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Analysis of Groundwater Depletion and Recharge in Northwestern Bangladesh

Muhammad S. Khan
University of Rhode Island

ANALYSIS OF GROUNDWATER DEPLETION AND RECHARGE IN NORTHWESTERN BANGLADESH

BY

MUHAMMAD S. KHAN

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ABSTRACT

The decline of groundwater levels during the dry season was evaluated in a study area in northwestern Bangladesh. The feasibility of using recharge basins and recharge wells as a means for recharging the groundwater during the dry season was analyzed.

A two-dimensional finite-difference computer model of groundwater flow (MODFLOW) was used in conjunction with a field scale computer model of runoff from agricultural management systems (CREAMS) to evaluate the natural or artificial recharge to the groundwater from precipitation. Effects of artificial recharge from six recharge wells and four recharge basins were analyzed. Irrigation during the dry season utilizing the artificially recharged groundwater proved to be technically feasible.

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I. INTRODUCTION

The movement of groundwater is a part of the hydrologic cycle. An understanding of the role of groundwater in this cycle and the ability of man to manipulate it is mandatory if integrated analyses are to be performed to assess the problems associated with the watershed resources and enhance its availability. Groundwater should be treated as more than a human resource for it is also an important feature in the maintenance of ecologic balance. Its excess or deficiencies may lead to human and/or environmental problems, but at the same time, groundwater offers a medium for solutions to these problems.

Depletion of groundwater is a common phenomenon in the natural environment which may be the result of various artificial and natural circumstances, such as diversion of river flows or reduced recharge from precipitation. Depletion of groundwater may cause reduced growth of vegetation, posing adverse impact on the natural environment. Less availability of water for irrigation or drinking purposes and salt water intrusion along the coast line as a supplementary effect, may result from lowering of groundwater levels (Todd,1980; Freeze and Cherry,1979).

Attempts have been made to sustain the groundwater levels using various methods, such as recharging the groundwater artificially using recharge basins and wells (Kashef,1986), using subsurface dams (Hanson and Nilsson,1986; Suqio,Nakada, and Urish,1987) to maintain useable groundwater levels, and using irrigation return flows (Bouwer,1978). Use of recharge basins and recharge wells are widespread methods and their design, installation, operation, and maintenance do not require much effort. However, like any other artificial recharge method, implementation is not as simple as the theory holds. Major problems associated with the method include clogging of the recharge bed with finer particles (Kashef,1986) and air entrapment in the recharge wells (Freeze and Cherry,1979).

Evaluation of the potential impact of using artificial recharge methods to control groundwater levels is a complex task. An extensive analysis of the different processes involved in the hydrologic cycle is required to predict the effects of using such methods.

In order to analyze the feasibility of using recharge basins and recharge wells to recharge the groundwater artificially, numerical computer models may be used as tools to overcome the complexities involved in the analysis. However, a model has to be calibrated and validated with field observations before it can be used to predict the effect of future modifications to the existing field conditions.

In addition to analyzing the feasibility of using an artificial recharge method, the computer models may also be used to assess various management options. For example, a model may be used to determine optimal locations for recharge, the most suitable engineering approach and management practice to augment the groundwater recharge.

The objectives of this study were 1) to evaluate the decline of groundwater levels in a study area and 2) to analyze the feasibility of using recharge basins and recharge wells as a means for recharging the groundwater artificially.

Two computer models were involved in this study to evaluate the recharge to groundwater. A field scale model, CREAMS (Knisel,1980), was used to determine the deep percolation to groundwater. A finite-difference groundwater flow model, MODFLOW (McDonald and Harbaugh,1984), was used to determine the groundwater levels after recharge to groundwater takes place. Recharge basins and recharge wells were superimposed on the area to predict the possible increase in groundwater recharge.

II. MODELING APPROACH

2.1 Model Descriptions

CREAMS

The hydrology component of the CREAMS model was utilized to predict the deep percolation to groundwater using daily precipitation records. This physically based model can be applied on a field scale. A field is defined (Knisel,1980) as a management unit having (1) a single land use, (2) relatively homogeneous soils, (3) spatially uniform rainfall, and (4) single management practices, such as conservation tillage or terraces.

The simulation of hydrologic response includes models for infiltration, soil water movement, and soil/plant evapotranspiration between storms. A time step of one day was used for evaporation and soil water movement between storms. The simulation for the period between storms provides prediction of amount of seepage below the root zone. A schematic representation of the processes involved in the model is shown in Figure 2.1. A generalized flow chart of the simulation is presented in Figure 2.2.

Infiltration and runoff is predicted using SCS curve

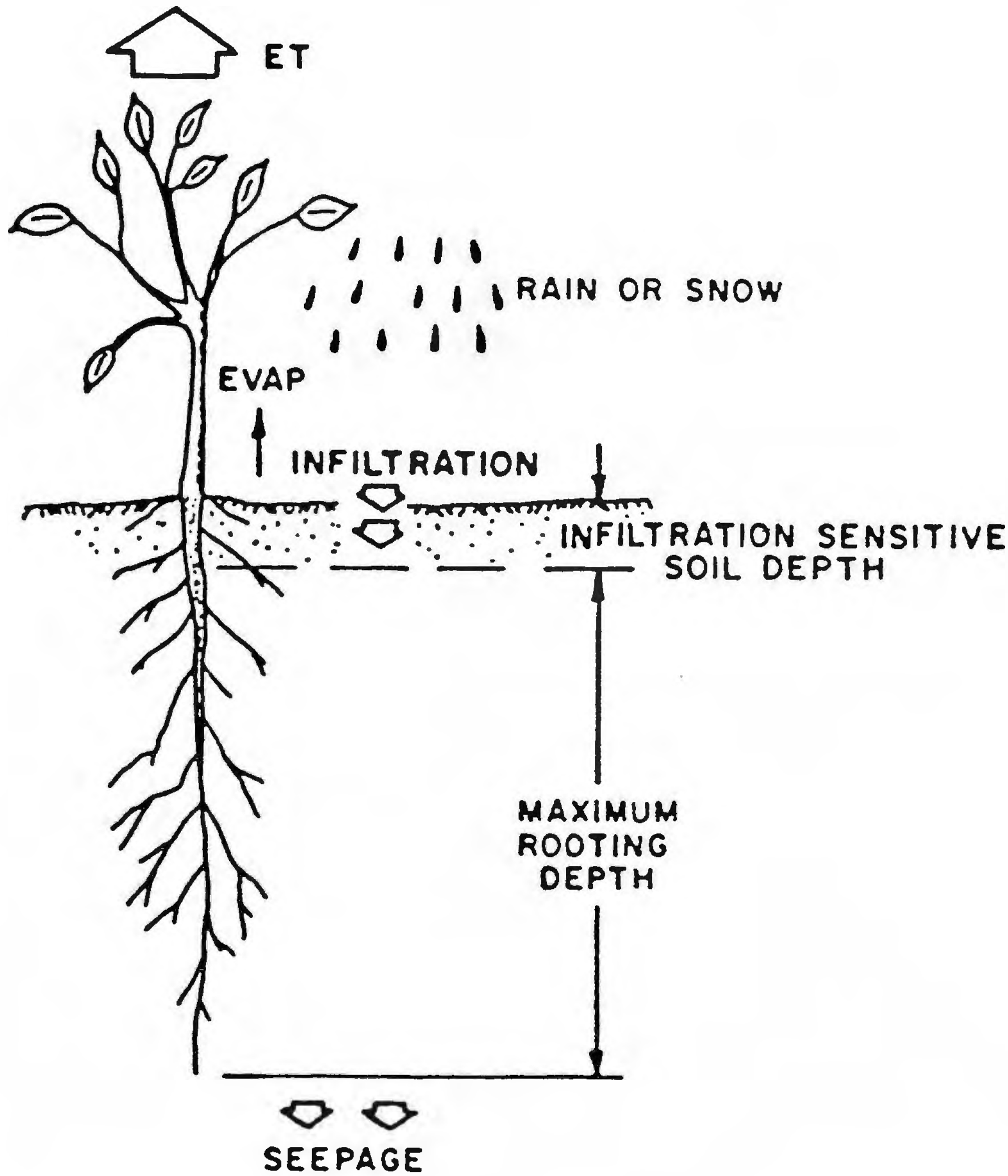


Figure 2.1 : Schematic representation of CREAMS hydrology option (Knisel, 1980).

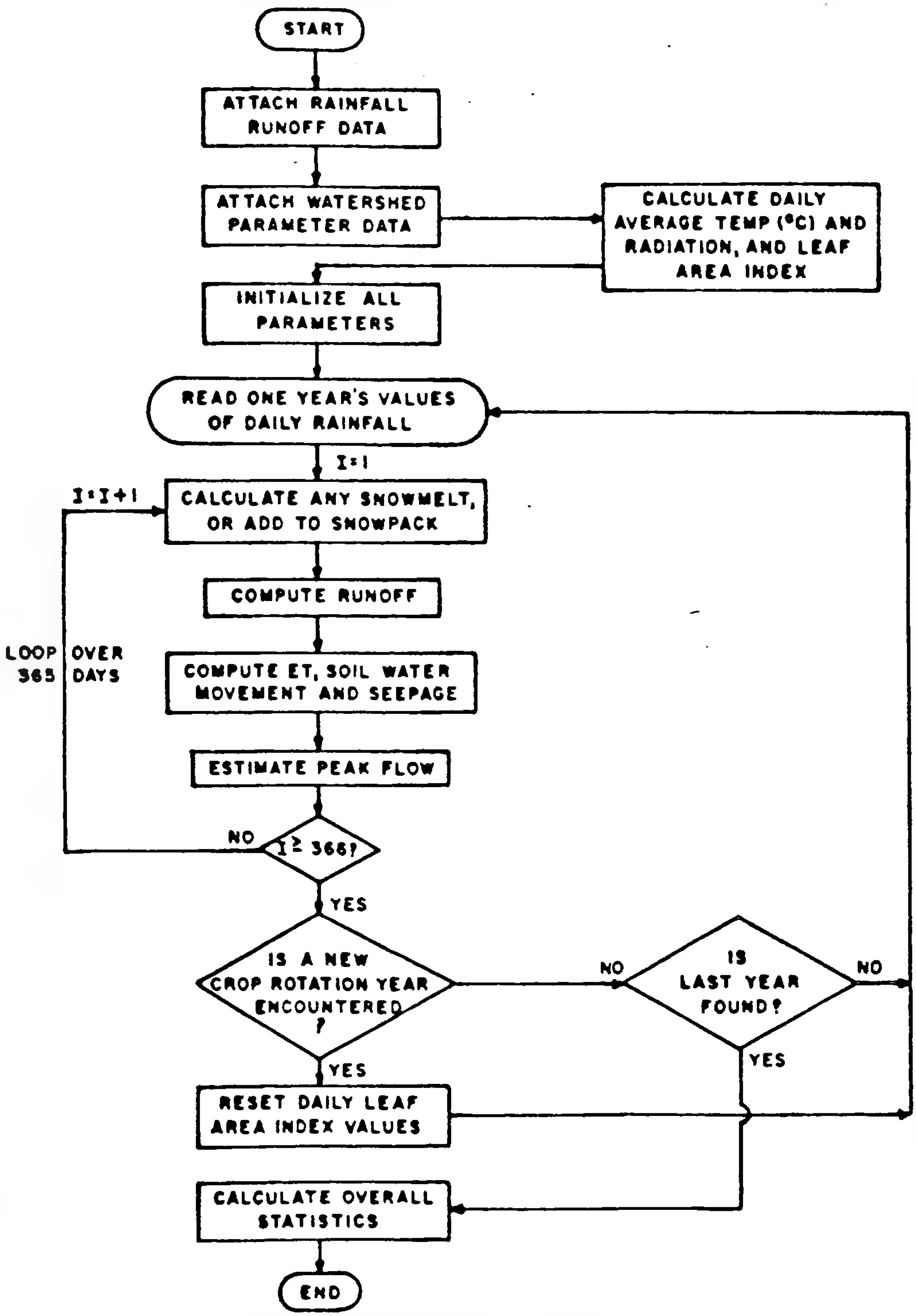


Figure 2.2 : Generalized flow chart for CREAMS hydrology option (Knisel, 1980).

number technique (USDA,1972) from daily rainfall. An antecedent rainfall index is used to estimate the antecedent moisture as one of the three conditions (I-dry, II-normal, and III-wet). The relation between rainfall and runoff for these three conditions is expressed as a curve number (CN). Runoff is predicted using the SCS equation :

$$Q = \frac{(P - 0.2s)^2}{P + 0.8s} \qquad [2.1]$$

where Q is the daily runoff; P is the daily rainfall; and s is the retention parameter, all having dimensions of length. The retention parameter is related to soil water content with the equation :

$$s = s_{mx} \left(\frac{UL - SM}{UL}\right) \qquad [2.2]$$

where SM is the soil water content in the root zone, UL is the upper limit of soil water storage in the root zone, and s_{mx} is the maximum value of s. The maximum value of s is estimated with the I moisture condition CN using the SCS equation :

$$s_{mx} = \frac{1000}{CN_I} - 10 \qquad [2.3]$$

where CN_I is the curve number (0 to 100) for moisture condition I. Curve numbers for other moisture conditions and different management practices or hydrologic conditions have been updated based on experiments performed under different field conditions.

To account for the soil water distribution along the depth, the root zone is divided into seven layers and weighing factors (decreasing with depth).

Water that enters the soil, becomes either evapotranspiration, storage, or seepage below the root zone. The components of the water balance equation in the soil are evaluated with a time step of one day. The water balance can be expressed by the equation :

$$SM_i = SM_{i-1} + F_i - ET_i - O_i + M_i \qquad [2.4]$$

where F_i = infiltration from direct precipitation on day i

ET_i = plant and soil evapotranspiration on day i.

O_i = seepage below the root zone on day i

M_i = snow melt amount on day i

SM = soil water storage in the root zone.

A snow accumulation and snow melt equation (Stewart et al.,1975) is used by the model to account for the snow melt component of the water balance equation.

The evapotranspiration (ET) component is computed by the method followed by Ritchie (1972). Potential evaporation is computed by the equation :

$$E_0 = \frac{1.28\ \Delta H_0}{\Delta + \gamma} \qquad [2.5]$$

where E_0 is the potential evaporation; Δ is the slope of the saturation vapor pressure curve at the mean air temperature; H_0 is the net solar radiation; and γ is a psychometric constant. Δ is computed with the equation :

$$\Delta = \frac{5304}{T^2}\ e^{(21.255\ -\ 5304/T)} \qquad [2.6]$$

where T is the daily temperature in degrees kelvin. H_0 is calculated with the equation :

$$H_0 = \frac{(1 - \lambda)\ (R)}{58.3} \qquad [2.7]$$

where R is the daily solar radiation in langleys and λ is the albedo for solar radiation.

Potential daily soil evaporation is predicted with the equation :

$$E_{SO} = E_0\ e^{-0.4\ (LAI)} \qquad [2.8]$$

where E_{SO} is the potential evaporation at the soil surface and LAI is the leaf area index defined as the area of the plant leaves relative to the soil surface area. Actual soil evaporation is computed in two stages. In the first stage, soil evaporation is limited only by the energy available at the surface, and thus is equal to the potential soil evaporation. Stage one upper limit of evaporation is computed with the equation :

$$U = 9(\alpha_s - 3)^{0.42} \qquad [2.9]$$

where U is the stage one upper limit in mm and α_s is soil evaporation parameter (ranges from 3.3 to 5.5 mm/$d^{1/2}$). When the accumulated soil evaporation exceeds U, the stage two evaporative process begins. Stage two daily soil evaporation is predicted with the equation :

$$E_s = \alpha_s[t^{1/2} - (t - 1)^{1/2}] \qquad [2.10]$$

where E_s is the soil evaporation for day t, and t is the number of days since stage two evaporation began.

Plant evaporation (transpiration) is computed with the equations :

$$E_p = \frac{(E_0)(LAI)}{3}, \quad 0 \le LAI \le 3 \qquad [2.11]$$

$$E_p = E_0 - E_s, \quad LAI > 3 \qquad [2.12]$$

If soil moisture is limited, plant evaporation is reduced with the equation :

$$E_{PL} = \frac{(E_p)(SM)}{0.25\ FC}, \quad SM \le 0.25\ FC \qquad [2.13]$$

where E_p is the normal plant evaporation; E_{PL} is plant evaporation reduced by limited SM; and FC is the field capacity of the soil. Evapotranspiration, the sum of plant and soil evaporation, can not exceed E_0.

Drought conditions are considered when the soil moisture falls below 15 bar amount or the permanent wilting point of the plant. Plant growth is stopped by holding the leaf area index constant until water becomes available.

Percolation or flow through the root zone is predicted using a soil storage routing technique (Williams and Hann,1978). The root zone is divided into seven layers or storages for routing. The routing equation is :

$$O = \sigma \left(F + \frac{ST}{\Delta t} \right), \quad \left(F + \frac{ST}{\Delta t}\right) > FC \qquad [2.14]$$

where F is the infiltration or inflow rate; ST is the storage volume; σ is the storage coefficient; and Δt is the routing interval (one day). If inflow plus storage does not exceed field capacity, FC, percolation is not predicted to occur. The storage coefficient is expressed by the equation :

$$\sigma = \frac{2\,\Delta t}{2t + \Delta t} \qquad [2.15]$$

where t is the travel time through a storage. Travel time is estimated with the equation :

$$t = \frac{SM - FC}{r_c} \qquad [2.16]$$

where SM is soil water storage, and r_c is the saturated hydraulic conductivity of the soil.

Since each soil storage is subject to ET losses, the daily predicted ET must be distributed properly through the storages. A simulation of water use by root growth is expressed by the equation :

$$u = u_0 \, e^{-4.16(RD)} \qquad [2.17]$$

where u is the water use rate by the crop at root depth, RD, and u_0 is the rate at the surface.

Extraction of water occurs from both surface and root zones in proportion to the relative root depth, which varies with leaf area index up to the maximum depth. Seepage from the root zone is predicted to occur when the moisture content exceeds the field capacity.

MODFLOW

In this study, MODFLOW (McDonald and Harbaugh,1984) was used to simulate the flow from external stresses, such as flow to and from wells, areal recharge, and flow through the bottom of the recharge basins. Groundwater flow within the aquifer is simulated using a block-centered finite-difference approach. Layers can be simulated as confined, unconfined, or a combination of confined and unconfined.

The three-dimensional movement of groundwater of constant density through porous earth material may be described by the partial differential equation :

$$\frac{\delta}{\delta x}(K_{xx}\frac{\delta h}{\delta x}) + \frac{\delta}{\delta y}(K_{yy}\frac{\delta h}{\delta y}) + \frac{\delta}{\delta z}(K_{zz}\frac{\delta h}{\delta z}) - W = S_s\frac{\delta h}{\delta t} \qquad [2.18]$$

where x, y, and z are cartesian coordinates aligned along the major axes of hydraulic conductivity K_{xx}, K_{yy}, K_{zz}; h is the potentiometric head (L); W is a volumetric flux per unit volume and represents sources and/or sinks of water (T^{-1}); S_s is the specific storage of the porous material (L^{-1}); and t is time (T).

In general, S_s, K_{xx}, K_{yy}, K_{zz} may be functions of space and h and W may be functions of space and time. Therefore, equation 2.18 describes groundwater flow under non-equilibrium conditions in a heterogeneous and anisotropic medium.

The continuity equation is the basis for development of the groundwater flow equation in finite-difference form. The continuity equation can be stated as : the sum of all flows into and out of the cell must be equal to the rate of change in storage within the cell. Under the assumption that the density of groundwater is constant, the continuity equation expressing the balance of flow for a cell is :

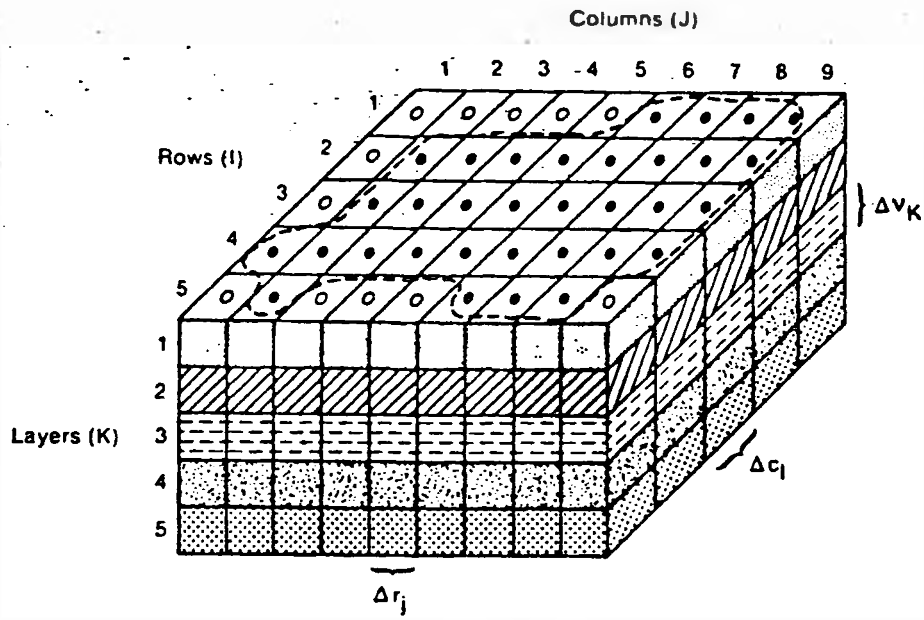
$$\sum Q_i = S_s\frac{\Delta h}{\Delta t}\,\Delta V \qquad [2.19]$$

where Q_i is a flow rate into the cell (L^3T^{-1}); S_s is the specific storage defined as the ratio of volume of water which can be injected per unit volume of aquifer material per unit change in head (L^{-1}); ΔV is the volume of the cell (L^3); and Δh is the change in head over a time interval of length Δt. Thus a system of equations is developed to represent the flow system in each cell of the aquifer system.

A mathematical model of groundwater flow consists of equation 2.18 along with specification of flow and/or head conditions at the boundaries of an aquifer system and specification of initial head conditions.

In order to utilize the mathematical model, the aquifer system must be discretized into a finite number of cells. Figure 2.3 shows a spatial discretization of an aquifer system into a mesh of points termed nodes, forming rows, columns, and layers. Conceptually, nodes represent prisms of porous material, termed cells, within which the hydraulic properties are constant so that any value associated with a node applies to or is distributed over the extent of a cell. According to the block-centered formulation, the blocks formed by the sets of parallel lines are the cells; the nodes are at the center of the cells.

Different cell types are used to represent various types of boundaries. In general, the types of boundaries that may be imposed in the model include constant-head, no-flow,



Explanation

- - - - Aquifer Boundary

● Active Cell

o Inactive Cell

Δr_J Dimension of Cell Along the Row Direction. Subscript (J) Indicates the Number of the Column

Δc_I Dimension of Cell Along the Column Direction. Subscript (I) Indicates the Number of the Row

Δv_K Dimension of the Cell Along the Vertical Direction. Subscript (K) Indicates the Number of the Layer

Figure 2.3 : A discretized hypothetical aquifer system (McDonald and Harbaugh, 1984).

constant-flow, and head dependent flow. An example of the use of no-flow and constant-head cells to simulate boundary conditions is shown in Figure 2.4. There are two types of boundaries that are integral to the model : an exterior no-flow boundary at the edges of the model grid and internal boundaries consisting of no-flow and constant-head cells. Other boundary conditions such as specified flux can be simulated as a combination of no-flow boundaries and external stresses. However, it is not necessary to place no-flow boundaries at the exterior nodes of the grid.

The period of simulation is divided into a series of 'stress periods' within which all external stresses are constant. Each stress period, in turn, may be divided into a series of time steps. The system of finite-difference equations representing the aquifer system is formulated and solved to produce head at each node at the end of each time step. A generalized flow chart for the simulation is presented in Figure 2.5.

The computer program consists of a main program and a large number of highly independent subroutines called modules. These modules are, in turn, organized into 'packages' and 'procedures'. Table 2.1 shows the list of packages that constitute the model.

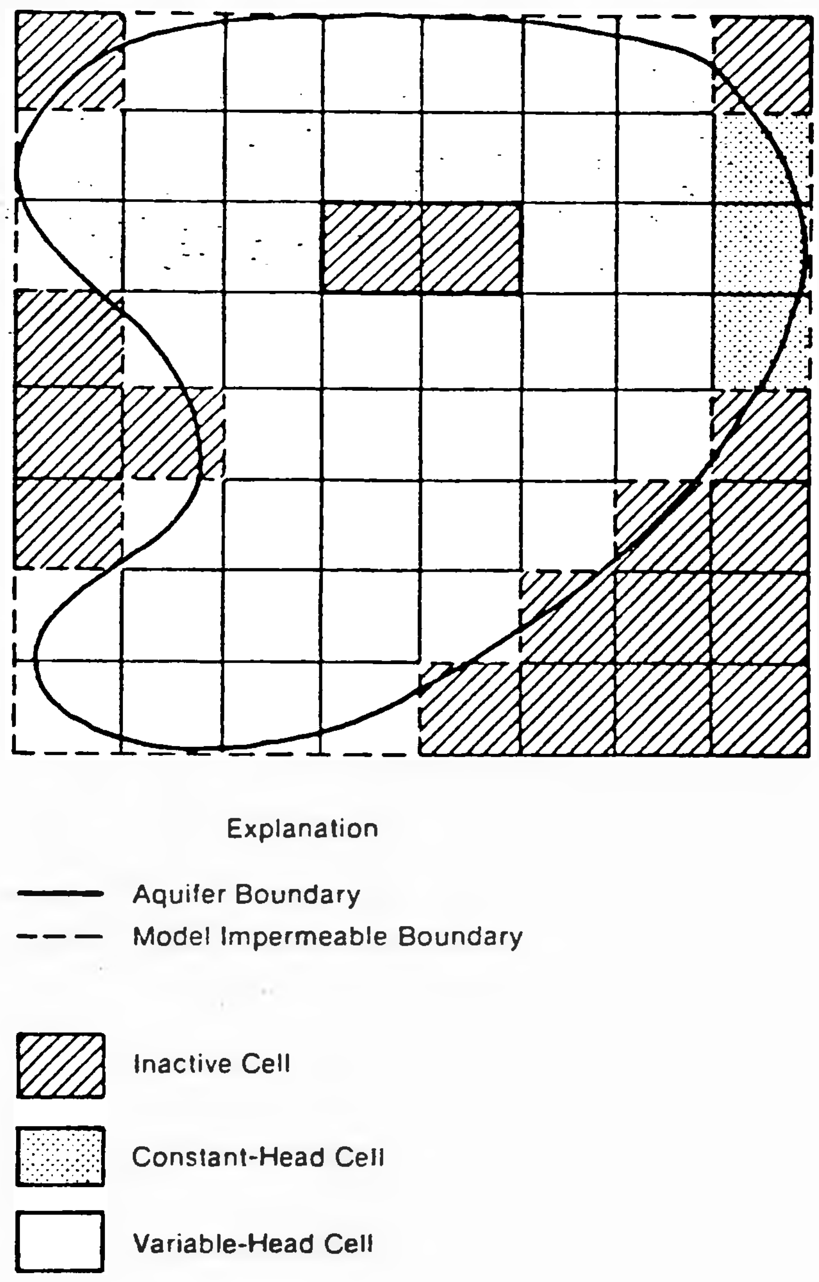
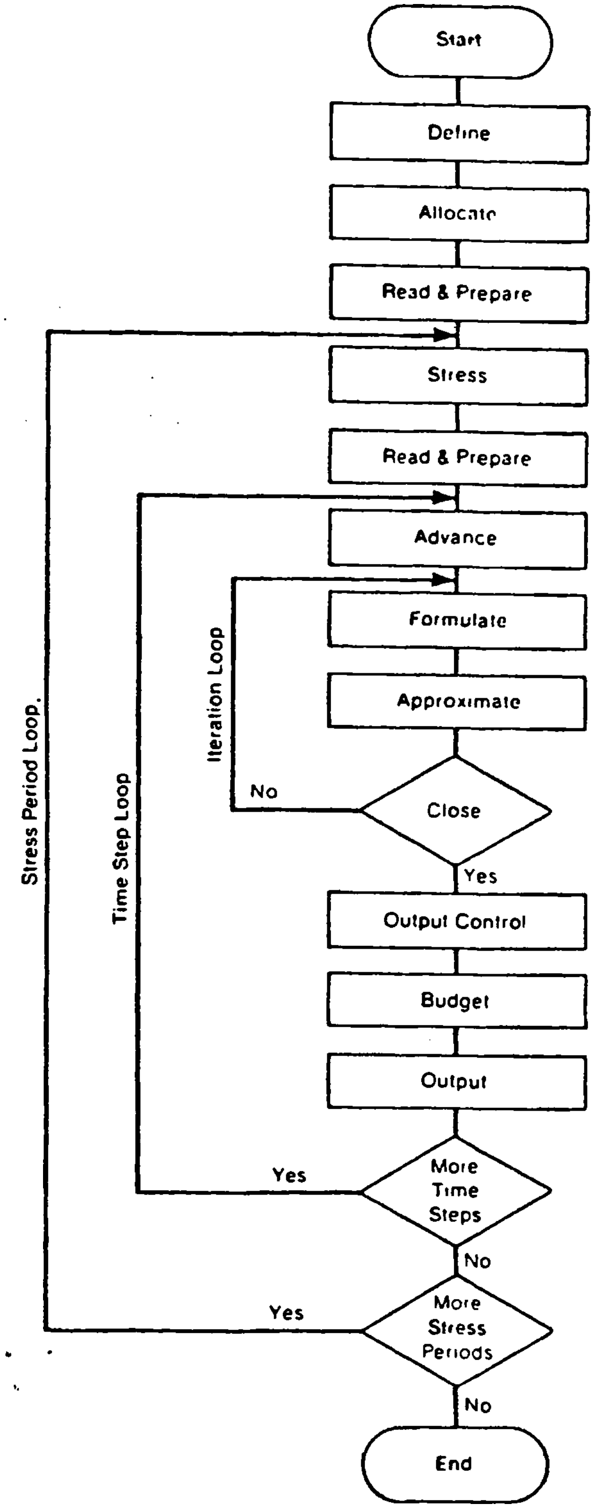


Figure 2.4 : Discretized aquifer showing boundaries and constant head cells (McDonald and Harbaugh, 1984).



DEFINE — Read data specifying number of rows, columns, layers, stress periods, and major program options

ALLOCATE — Allocate space in the computer to store data

READ AND PREPARE — Read data which is constant throughout the simulation. Prepare the data by performing whatever calculations can be made at this stage

STRESS — Determine the length of a stress period and calculate terms to divide stress periods into time steps

READ AND PREPARE — Read data which changes from one stress period to the next. Prepare the data by performing whatever calculations can be made at this stage

ADVANCE — Calculate length of time step and set heads at beginning of a new time step equal to heads calculated for the end of the previous time step.

FORMULATE — Calculate the coefficients of the finite difference equations for each cell.

APROXIMATE — Make one cut at approximating a solution to the system of finite difference equations.

OUTPUT CONTROL — Determine whether results should be written or saved on disk for this time step. Send signals to the BUDGET and OUTPUT procedures to indicate exactly what information should be put out

BUDGET — Calculate terms for the overall volumetric budget and calculate and save cell-by-cell flow terms for each component of flow.

OUTPUT — Print and save heads, drawdown and overall volumetric budgets in accordance with signals from OUTPUT CONTROL procedure.

Figure 2.5 : Generalized flow chart for MODFLOW (McDonald and Harbaugh, 1984).

Packages are completely independent of each other. They can be added or removed without affecting other packages. There must, however, be a Basic package and a solver package.

Table 2.1 : List of packages of MODFLOW.

Package Name	Abbreviation	Package Description
Basic	BAS	Manages the tasks that are part of the model as a whole.
Block-Centered Flow	BCF	Calculates terms of Finite-difference equations which represent flow.
Well	WEL	Adds terms representing flow to wells to the finite-difference equations.
Recharge	RCH	Adds terms representing areally distributed recharge to the finite-difference equations.
River	RIV	Adds terms representing flow to or from rivers to the finite-difference equations.
Drain	DRN	Adds terms representing flow to drains to the finite-difference equations.
Evapotrans-piration	EVT	Adds terms representing ET to the finite-difference equations.
General-Head Boundaries	GHB	Adds terms representing general-head boundaries to the finite-difference equations.
Strongly Implicit Procedure	SIP	Solver package for the system of finite-difference equations.
Slice-Successive Overrelaxation	SOR	Solver package for the system of finite-difference equations.

2.2 Input Data Requirements and Sources

In order to evaluate the existing hydrologic condition of the study area with the help of the computer models and to make any future predictions, information regarding different elements of the hydrologic cycle are required. Key data requirements for CREAMS and MODFLOW are listed in Table 2.2 and Table 2.3 respectively.

Table 2.2 : Data requirements for CREAMS.

Climatic Data :	Precipitation
	Temperature
	Solar Radiation
Geologic Data :	Ground Surface Characteristics
	Soil Characteristics
Agronomic Data :	Cropping Pattern and Calendar
	Crop Characteristics
	Irrigation

Maps and soil profiles of the area were used to set up the study site. Topographic, groundwater contour, and soil association maps were used to identify the boundaries.

Table 2.3 : Data requirements for MODFLOW

Aquifer Properties :	Areal dimension and boundaries
	Aquifer profile characteristics
	Storage coefficient
	Transmissivity
	Soil characteristics
Hydrologic Data :	Stream discharge and water level
	Groundwater level
Aquifer Stresses :	Groundwater recharge
	Groundwater withdrawal

The primary sources of information regarding the study area are the reports on investigations conducted by different government and private organizations. Such organizations include Bangladesh Water Development Board (BWDB), Bangladesh Agricultural Research Council (BARC), Geological Survey of Bangladesh (GSB), and Master Plan Organization (MPO). Raw data and information on detailed field investigations are available from the databases of some of these organizations.

MPO has been developing its own database collecting data from other sources. Most of the data used in this study was available from this database. Agronomic and some climatologic data were available from BARC database. BWDB has detailed information about the monitoring of both the surface and groundwater. Well driller logs were available from GSB and MPO. Groundwater level monitoring data, Bore hole logs, and daily rainfall records at Shibganj (Fig. 3.1) are included in Appendices A, B, and C respectively.

In order to set up the models and to calibrate them, detailed information on soil, topography, and hydrology of the study area were required. In addition to the information directly related to the study area, general information regarding the study site were available from the instruction manuals of the models. Information from similar study sites was also considered. Using such information as a guide line, the models were more precisely set up and calibrated using data from field investigations. Reliability of the methods of collecting and recording of some data sources were sometimes questionable. Data from such sources were often cross-examined with a parallel source whenever necessary.

2.3 Modeling Procedure

The primary intent of modeling the study area was to evaluate the recharge that is occurring to the groundwater.

Considering the complexities of the hydrologic processes both before and after recharge takes place, the modeling was carried out in two steps. In the first step, CREAMS was used to evaluate the percolation from the root zone to the groundwater. Then in the second step, MODFLOW was used to determine the groundwater levels or heads.

A preliminary assessment of the problem was made without detailed information. This assessment defined the responses of the groundwater levels to the climate and to the boundary stream. Detailed raw data collected from the existing databases were consolidated to satisfy the requirements of the computer models. A base map was prepared to define the overall study area. Some other maps were associated to supplement the base map with information regarding different soil characteristics. The boundaries of the study area were selected considering different hydrologic information (such as groundwater divide, streams) and different soil and cropping classifications.

In order to evaluate the percolation from the root zone to the groundwater, it was necessary to account for different hydrologic processes that take place above, on, and below the ground surface. Part of the precipitation goes back to the atmosphere in the form of evaporation. The remainder is either carried out of the site as surface runoff, stored in different forms, or infiltrated into the ground. Part of the infiltration is again evaporated as either soil or plant evaporation (transpiration). The magnitudes of all these elements depend largely on the soil, crop, and topographic characteristics. Two combinations of these characteristics were selected which would apparently yield extreme (minimum and maximum) percolation from the root zone. CREAMS was used to determine the percolation under these extreme conditions. The area was then divided into a number of different categories which would yield significantly different percolation.

A finite-difference grid of the modeled area was prepared to assign the percolation values from CREAMS and other relevant data to each node of MODFLOW.

MODFLOW was calibrated and validated using two sets of different field data. During the calibration procedure, the initial values of transmissivity obtained from different sources were used as a guide line. These values were then adjusted to have a better agreement between the observed and modeled values of groundwater heads. After calibration, the model was validated with a different set of field data.

Four recharge basins and six recharge wells were selected to simulate artificial recharge to the groundwater.

Topographic and groundwater contour maps were utilized to select the most suitable locations of these basins and wells. MODFLOW was used to determine the groundwater levels to quantify the magnitude of recharge.

Existing crop, crop calendar, and management practices of cultivation in the study area were modified to determine the impact of such modifications on the recharge to groundwater.

III. DESCRIPTION OF STUDY AREA

3.1 Location

The area selected for this study is located along the northwestern border of Bangladesh between latitudes 24°40′N & 24°45′N and between longitudes 88°10′E & 88°16′E (Figure 3.1). The study area is situated in the upazilla (administrative unit comparable to a county in the U.S.) Shibganj of Nawabganj district. Specific features of the modeled site are discussed separately in chapter 4.

The Mohananda river runs along the eastern boundary of the study area. The Ganges river runs into Bangladesh from India approximately 40 kilometers (25 miles) away from the western boundary of the study area.

3.2 Climate

Bangladesh has a tropical monsoon climate marked by sweltering temperatures and high humidity almost throughout the year. The country has four main seasons; Winter (December to February), Summer (March to May), Monsoon (June to September), and Autumn (October to November) (Mahmood,1987).

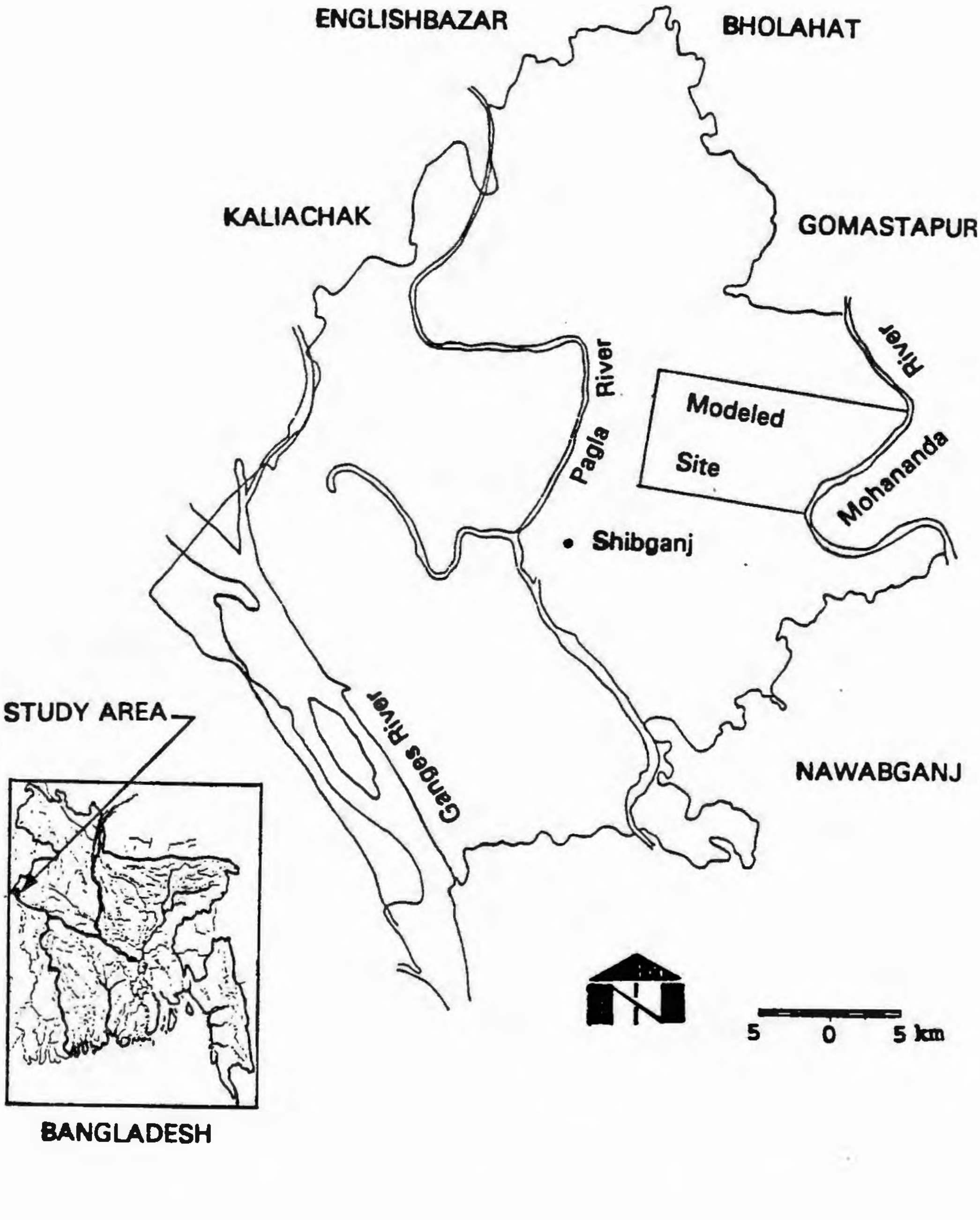


Figure 3.1 : Location of study area.

The study area is located along the northwestern border of the country, and is influenced by the Himalayan cold waves in Winter. However, in rare cases the temperature goes down to less than 41°F (5°C) and never touches the freezing point. Annual temperatures in this area range from 46°F (8°C) to 108°F (42°C) on the average. The coldest temperatures occur in the months of December and January and the warmest temperatures occur in April and May.

The average annual precipitation in this area is 59 inches (1500 mm). Rainfall occurs mostly during the south-west monsoon season from June to September. Tropical storms and thunderstorms are the sources of most of the precipitation in the monsoon season. Three years of monthly precipitation records measured at Shibganj are summarized in Table 3.1, the water year being April to March. The annual variation of rainfall is illustrated in Figures 4.3 and 4.4 and tabulated in Appendix C.

3.3 Land Use

The study area is comprised of approximately 101.2 sq. mile (262.5 sq. km) land with 72% cultivated land. Of the total area, approximately 44% is highland, 24% is medium highland, 13% is medium lowland, 8% is very lowland, and 6% is water bodies (MPO,1989). These lands are again divided into different land types depending on the flood phase (depth of flooding). Figure 3.2 shows the division of lands according to different flood phases.

Table 3.1 : Monthly precipitation (mm), Shibganj.

	1983 - 84	**1984 - 85**	**1985 - 86**
April	20.6	0.0	27.2
May	58.4	83.7	89.0
June	81.3	242.6	226.0
July	243.2	336.0	349.4
August	192.3	368.9	189.2
September	162.2	352.5	330.2
October	195.6	226.3	110.5
November	0.0	0.0	0.0
December	26.5	0.5	0.0
January	27.7	0.0	0.0
February	17.8	5.1	0.0
March	0.0	6.4	0.0
Total	1023.6	1622.0	1321.5

Source: BWDB,1990

Generally, groups of small homesteads constitute the residential areas. Most of the roads are unpaved. Almost all the commercial and industrial activities take place at the upazilla headquarter, Shibganj. A land use map of the study area is shown in Figure 3.3. Table 3.2 explains the different land use associations.

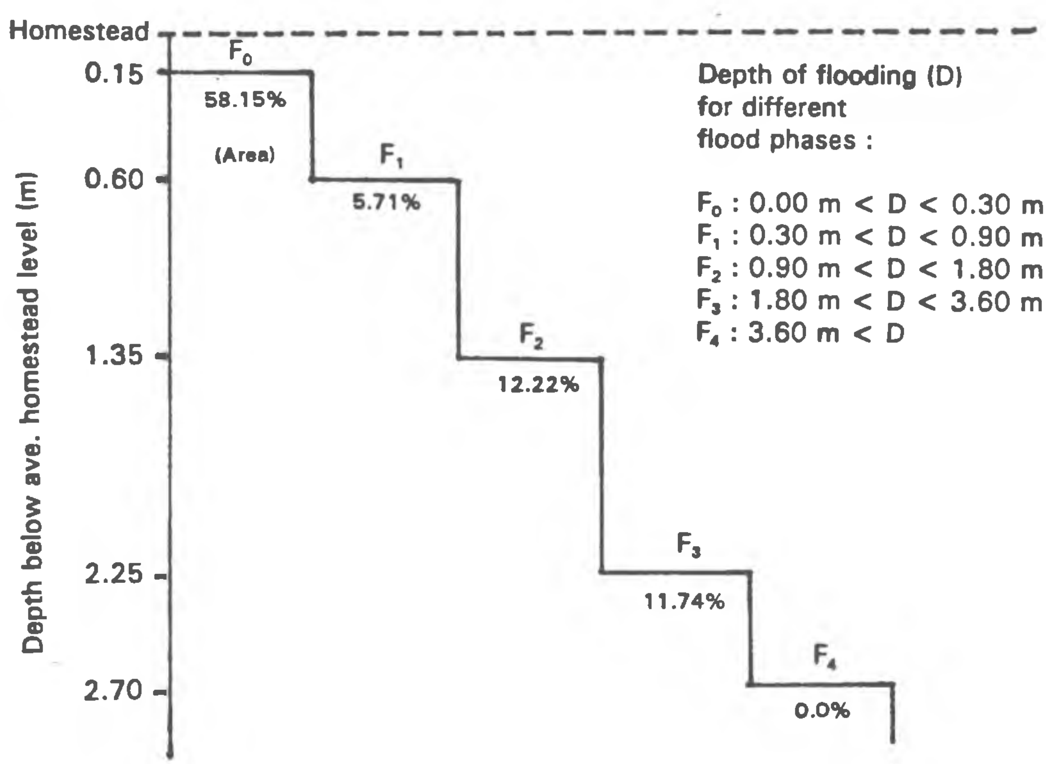


Figure 3.2 : Different land types according to flood phase.

Figure 3.3 : Land use map of the study area. (Legend explained in Table 3.2).

Table 3.2 : Land use associations, Shibganj.

Association No.	Explanation
1	Mainly mango orchards and Aus - Rabi crops; and residential.
5	Mainly Aus - Rabi crops with sugarcane.
6a	Predominantly Aus - Rabi crops.
10a	Mainly broadcast Amon - fallow/Rabi crops with some Aus - Rabi crops and Aus transplanted Amon - fallow/Rabi crops.
10b	Mainly broadcast Amon - fallow/Rabi crops.

3.4 Water Use

There are three categories of water use in the study area; irrigation, domestic use, and industrial use. A major portion of the available water is used for irrigation. Most of the domestic usage is dependent on the available surface water from rivers, canals, and ponds. Drinking water is available from hand tube wells.

The water duty of the area for irrigation is 151 ha/Mm^3. In other words, 151 ha land can be irrigated annually with 1 million m^3 of water. The discharge per well is as follows : Shallow Tube Well (STW) - 0.75 to 1.0 ft^3/sec; Deep Tube Well (DTW) - 2.0 ft^3/sec. The maximum pumping stress of these wells are from April to May. Command areas of DTWs vary from 35 to 85 acres with an average of 54.71 acres; command areas of STWs vary from 5 to 15 acres with an average of 9.81 acres (MPO,1989).

Rice and Rabi crops are the major crops produced in the study area. Some sugarcane, potato, and jute are also produced. There are three major categories of rice that are produced in this area : Aus, Amon, and Boro. Irrigation periods for these crops are as follows : Aus - mid March to June; Amon - July to October; HYV (High Yielding Variety) Boro - January to April; and Local Boro - December to mid April (BARC,1989).

3.5 Geology and Hydrogeology

The study area is comprised entirely of one geomorphic unit - the flood plains being 97% of the total area. Active Gangetic flood plains and young meandering flood plains are the major physiographic units. The surface elevation from mean sea level ranges from 65 to 85 ft. in most parts of the area (MPO,1989).

The flood plains soils generally occupy a gentle landscape of low level to very gently sloping. The soil is mainly olive-brown, mixed grayish brown to olive brown, loamy to clay, silt loams or silty clay loams and are identified by calcareous nature (MPO,1989). Figure 3.4 shows different soil associations and land capability associations in the study area based on relief, age, and degree of weathering of surface sediments. Tables 3.3 and 3.4 explains the different soil and land capability associations. Table 4.2 describes the composition of the soil associations.

The study area constitutes a portion of the Indian platform of the Bengal Geosyncline. The subsurface stratigraphy of the area is presented in Table 3.5 based on drilled hole data obtained from the Geological Survey of Bangladesh (GSB).

Almost the whole of the study area is part of the active young Gangetic and mixed Gangetic and Mohananda flood plains and is underlain by unconsolidated recent and subrecent sequence of sand, silt, and clay.

The thickness of the upper silt and clay layer is about 49 ft. in the northwest and eastern side of the Pagla river and below 16 ft. in the rest of the area.

Maximum depth to groundwater table from the land surface varies from 20 to 30 ft. in the major portion of the area and 30 to 38 ft. in some small strips. The minimum depth to the groundwater table varies from 2 to 5 ft. throughout the area.

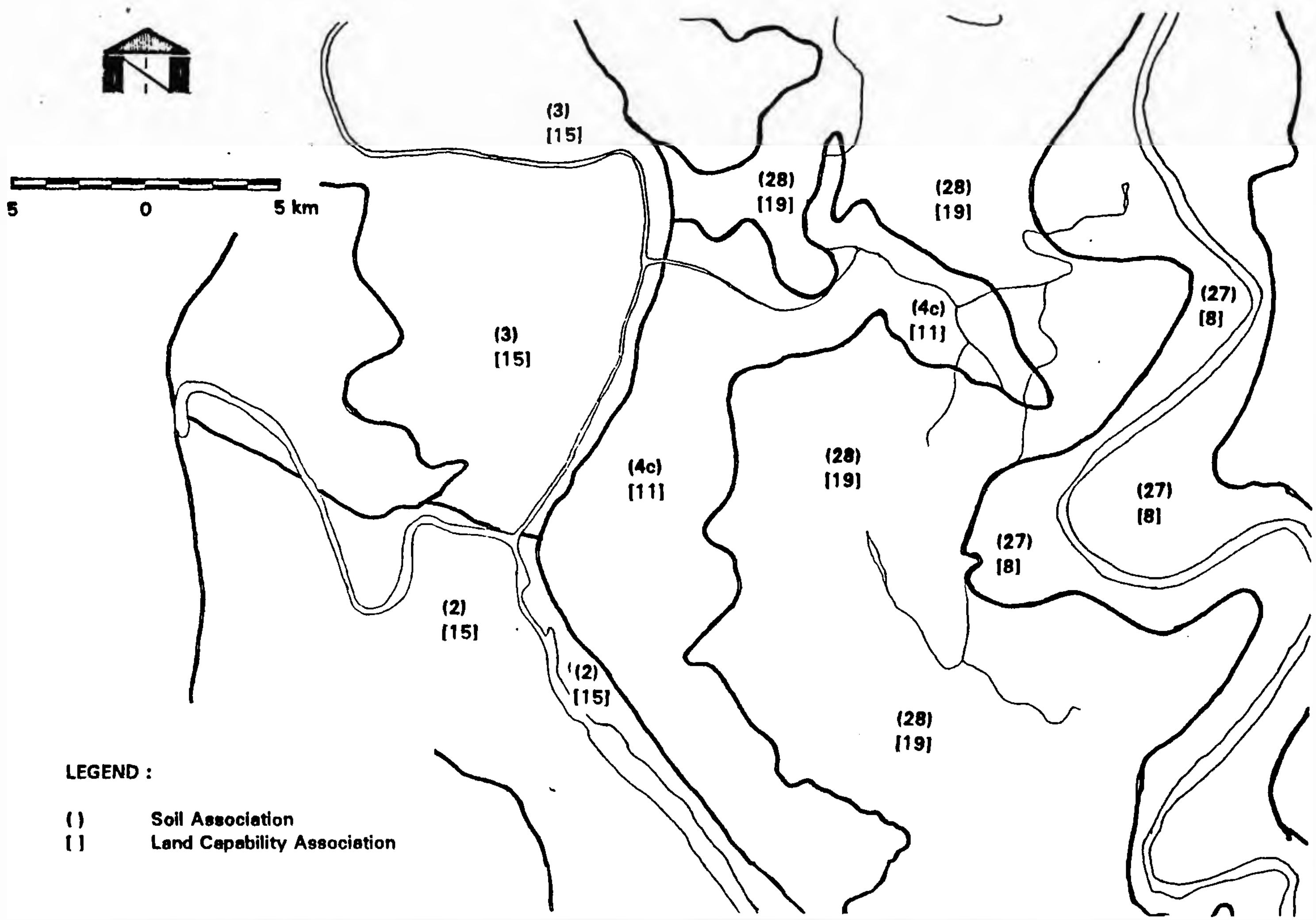


Figure 3.4 : Soil Associations and Land capability Associations. (Legend explained in Tables 3.3 and 3.4)

Table 3.3 : Soil associations, Shibganj.

Association No.	Explanation
2	Gopalpur - Sara - Ishurdi Association.
3	Sara - Pakuria - Gopalpur Association.
4c	Sara - Gopalpur Association, moderately well drained variants.
27	Sara - Gopalpur - Gomastapur Association.
28	Santhia - Gomastapur Association.

Table 3.4 : Land capability associations, Shibganj.

Association No.	Explanation
8	Good and moderate agricultural land; predominantly highland, mainly with droughty soil.
10	Mainly moderate with some good agricultural land; part man made highland with irregular relief, part medium highland.
11	Predominantly moderate agricultural land; level highland with droughty soils.
15	Predominantly moderate agricultural land; mainly medium highland with moderate hazard of river erosion.
19	Mainly poor with some good agricultural land; mainly medium lowland with some highland, mainly droughty in the dry season.

The minimum groundwater elevation from mean sea level is around 47 ft. near the river Mohananda and increases northwestward up to 65 ft. Groundwater fluctuates through a zone of 25 ft. in the central part of the area and decreases

Table 3.5 : Hydrostratigraphy of the study area.

Age	Formation	Thickness (m)	Lithology	Aquifer potential
Recent	Alluvium	110	Sand, silt, and clay	Excellent
	Unconformity			
Paleocene	Cherra Sandstone	200	Grey and white Sandstone with subordinate shale and coal; kaolinised zone at base	Generally good
	Unconformity			
Late Cretaceous	Shibganj Formation (Trapwash)	300	Coarse, yellow brown sandstone, volcanic matter and white clay	Good
	Unconformity			
Late Jurassic to Early Cretaceous	Rajmahal Trap	335	Amygdaloidal Basalt; serpentized shale and agglomerate	None
	Unconformity			
Pre-Cambrian	Basement Complex			

to 7 to 10 ft. in the rest of the area. Water table decline during the dry season over a period of five years (1984 to 1988) varied from 0.43 to 10.10 ft. (MPO,1989). The general trend of groundwater movement is south towards the Mohananda river.

The transmissivity of the aquifer materials ranges from

35000 to 47500 ft^2/day and specific yield value varies from 10 to 15% (BWDB,1990; MPO,1989).

Figure 3.5 shows the locations of groundwater monitoring wells and other investigation wells in the study area. Figure 3.6 shows two cross-sections of the soil strata as shown on Figure 3.5.

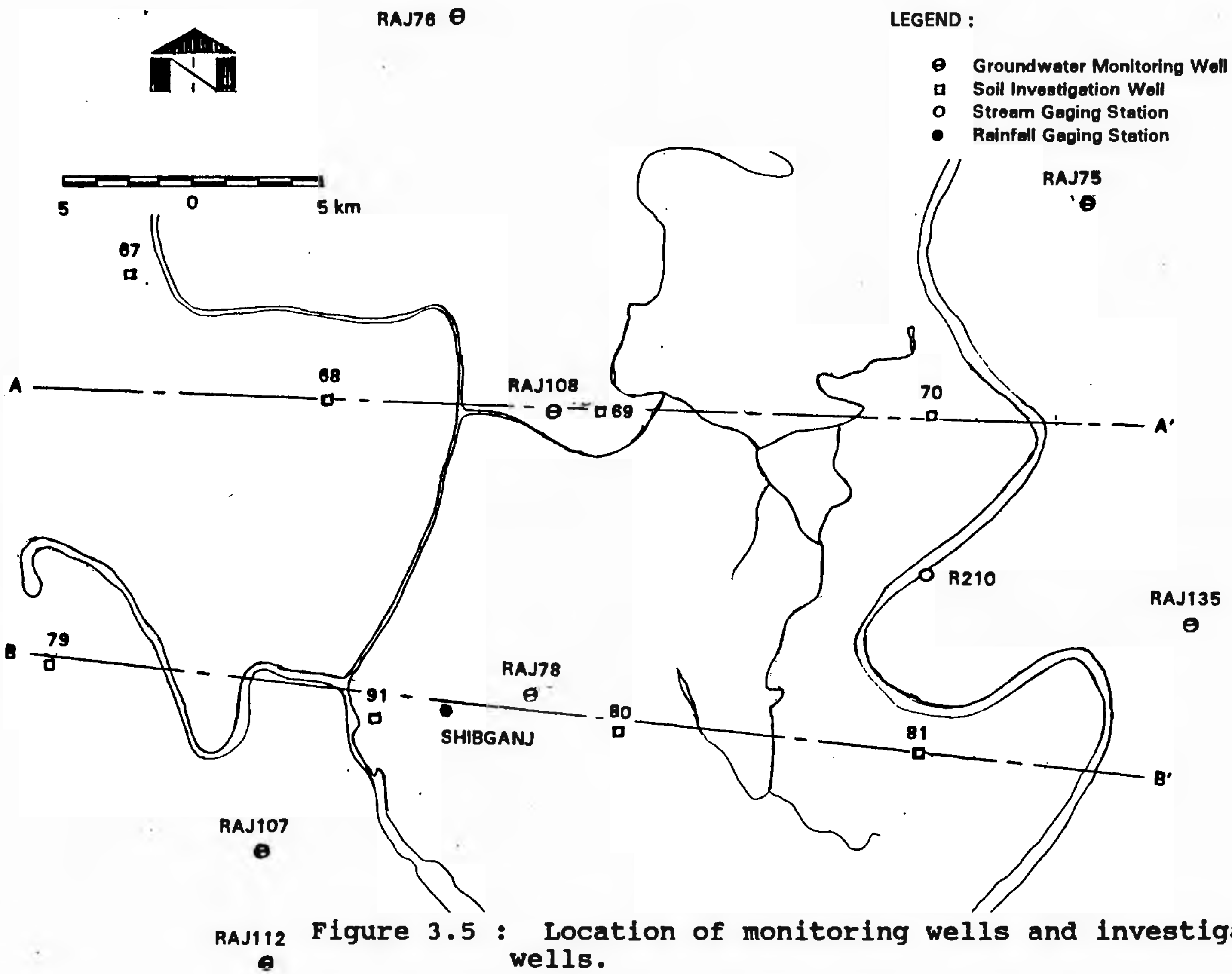


Figure 3.5 : Location of monitoring wells and investigation wells.

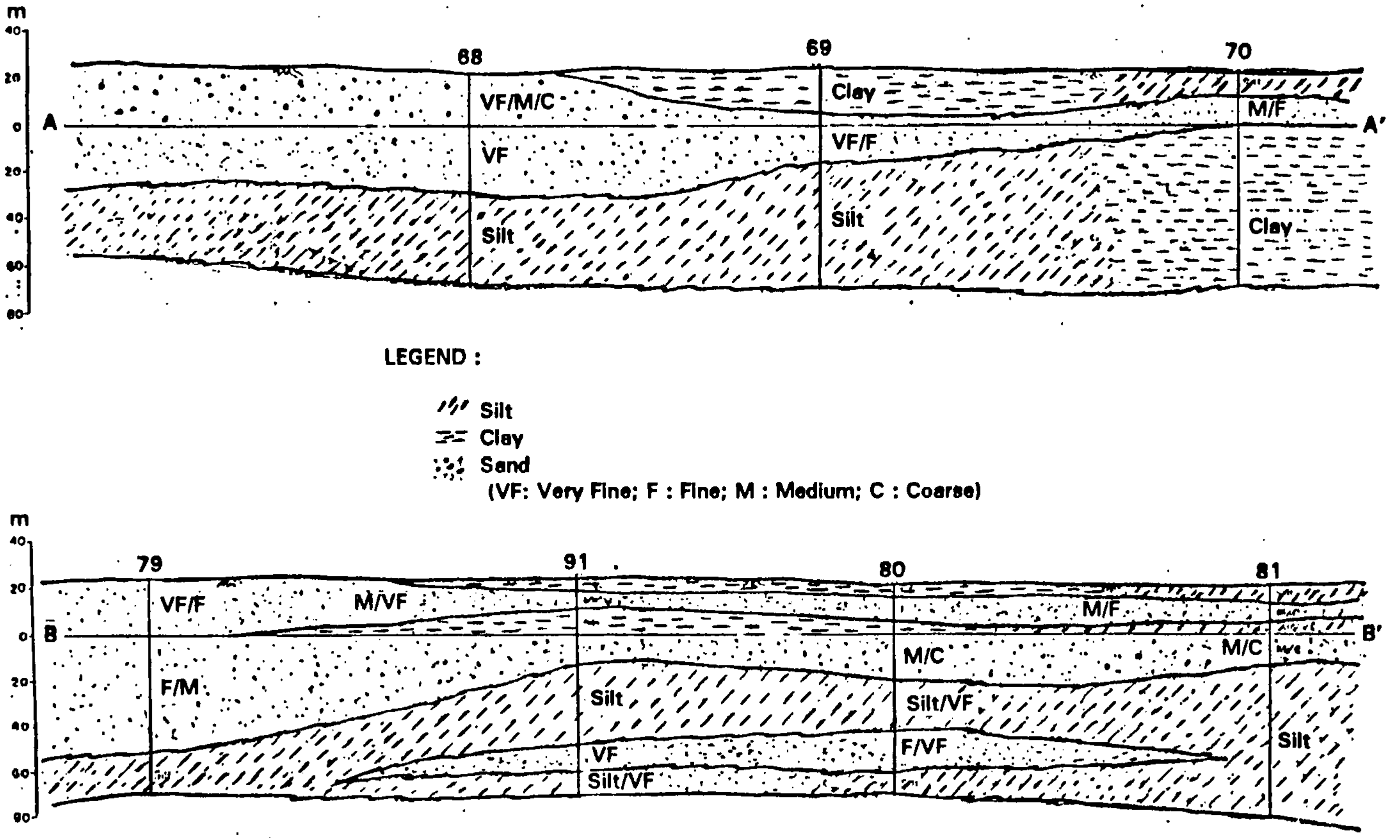


Figure 3.6 : Cross-sections of the soil strata.

IV. ANALYSIS

4.1 Hydrologic Budgets

Preliminary analysis of the study area involved estimating the overall water budget of the aquifer in terms of water loss or gain within a specified period of time. As a first approximation for the overall study area, the Thornthwaite method (Dunne and Leopold,1978) was used for 1986. The potential evapotranspiration was estimated to be 34.61 inches. The average annual rainfall was 56.45 inches (1434 mm).

The actual amount of recharge to the groundwater is, however, only a fraction of the difference between the rainfall and evapotranspiration due to loss in surface runoff. Identifying the annual storms in several groups and using the U.S. Soil Conservation Service Curve number technique (Dunne and Leopold,1978), the annual runoff volume was estimated to be 12.49 inch. The remaining 9.35 inch is the available recharge to the groundwater.

Regional groundwater maps were constructed from representative dry season and wet season water table data (Figures 4.1 and 4.2). An average variation of 10 ft was

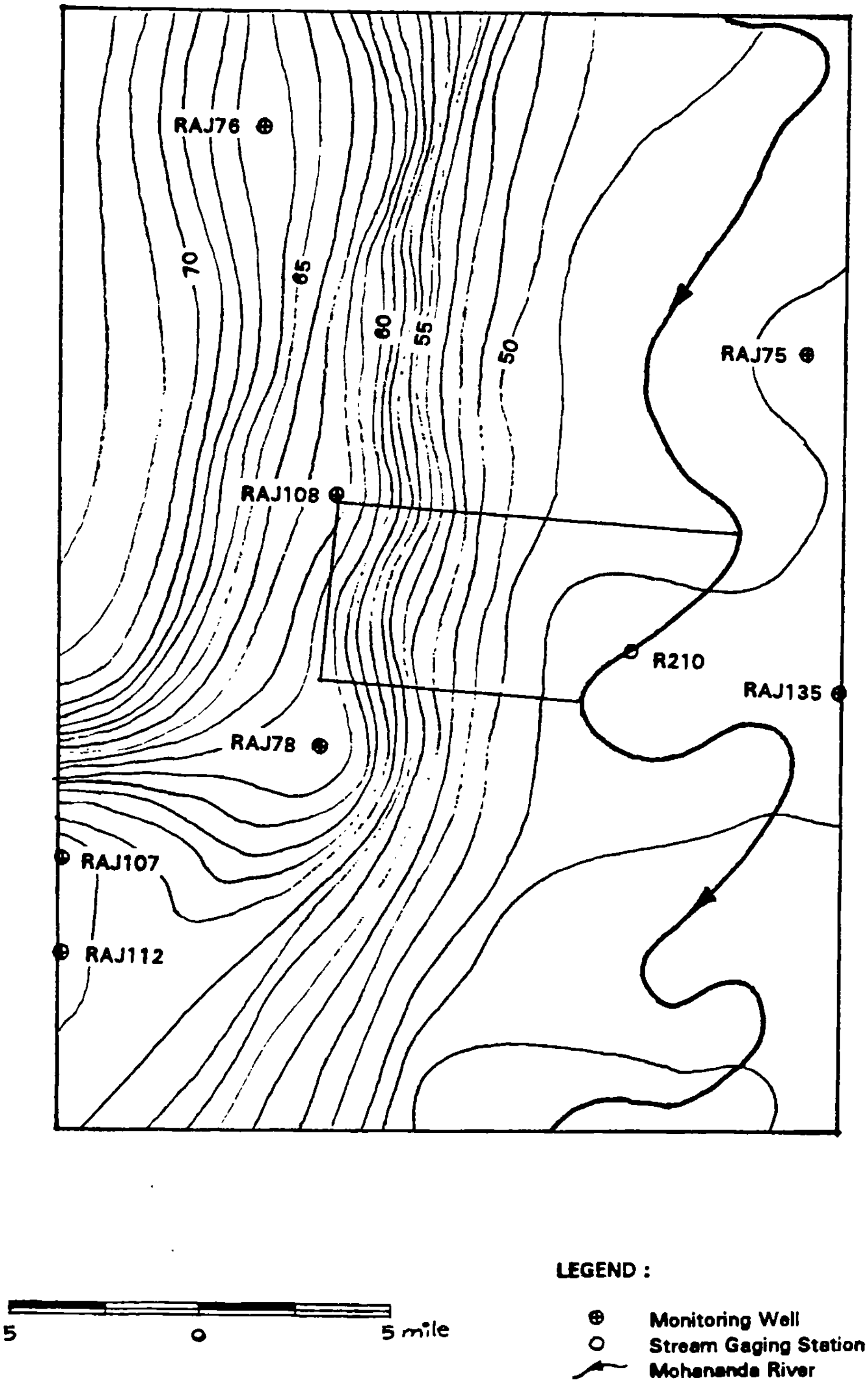


Figure 4.1 : Regional groundwater map; June 16, 1986.

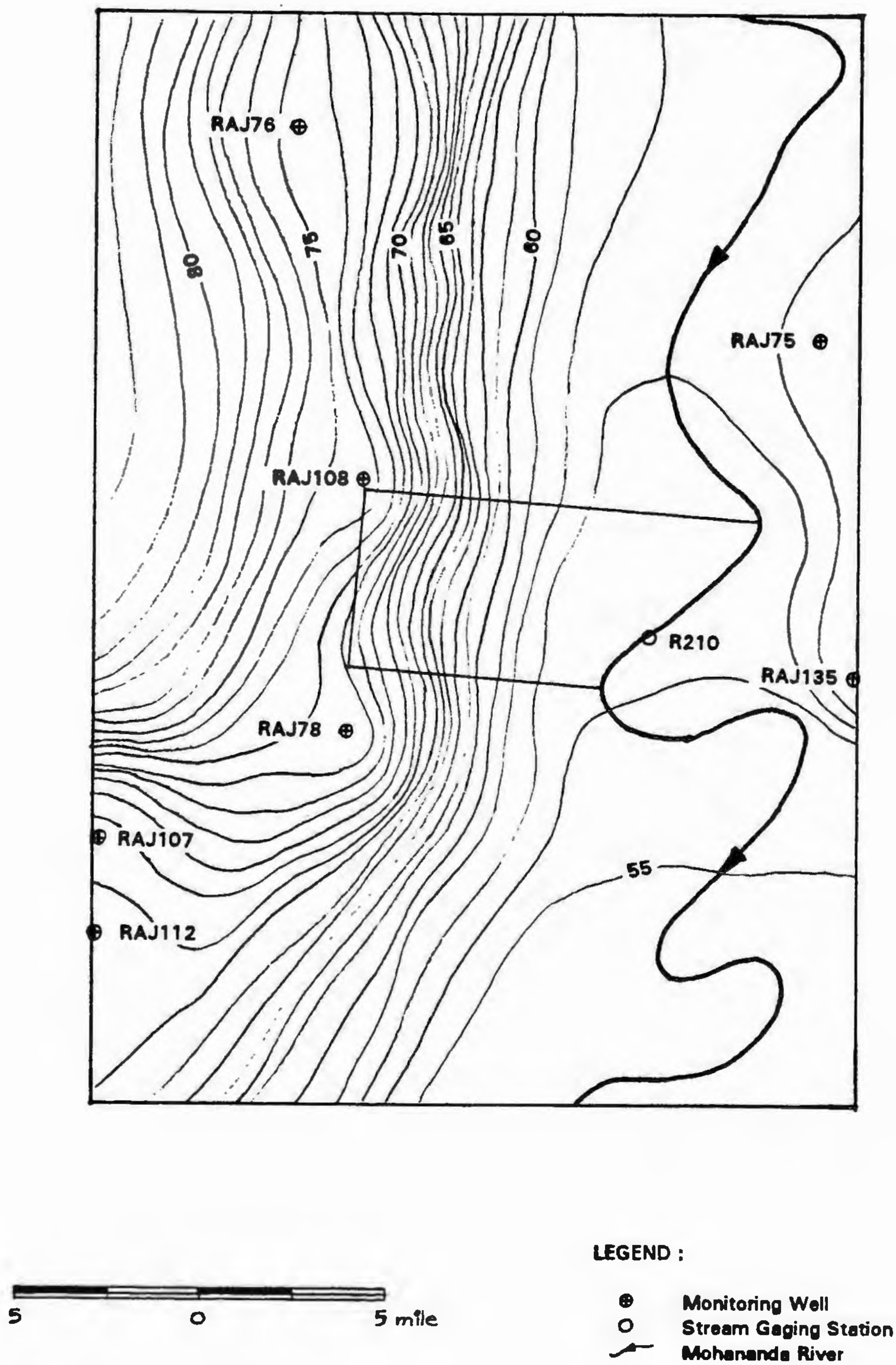


Figure 4.2 : Regional groundwater map; October 20, 1986.

observed between the minimum and maximum water levels. Weekly water levels in the observation wells for 1986 are shown in Figures 4.3 and 4.4.

The rates of decline of the water levels in the wells during the dry season reflect the approximate groundwater flow when transmissivity is considered. The well hydrographs in general show very little difference in water table elevations at the beginning and the end of the year suggesting insignificant change in annual storage. The hydrographs reach their peaks toward the end of the monsoon and have a constant decline during the dry season.

In order to obtain a more precise hydrologic budget, evapotranspiration, runoff, and deep percolation from the root zone were estimated with CREAMS using daily precipitation records and mean monthly temperatures. For a silty loam soil with irrigated rice in 1986, predicted runoff was 13.85 inch, evapotranspiration was 51.10 inch, change in soil moisture in the root zone was 0.09 inch, deep percolation was 7.89 inch, and the applied irrigation to the root zone was 16.31 inch. Irrigation in this case means the amount of water actually supplied to the root zone by ponding either the rain water or the pumped water to meet the water demand of the plant. The significant difference between the evaporation estimates of Thornthwaite method and CREAMS prediction is due to the fact

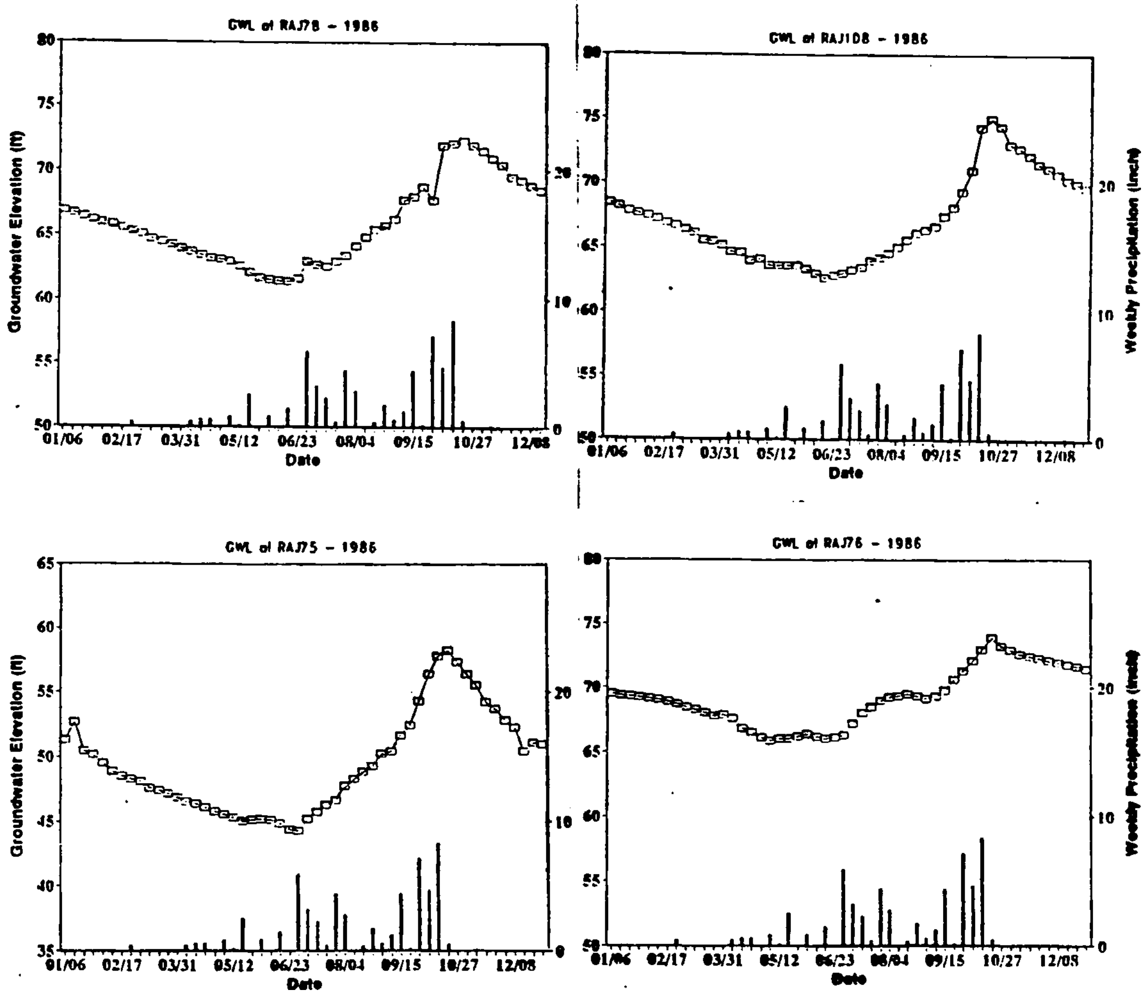


Figure 4.3 : Weekly water levels in observation wells.

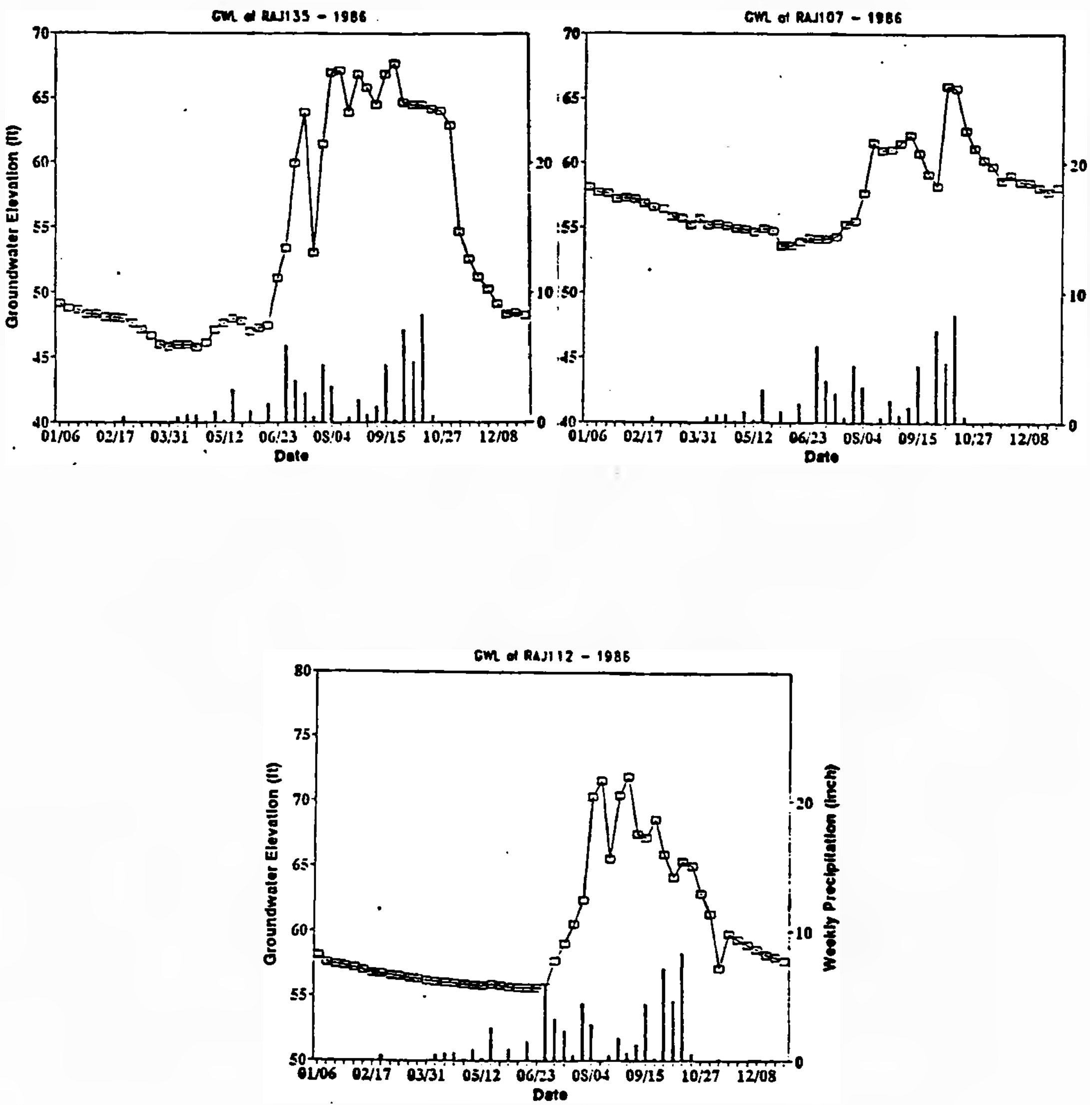


Figure 4.4 : Weekly water levels in observation wells.

that there is no correction for different vegetation types in Thornthwaite method (Dunne and Leopold,1978), whereas CREAMS uses Leaf Area Index values to consider different growth stages of the plant.

After considering different soil types and land uses, areal recharge resulting from the deep percolation was determined for MODFLOW predictions. Detailed discussion of these estimates are done in section 4.4. Considering a stress period of one month, for example June of 1986, the volumetric budget for the modeled site was as follows. Inflow to the aquifer from areal recharge was 6.23 X 10^6 ft^3; outflow through the pumping wells was 1.97 X 10^6 ft^3, to the stream (constant head boundary) was 3.16 X 10^6 ft^3; and the change in storage was 1.10 X 10^6 ft^3.

4.2 Hydrology of Boundary Stream

The Mohananda river runs along the eastern border of the study area. The rating curve for the river at station 210 (Tentulia) is shown in Figure 4.5. The discharge hydrograph of the river is shown in Figure 4.6. The discharge hydrograph reaches its peak before the end of the wet season indicated. This may occur because the contributing watershed of the river is much larger than the study area whereas the precipitation

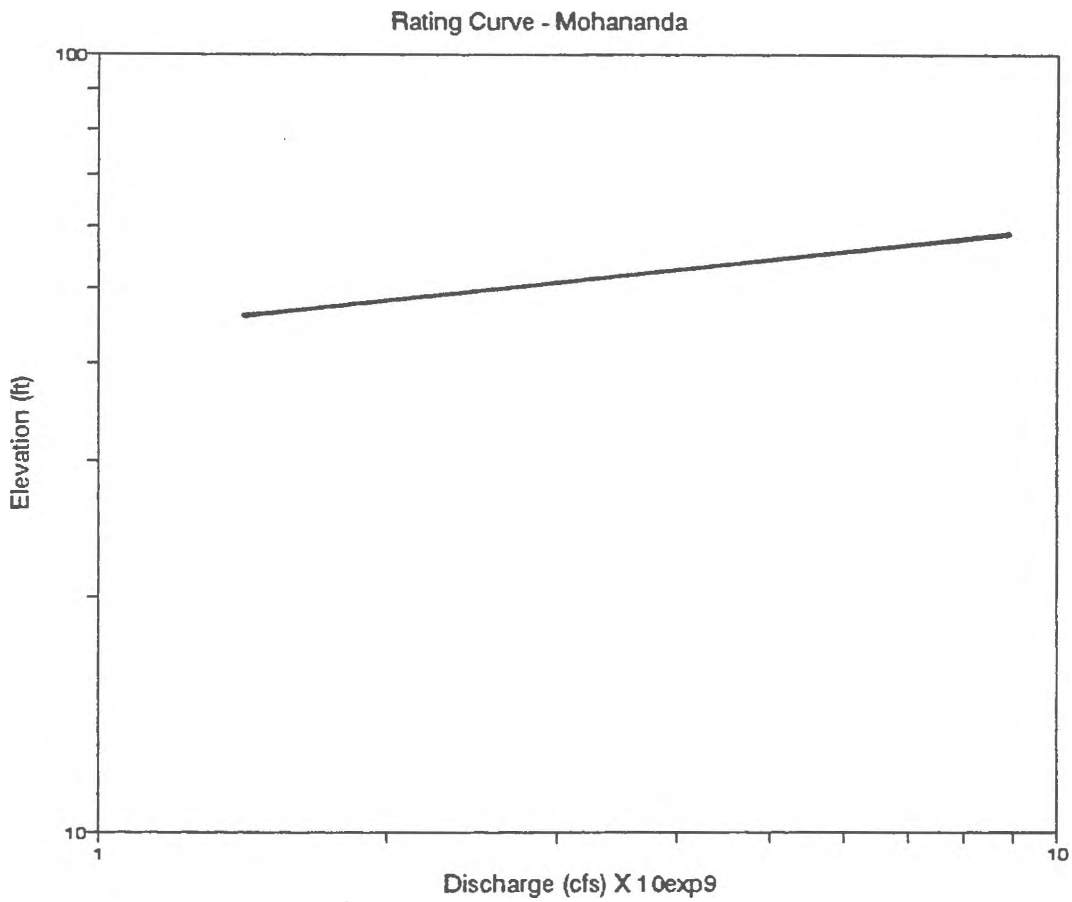


Figure 4.5 : Rating curve for the Mohananda river at Tentulia, Shibganj (MPO, 1989).

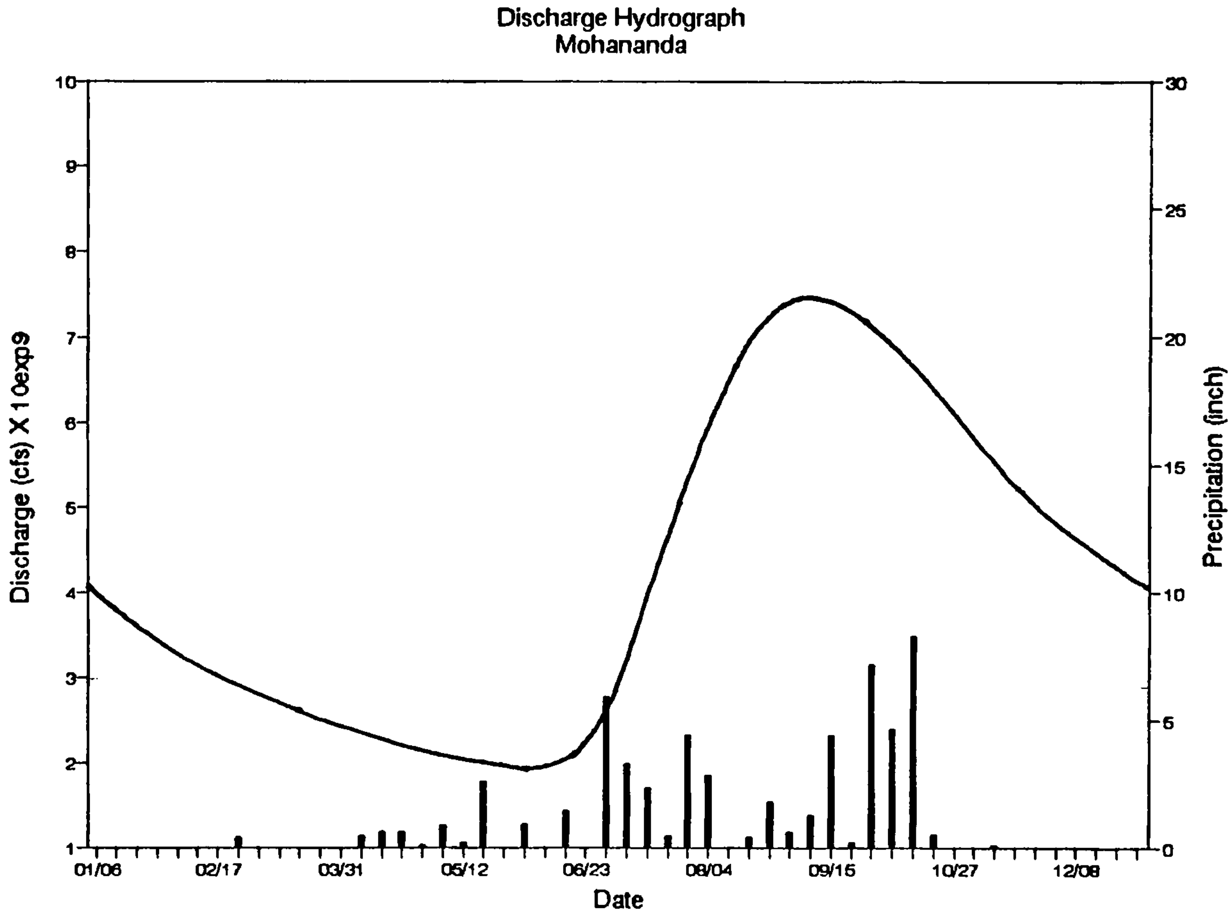


Figure 4.6 : Discharge hydrograph for the Mohananda river at Tentulia, Shibganj (MPO, 1989). Precipitation at Shibganj.

records shown reflect the pattern only in the more localized study area.

In order to determine whether the boundary stream is hydrologically connected to the aquifer, the river stages at station 210 during the dry and wet seasons were compared with the corresponding groundwater levels in the observation wells near the stream. It was observed that the groundwater levels during both the dry and wet season were at higher elevations than the river stages. However, the lowest water levels in the two wells RAJ75 and RAJ135 on the east side of the river were approximately at the same elevations as the river stage. Considering the depth of the river, it can be deduced that the river is hydrologically connected to the aquifer in the study area throughout the year. Moreover, observing the gradients of the groundwater table during the dry and wet seasons, the river can be identified as a gaining (effluent) stream.

4.3 Sensitivity of the Models

A brief sensitivity analysis of the models was performed. This was necessary to evaluate performed response before the modeled site could be divided into areas yielding significantly different percolation and before the models could be calibrated.

CREAMS

One of the important parameters controlling the predicted percolation values was the curve number used to calculate runoff. Although listed values of curve number suggested for different hydrologic condition and cultural practice (Knisel,1980) were followed, the curve number was later modified. Considering the fact that ponding is required for the cultivation of rice, which would mean lower runoff across the dikes, a lower curve number than the suggested value was selected. Figure 4.7 shows the variation of predicted annual percolation values with curve number.

Five different soil types were selected to predict percolation. For an annual precipitation (1979) of 56.63 inch, for example, percolation from a clay soil was 10.20 inch; and from a sand loam soil was 18.26 inch. For these soil types, the predicted percolation values were most sensitive to the saturated hydraulic conductivity of the soils. Figure 4.8 shows the variation of predicted annual percolation values with saturated hydraulic conductivity.

The main crops in the modeled site were B.Amon (rice) and Rabi (winter crop). The predicted percolation values did not change significantly for different variety of rice or winter crops. However, the difference in land use caused a significant difference in the predicted values of percolation.

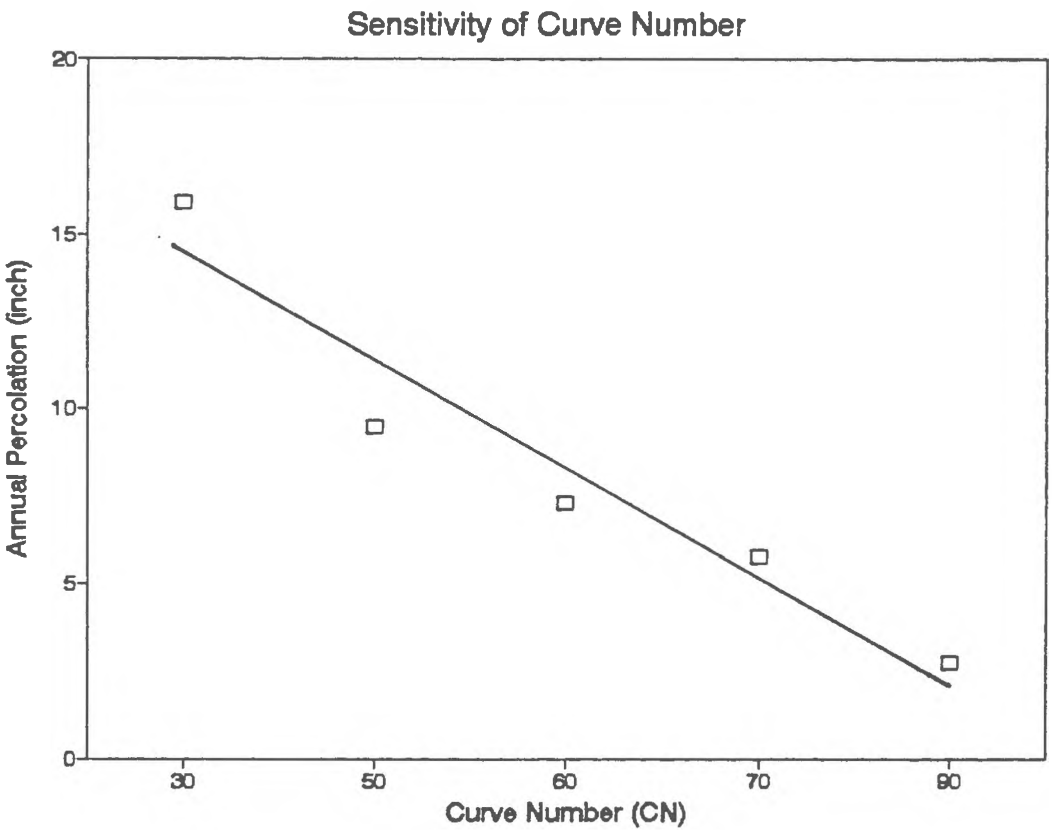


Figure 4.7 : Variation of predicted percolation with curve number.

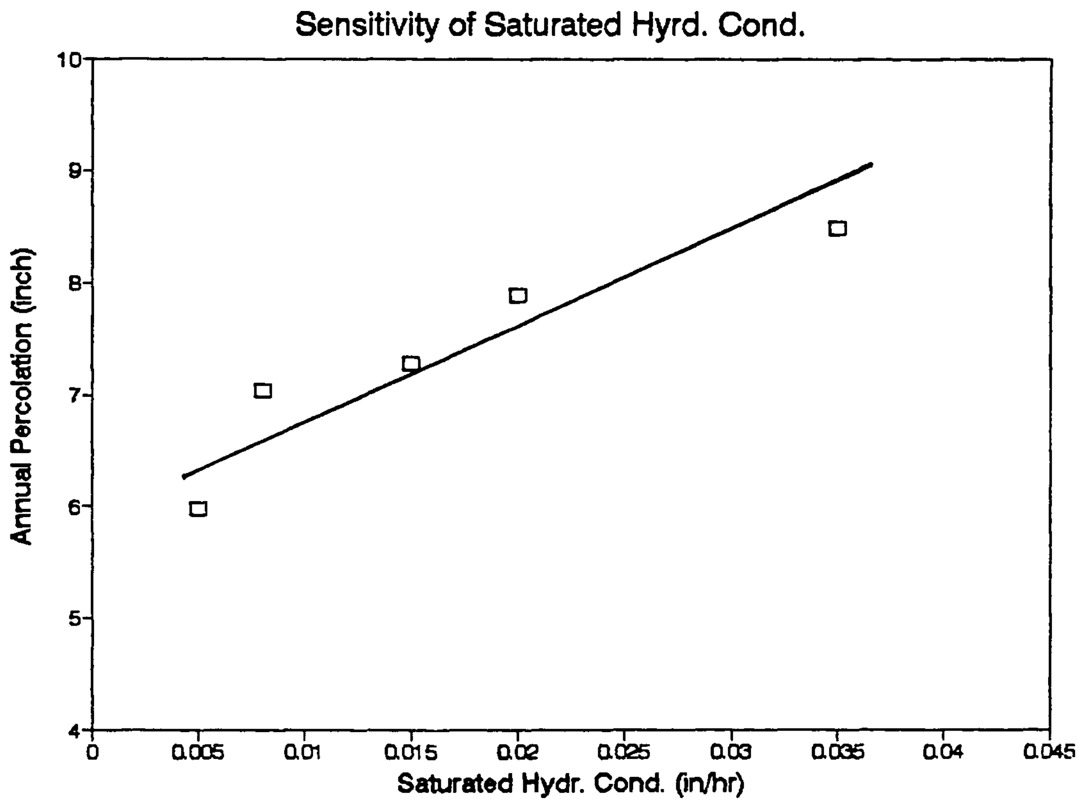


Figure 4.8 : Variation of predicted percolation with saturated hydraulic conductivity.

MODFLOW

During the calibration procedure of MODFLOW, it was observed that the predicted head values depend largely on the estimated transmissivity of the aquifer and the areal recharge to the aquifer. Although the change in the predicted heads were more sensitive to percent change in recharge than to percent change in transmissivity, areal recharge to the aquifer was kept the same as the predicted percolation values of CREAMS while transmissivity estimates were modified. Figure 4.9 shows the variation of predicted head values with assumed transmissivity.

The iterative procedure used in calculating heads in MODFLOW prediction yields an approximation to the solution of the system of finite-difference equations for each time step (McDonald and Harbaugh,1984). The rounding off error or truncation error is also associated with this procedure. However, even if a formal solution of the differential equations could be obtained, it would normally be only an approximation to the actual conditions in the field, because the hydraulic conductivity is seldom known with accuracy and uncertainties with regard to hydrologic boundaries are generally present.

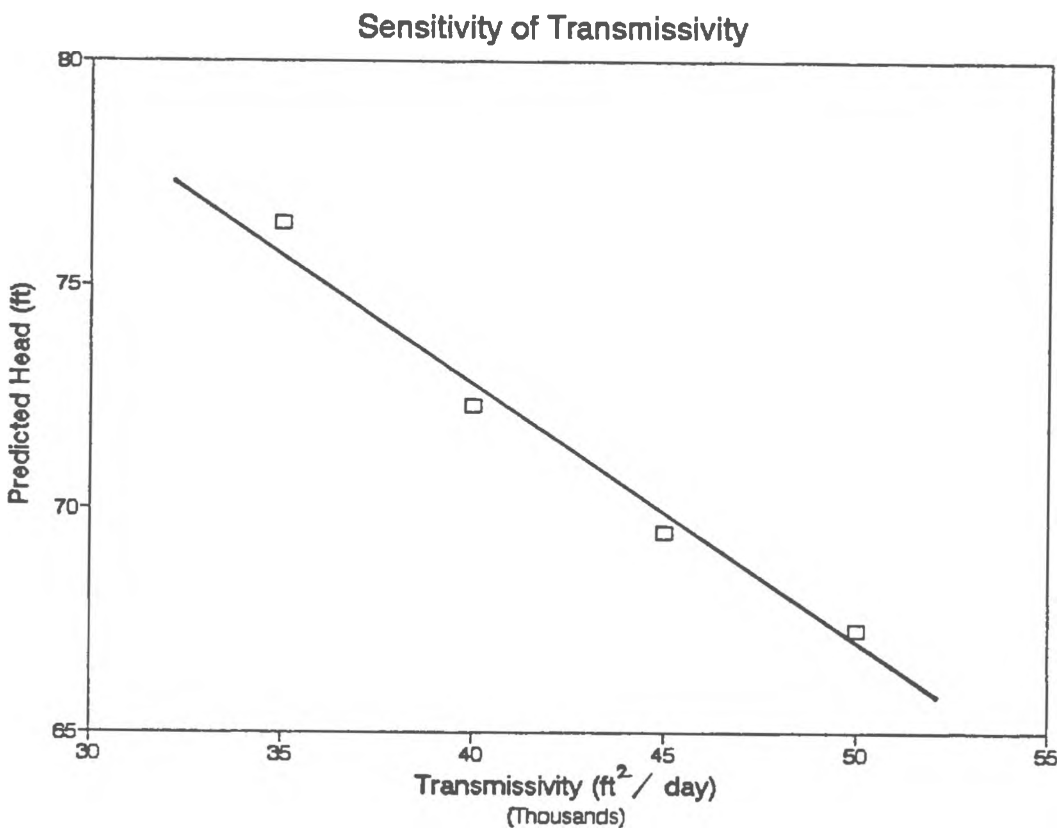


Figure 4.9 : Variation of predicted head with transmissivity.

4.4 Groundwater Recharge in Existing Conditions

An area of approximately 46.74 km^2 (5.03×10^8 ft^2) was selected to evaluate the hydrologic budgets. Regional groundwater maps for a wet season and a dry season (Figures 4.1 and 4.2) were examined and compared to select the boundaries for MODFLOW. The modeled site with different land use and soil associations are shown in Figure 4.10. Groundwater elevations in the modeled site for a wet season and a dry season are shown in Figures 4.11 and 4.12 respectively. Considering the soil associations and the sensitivity of predicted percolation values, five different soil types were selected for CREAMS; namely, Clay (C), Silty clay (SiC), Silty clay loam (SiCL), Silty loam (SiL), and Sandy loam (SL). Physical soil properties including porosity, field capacity, and wilting point corresponding to each of the soil types were estimated from the listed experimental values (Knisel,1980; MPO,1989). The selected crops for simulation were B.Amon and Rabi. The leaf area index (LAI) values of the crops were calculated from the crop coefficient (K_c) curves for the corresponding crops (Doorenbos and Pruitt,1977). Initial and final water contents of soil for irrigation were also estimated (Jensen,1980).

Table 4.1 shows the predicted percolation values for 1986 determined with CREAMS for each soil type.

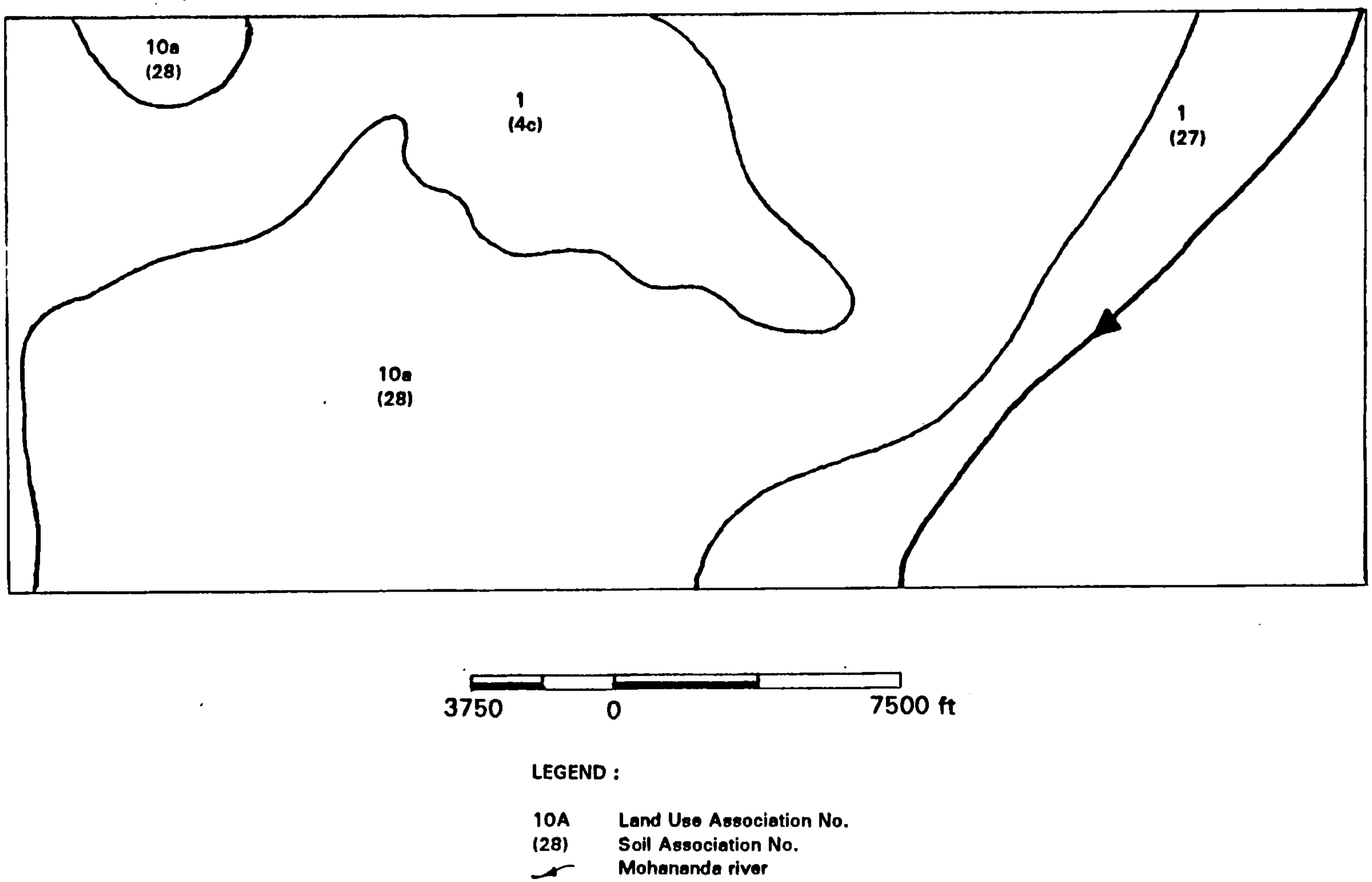
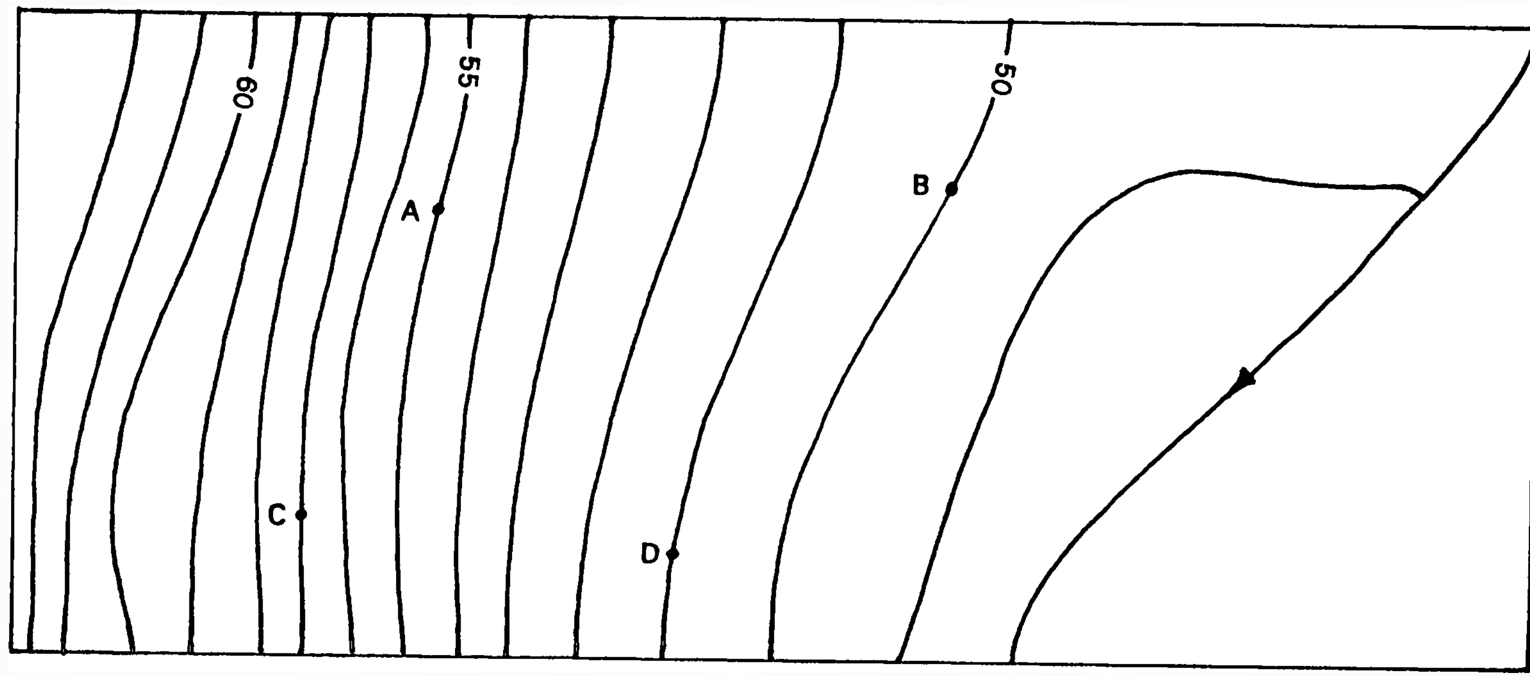


Figure 4.10 : Modeled site with different land use and soil associations.

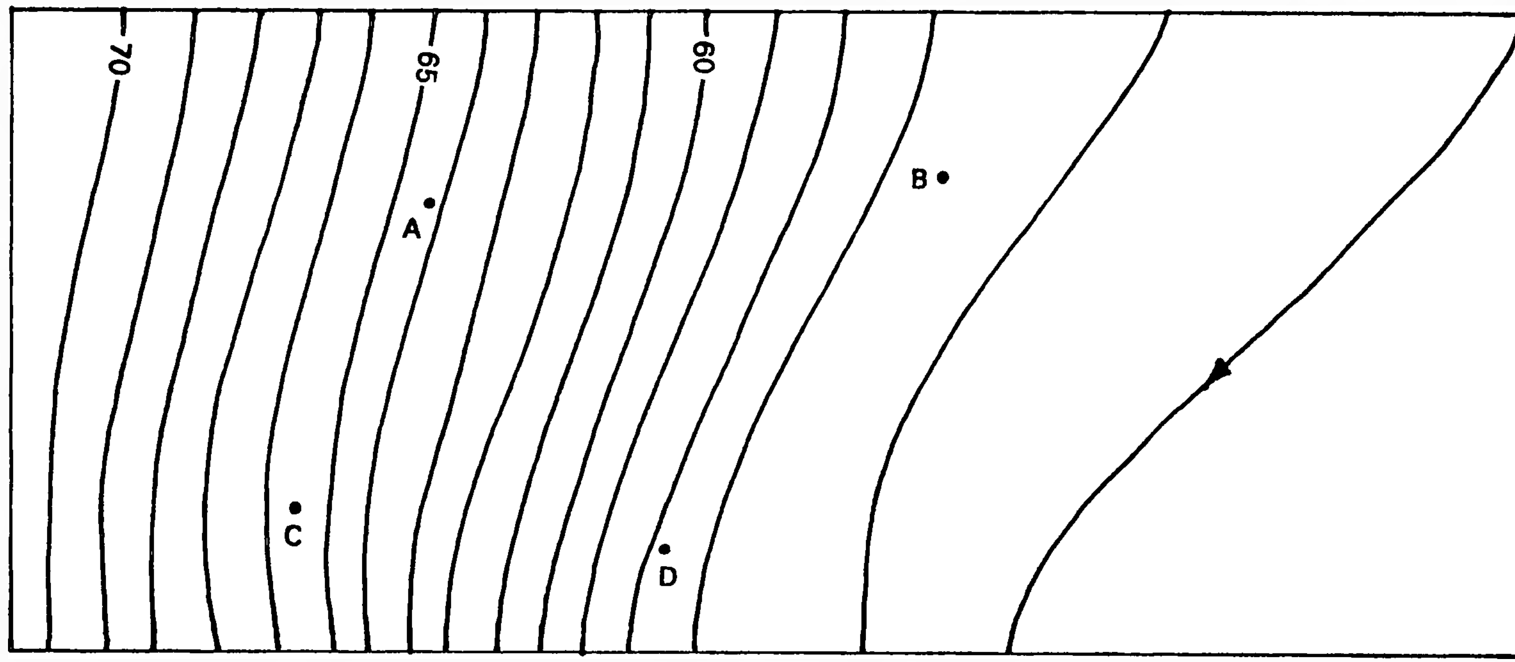


LEGEND :

A,B.. Observation points for comparison

3750 0 7500 ft

Figure 4.11 : Groundwater elevations as of June 16, 1986.



LEGEND :

A,B.. Observation points for comparison

3750 0 7500 ft

Figure 4.12 : Groundwater elevations as of October 20, 1986.

Table 4.1 : Predicted percolation values (inch) for different soil types, 1986.

Month	Soil type				
	C	SiC	SiCL	SiL	SL
Jan	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00
Mar	0.00	0.00	0.00	0.00	0.00
Apr	0.00	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00	0.00
Jun	0.05	1.28	0.00	0.00	0.05
Jul	1.45	1.08	1.92	2.74	4.93
Aug	0.88	0.65	0.94	0.84	0.91
Sep	0.40	1.23	0.42	0.61	2.60
Oct	2.95	2.80	3.93	3.68	6.99
Nov	0.26	0.00	0.09	0.03	0.00
Dec	0.00	0.00	0.00	0.00	0.00

These predicted values were then modified for each soil association based on the percent of each soil type in different soil associations. Table 4.2 shows the weighted percolation values for each soil association for 1986.

The weighted percolation values from CREAMS were used as areal recharge to the aquifer. Boundaries were selected for MODFLOW after examining the regional groundwater maps for a wet season and a dry season. The Mohananda river was selected as a constant-head boundary. The modeled site was divided

Table 4.2 : Weighted percolation values (inch) for different soil associations, 1986.

	Soil Type	Soil Association Number		
		4c	27	28
% of total	C	-	-	27
	SiC	5	-	17
	SiCL	43	33	56
	SiL	52	58	-
	SL	-	8	-
Weighted Percolation (inch)	Jan	0.00	0.00	0.00
	Feb	0.00	0.00	0.00
	Mar	0.00	0.00	0.00
	Apr	0.00	0.00	0.00
	May	0.00	0.00	0.00
	Jun	0.064	0.004	0.231
	Jul	2.300	2.613	1.649
	Aug	0.872	0.869	0.872
	Sep	0.557	0.698	0.550
	Oct	3.743	3.990	3.472
	Nov	0.050	0.044	0.119
	Dec	0.00	0.00	0.00

into 15 rows and 32 columns. The grid spacing was reduced near the stream and the proposed sites of recharge basins and recharge wells.

A steady state simulation of a dry month (June,1986) was performed to calibrate the transmissivity values at different nodes of the modeled site. Transmissivity values were first estimated from the pump test results (MPO,1989) and later adjusted for calibration. The groundwater contour map after calibration for June, 1986 is shown in Figure 4.13.

The calibration was verified with a steady state simulation of a dry month (October,1986). The corresponding groundwater contour map is shown in Figure 4.14. Table 4.3 shows the calibration and verification data for four locations within the modeled site.

A transient simulation of five wet months (June to October,1986) was performed next, with one-month stress periods. The resulting groundwater contour map is shown in Figure 4.15.

Table 4.3 : MODFLOW Calibration and validation data.
Water Levels (ft)

Location	Calibration		1-α	Validation		1-α
	Observed	Predicted		Observed	Predicted	
A	55.0	54.5	.98	64.3	67.6	.85
B	50.0	50.0		56.7	59.7	
C	57.0	56.2		65.6	68.5	
D	51.0	51.9		57.8	63.0	

1-α : t-test confidence level.
Calibration : June, 1986; Validation : October, 1986.

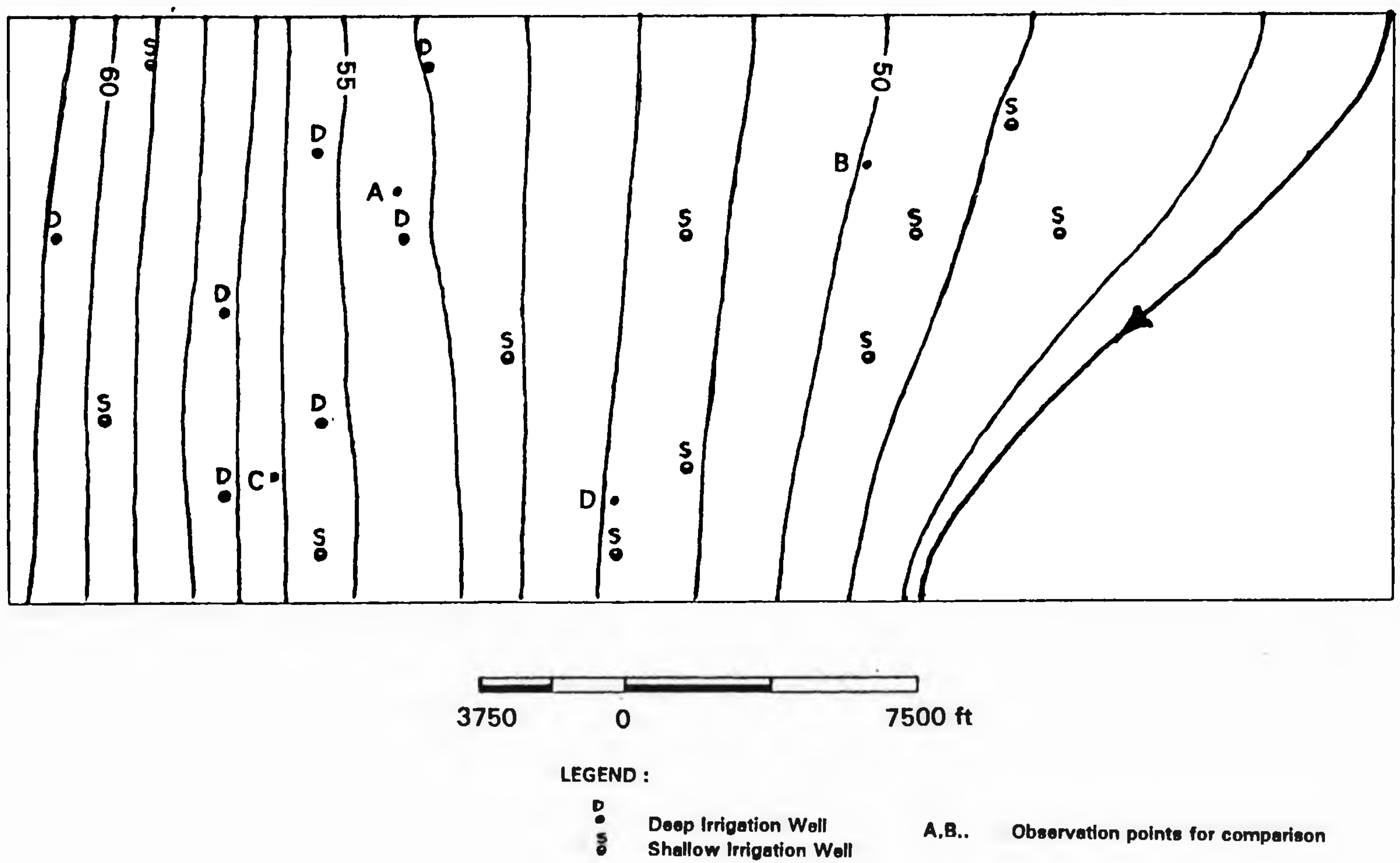


Figure 4.13 : Calibrated groundwater contour; June, 1986.

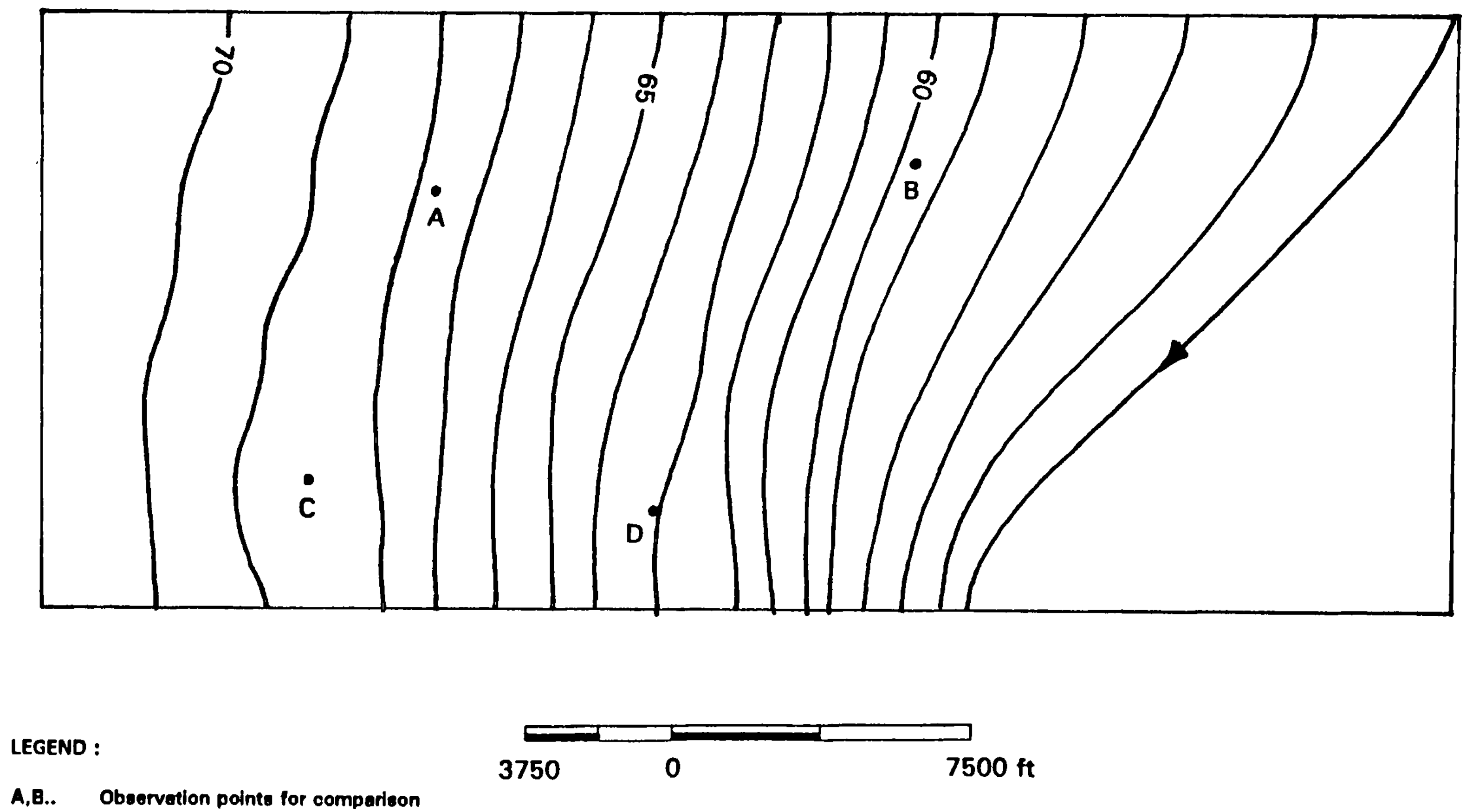


Figure 4.14 : Verification of calibration; October, 1986.

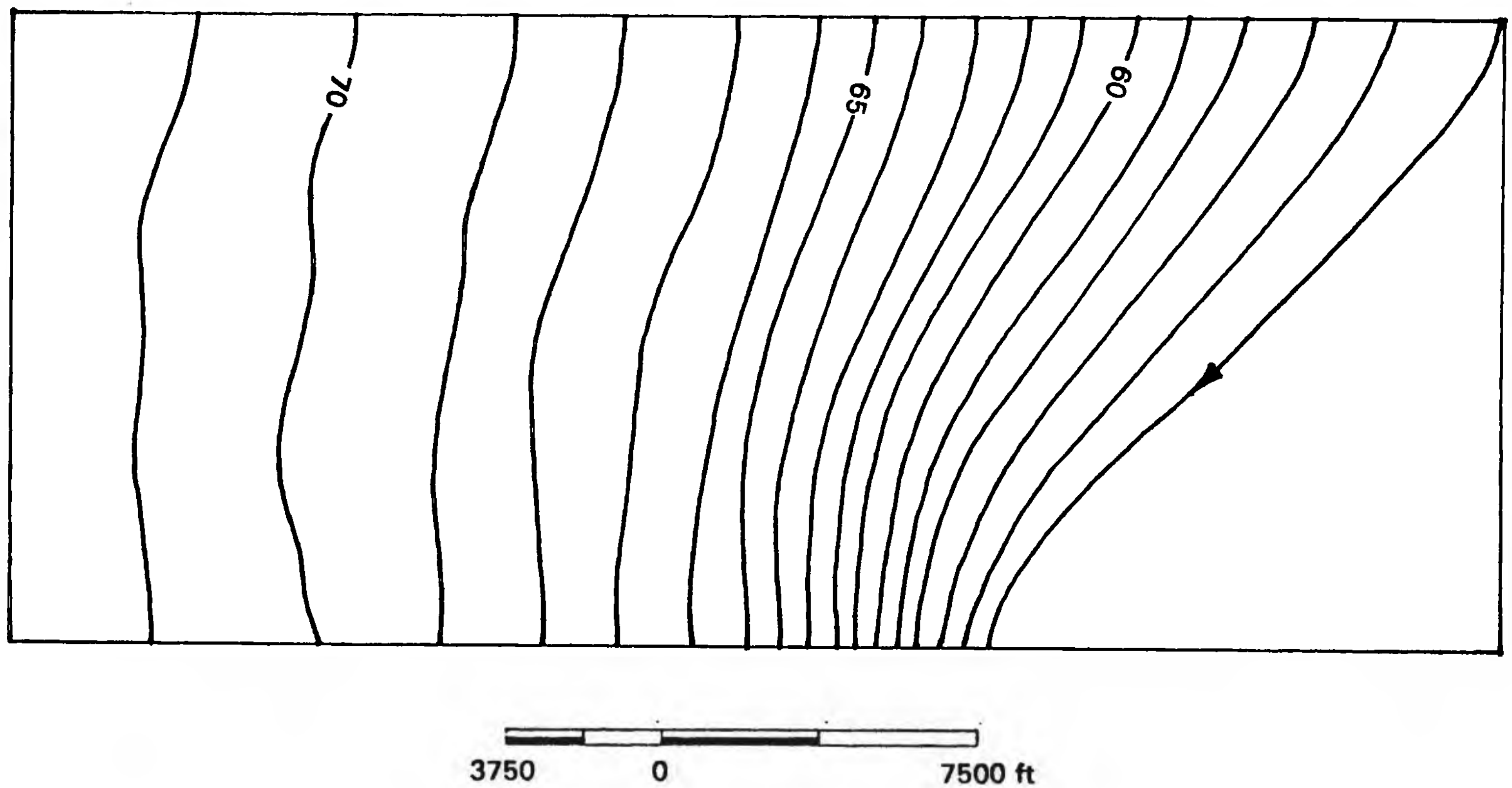


Figure 4.15 : Transient simulation from June to October,1986.

The hydrologic budgets evaluated for 1986 after calibration are shown in Table 4.4.

Table 4.4 : Hydrologic budgets for 1986.

		Volume (inch or ft^3)
Root zone (inch)	Rain	56.45
	Runoff	19.61
	ET	45.57
	Soil Moisture Balance	0.28
	Irrigation	15.50
	Percolation	7.05
Aquifer (ft^3)	Areal Recharge	2.96×10^8
	Discharge Wells	9.85×10^6
	Flow to stream	2.86×10^8
	Change in storage	1.24×10^3

4.5 Groundwater Recharge with Recharge Wells and Basins

In order to evaluate the feasibility of using recharge wells and basins to increase the groundwater levels during the dry season, median percolation values were used rather than percolation from an average rainfall year like 1986. The median percolation value of a certain soil type would be that percolation, less than which would occur in 50% of the years. CREAMS was used to predict the monthly percolation in each soil type for 10 years for this purpose. An example of graphically determining the median percolation value is shown in Figure 4.16. Detailed results are tabulated in Appendix D.

The median percolation values determined graphically were modified for each soil association as discussed in section 4.4. A transient simulation of the dry period (October to June) was performed to predict the resulting groundwater heads after the simulation period. The predicted groundwater contour map is shown in Figure 4.17.

Six recharge wells and four recharge basins were selected to recharge the groundwater during the dry season (Figure 4.18). Topographic and land use maps were examined to select the suitable locations of the wells and basins. Also total amount of runoff that can be captured during the wet season was estimated for each location using CREAMS. The evaporative loss from storage was also considered for each stress period.

The River Package in MODFLOW was included to simulate the effect of having recharge basins. Conductance of the bed of the basins was calculated from the soil properties and basin dimensions. The elevations of water levels in each basin for each stress period were determined considering the approximate amount of water recharged to the groundwater in the previous stress period and the evaporative loss from the surface of

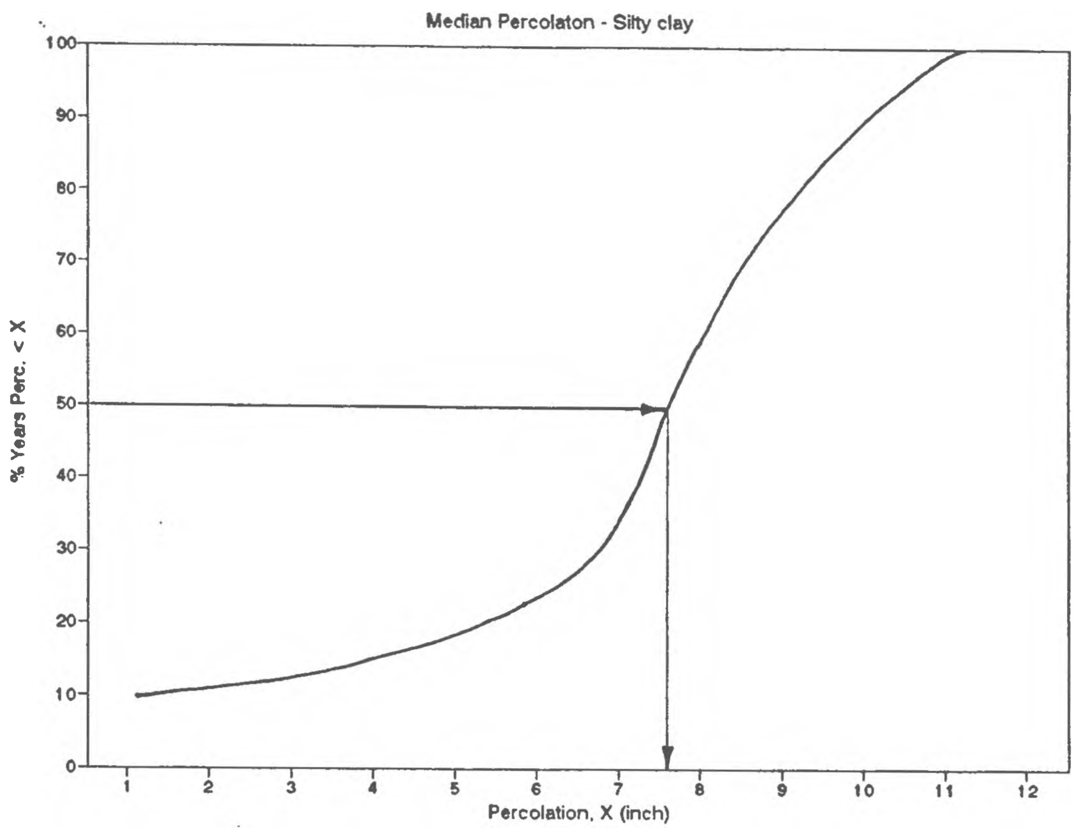


Figure 4.16 : Median percolation value for silty clay.

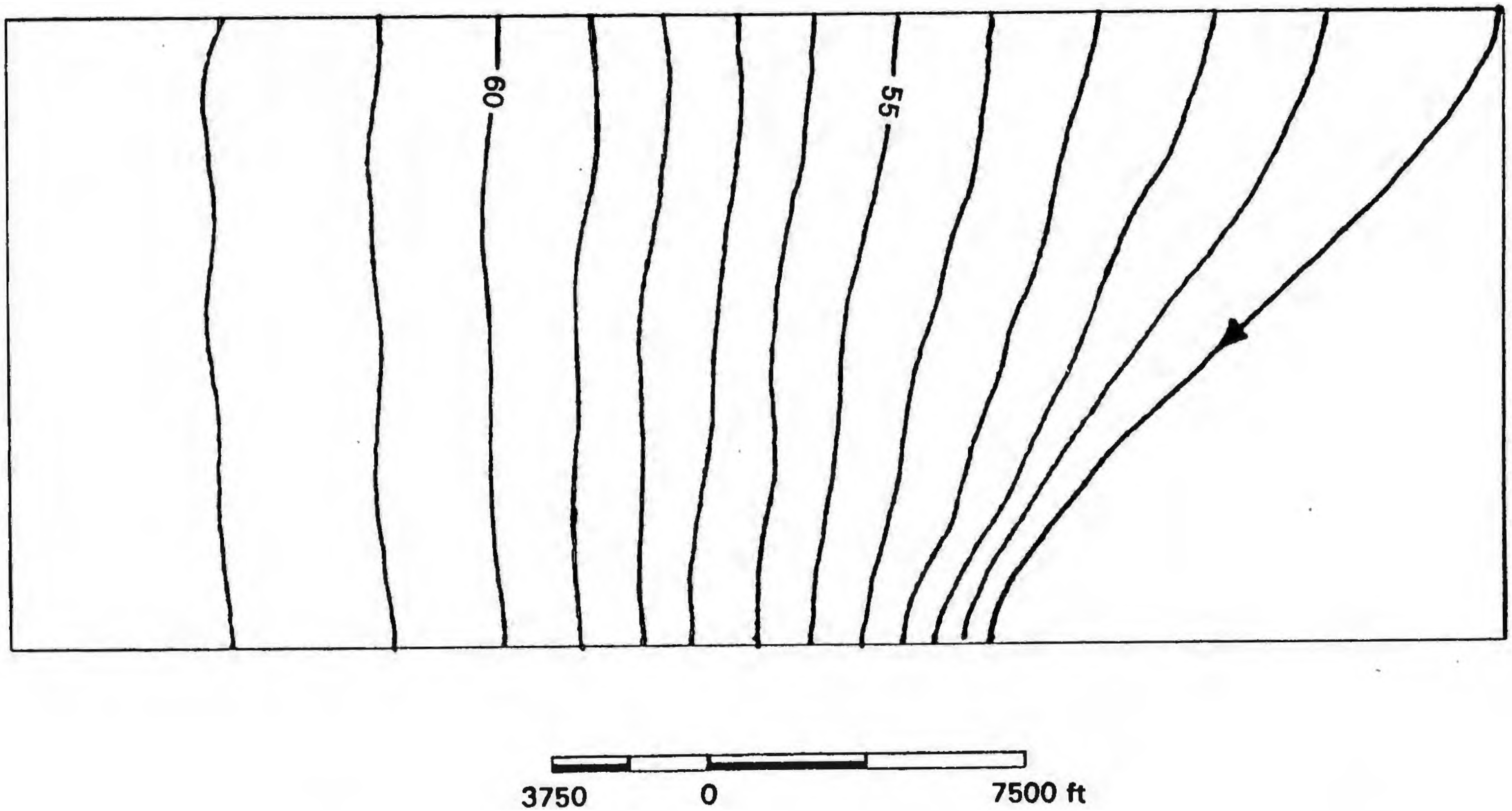


Figure 4.17 : Transient simulation from October to June.

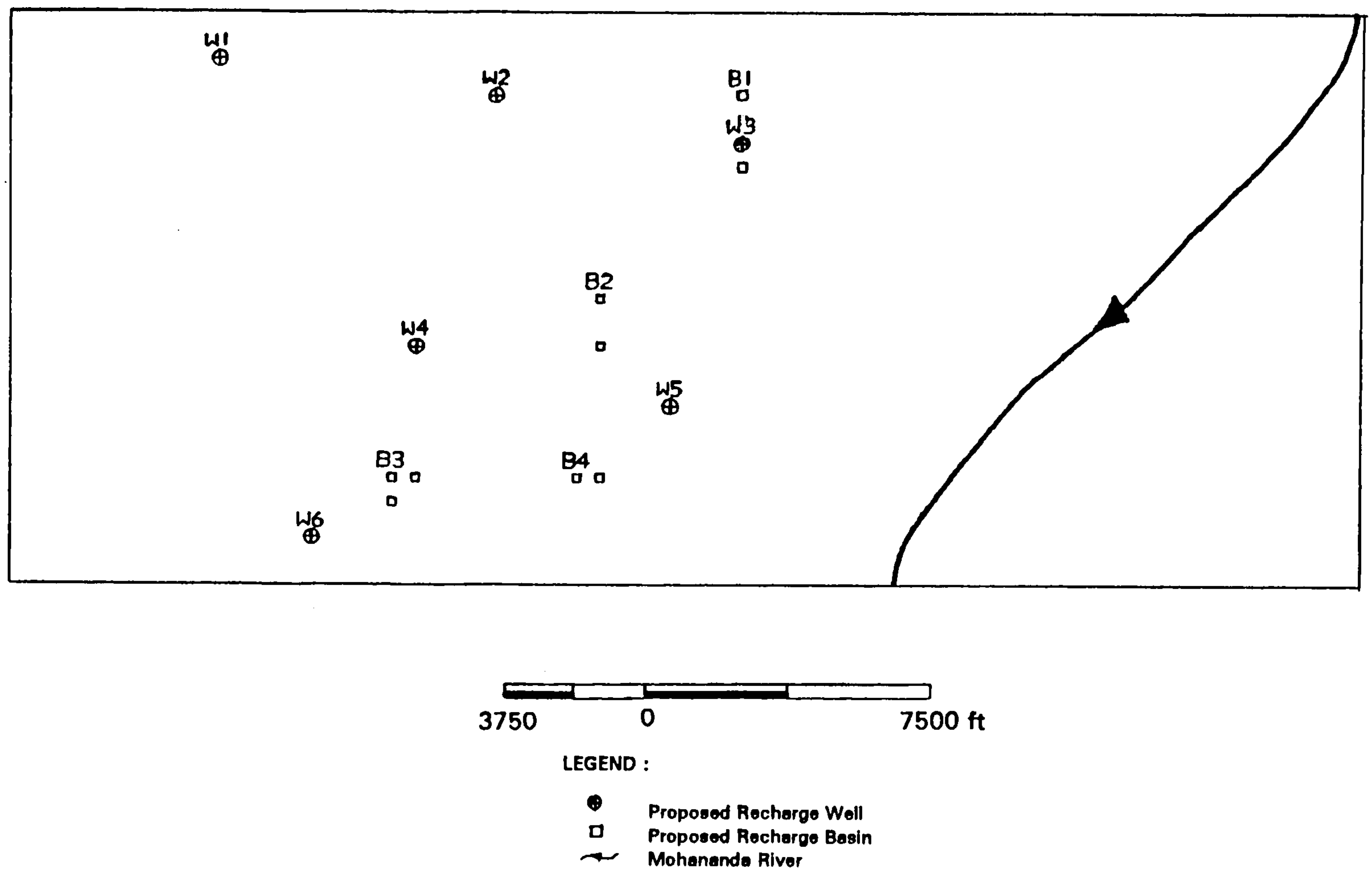


Figure 4.18 : Locations of proposed recharge wells and basins.

water in the basin.

The rates of infiltration through the recharge wells in each stress period were determined from the amount of water available during the wet season. A constant infiltration rate was assumed as long as water is available. Therefore, some of the wells were inoperative toward the end of the dry season due to lack of water to infiltrate.

Effects of recharge wells and recharge basins were simulated separately first (Figures 4.19 and 4.20). Then the combined effects of recharge wells and basins were simulated (Figure 4.21). A comparison of Figures 4.19 and 4.20 with Figure 4.17 would suggest an increase in the groundwater levels when recharge wells and basins are used. Moreover, for this modeled site, recharge basins would increase the groundwater levels more than the recharge wells.

A simulation with recharge wells and basins for the wet season (June to October) resulted in similar increase in groundwater levels (Figure 4.22).

In order to examine the feasibility of irrigating the land in the dry season to utilize the increased groundwater levels, the existing pumping wells were used along with 5 additional shallow pumping wells. Results of the simulation

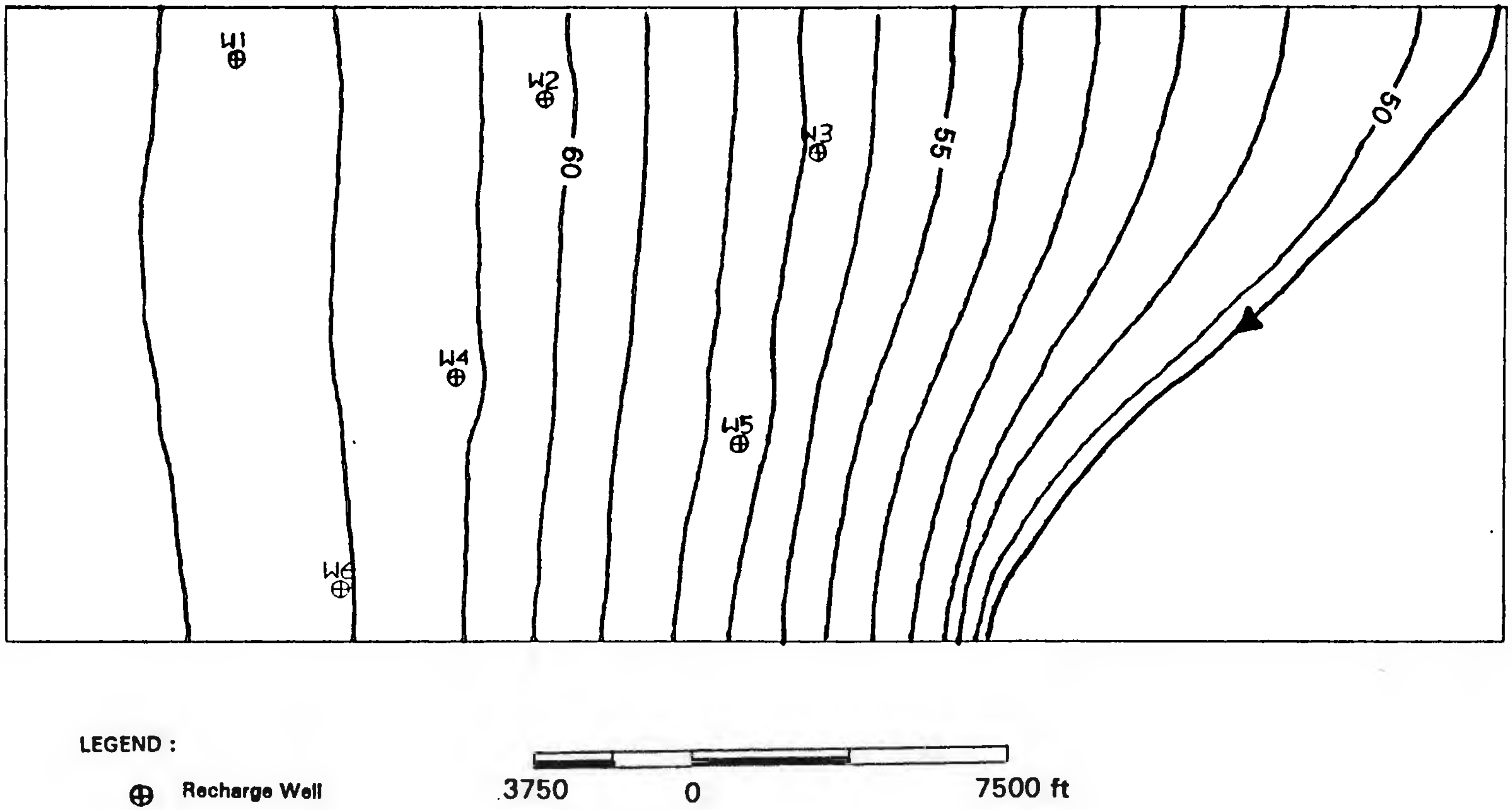


Figure 4.19 : Predicted groundwater levels with recharge wells only; Simulation from October to June.

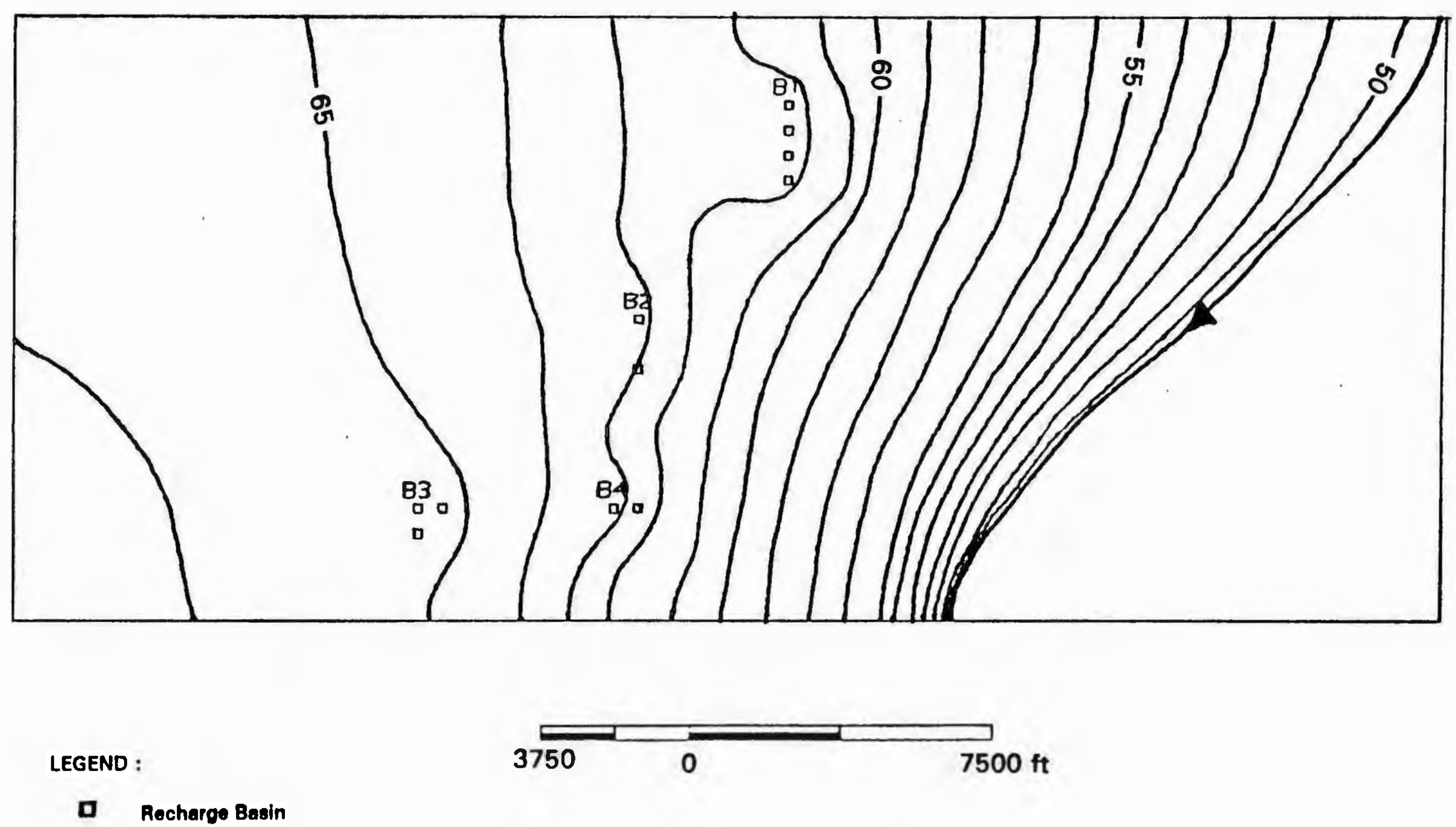


Figure 4.20 : Predicted groundwater levels with recharge basins only; Simulation from October to June.

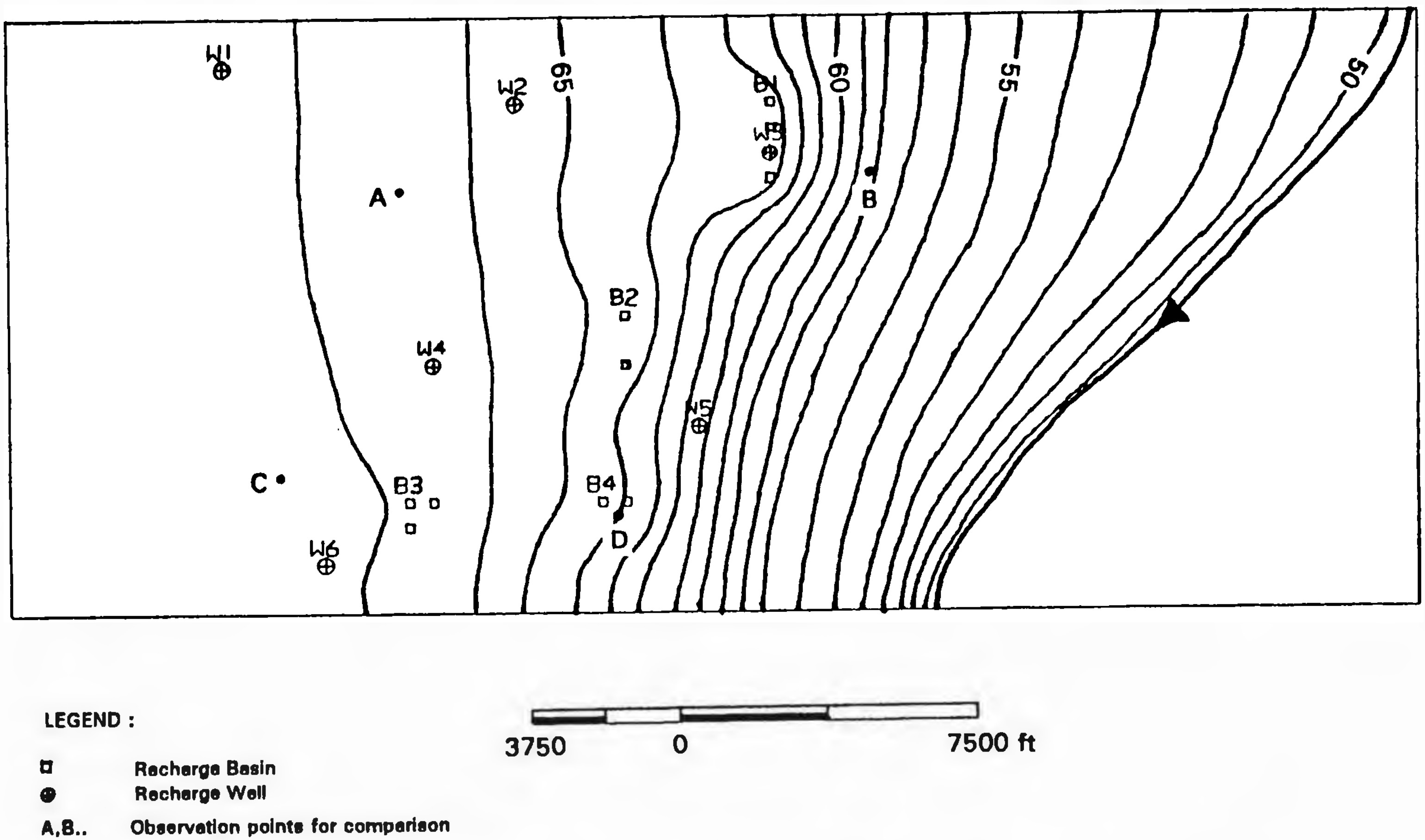


Figure 4.21 : Predicted groundwater levels with recharge wells and basins; Simulation from October to June.

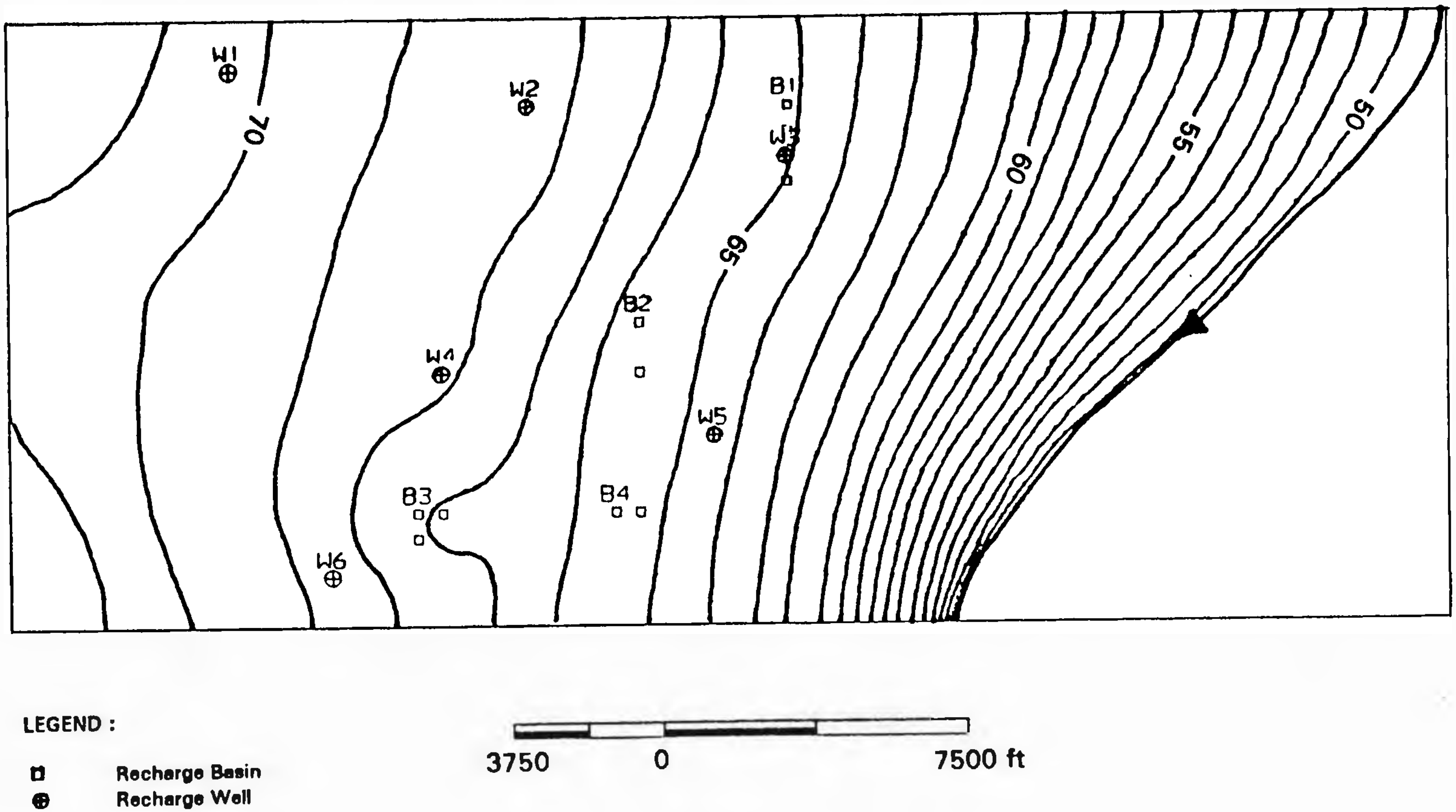


Figure 4.22 : Predicted groundwater levels with recharge wells and basins; Simulation from June to October.

are shown in Figure 4.23. Table 4.5 shows the hydrologic budgets for this simulated year. Table 4.6 shows the simulation data for two schemes using artificial recharge.

Table 4.5 : Hydrologic budgets for simulated year with recharge wells and basins.

		Volume (ft^3)
Aquifer	Areal Recharge	3.43×10^8
	Artificial Recharge	1.03×10^7
	Discharge Wells	2.23×10^7
	Flow to stream	3.31×10^8
	Change in storage	2.68×10^3

Table 4.6 : Simulation data for artificial recharge.

Location	Water Levels (ft)			
	Scheme 1		Scheme 2	
	Original	Simulation	Original	Simulation
A	55.0	66.5	55.0	61.4
B	50.0	58.0	50.0	56.4
C	57.0	67.2	57.0	62.2
D	51.0	64.0	51.0	58.5

Scheme 1 : Artificial recharge in existing condition.

Scheme 2 : Artificial recharge with proposed irrigation.

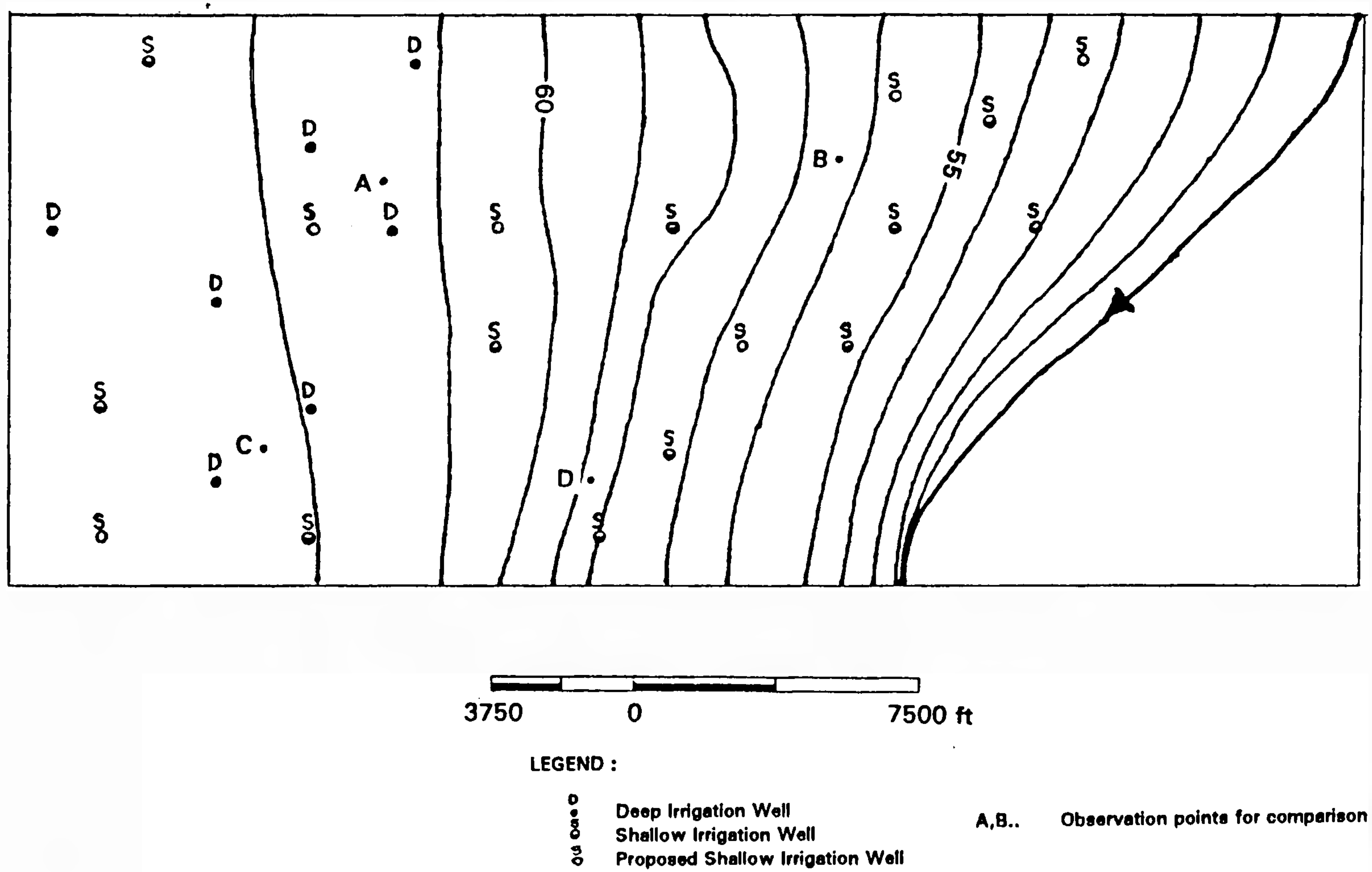


Figure 4.23 : Simulation with dry season irrigation; October to June.

4.6 Modification in Cropping and Management Practices

In order to examine any possible increase in percolation during the wet season due to change in cropping or management practices, hypothetical situations of the modeled site were simulated using CREAMS with different crops and management practices. Non-irrigated B.Aus (rice) increased the annual percolation by 2.3 to 4.6% for different soil types. Winter crops, however, did not make any difference.

Although dikes built around the paddy fields reduce the area of cultivable land, ponded rice still proved to be suitable for groundwater recharge. In fact, any management practice that would lower the curve number and hence lower the runoff is suitable for natural recharge.

V. CONCLUSIONS AND RECOMMENDATIONS

In this study area, most of the rainfall occurs during the monsoon (July to October). The rest of the year is virtually rainless. As a result, the natural recharge to the groundwater occurs only during the wet season. The semi-impervious top layer (mostly silty clay) of the ground surface does not allow much water to infiltrate and most of the runoff is not available for natural recharge. Also, during the wet season, the wet soil reduces the infiltration rate significantly (Dunne and Leopold,1978).

During the peak dry season, the water table drops 16 to 33 ft. below the ground level, below the pumping suction limit of most of the shallow wells (BWDB,1990), thereby significantly reducing the irrigation capability and hence crop production. Installing more deep wells to withdraw water during the dry season would increase the irrigation capability during the dry season. But the same irrigation capability could be achieved with shallow wells throughout the year if the groundwater is artificially recharged to rise within the suction limit of the shallow wells during the dry season.

In this region, the percent of area under production of different varieties of rice have decreased approximately 17 to

44% depending on the variety over a period of 11 years (1978 to 1988) (MPO,1989). This decrease is especially more prominent during the period 1981 - 1982 for the B.Amon variety and other irrigated rice. The reduction in agricultural land use availability for this period due to increase in residential and other land use was approximately 10%.

A change in the general trend of the dry season groundwater levels during the period 1981 - 82 were observed in the observation wells, especially in those towards the south of the area (Figure 5.1). These changes are apparently caused by the upstream diversion of the river flows in the Ganges (Abbas,1982; Begum,1987) which occurred during this time. However, analyses based on a larger watershed than that of this study has to be performed to determine any connection between these facts.

In this study, the installation of recharge wells and basins to increase the groundwater levels during the dry season was examined and proved to be feasible. The effects of using six recharge wells and four recharge basins were computer simulated to predict the increase in groundwater elevations during the dry season. Significantly higher water elevations than the existing condition were observed at the end of the dry season. In general, the water table in the area of artificial recharge was raised by 8 to 11 ft. Another

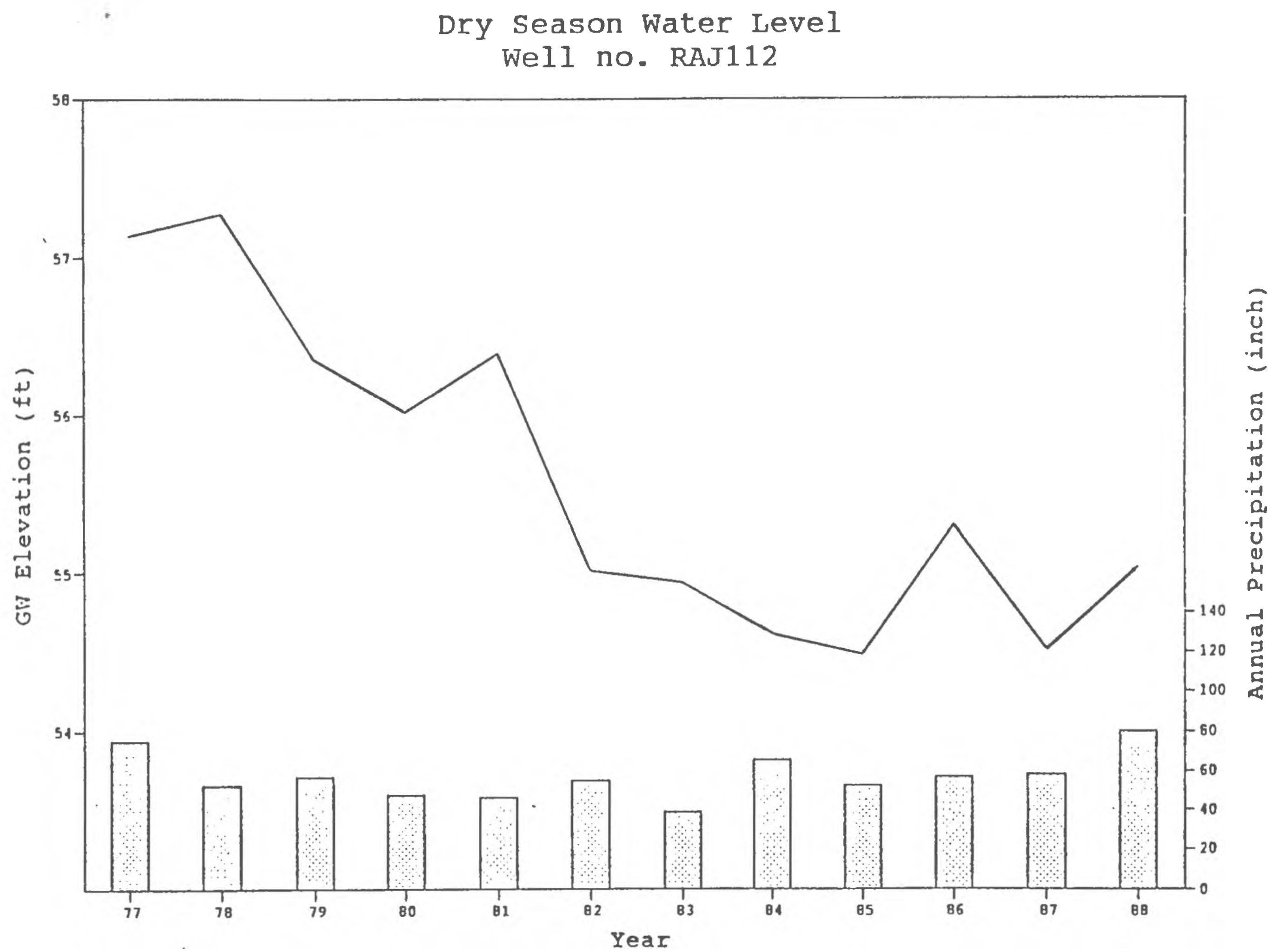


Figure 5.1 : Dry season water levels (77-88); well RAJ112. Precipitation at Shibganj.

simulation with increased irrigation (mostly with shallow pumping wells) showed that dry season pumping in conjunction with artificial recharge is feasible to increase annual rice production.

The practicality of installation and maintenance of recharge wells and basins, however, should be analyzed further. The method of construction of recharge wells may be different depending on the hydrogeologic conditions (Task Group of Artificial Ground Water Recharge,1965). Clogging of screens is the most serious problem in recharge wells (Olsthoorn,1982). Thus, screen open area and screen length must be optimal. Screens should be twice as long as for a withdrawal well pumping the same volume of water (Driscoll,1986). Other common practical problems include air entrapment and effect of injection and shut down periods (Sternau,1967; Rahman et al.,1969; Todd,1980; Bouwer,1978).

Runoff during the wet season should be captured in storage, and allowed to recharge groundwater later in the year through the recharge wells. The recharge basins consist of excavated basins in the ground or are created by dikes or levees surrounding the natural ground surface (Kashef,1986). Todd (1980), Task Group of Artificial Ground Water Recharge (1965), Bianchi and Muckel (1970), and Bouwer (1978) discussed the layout of a basin, or a series of basins, and methods of their construction and maintenance. The most common problem associated with the maintenance of these basins is clogging of the recharge bed with fine particles. This problem may be overcome with periodic scraping of the top layer. Another practical problem associated with the recharge basins or the storage basin for recharge wells is the evaporation loss. Coverage (such as polyethylene sheet) could be used to minimize this loss. Underground storage tanks for recharge wells may also be feasible.

The high silt content in the runoff may be reduced significantly using both structural and non-structural Best Management Practices (BMP) (Land Management Project,1990). Improving quality and controlling the quantity of runoff to receiving surface water and groundwater is a common purpose among these primarily preventive practices. Structural BMPs include sediment basins, artificial wet lands, and extended detention wet and dry basins. Non-structural BMPs include land use and site planning techniques, protection of natural buffer areas, and fertilizer management.

The approach followed in this study for a limited region in Bangladesh to augment the groundwater storage utilizing natural water supply may be used in other regions with similar hydrogeologic conditions. However, much depends on the rainfall magnitude and pattern. Precipitation should be abundant during the wet season to recharge the groundwater during the dry season. Finally, the precise locations for installing the proposed systems have to be determined and further analyzed with more site specific field observation and evaluation.

APPENDIX A

Groundwater Level Monitoring Data

RAJ73 1978
Well depth: 38.29 m; Dia: 0.04 m
R.L. 39.32 m

Date	Depth to GW (m)	GW Elev. (m)	(ft)
01/04	14.02	46	82.90
01/11	14.18	46.5	82.40
01/18	14.23	46.67	82.23
01/25	14.38	47.17	81.73
02/01	14.51	47.58	81.32
02/08	14.61	47.92	80.98
02/15	14.63	48	80.90
02/22	14.71	48.25	80.65
03/01	14.76	48.42	80.48
03/08	14.89	48.83	80.07
03/15	14.97	49.09	79.81
03/22	15.02	49.25	79.65
03/29	15.07	49.42	79.48
04/05	15.19	49.83	79.07
04/12	15.24	50	78.90
04/19	15.32	50.25	78.65
04/26	15.42	50.58	78.32
05/03	16.23	53.25	75.65
05/10	16.46	54	74.90
05/17	16.97	55.67	73.23
05/24	17.02	55.83	73.07
05/31	16.52	54.17	74.73
06/07	16.46	54	74.90
06/14	16.39	53.75	75.15
06/21	16.34	53.58	75.32
06/28	15.80	51.83	77.07
07/05	15.34	50.33	78.57
07/12	15.27	50.08	78.82
07/19	14.79	48.5	80.40

07/26	14.33	47	81.90
08/02	14.10	46.25	82.65
08/09	14.02	46	82.90
08/16	13.90	45.58	83.32
08/23	13.67	44.83	84.07
08/30	13.49	44.25	84.65
09/06	13.11	43	85.90
09/13	12.91	42.33	86.57
09/20	12.93	42.42	86.48
09/27	13.03	42.75	86.15
10/04	13.11	43	85.90
10/11	13.24	43.42	85.48
10/18	13.31	43.67	85.23
10/25	13.47	44.17	84.73
11/01	13.67	44.83	84.07
11/08	14.00	45.92	82.98
11/15	13.90	45.58	83.32
11/22	13.97	45.83	83.07
11/29	14.08	46.17	82.73
12/06	14.13	46.33	82.57
12/13	14.18	46.5	82.40
12/20	14.33	47	81.90
12/27	14.38	47.17	81.73

RAJ75 1986

Well depth: 40.80 m; Dia: 0.04 m

R.L. 23.2 m

Date	Depth to GW (m)	GW Elev. (m)	(ft)
01/06	7.62	15.64	51.30
01/13	7.22	16.04	52.61
01/20	7.88	15.38	50.45
01/27	7.98	15.28	50.12
02/03	8.18	15.08	49.46
02/10	8.36	14.9	48.87
02/17	8.48	14.78	48.48
02/24	8.54	14.72	48.28
03/03	8.61	14.65	48.05
03/10	8.75	14.51	47.59
03/17	8.82	14.44	47.36
03/24	8.89	14.37	47.13
03/31	8.99	14.27	46.81
04/07	9.07	14.19	46.54
04/14	9.12	14.14	46.38
04/21	9.22	14.04	46.05
04/28	9.3	13.96	45.79
05/05	9.38	13.88	45.53
05/12	9.46	13.8	45.26
05/19	9.54	13.72	45.00
05/26	9.5	13.76	45.13
06/02	9.48	13.78	45.20
06/09	9.5	13.76	45.13
06/16	9.6	13.66	44.80
06/23	9.73	13.53	44.38
06/30	9.76	13.5	44.28
07/07	9.48	13.78	45.20
07/14	9.32	13.94	45.72
07/21	9.15	14.11	46.28

07/28	9.04	14.22	46.64
08/04	8.71	14.55	47.72
08/11	8.54	14.72	48.28
08/18	8.38	14.88	48.81
08/25	8.23	15.03	49.30
09/01	7.95	15.31	50.22
09/08	7.88	15.38	50.45
09/15	7.52	15.74	51.63
09/22	7.28	15.98	52.41
09/29	6.71	16.55	54.28
10/06	6.07	17.19	56.38
10/13	5.64	17.62	57.79
10/20	5.51	17.75	58.22
10/27	5.79	17.47	57.30
11/03	6.07	17.19	56.38
11/10	6.33	16.93	55.53
11/17	6.73	16.53	54.22
11/24	6.88	16.38	53.73
12/01	7.16	16.1	52.81
12/08	7.32	15.94	52.28
12/15	7.89	15.37	50.41
12/22	7.69	15.57	51.07
12/29	7.72	15.54	50.97

RAJ76 1986
Well depth: 9.60 m; Dia: 1.35 m
R.L. 27.83 m

Date	Depth to GW (m)	GW Elev. (m)	(ft)
01/06	6.65	21.18	69.47
01/13	6.68	21.15	69.37
01/20	6.7	21.13	69.31
01/27	6.72	21.11	69.24
02/03	6.75	21.08	69.14
02/10	6.78	21.05	69.04
02/17	6.83	21	68.88
02/24	6.89	20.94	68.68
03/03	6.96	20.87	68.45
03/10	7.02	20.81	68.26
03/17	7.09	20.74	68.03
03/24	7.16	20.67	67.80
03/31	7.13	20.7	67.90
04/07	7.23	20.6	67.57
04/14	7.45	20.38	66.85
04/21	7.55	20.28	66.52
04/28	7.67	20.16	66.12
05/05	7.75	20.08	65.86
05/12	7.7	20.13	66.03
05/19	7.7	20.13	66.03
05/26	7.65	20.18	66.19
06/02	7.6	20.23	66.35
06/09	7.65	20.18	66.19
06/16	7.7	20.13	66.03
06/23	7.67	20.16	66.12
06/30	7.62	20.21	66.29
07/07	7.35	20.48	67.17
07/14	7.1	20.73	67.99
07/21	6.95	20.88	68.49

07/28	6.8	21.03	68.98
08/04	6.73	21.1	69.21
08/11	6.7	21.13	69.31
08/18	6.65	21.18	69.47
08/25	6.7	21.13	69.31
09/01	6.75	21.08	69.14
09/08	6.7	21.13	69.31
09/15	6.55	21.28	69.80
09/22	6.3	21.53	70.62
09/29	6.1	21.73	71.27
10/06	5.85	21.98	72.09
10/13	5.6	22.23	72.91
10/20	5.3	22.53	73.90
10/27	5.5	22.33	73.24
11/03	5.6	22.23	72.91
11/10	5.7	22.13	72.59
11/17	5.75	22.08	72.42
11/24	5.8	22.03	72.26
12/01	5.85	21.98	72.09
12/08	5.9	21.93	71.93
12/15	5.95	21.88	71.77
12/22	6	21.83	71.60
12/29	6.05	21.78	71.44

RAJ78 1986

Well depth: 8.53 m; Dia: 2.69 m

R.L. 24.98 m

Date	Depth to GW (m)	GW Elev. (m)	(ft)
01/06	4.6	20.38	66.85
01/13	4.67	20.31	66.62
01/20	4.75	20.23	66.35
01/27	4.83	20.15	66.09
02/03	4.88	20.1	65.93
02/10	4.93	20.05	65.76
02/17	5	19.98	65.53
02/24	5.08	19.9	65.27
03/03	5.16	19.82	65.01
03/10	5.26	19.72	64.68
03/17	5.34	19.64	64.42
03/24	5.4	19.58	64.22
03/31	5.49	19.49	63.93
04/07	5.56	19.42	63.70
04/14	5.64	19.34	63.44
04/21	5.72	19.26	63.17
04/28	5.75	19.23	63.07
05/05	5.79	19.19	62.94
05/12	5.92	19.06	62.52
05/19	6.05	18.93	62.09
05/26	6.17	18.81	61.70
06/02	6.22	18.76	61.53
06/09	6.25	18.73	61.43
06/16	6.27	18.71	61.37
06/23	6.2	18.78	61.60
06/30	5.79	19.19	62.94
07/07	5.87	19.11	62.68
07/14	5.92	19.06	62.52
07/21	5.79	19.19	62.94

07/28	5.66	19.32	63.37
08/04	5.44	19.54	64.09
08/11	5.23	19.75	64.78
08/18	5.05	19.93	65.37
08/25	4.95	20.03	65.70
09/01	4.8	20.18	66.19
09/08	4.34	20.64	67.70
09/15	4.27	20.71	67.93
09/22	4.04	20.94	68.68
09/29	4.35	20.63	67.67
10/06	3.05	21.93	71.93
10/13	3	21.98	72.09
10/20	2.95	22.03	72.26
10/27	3.05	21.93	71.93
11/03	3.17	21.81	71.54
11/10	3.35	21.63	70.95
11/17	3.51	21.47	70.42
11/24	3.78	21.2	69.54
12/01	3.88	21.1	69.21
12/08	3.99	20.99	68.85
12/15	4.12	20.86	68.42

RAJ107 1986

Well depth: 6.85 m; Dia: 1.19 m

R.L. 21.46 m

Date	Depth to GW (m)	GW Elev. (m)	(ft)
01/06	3.76	17.7	58.06
01/13	3.88	17.58	57.66
01/20	3.91	17.55	57.56
01/27	4.04	17.42	57.14
02/03	4.01	17.45	57.24
02/10	4.04	17.42	57.14
02/17	4.14	17.32	56.81
02/24	4.22	17.24	56.55
03/03	4.27	17.19	56.38
03/10	4.45	17.01	55.79
03/17	4.49	16.97	55.66
03/24	4.65	16.81	55.14
03/31	4.5	16.96	55.63
04/07	4.65	16.81	55.14
04/14	4.62	16.84	55.24
04/21	4.67	16.79	55.07
04/28	4.73	16.73	54.87
05/05	4.75	16.71	54.81
05/12	4.8	16.66	54.64
05/19	4.73	16.73	54.87
05/26	4.77	16.69	54.74
06/02	5.13	16.33	53.56
06/09	5.13	16.33	53.56
06/16	5.04	16.42	53.86
06/23	4.95	16.51	54.15
06/30	4.98	16.48	54.05
07/07	4.98	16.48	54.05
07/14	4.92	16.54	54.25
07/21	4.63	16.83	55.20

07/28	4.55	16.91	55.46
08/04	3.89	17.57	57.63
08/11	2.69	18.77	61.57
08/18	2.87	18.59	60.98
08/25	2.85	18.61	61.04
09/01	2.7	18.76	61.53
09/08	2.51	18.95	62.16
09/15	2.93	18.53	60.78
09/22	3.43	18.03	59.14
09/29	3.71	17.75	58.22
10/06	1.34	20.12	65.99
10/13	1.4	20.06	65.80
10/20	2.39	19.07	62.55
10/27	2.81	18.65	61.17
11/03	3.1	18.36	60.22
11/10	3.25	18.21	59.73
11/17	3.58	17.88	58.65
11/24	3.45	18.01	59.07
12/01	3.61	17.85	58.55
12/08	3.63	17.83	58.48
12/15	3.75	17.71	58.09
12/22	3.86	17.6	57.73
12/29	3.75	17.71	58.09

RAJ108 1986
Well depth: 8.76 m; Dia: 1.58 m
R.L. 24.99 m

Date	Depth to GW (m)	GW Elev. (m)	(ft)
01/06	4.15	20.84	68.36
01/13	4.22	20.77	68.13
01/20	4.32	20.67	67.80
01/27	4.39	20.6	67.57
02/03	4.45	20.54	67.37
02/10	4.52	20.47	67.14
02/17	4.62	20.37	66.81
02/24	4.67	20.32	66.65
03/03	4.77	20.22	66.32
03/10	4.85	20.14	66.06
03/17	5.01	19.98	65.53
03/24	5.05	19.94	65.40
03/31	5.13	19.86	65.14
04/07	5.29	19.7	64.62
04/14	5.31	19.68	64.55
04/21	5.49	19.5	63.96
04/28	5.46	19.53	64.06
05/05	5.59	19.4	63.63
05/12	5.6	19.39	63.60
05/19	5.61	19.38	63.57
05/26	5.61	19.38	63.57
06/02	5.69	19.3	63.30
06/09	5.79	19.2	62.98
06/16	5.89	19.1	62.65
06/23	5.84	19.15	62.81
06/30	5.79	19.2	62.98
07/07	5.72	19.27	63.21
07/14	5.66	19.33	63.40
07/21	5.49	19.5	63.96

07/28	5.41	19.58	64.22
08/04	5.31	19.68	64.55
08/11	5.16	19.83	65.04
08/18	5	19.99	65.57
08/25	4.83	20.16	66.12
09/01	4.77	20.22	66.32
09/08	4.67	20.32	66.65
09/15	4.44	20.55	67.40
09/22	4.22	20.77	68.13
09/29	3.86	21.13	69.31
10/06	3.35	21.64	70.98
10/13	2.34	22.65	74.29
10/20	2.13	22.86	74.98
10/27	2.31	22.68	74.39
11/03	2.74	22.25	72.98
11/10	2.84	22.15	72.65
11/17	3	21.99	72.13
11/24	3.2	21.79	71.47
12/01	3.3	21.69	71.14
12/08	3.45	21.54	70.65
12/15	3.58	21.41	70.22
12/22	3.66	21.33	69.96
12/29	3.76	21.23	69.63

RAJ110 1986
Well depth: 38.81 m; Dia: 0.04 m
R.L. 23.71 m

Date	Depth to GW (m)	GW Elev. (m)	(ft)
01/06	6.08	17.63	57.83
01/13	6.13	17.58	57.66
01/20	6.2	17.51	57.43
01/27	6.25	17.46	57.27
02/03	6.3	17.41	57.10
02/10	6.35	17.36	56.94
02/17	6.38	17.33	56.84
02/24	6.41	17.3	56.74
03/03	6.44	17.27	56.65
03/10	6.48	17.23	56.51
03/17	6.52	17.19	56.38
03/24	6.53	17.18	56.35
03/31	6.57	17.14	56.22
04/07	6.59	17.12	56.15
04/14	6.62	17.09	56.06
04/21	6.64	17.07	55.99
04/28	6.66	17.05	55.92
05/05	6.68	17.03	55.86
05/12	6.7	17.01	55.79
05/19	6.67	17.04	55.89
05/26	6.72	16.99	55.73
06/02	6.71	17	55.76
06/09	6.72	16.99	55.73
06/16	6.7	17.01	55.79
06/23	6.72	16.99	55.73
06/30	6.7	17.01	55.79
07/07	6.4	17.31	56.78
07/14	5.74	17.97	58.94
07/21	5.26	18.45	60.52

07/28	4.59	19.12	62.71
08/04	1.47	22.24	72.95
08/11	2.08	21.63	70.95
08/18	3.77	19.94	65.40
08/25	2.01	21.7	71.18
09/01	1.68	22.03	72.26
09/08	3.31	20.4	66.91
09/15	3.35	20.36	66.78
09/22	2.91	20.8	68.22
09/29	3.34	20.37	66.81
10/06	3.96	19.75	64.78
10/13	3.53	20.18	66.19
10/20	4.08	19.63	64.39
10/27	4.64	19.07	62.55
11/03	5.09	18.62	61.07
11/10	5.34	18.37	60.25
11/17	5.52	18.19	59.66
11/24	5.66	18.05	59.20
12/01	5.73	17.98	58.97
12/08	5.88	17.83	58.48
12/15	6.11	17.6	57.73
12/22	6.19	17.52	57.47
12/29	6.19	17.52	57.47

RAJ111 1986
Well depth: 31.19 m; Dia: 0.04 m
R.L. 22.73 m

Date	Depth to GW (m)	GW Elev. (m)	(ft)
01/06	5.95	16.78	55.04
01/13	6.03	16.7	54.78
01/20	6.09	16.64	54.58
01/27	6.13	16.6	54.45
02/03	6.15	16.58	54.38
02/10	6.2	16.53	54.22
02/17	6.25	16.48	54.05
02/24	6.29	16.44	53.92
03/03	6.3	16.43	53.89
03/10	6.34	16.39	53.76
03/17	6.35	16.38	53.73
03/24	6.4	16.33	53.56
03/31	6.43	16.3	53.46
04/07	6.44	16.29	53.43
04/14	6.48	16.25	53.30
04/21	6.49	16.24	53.27
04/28	6.52	16.21	53.17
05/05	6.53	16.2	53.14
05/12	6.54	16.19	53.10
05/19	6.52	16.21	53.17
05/26	6.55	16.18	53.07
06/02	6.54	16.19	53.10
06/09	6.58	16.15	52.97
06/16	6.58	16.15	52.97
06/23	6.6	16.13	52.91
06/30	6.55	16.18	53.07
07/07	5.97	16.76	54.97
07/14	5.63	17.1	56.09
07/21	5.19	17.54	57.53

07/28	4.45	18.28	59.96
08/04	1.38	21.35	70.03
08/11	2.26	20.47	67.14
08/18	3.61	19.12	62.71
08/25	1.79	20.94	68.68
09/01	1.69	21.04	69.01
09/08	3.1	19.63	64.39
09/15	3.17	19.56	64.16
09/22	3.2	19.53	64.06
09/29	3.35	19.38	63.57
10/06	3.56	19.17	62.88
10/13	3.75	18.98	62.25
10/20	3.9	18.83	61.76
10/27	4.5	18.23	59.79
11/03	4.5	18.23	59.79
11/10	5.18	17.55	57.56
11/17	5.37	17.36	56.94
11/24	5.52	17.21	56.45
12/01	5.64	17.09	56.06
12/08	5.74	16.99	55.73
12/15	5.85	16.88	55.37
12/22	5.89	16.84	55.24
12/29	5.99	16.74	54.91

RAJ112 1986
Well depth: 31.90 m; Dia: 0.04 m
R.L. 23.27 m

Date	Depth to GW (m)	GW Elev. (m)	(ft)
01/06	5.56	17.72	58.12
01/13	5.72	17.56	57.60
01/20	5.77	17.51	57.43
01/27	5.8	17.48	57.33
02/03	5.85	17.43	57.17
02/10	5.91	17.37	56.97
02/17	5.97	17.31	56.78
02/24	5.99	17.29	56.71
03/03	6.03	17.25	56.58
03/10	6.04	17.24	56.55
03/17	6.09	17.19	56.38
03/24	6.11	17.17	56.32
03/31	6.16	17.12	56.15
04/07	6.19	17.09	56.06
04/14	6.2	17.08	56.02
04/21	6.22	17.06	55.96
04/28	6.25	17.03	55.86
05/05	6.26	17.02	55.83
05/12	6.28	17	55.76
05/19	6.25	17.03	55.86
05/26	6.28	17	55.76
06/02	6.3	16.98	55.69
06/09	6.32	16.96	55.63
06/16	6.33	16.95	55.60
06/23	6.34	16.94	55.56
06/30	6.3	16.98	55.69
07/07	5.7	17.58	57.66
07/14	5.28	18	59.04
07/21	4.83	18.45	60.52

07/28	4.27	19.01	62.35
08/04	1.84	21.44	70.32
08/11	1.46	21.82	71.57
08/18	3.29	19.99	65.57
08/25	1.8	21.48	70.45
09/01	1.36	21.92	71.90
09/08	2.7	20.58	67.50
09/15	2.78	20.5	67.24
09/22	2.36	20.92	68.62
09/29	3.18	20.1	65.93
10/06	3.71	19.57	64.19
10/13	3.35	19.93	65.37
10/20	3.45	19.83	65.04
10/27	4.09	19.19	62.94
11/03	4.59	18.69	61.30
11/10	5.87	17.41	57.10
11/17	5.05	18.23	59.79
11/24	5.2	18.08	59.30
12/01	5.32	17.96	58.91
12/08	5.42	17.86	58.58
12/15	5.54	17.74	58.19
12/22	5.6	17.68	57.99
12/29	5.7	17.58	57.66

RAJ135 1986
Well depth: 40.60 m; Dia: 0.04 m
R.L. 23.67 m

Date	Depth to GW (m)	GW Elev. (m)	(ft)
01/06	8.7	14.97	49.10
01/13	8.8	14.87	48.77
01/20	8.85	14.82	48.61
01/27	8.95	14.72	48.28
02/03	8.95	14.72	48.28
02/10	9.01	14.66	48.08
02/17	9.03	14.64	48.02
02/24	9.05	14.62	47.95
03/03	9.15	14.52	47.63
03/10	9.3	14.37	47.13
03/17	9.45	14.22	46.64
03/24	9.65	14.02	45.99
03/31	9.7	13.97	45.82
04/07	9.65	14.02	45.99
04/14	9.66	14.01	45.95
04/21	9.72	13.95	45.76
04/28	9.6	14.07	46.15
05/05	9.3	14.37	47.13
05/12	9.15	14.52	47.63
05/19	9.05	14.62	47.95
05/26	9.1	14.57	47.79
06/02	9.35	14.32	46.97
06/09	9.25	14.42	47.30
06/16	9.2	14.47	47.46
06/23	8.1	15.57	51.07
06/30	7.4	16.27	53.37
07/07	5.4	18.27	59.93
07/14	4.2	19.47	63.86
07/21	7.5	16.17	53.04

07/28	4.95	18.72	61.40
08/04	3.25	20.42	66.98
08/11	3.2	20.47	67.14
08/18	4.2	19.47	63.86
08/25	3.3	20.37	66.81
09/01	3.6	20.07	65.83
09/08	4.02	19.65	64.45
09/15	3.3	20.37	66.81
09/22	3.04	20.63	67.67
09/29	3.95	19.72	64.68
10/06	4.02	19.65	64.45
10/13	4.02	19.65	64.45
10/20	4.1	19.57	64.19
10/27	4.15	19.52	64.03
11/03	4.5	19.17	62.88
11/10	7.01	16.66	54.64
11/17	7.65	16.02	52.55
11/24	8.07	15.6	51.17
12/01	8.35	15.32	50.25
12/08	8.7	14.97	49.10
12/15	8.95	14.72	48.28
12/22	8.9	14.77	48.45
12/29	8.96	14.71	48.25

APPENDIX B

Bore Hole Logs

GEOLOGICAL DATA RECORD CARD

BARIND INTEGRATED AREA DEVELOPMENT PROJECT, RAJSHAHI.

TEST WELL NO. 68 JL NO. 88 PLOT NO. ______ MOUZA Doksin Amorpur

LATITUDE 24°44'15"N LONGITUDE 88°08'27"E UPA-ZILL Shibganj DISTRICT Nawabganj

PROJECT BIAD Project, Rajshahi ORGANIZATION BADC

DRILLING CONDUCTED BY Ground Water Circle-1 DATE COMMENCED ______ COMPLETED ______

DATA RECORDED IN THE FIELD BY Geologist, M. Shahidul Alam

DRILLING EQUIPMENT USED Rig no X1 PURPOSE Ground Water Investigation

TOTAL DEPTH (Metre/ft) 92.05m/302 ft GROUND LEVEL(Metre/ft)PWD DATUM 20.73

STATIC WATER LEVEL BELOW GL.(Metre) AT HRS DATED 1.37m. at 0700 hrs on

COMPLETE LOG

AGE	FORMATION	DEPTH Metres/ft	THICKNESS Metres/ft	LITHOLOGY	COLOR
Recent	Alluvium	0 - 17.68	17.68	Very fine to Medium SAND, trace mica.	Grey
		17.68 - 23.77	6.09	medium to very fine SAND, trace mica.	Do
		23.77 - 35.05	11.28	medium to coarse SAND, trace mica. .	Do
		35.05 - 53.95	18.90	Very fine SAND, SILT trace mica.	Do
		53.95 - 71.63	17.68	SILT.	Do
		71.63 - 92.05	21.02	SILT, very fine SAND, trace mica.	Do

c/s
DE (BIADP)
BADC Shibganj nawabganj

c/s
Dy. Director
GWD-II BADC Dhaka

GEOLOGICAL DATA RECORD CARD

BARIND INTEGRATED AREA DEVELOPMENT PROJECT, RAJSHAHI.

TEST WELL NO. 69 JL NO. 56 PLOT NO. 48 MOUZA Kansat Sikarpur

LATITUDE 24°44'00"N LONGITUDE 88°11'57"E UPA-ZILL Shibganj DISTRICT Nawabganj

PROJECT BIAD project Rajshahi ORGANIZATION BADC

DRILLING CONDUCTED BY Ground Water Circle.1 DATE COMMENCED 16.2.89 COMPLETED 22.2.89

DATA RECORDED IN THE FIELD BY Geologist, M. Shahidul Alam

DRILLING EQUIPMENT USED Rig no XI PURPOSE Ground Water Investigation

TOTAL DEPTH (Metre/ft) 92.05m/302 ft GROUND LEVEL(Metre/ft)PWD DATUM 22.25

STATIC WATER LEVEL BELOW GL.(Metre) At HRS DATED 1.75 m. at 0700 hrs on 22.2.89

COMPLETE LOG

AGE	FORMATION	DEPTH Metres/ft	THICKNESS Metres/ft	LITHOLOGY	COLOR
Recent	Alluvium	0-10.06	10.06	CLAY, trace silt .	Grey
		10.06-11.28	1.22	Very fine SAND, trace mica .	Do
		11.28-14.94	3.66	CLAY, trace silt .	Do
		14.94-19.51	4.57	Plastic CLAY	Brown
		19.51-36.27	16.76	Very fine SAND, trace mica .	Do
		36.27-40.84	4.57	Fine SAND, trace very fine sand & mica	Grey
		40.84-92.05	51.21	SILT, little clay	Do

c/s
AE (BIADP)
BADC Shibganj zone
Nawabganj

c/s
Dy. Director
GWC-II, BWDB, Dhaka

GEOLOGICAL DATA RECORD CARD

BARIND INTEGRATED AREA DEVELOPMENT PROJECT,

RAJSHAHI.

TEST WELL NO. 70 JL NO. 164 PLOT NO. .... MOUZA Chandida...
LATITUDE 24°43'50"N LONGITUDE 88°16'00"E UPA-ZILL Shibganj DISTRICT Nawabg...
PROJECT BIAD project Rajshahi ORGANIZATION BADC
DRILLING CONDUCTED BY Ground Water Circle-1 DATE COMMENCED 24.8.8.. COMPLETED 28.8.8..
DATA RECORDED IN THE FIELD BY Geologist, M. Shahidul Alam.
DRILLING EQUIPMENT USED Rig no. XI PURPOSE Ground Water Investi...
TOTAL DEPTH (Metre/ft) 92.05m/302ft GROUND LEVEL(Metre/ft)PWD DATUM 22.4...
STATIC WATER LEVEL BELOW GL.(Metre) At HRS DATED 3.71 m at 0700 hrs on 28...

COMPLETE LOG

AGE	FORMATION	DEPTH Metres/ft	THICKNESS Metres/ft	LITHOLOGY	COLO...
Recent	Alluvium	0-4.27	4.27	SILT, trace very fine sand trace mica	Bro...
		4.27-14.94	3.50	SILT with Clay.	Gre...
		14.94-20.73	5.79	Very fine SAND, trace silt & mica.	Do
		20.73-22.86	1.83	Fine to Medium SAND, trace mica.	Do
		22.86-35.97	13.41	CLAY, trace silt	Do
		35.97-41.15	5.18	Silty CLAY	Do
		41.15-92.05	50.90	SILT	Do

C/S
AE (BIADP)
BADC Shibganj Zone
Nawabganj

C/S
Dy. Director
GWD-II BWDB Dhaka

GEOLOGICAL DATA RECORD CARD

BARIND INTEGRATED AREA DEVELOPMENT PROJECT,

RAJSHAHI.

TEST WELL NO. 79 JL NO. 106 PLOT NO. 919/920 MOUZA Raninagar

LATITUDE 24°41'15" N LONGITUDE 88°04'58" E UPA-ZILL Shibganj DISTRICT Nawabganj

PROJECT BIAD Project, Rajshahi. ORGANIZATION BADC

DRILLING CONDUCTED BY Ground Water Circle-1 DATE COMMENCED 17.6.89 COMPLETED 22.6.89

DATA RECORDED IN THE FIELD BY Geologist, M. Shahidul Alam.

DRILLING EQUIPMENT USED Rig no. XI PURPOSE Ground Water Investigation

TOTAL DEPTH (Metre/ft) 92.05m/302ft GROUND LEVEL(Metre/ft) PWD DATUM 23.48

STATIC WATER LEVEL BELOW GL.(Metre) AT HRS DATED 3.81m at 0700 hrs on 22.6.89

COMPLETE LOG

AGE	FORMATION	DEPTH Metres/ft	THICKNESS Metres/ft	LITHOLOGY	COLOR
Recent	Alluvium	0 - 4.57	4.57	Very fine SAND, trace silt & mica.	Lt. Grey
		4.57-17.98	13.41	Fine to Very fine SAND, trace mica.	Grey
		17.98-23.77	5.79	Very fine SAND and MICA, trace silt.	Do
		23.77-30.18	6.41	Fine to medium SAND, trace mica.	Lt. Brown.
		30.18-35.97	5.79	Very fine SAND, trace mica & silt.	Grey
		35.97-38.10	2.13	Very fine SAND, trace mica.	Do
		38.10-45.11	7.01	Medium to Coarse SAND with pebbles trace mica.	Do
		45.11-75.90	30.79	Coarse SAN, gravel trace silt & mica.	Do
		75.90-89.92	14.02	SILT with pebbles.	Do
		89.92-92.05	2.13	SILT, trace pebbles.	Do

S/d   S/d

AE (BIADP)   Dy. Director

BADC Shibganj zone   GWD-II, BADC Dhaka.

Nawabganj

GEOLOGICAL DATA RECORD CARD

BARIND INTEGRATED AREA DEVELOPMENT PROJECT, RAJSHAHI.

TEST WELL NO. 20 JL NO. 171 PLOT NO. ________ MOUZA Pithalitala

LATITUDE 24°40'15"N LONGITUDE 88°12'07"E UPA-ZILL Shibganj DISTRICT Nawabganj

PROJECT BIAD project, Rajshahi ORGANIZATION BADC

DRILLING CONDUCTED BY Ground Water Circle-I DATE COMMENCED 14.11.88 COMPLETED 25.11.88

DATA RECORDED IN THE FIELD BY Jalaluddin Khan Drilling supr.

DRILLING EQUIPMENT USED Rig no X1 PURPOSE Ground Water Investigation

TOTAL DEPTH (Metre/ft) 92.05m/302ft GROUND LEVEL(Metre/ft)PWD DATUM 20.62

STATIC WATER LEVEL BELOW GL.(Metre) At HRS DATED 3.05m at 0700 hrs on 26.11.88

COMPLETE LOG

AGE	FORMATION	DEPTH Metres/ft	THICKNESS Metres/ft	LITHOLOGY	COLOR
Recent	Alluvium	0-5.18		CLAY, little silt.	Grey
		5.18-14.63		Fine SAND, trace very fine sand & mica.	Do
		14.63-15.85		CLAY, trace silt.	Do
		15.85-40.54		Medium SAND, trace coarse sand, fine sand & mica.	Do
		40.54-60.96		SILT, trace very fine sand & concretion trace mica	Do
		60.96-72.33		Fine SAND, trace very fine sand silt & mica.	Do
		72.33-92.05		SILT, trace clay.	Do

C/S	C/S
AE (BIADP)	Dy. Director
BADC, Shibganj zone	GWD-II, BWDB.
Nawabganj.	Dhaka.

GEOLOGICAL DATA RECORD CARD

BARIND INTEGRATED AREA DEVELOPMENT PROJECT,

RAJSHAHI.

TEST WELL NO. 81 JL NO. 180 PLOT NO. ______ MOUZA Mahespur

LATITUDE 24°40'00"N LONGITUDE 88°15'50"E UPA-ZILL Shibganj DISTRICT Nawabganj

PROJECT BIAD project Rajshahi ORGANIZATION BADC

DRILLING CONDUCTED BY Ground Water Circle-1 DATE COMMENCED 16.3.89 COMPLETED 22.3.89

DATA RECORDED IN THE FIELD BY Geologist, M. Shahidul Alam

DRILLING EQUIPMENT USED Rig no. XI PURPOSE Groundwater Investigation

TOTAL DEPTH (Metre/ft) 104.24/342ft. GROUND LEVEL (Metre/ft) PWD DATUM 21.29

STATIC WATER LEVEL BELOW GL. (Metre) At HRS DATED 3.81 m. at 0700 hrs on 22.3.89

COMPLETE LOG

AGE	FORMATION	DEPTH Metres/ft	THICKNESS Metres/ft	LITHOLOGY	COLOR
Recent	Alluvium	0-10.97	10.97	SILT, with little clay.	Lt. Brown
		10.97-14.02	3.05	Fine to Medium SAND, trace mica.	Grey
		14.02-23.47	9.45	SILT and very fine SAND, trace mica.	Brown
		23.47-28.35	4.88	Medium to Coarse SAND, trace mica.	Do
		28.35-35.97	7.62	Fine to Medium SAND, trace Coarse sand & mica.	Grey
		35.92-50.29	14.37	SILT with little clay.	Do
		50.29-54.25	3.96	SILT	Do
		54.25-104.24	49.99	Clayey SILT	Do

C/S C/S

AE (BIADP) Dy. Director
BADC Shibganj zone. GWD-D, BADC, Dhaka.
Nawabganj.

GEOLOGICAL DATA RECORD CARD

BARIND INTEGRATED AREA DEVELOPMENT PROJECT,

RAJSHAHI.

TEST WELL NO. 91 JL NO. 94 PLOT NO. 23297 MOUZA Durlobhpur

LATITUDE 24°10'30"N LONGITUDE 88°03'00"E UPA·ZILL Shibganj DISTRICT Nawabganj

PROJECT BIAD Project, Rajshahi ORGANIZATION BADC

DRILLING CONDUCTED BY Ground Water Circle-V DATE COMMENCED 11.12.88 COMPLETED 16.12.88

DATA RECORDED IN THE FIELD BY Geologist M Shahidul Alam.

DRILLING EQUIPMENT USED Rig no. 81 PURPOSE Ground Water Investigation.

TOTAL DEPTH (Metre/ft) 92.05m/302ft GROUND LEVEL(Metre/ft)PWD DATUM 21.55

STATIC WATER LEVEL BELOW GL.(Metre) At HRS DATED 2.44 m at 0630hrs on 16.12.88

COMPLETE LOG

AGE	FORMATION	DEPTH Metres/ft	THICKNESS Metres/ft	LITHOLOGY	COLOR
Recent	Alluvium	0 - 5.49	5.49	CLAY	Brown
		5.49-15.24	9.75	Medium SAND, little very fine sand trace silt and mica.	Grey
		15.24-20.73	5.49	CLAY.	Brown
		20.73-38.10	17.37	Medium SAND, little fine sand trace silt and mica.	Grey
		38.10-71.63	33.53	SILT, trace very fine sand trace mica.	Do
		71.63-84.73	13.10	Very fine SAND and SILT, trace mica	Do
		84.73-92.05	7.32	SILT, trace very fine sand & mica	Do

Sd/- Sd/-

AE (BIADP) Dy. Director
BADC, Shibganjzone. GWD-II, BWDB, Dhaka
Nawabganj.

APPENDIX C

Daily Precipitation Records (mm)

at Shibganj

YEAR : 1979; Rainfall (mm)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0	0	0	0	0	0	0	10.2	0	18.3	0	0
2	0	0	0	0	0	0	70.4	0	0	7.9	0	0
3	0	0	0	0	0	0	0	1.8	14.0	0	0	0
4	0	0	0	0	0	0	0	0	19.0	0	0	0
5	0	0	0	0	0	0	0	0	1.8	0	0	0
6	0	0	0	0	0	0	0	4.6	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	53.1	0	0	0	0	0	3.3	32.8	0	0	0
10	0	0	0	0	0	10.2	0	0	0	12.7	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	60.2	189.7	0	0	0	0	0
13	0	0	0	1.8	0	0	0	0	3.0	0	0	0
14	0	0	0	26.7	0	0	10.7	0	0	0	0	0
15	0	0	0	0	0	0	0	77.5	0	0	0	0
16	0	0	0	2.5	0	0	11.9	104.1	2.0	0	0	0
17	0	0	0	0	0	0	0	21.6	0	0	0	0
18	0	0	0	7.6	0	0	22.9	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	34.3	1.8	0	0	0	0	0	0	1.8	0	0	0
21	0	0	0	0	0	0	58.4	0	0	0	0	0
22	0	0	0	0	0	0	27.9	0	0	0	0	0
23	0	0	0	0	0	12.7	0	0	0	0	0	0
24	0	0	0	0	0	0	78.7	0	0	0	0	0
25	0	0	0	0	0	0	9.7	0	0	0	0	0
26	0	0	0	0	0	1.8	16.0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	45.7	0	0	0	0	0
29	0.8	0	0	0	0	0	0	0	1.3	0	0	0
30	9.6	0	0	104.9	0	0	0	0	190.5	0	0	0
31	0	0	0	0	0	0	0	40.5	0	0	0	0

YEAR : 1980; Rainfall (mm)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0	0	0	0	0	0	0	17.3	0	0	0	0
2	0	0	0	0	0	0	18.3	17.0	0	0	0	0
3	0	0	0	0	0	0	0	35.3	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	5.1	0	0	0	30.2	0	0	0	0	0	0
6	0	0	0	0	0	0	0	6.9	16.5	0	0	0
7	0	0	0	0	0	25.7	16.0	0	22.4	0	0	0
8	0	0	0	0	17.5	0	0	0	17.0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	13.0	0	0	62.7	0	0	0	0
11	0	0	0	0	0	0	2.5	31.2	54.6	0	0	0
12	0	0	0	0	0	0	23.4	1.3	17.0	78.5	0	0
13	0	0	0	0	0	0	2.8	3.8	64.0	0	0	0
14	0	0	0	0	0	0	2.3	0	15.2	0	0	0
15	0	0	0	0	0	50.3	0	0	13.2	3.8	0	0
16	0	0	0	0	0	0	0	0	14.7	0	0	0
17	0	3.6	0	0	0	23.1	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	22.4	0	0	0	0	0
21	0	0	0	0	0	0	0	0	6.9	47.0	0	0
22	0	0	0	0	0	0	0	0	0	0	17.8	0
23	0	0	0	1.8	0	18.0	0	0.8	0	0	14.0	0
24	0	0	0	0	0	53.1	0	76.7	0	0	0	0
25	0	0	0	0	10.4	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	35.6	0	27.9	4.8	0	0	0	0
29	0	0	0	0	5.1	9.9	0	0	0	0	0	0
30	0	0	0	0	0	82.0	8.1	17.3	0	0	0	0
31	0	0	3.0	0	0	0	17.3	0	0	0	0	0

YEAR : 1981; Rainfall (mm)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	5.1	0	0	0	0	0
3	0	0	0	0	0	0	12.7	5.1	0	0	0	0
4	0	0	0	0	0	0	5.1	7.6	14.5	12.7	0	0
5	0	0	0	0	0	35.6	2.5	16.5	5.1	5.1	0	0
6	0	0	0	0	0	0	5.1	17.8	0	0	0	0
7	0	0	0	0	0	0	7.6	25.4	0	0	0	0
8	12.4	0	0	0	0	0	30.5	73.7	0	0	0	0
9	0	0	12.4	0	0	0	39.4	16.0	0	0	0	0
10	0	0	0	0	16.5	0	6.9	0	0	0	0	0
11	0	0	0	0	0	0	0	3.6	12.7	5.1	0	0
12	0	0	0.8	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	15.2	5.1	0	0	0
14	0	0	1.3	0	0.5	0	0	0	0	0	0	0
15	0	0	0	0	0	0	1.3	0	5.1	0	0	0
16	0	0	0	0	10.9	0	30.5	19.0	11.4	0	0	0
17	0	0	0	0	0.5	0	27.9	10.2	35.6	0	0	0
18	0	0	0	0	0	61.0	10.2	6.1	90.7	0	0	0
19	0	0	0	17.8	0	0	8.9	0	30.5	0	0	0
20	0	0	45.6	0	0	0	0	0	26.7	0	0	0
21	0	0	0	0	0	0	0	5.6	0	0	0	0
22	0	0	7.6	0	0.5	0	0	20.1	20.3	0	0	0
23	0	0	17.8	0	45.7	0	0	4.8	0	0	0	0
24	0	0	0	5.1	8.1	0	0	2.5	0	0	0	0
25	0	0	0	0	3.8	0	0	71.1	0	0	0	0
26	0	0	0	0	0	0	0	10.2	0	0	0	0
27	0	0	0	0	0	0	0	0	0.8	0	0	0
28	0	0	0	0	0	0	0	0	5.1	0	0	0
29	0	0	0	0	0	0	12.7	7.6	0	0	0	0
30	0	0	0	0	0	0	0	22.9	6.4	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0

YEAR : 1982; Rainfall (mm)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0	0	0	0	0	0	0	26.2	0	0	0	0
2	0	0	0	0	0	0	0	3.8	0	3.0	0	0
3	0	0	0	0	0	5.1	8.9	34.8	0	6.4	0	0
4	0	0	0	0	0	3.8	0	20.6	0	16.5	0	0
5	0	0	0	0	0	0	0	6.4	0	43.7	0	0
6	0	0	0	0	0	0	7.6	2.5	0	0	0	0
7	0	0	0	0	0	53.3	23.6	0	0	0	0	0
8	24.4	0	0	0	0	0	53.3	0	0	0	0	0
9	0	0	0	0	0	0	17.0	5.6	0	0	0	0
10	0	0	0	0	0	2.5	63.5	7.4	0	0	0	0
11	0	0	0	0	0	7.6	30.7	0	0	0	0	0
12	0	0	0	0	0	10.2	5.8	0	0	0	0	0
13	0	0	0	0	0	0	2.5	37.3	0	0	0	0
14	0	0	0	0	0	8.6	26.2	16.0	1.3	0	0	0
15	0	0	0	0	0	41.1	6.9	0	0	0	0	0
16	0	0	0	0	0	71.9	3.8	0	0	0	0	0
17	0	0	0	0	102.4	38.1	0	0	0	0	0	0
18	0	0	0	0	0	38.9	5.1	0	0	0	0	0
19	0	0	0	0	0	12.7	13.5	2.5	0	0	0	0
20	0	0	0	0	0	22.4	3.8	0	0	0	0	0
21	0	0	0	0	0	30.5	0	0	0	0	0	0
22	0	0	0	0	0	5.1	23.4	0	0	0	0	0
23	0	0	0	0	0	5.6	0	15.7	0	0	0	0
24	0	0	0	0	0	48.3	23.6	72.4	0	0	0	0
25	0	0	0	0	0	0	0	19.8	0	0	0	0
26	0	0	0	0	0	18.5	0	92.7	1.8	0	0	0
27	0	0	0	0.8	0	7.6	7.1	0	0	0	0	0
28	0	0	0	0	0	7.1	0	0	5.1	0	0	0
29	0	0	0	0	0	10.7	0	0	0	0	0	0
30	0	0	0	0	0	7.1	0	0	0	0	0	0
31	0	0	0	0	21.6	0	17.0	0	0	0	0	0

YEAR : 1983; Rainfall(mm)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0	0	0	0	0	0	0	0	0	12.7	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	19.1	0	0	0	0	0
4	0	0	0	0	0	0	0	12.7	0	0	0	0
5	0	0	0	0	0	8.9	0	12.7	12.7	0	0	0
6	0	0	0	0	0	0	9.4	19.1	10.2	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	33.0	0	0
9	0	0	0	0	0	12.7	0	0	0	50.8	0	0
10	0	0	0	0	0	0	0	0	0	76.2	0	0
11	0	0	0	7.9	7.6	2.5	0	0	0	10.2	0	0
12	0	0	0	0	0	0	0	0	0	5.1	0	0
13	0	0	0	0	0	0	0	0	0	7.6	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	10.2	0	0	0
16	0	0	0	3.8	10.2	0	8.9	5.1	7.6	0	0	0
17	0	0	0	6.4	0	0	0	0	5.1	0	0	0
18	0	0	0	2.5	0	0	0	17.8	5.1	0	0	0
19	0	0	0	0	0	0	25.4	19.1	20.3	0	0	0
20	0	0	3.6	0	0	0	0	0	5.1	0	0	0
21	0	0	0	0	2.5	0	35.6	17.8	0	0	0	0
22	0	0	0	0	25.4	35.6	0	20.6	30.5	0	0	0
23	0	0	0	0	0	0	0	19.1	5.1	0	0	0
24	0	0	0	0	0	0	0	38.1	0	0	0	0
25	0	0	0	0	0	0	15.2	10.2	0	0	0	0
26	0	0	0	0	0	0	30.5	0	35.6	0	0	3.6
27	0	0	0	0	0	3.8	50.8	0	0	0	0	22.9
28	6.3	0	0	0	0	6.4	25.4	0	0	0	0	0
29	0	0	0	0	0	11.4	12.7	0	0	0	0	0
30	0	0	0	0	12.7	0	10.2	0	12.7	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0

YEAR : 1984; Rainfall (mm)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0	0	0	0	0	0	0	7.6	12.7	0	0	0
2	0	0	0	0	0	0	5.1	8.6	15.2	0	0	0
3	0	0	0	0	0	0	17.8	5.8	26.2	0	0	0
4	0	0	0	0	0	17.8	0	0	11.4	114.6	0	0
5	0	0	0	0	0	50.8	7.6	1.3	10.2	0	0	0
6	0	0	0	0	3.6	18.3	2.5	0	52.1	0	0	0
7	0	0	0	0	0	12.7	0	0	17.8	0	0	0
8	0	0	0	0	3.3	15.2	0	5.1	16.0	0	0	0
9	0	0	0	0	0	0	10.2	0	22.9	0	0	0
10	0	0	0	0	18.8	0	17.8	7.6	25.7	0	0	0
11	0	0	0	0	0	0	20.3	6.4	10.2	0	0	0
12	0	0	0	0	0	0	94.0	0	11.4	0	0	0
13	0	0	0	0	0	0	30.5	2.5	15.2	11.4	0	0
14	0	0	0	0	0	0	17.8	0	17.8	17.8	0	0.5
15	0	0	0	0	0	29.2	27.9	5.1	4.3	54.6	0	0
16	0	0	0	0	14.0	18.5	11.7	1.5	22.4	27.9	0	0
17	27.7	0	0	0	0	0	0	10.2	17.8	0	0	0
18	0	0	0	0	0	0	15.2	7.6	20.3	0	0	0
19	0	10.2	0	0	0	0	5.1	17.8	0	0	0	0
20	0	7.6	0	0	0	0	0	21.6	0	0	0	0
21	0	0	0	0	0	7.6	10.2	91.4	22.9	0	0	0
22	0	0	0	0	0	10.2	3.3	20.3	0	0	0	0
23	0	0	0	0	0	13.7	3.8	53.3	0	0	0	0
24	0	0	0	0	0	13.0	0	17.8	0	0	0	0
25	0	0	0	0	25.7	16.3	1.5	8.9	0	0	0	0
26	0	0	0	0	18.3	8.4	5.1	20.3	0	0	0	0
27	0	0	0	0	0	3.3	7.6	0	0	0	0	0
28	0	0	0	0	0	0	15.2	2.5	0	0	0	0
29	0	0	0	0	0	0	2.5	7.6	0	0	0	0
30	0	0	0	0	0	7.6	3.3	10.2	0	0	0	0
31	0	0	0	0	0	0	0	27.9	0	0	0	0

YEAR : 1985; Rainfall (mm)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0	0	0	0	0	14.0	19.1	0	10.2	0	0	0
2	0	0	0	0	0	0	0	0	15.2	0	0	0
3	0	0	0	0	0	0	11.4	3.8	12.7	0	0	0
4	0	0	0	0	7.6	0	22.9	2.5	22.9	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	5.1	0	0	11.4	12.7	8.9	0	0	0
7	0	0	0	0	13.2	66.0	12.7	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	22.9	0	0	0	0	0
10	0	0	0	0	0	0	14.0	0	0	0	0	0
11	0	0	0	0	0	0	0	5.1	91.4	0	0	0
12	0	0	0	0	14.0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	27.9	0	0	0
14	0	0	0	0	0	52.1	0	0	24.1	0	0	0
15	0	5.1	0	0	13.5	0	0	0	10.2	0	0	0
16	0	0	0	0	0	0	12.7	0	12.7	50.8	0	0
17	0	0	0	0	0	55.9	8.9	0	15.2	55.9	0	0
18	0	0	0	0	0	0	0	0	0	3.8	0	0
19	0	0	0	0	0	15.2	0	0	0	0	0	0
20	0	0	0	3.8	0	11.4	61.0	15.2	0	0	0	0
21	0	0	0	0	12.7	0	0	7.6	0	0	0	0
22	0	0	0	0	0	0	15.2	5.1	0	0	0	0
23	0	0	0	0	0	0	12.7	0	0	0	0	0
24	0	0	6.4	0	10.2	2.5	12.7	0	12.7	0	0	0
25	0	0	0	0	2.5	0	38.1	61.0	0	0	0	0
26	0	0	0	0	0	0	10.2	12.7	22.9	0	0	0
27	0	0	0	0	0	0	12.7	10.2	12.7	0	0	0
28	0	0	0	5.1	8.9	0	0	15.2	25.4	0	0	0
29	0	0	0	0	6.4	3.8	50.8	0	0	0	0	0
30	0	0	0	13.2	0	5.1	0	38.1	5.1	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0

YEAR : 1986; Rainfall (mm)

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0.00	0.00	0.00	0.00	0.00	0.00	17.80	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.20	5.10	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	22.90	53.30	0.00	0.00	0.00	0.00
0.00	0.00	0.00	3.80	17.80	0.00	17.80	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	7.60	0.00	0.00	24.10	17.80	0.00	2.50	0.00	0.00
0.00	0.00	0.00	0.00	3.80	0.00	0.00	0.00	0.00	63.50	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	10.20	0.00	3.80	47.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	7.60	0.00	10.20	177.80	0.00	0.00
0.00	0.00	0.00	7.60	0.00	0.00	7.60	0.00	17.80	5.10	0.00	0.00
0.00	0.00	0.00	0.00	5.10	0.00	15.20	0.00	2.50	0.00	2.50	0.00
0.00	0.00	0.00	0.00	0.00	13.00	22.90	0.00	10.20	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	76.20	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	7.60	0.00	20.30	0.00	0.00	0.00
0.00	0.00	0.00	7.60	2.50	0.00	5.10	0.00	2.50	27.90	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.70	0.00	0.00
0.00	0.00	0.00	7.60	30.50	22.90	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	7.60	17.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.20	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	14.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	11.40	19.10	0.00	0.00	0.00	0.00
0.00	10.00	0.00	0.00	0.00	0.00	7.60	20.30	5.10	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.10	30.50	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	17.80	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	5.10	63.50	0.00	5.10	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	12.70	0.00	82.60	0.00	0.00	0.00
0.00	0.00	0.00	2.50	22.90	88.90	10.20	0.00	50.80	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.10	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	38.10	0.00	0.00	7.60	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

YEAR : 1987; Rainfall (mm)

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0.00	0.00	0.00	0.00	14.00	0.00	0.00	12.70	6.40	0.00	0.00	0.00
0.00	0.00	0.00	0.00	6.40	0.00	6.90	19.10	5.10	0.00	0.00	0.00
0.00	0.00	0.00	0.00	7.60	0.00	10.20	25.40	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	2.50	0.00	17.80	11.40	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	3.80	7.60	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	55.90	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	16.50	2.50	6.40	11.40	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.60	6.40	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	76.20	2.50	8.90	0.00	0.00	0.00
0.00	0.00	3.80	10.20	0.00	38.10	0.00	104.10	2.50	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	12.70	6.40	15.20	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	7.60	33.00	11.40	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	10.20	25.40	58.40	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	11.40	0.00	0.00	0.00	0.00	2.50
0.00	0.00	0.00	0.00	0.00	0.00	5.10	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	30.50	0.00	0.00	0.00	0.00	3.80	0.00
0.00	0.00	0.00	0.00	0.00	0.00	71.10	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	11.40	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	5.10	19.10	22.90	0.00	2.50	0.00	0.00
0.00	0.00	0.00	0.00	0.00	6.40	52.10	24.10	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	3.80	8.90	38.10	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	15.20	6.90	39.40	1.30	0.00	0.00	0.00
0.00	0.00	0.00	30.50	0.00	0.00	24.60	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	17.80	19.10	0.00	33.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	38.10	6.40	25.40	0.00	0.00	0.00
0.00	0.00	0.00	24.10	0.00	0.00	10.90	0.00	0.00	0.00	0.00	0.00
0.00	15.20	0.00	22.90	0.00	0.00	5.60	44.50	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	7.60	10.20	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	20.30	0.00	3.80	15.20	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	6.40	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	5.80	0.00	0.00	0.00	0.00	0.00

YEAR : 1988; Rainfall (mm)

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	60.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.00	0.00	0.00
0.00	0.00	0.00	0.00	2.03	0.00	2.54	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	12.70	0.00	0.00	38.00	0.00	0.00
0.00	0.00	0.00	0.00	2.54	0.00	50.80	0.00	30.00	140.00	0.00	0.00
0.00	0.00	0.00	0.00	1.78	0.00	5.08	10.00	20.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	7.62	30.00	60.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	24.13	25.40	8.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	1.27	5.08	38.10	10.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	50.80	5.00	0.00	0.00	0.00	0.00
0.00	0.00	30.50	0.00	0.00	69.85	7.62	60.00	30.00	0.00	0.00	0.00
0.00	0.00	17.80	0.00	0.00	78.74	0.00	30.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	11.43	38.10	0.00	15.00	0.00	0.00	0.00	0.00
0.00	1.30	10.20	1.27	0.00	5.08	0.00	15.00	15.00	0.00	0.00	0.00
0.00	1.50	0.00	0.00	5.08	8.89	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	20.32	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	2.54	25.40	10.00	0.00	0.00	0.00	0.00
0.00	0.00	14.00	0.00	0.00	5.08	0.00	0.00	0.00	2.00	0.00	0.00
0.00	0.00	0.00	20.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	22.90	0.00	1.78	0.00	5.08	0.00	0.00	0.00	0.00	0.00	0.00
0.00	7.60	0.00	1.52	20.32	127.00	0.00	0.00	15.00	0.00	0.00	0.00
0.00	5.10	0.00	2.54	0.00	0.00	0.00	40.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	8.89	0.00	50.80	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	8.89	90.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	12.70	120.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	2.54	0.00	20.32	17.78	45.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	6.35	19.05	0.00	60.00	20.00	0.00	35.00	0.00
0.00	0.00	0.00	0.00	11.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	20.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX D

Predicted Percolation Values (inch) from CREAMS

Expected Percolation

Soil: Clay; Crop: B. Aman & Rabi

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	Average
January	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0
April	0.082	0	0	0	0	0	0	0	0	0	0.008
May	1.337	0	0	0.275	0	0	0	0	0.383	0	0.2
June	0.051	0.34	0	0.73	0	0.076	0.665	0.05	0.021	3.021	0.495
July	5.749	1.306	0	2.586	0	0.993	0.905	1.451	1.201	1.713	1.59
August	1.107	0.547	0.521	1.829	0.297	0.679	1.053	0.876	2.793	1.918	1.162
September	0.932	0.672	1.094	0.714	0.108	1.139	2.388	0.399	1.108	1.296	0.985
October	0.939	0.377	0.446	0	0.441	2.514	0.685	2.946	0.103	1.056	0.951
November	0	0.679	0	0	0.149	0.45	0.34	0.262	0	0.036	0.192
December	0	0.073	0	0	0	0	0	0	0	0	0.007
Total	10.197	3.993	2.061	6.135	0.996	5.85	6.035	5.984	5.608	9.04	5.59

Soil: Silty clay; Crop: B. Aman & Rabi

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	Average
January	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0
April	1.69	0	0	0	0	0	0	0	0.291	0	0.198
May	0.659	0	0.18	1.65	0	0	0	0	0.527	0	0.302
June	0.643	2.725	0.66	2.094	0	0.548	1.731	1.28	0	4.695	1.438
July	5.68	0.65	0.294	2.623	0	0.58	1.175	1.079	2.946	1.823	1.685
August	0.887	1.769	0.924	2.411	0.078	1.605	1.122	0.652	3.224	2.539	1.521
September	0.955	1.883	1.313	0.128	0	2.415	2.994	1.232	0.627	0.863	1.241
October	0.324	1.614	0.025	0	0.196	1.697	0.154	2.797	0	0.826	0.763
November	0	0.024	0	0	0	0	0	0	0	0	0.002
December	0	0	0	0	0	0	0	0	0	0	0
Total	10.838	8.667	3.397	8.906	0.274	6.844	7.176	7.041	7.615	10.746	7.15

Soil: Silty clay loam; Crop: B. Aman & Rabi

	1979	1980	1981	1982	1983	1934	1985	1986	1987	1988	Average
January	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0
May	1.942	0	0	0.444	0	0	0	0	1.083	0.01	0.348
June	0	0.292	0	1.693	0	0.317	0.557	0	0	2.683	0.554
July	4.353	2.285	0	3.462	0	1.498	0.722	1.917	1.308	2.613	1.816
August	2.359	1.123	1.323	1.713	0.755	0.807	1.417	0.936	4.898	2.244	1.757
September	0.258	1.465	2.026	0.878	0.211	3.957	3.877	0.416	1.909	2.606	1.76
October	1.938	0.868	0.56	0	0.932	2.941	1.268	3.931	0.041	1.36	1.384
November	0	0.468	0	0	0.046	0.234	0.233	0.087	0	0	0.107
December	0	0.133	0	0	0	0	0	0	0	0	0.013
Total	10.851	6.634	3.909	8.19	1.943	9.754	8.073	7.286	9.238	11.516	7.739

Soil: Silt loam; Crop: B. Aman & Rabi

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	Average
January	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0
May	1.883	0	0	0.528	0	0	0	0	1.18	0	0.359
June	0	0	0.19	2.355	0	0.704	1.097	0	0	2.539	0.689
July	3.615	1.105	0.311	3.901	0	1.765	0.735	2.735	2.565	2.933	1.966
August	2.525	1.496	1.113	1.91	0.855	0.984	1.479	0.841	5.668	2.348	1.922
September	0.138	1.773	2.289	0.87	0.216	4.936	4.484	0.608	1.991	2.951	2.025
October	1.75	0.081	0.487	0	1.12	2.869	1.221	3.679	0.012	1.627	1.285
November	0	0	0	0	0.01	0.129	0.122	0.028	0	0	0.029
December	0	0	0	0	0	0	0	0	0	0	0
Total	9.911	4.454	4.39	9.564	2.2	11.387	9.139	7.892	11.416	12.398	8.275

Soil: Sand loam; Crop: B. Aman & Rabi

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	Average
January	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0.194	0	0.019
May	2.571	0	0	1.087	0	0	0	0	1.747	0.299	0.57
June	0	0.942	0.211	5.259	0	0.437	1.164	0.046	0	5.076	1.314
July	7.54	2.169	0.915	5.882	0.512	3.548	0.827	4.926	6.284	4.443	3.704
August	4.832	2.127	3.709	3.293	2.323	3.407	1.711	0.905	10.452	4.587	3.735
September	0.09	3.767	4.291	1.12	0.534	10.145	6.744	2.596	2.529	5.123	3.694
October	3.224	1.291	0.249	0.457	4.049	3.914	1.806	6.993	0.012	3.402	2.54
November	0	0.223	0	0	0	0	0.011	0	0	0	0.023
December	0	0.12	0	0	0	0	0	0	0	0	0.012
Total	18.257	10.64	9.375	17.098	7.418	21.452	12.263	15.466	21.218	22.929	15.611

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