```

```
        ERFX1=ERFX
        X=TERM22/TERM
        CALL ERF(X,ERFX)
        ERFX2=ERFX
        X=TERM33/TERM
        CALL ERF(X,ERFX)
        ERFX3=ERFX
        X=TERM44/TERM
        CALL ERF(X,ERFX)
        ERFX4=ERFX
        ATERM1=ERFX1*ERFX2
        ATERM2=ERFX3*ERFX2
        ATERM3=ERFX1*ERFX4
        ATERM4=ERFX3*ERFX4
        SUM1=SUM1+0.5*ATERM1*GW(I)
        SUM2=SUM2+0.5*ATERM2*GW(I)
        SUM3=SUM3+0.5*ATERM3*GW(I)
        SUM4=SUM4+0.5*ATERM4*GW(I)
 10     CONTINUE
        RES=(SUM1+SUM2+SUM3+SUM4)*TIME*0.25/PHI
        RETURN
        END


        SUBROUTINE EXI(U,EXFN)
        X=U
        IF(X-1.0)10,10,20
 10     EXFN=-ALOG(X)-0.57721566+0.99999193*X-0.24991055*X**2
     1  +0.05519968*X**3-0.00976004*X**4+0.00107857*X**5
        RETURN
 20     CONTINUE
        IF(X- 80.)50,40,40
 50     CONTINUE
        EXFN=((X**4+8.5733287*X**3+18.059017*X**2+8.6347608*X
      1 +0.26777373)/(X**4+9.5733223*X**3+25.632956*X**2+21.099653*X
      2 +3.9584969))/(X*EXP(X))
        RETURN
 40     EXFN=0.
        RETURN
        END


        SUBROUTINE MATIN (AAA,MMM)
        DIMENSION AAA(30,30),B(30),C(30)
        NN=MMM-1
        AAA(1,1)=1./AAA(1,1)
        DO 8 M=1,NN
        K=M+1
        DO 3 I=1,M
        B(I)=0.0
        DO 3 J=1,M
 3      B(I)=B(I)+AAA(I,J)*AAA(J,K)
        D=0.0
        DO 4 I=1,M
 4      D=D+AAA(K,I)*B(I)
        D=-D+AAA(K,K)
 C      WRITE(2,*)'D=',D
```

```
      AAA(K,K)=1./D
C     WRITE(2,*)'K=',K,'AAA(K,K)=',AAA(K,K)
      DO 5 I=1,M
5     AAA(I,K)=-B(I)*AAA(K,K)
      DO 6 J=1,M
      C(J)=0.0
      DO 6 I=1,M
6     C(J)=C(J)+AAA(K,I)*AAA(I,J)
      DO 7 J=1,M
7     AAA(K,J)=-C(J)*AAA(K,K)
      DO 8 I=1,M
      DO 8 J=1,M
8     AAA(I,J)=AAA(I,J)-B(I)*AAA(K,J)
      RETURN
      END
```

APPENDIX - 4 : EXAMPLE OUT PUT OF PROGRAM

CASE : MEANDERING STREAM,AQUIFER AND WELL INTERACTION WITHOUT CONSIDERING OF FLOOD WAVE

REACH TRANSMISSIVITY:

REACHT(1)=	115.45
REACHT(2)=	121.95
REACHT(3)=	138.11
REACHT(4)=	144.07
REACHT(5)=	144.08
REACHT(6)=	138.16
REACHT(7)=	122.04
REACHT(8)=	115.59

FLOOD WAVE:

WAVE(1, 1)=	.00000	SIGMA(1, 1)=	98.00000
WAVE(1, 2)=	.00000	SIGMA(1, 2)=	98.00000
WAVE(1, 3)=	.00000	SIGMA(1, 3)=	98.00000
WAVE(1, 4)=	.00000	SIGMA(1, 4)=	98.00000
WAVE(1, 5)=	.00000	SIGMA(1, 5)=	98.00000
WAVE(1, 6)=	.00000	SIGMA(1, 6)=	98.00000
WAVE(1, 7)=	.00000	SIGMA(1, 7)=	98.00000
WAVE(1, 8)=	.00000	SIGMA(1, 8)=	98.00000
WAVE(1, 9)=	.00000	SIGMA(1, 9)=	98.00000
WAVE(1,10)=	.00000	SIGMA(1,10)=	98.00000
WAVE(2, 1)=	.00000	SIGMA(2, 1)=	98.01720
WAVE(2, 2)=	.00000	SIGMA(2, 2)=	98.01720
WAVE(2, 3)=	.00000	SIGMA(2, 3)=	98.01720
WAVE(2, 4)=	.00000	SIGMA(2, 4)=	98.01720
WAVE(2, 5)=	.00000	SIGMA(2, 5)=	98.01720
WAVE(2, 6)=	.00000	SIGMA(2, 6)=	98.01720
WAVE(2, 7)=	.00000	SIGMA(2, 7)=	98.01720
WAVE(2, 8)=	.00000	SIGMA(2, 8)=	98.01720
WAVE(2, 9)=	.00000	SIGMA(2, 9)=	98.01720
WAVE(2,10)=	.00000	SIGMA(2,10)=	98.01720
WAVE(3, 1)=	.00000	SIGMA(3, 1)=	98.03065
WAVE(3, 2)=	.00000	SIGMA(3, 2)=	98.03065
WAVE(3, 3)=	.00000	SIGMA(3, 3)=	98.03065
WAVE(3, 4)=	.00000	SIGMA(3, 4)=	98.03065
WAVE(3, 5)=	.00000	SIGMA(3, 5)=	98.03065
WAVE(3, 6)=	.00000	SIGMA(3, 6)=	98.03065
WAVE(3, 7)=	.00000	SIGMA(3, 7)=	98.03065
WAVE(3, 8)=	.00000	SIGMA(3, 8)=	98.03065
WAVE(3, 9)=	.00000	SIGMA(3, 9)=	98.03065
WAVE(3,10)=	.00000	SIGMA(3,10)=	98.03065
WAVE(4, 1)=	.00000	SIGMA(4, 1)=	98.04109
WAVE(4, 2)=	.00000	SIGMA(4, 2)=	98.04109
WAVE(4, 3)=	.00000	SIGMA(4, 3)=	98.04109
WAVE(4, 4)=	.00000	SIGMA(4, 4)=	98.04109
WAVE(4, 5)=	.00000	SIGMA(4, 5)=	98.04109
WAVE(4, 6)=	.00000	SIGMA(4, 6)=	98.04109

```
WAVE( 4, 7)=  .00000   SIGMA( 4, 7)= 98.04109
WAVE( 4, 8)=  .00000   SIGMA( 4, 8)= 98.04109
WAVE( 4, 9)=  .00000   SIGMA( 4, 9)= 98.04109
WAVE( 4,10)=  .00000   SIGMA( 4,10)= 98.04109
WAVE( 5, 1)=  .00000   SIGMA( 5, 1)= 98.05109
WAVE( 5, 2)=  .00000   SIGMA( 5, 2)= 98.05109
WAVE( 5, 3)=  .00000   SIGMA( 5, 3)= 98.05109
WAVE( 5, 4)=  .00000   SIGMA( 5, 4)= 98.05109
WAVE( 5, 5)=  .00000   SIGMA( 5, 5)= 98.05109
WAVE( 5, 6)=  .00000   SIGMA( 5, 6)= 98.05109
WAVE( 5, 7)=  .00000   SIGMA( 5, 7)= 98.05109
WAVE( 5, 8)=  .00000   SIGMA( 5, 8)= 98.05109
WAVE( 5, 9)=  .00000   SIGMA( 5, 9)= 98.05109
WAVE( 5,10)=  .00000   SIGMA( 5,10)= 98.05109
WAVE( 6, 1)=  .00000   SIGMA( 6, 1)= 98.06153
WAVE( 6, 2)=  .00000   SIGMA( 6, 2)= 98.06153
WAVE( 6, 3)=  .00000   SIGMA( 6, 3)= 98.06153
WAVE( 6, 4)=  .00000   SIGMA( 6, 4)= 98.06153
WAVE( 6, 5)=  .00000   SIGMA( 6, 5)= 98.06153
WAVE( 6, 6)=  .00000   SIGMA( 6, 6)= 98.06153
WAVE( 6, 7)=  .00000   SIGMA( 6, 7)= 98.06153
WAVE( 6, 8)=  .00000   SIGMA( 6, 8)= 98.06153
WAVE( 6, 9)=  .00000   SIGMA( 6, 9)= 98.06153
WAVE( 6,10)=  .00000   SIGMA( 6,10)= 98.06153
WAVE( 7, 1)=  .00000   SIGMA( 7, 1)= 98.07498
WAVE( 7, 2)=  .00000   SIGMA( 7, 2)= 98.07498
WAVE( 7, 3)=  .00000   SIGMA( 7, 3)= 98.07498
WAVE( 7, 4)=  .00000   SIGMA( 7, 4)= 98.07498
WAVE( 7, 5)=  .00000   SIGMA( 7, 5)= 98.07498
WAVE( 7, 6)=  .00000   SIGMA( 7, 6)= 98.07498
WAVE( 7, 7)=  .00000   SIGMA( 7, 7)= 98.07498
WAVE( 7, 8)=  .00000   SIGMA( 7, 8)= 98.07498
WAVE( 7, 9)=  .00000   SIGMA( 7, 9)= 98.07498
WAVE( 7,10)=  .00000   SIGMA( 7,10)= 98.07498
WAVE( 8, 1)=  .00000   SIGMA( 8, 1)= 98.09219
WAVE( 8, 2)=  .00000   SIGMA( 8, 2)= 98.09219
WAVE( 8, 3)=  .00000   SIGMA( 8, 3)= 98.09219
WAVE( 8, 4)=  .00000   SIGMA( 8, 4)= 98.09219
WAVE( 8, 5)=  .00000   SIGMA( 8, 5)= 98.09219
WAVE( 8, 6)=  .00000   SIGMA( 8, 6)= 98.09219
WAVE( 8, 7)=  .00000   SIGMA( 8, 7)= 98.09219
WAVE( 8, 8)=  .00000   SIGMA( 8, 8)= 98.09219
WAVE( 8, 9)=  .00000   SIGMA( 8, 9)= 98.09219
WAVE( 8,10)=  .00000   SIGMA( 8,10)= 98.09219
```

RECHARGE RATE AND CHEKING RESIDUE

```
QRATE( 1, 1)=  .10180   RESIDUE=   .000
QRATE( 2, 1)=  .07149   RESIDUE=   .000
QRATE( 3, 1)=  .07926   RESIDUE=   .000
QRATE( 4, 1)=  .08219   RESIDUE=   .000
QRATE( 5, 1)=  .08186   RESIDUE=  -.001
QRATE( 6, 1)=  .07810   RESIDUE=   .000
QRATE( 7, 1)=  .06962   RESIDUE=   .000
QRATE( 8, 1)=  .09653   RESIDUE=   .000
```

```
QRATE( 1, 2)=  .07152   RESIDUE=   .000
QRATE( 2, 2)=  .04146   RESIDUE=   .000
QRATE( 3, 2)=  .04836   RESIDUE=   .000
QRATE( 4, 2)=  .05256   RESIDUE=   .000
QRATE( 5, 2)=  .05237   RESIDUE=   .000
QRATE( 6, 2)=  .04765   RESIDUE=   .000
QRATE( 7, 2)=  .04030   RESIDUE=   .000
QRATE( 8, 2)=  .06730   RESIDUE=   .000
QRATE( 1, 3)=  .06071   RESIDUE=   .000
QRATE( 2, 3)=  .03335   RESIDUE=   .000
QRATE( 3, 3)=  .03995   RESIDUE=   .000
QRATE( 4, 3)=  .04460   RESIDUE=   .000
QRATE( 5, 3)=  .04443   RESIDUE=   .000
QRATE( 6, 3)=  .03933   RESIDUE=   .000
QRATE( 7, 3)=  .03234   RESIDUE=   .000
QRATE( 8, 3)=  .05678   RESIDUE=   .000
QRATE( 1, 4)=  .05496   RESIDUE=   .000
QRATE( 2, 4)=  .02969   RESIDUE=   .000
QRATE( 3, 4)=  .03610   RESIDUE=   .000
QRATE( 4, 4)=  .04103   RESIDUE=   .000
QRATE( 5, 4)=  .04087   RESIDUE=   .000
QRATE( 6, 4)=  .03554   RESIDUE=   .000
QRATE( 7, 4)=  .02874   RESIDUE=   .000
QRATE( 8, 4)=  .05116   RESIDUE=   .000
QRATE( 1, 5)=  .05131   RESIDUE=   .000
QRATE( 2, 5)=  .02757   RESIDUE=   .000
QRATE( 3, 5)=  .03385   RESIDUE=   .000
QRATE( 4, 5)=  .03896   RESIDUE=   .000
QRATE( 5, 5)=  .03881   RESIDUE=   .000
QRATE( 6, 5)=  .03331   RESIDUE=   .000
QRATE( 7, 5)=  .02666   RESIDUE=   .000
QRATE( 8, 5)=  .04759   RESIDUE=   .000
QRATE( 1, 6)=  .04874   RESIDUE=   .000
QRATE( 2, 6)=  .02615   RESIDUE=   .000
QRATE( 3, 6)=  .03234   RESIDUE=   .000
QRATE( 4, 6)=  .03758   RESIDUE=   .000
QRATE( 5, 6)=  .03743   RESIDUE=   .000
QRATE( 6, 6)=  .03181   RESIDUE=   .000
QRATE( 7, 6)=  .02526   RESIDUE=   .000
QRATE( 8, 6)=  .04507   RESIDUE=   .000
QRATE( 1, 7)=  .04681   RESIDUE=   .000
QRATE( 2, 7)=  .02511   RESIDUE=   .000
QRATE( 3, 7)=  .03122   RESIDUE=   .000
QRATE( 4, 7)=  .03658   RESIDUE=   .000
QRATE( 5, 7)=  .03644   RESIDUE=   .000
QRATE( 6, 7)=  .03071   RESIDUE=   .000
QRATE( 7, 7)=  .02424   RESIDUE=   .000
QRATE( 8, 7)=  .04317   RESIDUE=   .000
QRATE( 1, 8)=  .04529   RESIDUE=   .000
QRATE( 2, 8)=  .02430   RESIDUE=   .000
QRATE( 3, 8)=  .03036   RESIDUE=   .000
QRATE( 4, 8)=  .03581   RESIDUE=   .000
QRATE( 5, 8)=  .03567   RESIDUE=   .000
QRATE( 6, 8)=  .02985   RESIDUE=   .000
QRATE( 7, 8)=  .02344   RESIDUE=   .000
QRATE( 8, 8)=  .04167   RESIDUE=   .000
```

QRATE(1, 9)=	.04405	RESIDUE=	.000
QRATE(2, 9)=	.02364	RESIDUE=	.000
QRATE(3, 9)=	.02966	RESIDUE=	.000
QRATE(4, 9)=	.03519	RESIDUE=	.000
QRATE(5, 9)=	.03506	RESIDUE=	.000
QRATE(6, 9)=	.02916	RESIDUE=	.000
QRATE(7, 9)=	.02280	RESIDUE=	.000
QRATE(8, 9)=	.04045	RESIDUE=	.000
QRATE(1,10)=	.04302	RESIDUE=	.000
QRATE(2,10)=	.02309	RESIDUE=	.000
QRATE(3,10)=	.02908	RESIDUE=	.000
QRATE(4,10)=	.03469	RESIDUE=	.000
QRATE(5,10)=	.03456	RESIDUE=	.000
QRATE(6,10)=	.02859	RESIDUE=	.000
QRATE(7,10)=	.02226	RESIDUE=	.000
QRATE(8,10)=	03943	RESIDUE=	.000

REFFERENCE

1. Morel-Seytoux, H.J and C.J. Daly (1975), 'A Discrete Kernel Generator for Stream Aquifer Studies', Water Resources Research, V.II,no-29, pp: 253-260.

2. Eagleson,' Dynamic Hydrology', McGraw Hill Book Company, New York, 1970.

3. Morel-Seytoux, H.J., T. Illangasekare, G. Peters, 1979, ' Field Verification of The Concept of Reach Transmissivity.', Proceedings of The Canbera Symposium, December, IASHI-AISH Publ. no. 128, pp: 355-359.

4. Bouwer.H, 'Groundwater Hydrology', McGraw Hill Book Company, New York, 1978

5. Hantush. M.S. (1967), 'Growth and Decay of Groundwater Mounds in Response to Uniform Percolation.' ,Water Resources Research, V.3, pp: 227-234.

6. Herbert. R. 1970, 'Modeling Partially Penetrating Rivers on Aquifers Model.', Groundwater, Vol. 8, pp: 29-36.

7. Francis W. Sears, Mark W. Zemansky, Hugh D. Young,' University Physics', Six edition, Narosa publishing house, 1985.