STUDY OF WATER-LOGGING PROBLEMS OF WEST PAKISTAN WITH ELECTRIC ANALOGUE COMPUTERS

MAQSOOD ALI SHAH GILANI*

SYNOPSIS

Lowering of the water-table in an area to reclaim the affected land from water-logging and soil salinity involves a complicated water-management problem, because many variable factors affect the ground water system in the area. Many refined techniques have been developed for the analytical treatment of field problems. However, analytical formulations are possible only for boundary problems of simple geometry. A new technique, namely the electric analogue computer, provides a powerful tool for analysis of very complicated boundary-value problems and clarifies the physical interpretation. Analogue computers are versatile and simple and of low to moderate cost. The use of analogue computers enables ground water development schemes to be tested rapidly and accurately, thus permitting the appraisal of the relative merits of alternate choices of development.

In the present paper the electric analogue computers, their construction and applications have been discussed. Studies have been made to analyze the problems related to water-logging in three different areas of West Pakistan. The effects of pumping in the Upper Rechna and Lower Thal Doab Project areas for the lowering of ground water levels have been computed on respective analogue models of the two areas. The drawdown contour maps after 20 years of continuous pumping have been prepared from computer solution for non-equilibrium state. Some of the representative graphs for transient ground water level changes have also been shown.

On the Chaj Doab analogue model, analyses have been made for the steady state conditions that prevailed prior to the canal irrigation period and the non-steady state conditions for the canal irrigation period from the year 1900 to 1960. The rise in groundwater levels, the rate of infiltration from the main canals and their distributaries, net recharge rate to ground water reservoir and the rate of evapotranspiration have been determined. The close agreement between the results of the analogue computer studies and the actually observed field data of ground water levels in Chaj Doab is noteworthy.

The above studies indicate that the use of electric analogue computers can go a long way in analyzing the development projects for water-logging problems.

*M.Sc. (Pb.), M.S. (Ariz: U.S.A.) Senior Hydrologist, WASID, WAPDA.

INTRODUCTION

Summer irrigation by means of inundation canals has been practised in the flood plains of West Pakistan for hundreds of years. Near the rivers the water-tables have always tended to approach the surface but the configuration of the saturated zone of the unconsolidated alluvium, which over much of the region has a depth up to 1000 ft. or more, was almost stable. The depth to water-table increased with the distance from the rivers and over a greater part of the Indus Plain ground water-tables were at a considerable depth below the ground surface. The infiltration of water from the rivers and the deep percolation of rainfall and the water supplied in the seasonal inundation irrigation within any particular area was in equilibrium with the discharge of ground water by evapo-transpiration and by movement out of the area towards the sea. This situation existed before the introduction of weir controlled (barrage) irrigation systems. However, with the introduction of water brought from the rivers by the large new irrigation systems, the equilibrium between ground water recharge and discharge was disturbed. The deep percolation of seepage from canals and from water applied to the lands for irrigation formed a new increment of recharge, which, added to the normal recharge from the rivers and precipitation, was greater than the rate at which water could be discharged from the aquifer. As a result, water-tables have risen ever since the barrage controlled irrigation systems were placed in operation. Rising water-tables and the salinization of land as the result of canal irrigation threaten the agricultural economy of West Pakistan. Hundreds of thousands of acres of once productive crop-lands have gone out of production. Since 1954 the Water and Soils Investigation Division (WASID) of the West Pakistan Water and Power Development Authority (WAPDA) has inventoried the water and soil resources and investigated the relations between irrigation activities, the natural hydrologic factors, and the incidence of water-logging and subsurface drainage problems. On the basis of these investigations, West Pakistan WAPDA has prepared a long-range program for reclaiming the irrigated lands affected by water-logging and salinity. The essential feature of this program is a proposed network of tubewells. Ground water withdrawals will serve the dual purpose of helping to supply irrigation requirements and of providing subsurface drainage.

Lowering of water-table in order to reclaim the affected land involves a complicated water management problem, because many variable factors affect the ground water system in the area. Basically, the problem confronting us is the study of cause and effect relationship. The cause may be that of pumping from or the addition of water to the ground water system. The corresponding effect is respectively the lowering and the rise in ground water levels. The desirability, therefore, is to determine the changes in water levels. The factors relating to cause and effect must also be considered. The changes in water level will be controlled by the location of water removal (or water addition) and the physical characteristics of the rock material in which the water flows. The physical characteristics of greatest importance is the friction coefficient for water motion in the rocks. Actually, the inverse of this is used and is called the rock permeability. Moreover, the removal (or addition) of water to the storage in the pore spaces causes the water levels to change with time. Therefore, when it is necessary to analyze the water level change in a transient sense it is necessary to consider the question of ground water storage in the voids of the rock material. These two relating factors, namely the coefficients of permeability and storage are most important in studying the ground water problems.

Many refined techniques have been developed for the analytical treatment of cause-effect relationships of field problems. However, analytical formulations are possible only for boundary problems of simple geometry. Electric analogue computer provides a powerful tool for analysis of very complicated boundary value problems and clarifies the physical interpretation.

Different types of studies have been made on the electric analogue models of Chaj Doab, Upper Rechna Doab and Lower Thal Doab Project Areas of West Pakistan (Figure 1). On the Chaj Doab model, the cause of water-logging has been delineated, while the effect of pumping on the ground water levels has been determined in the other two areas under different hydrologic conditions.

ANALOGUE MODELS

Two systems are said to be analogous if their response to similar input stress is similar in form. Excitation (cause) and response (effect) values are expressed generally in terms of variables dependent upon time and position in the field. The application of electric analogue for simulating geologic and hydrologic conditions is based on the correspondence between the basic laws of electrical and laminar fluid flow. In an electric circuit a resistor impedes the free flow of current, just as in nature the rocks or other water bearing materials impede the free flow of fluid. Similarly, a capacitor in a circuit stores electric energy in a way comparable to water storage in permeable earth material. Voltage and amperage in an electric circuit correspond faithfully to the head and volume rate of flow in the ground water reservoir. The extension of the electric analogue approach to field problems is done in a way that the behaviour of the system to be simulated is described by means

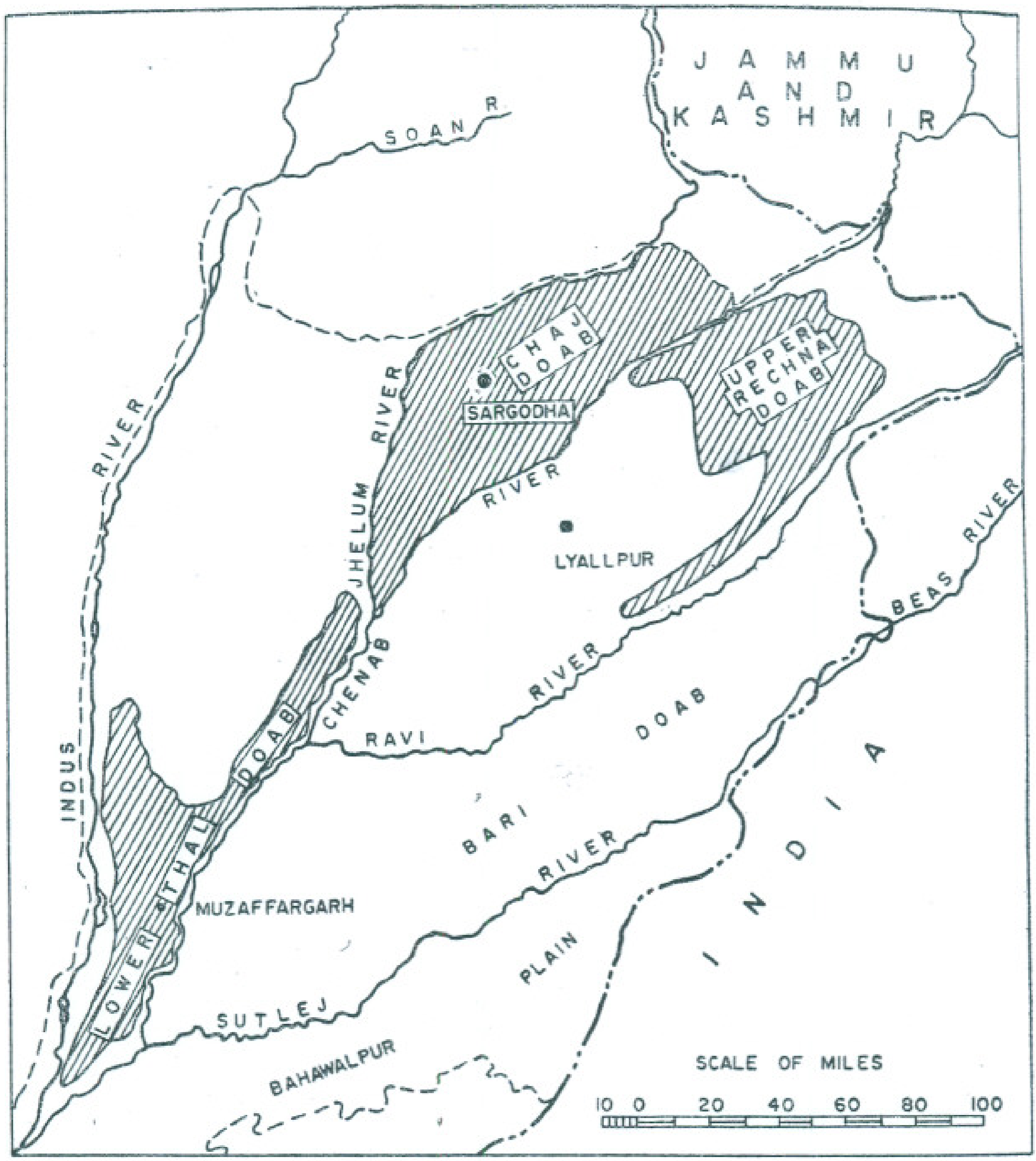


Fig. 1. Map showing the location of Lower Thal Doab, Chaj Doab and Upper Rechna Doab project areas.

of differential equations, and an electrical system is found in which equations are similar in form. The famous law of Darcy in ground water flow and that of Ohm in electric current flow are perfectly analogous. Complete analogy for various differential equations representing the ground water flow systems and the corresponding electrical systems are obtained from Theis equation and Darcy's Law as well as their electrical equivalents, Coulomb's Law and Ohm's Law.

Two equations that describe diffusion of hydraulic and electric energy when inertia and inductance are neglected, are given by Jacob (1950) and Karplus (1958) respectively :

$$\nabla^2 h = \frac{S}{T} \quad \frac{\partial h}{\partial t} \qquad \text{..........(1)}$$

$$\nabla^2 V = \varrho \frac{C}{V_0} \quad \frac{\partial V}{\partial t} \qquad \text{..........(2)}$$

where h is the head in the aquifer above an arbitrary horizontal reference plane.

T is the coefficient of transmissibility (permeability times thickness of aquifer).

S is the storage coefficient (unit storage coefficient times thickness of aquifer).

ϱ is the specific resistance of the analogue matrix in the direction of flow.

$\frac{C}{V_0}$ is the electrical capacity per unit volume of reservoir or the analogue matrix

V is the voltage at some point (x, y, z) in the analogue.

V_0 is $(\triangle x.\triangle y.\triangle z)$ of reservoir or analogue matrix.

∇^2 is the operator $\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$

The above equations (1 & 2) are analogous as may be seen by substituting into these, the following expressions from Theis Equation (1938) and Darcy's Law as well as their electrical equivalents, Coulomb's Law and Ohm's Law, and expressing the space variable as discrete quantities. From Theis equation,

$$S = \frac{Q_w}{\triangle h.\triangle x.\triangle y} \qquad \text{..........(3)}$$

From Darcy's Law assuming flow in the x direction only:

$$T = \frac{q_w}{\triangle y.\frac{\triangle h}{\triangle x}} \qquad \text{..........(4)}$$

Also from Coulomb's Law.

$$C = \frac{Q_E}{\triangle V} \quad \text{..........(5)}$$

and from Ohm's Law, assuming flow in the x-direction only,

$$\varrho = \frac{R.\triangle y.\triangle z}{\triangle x} = \frac{\triangle V.\triangle y.\triangle z}{\triangle x \, q_E} \quad \text{..........(6)}$$

where ϱ is resistivity of the conductor.

Q_W is the quantity of water.

Q_E is the quantity of electricity.

q_w is the rate of flow of water

q_E is the rate of flow of electricity.

R is the resistance of uniform conductor of length $\triangle x$ and cross sectional area $\triangle y.\triangle z$.

Substituting the various terms, the equations (1) and (2) become

$$\nabla_x^2 h = \frac{Q_w}{q_w \cdot \triangle x^2} \quad \frac{\partial h}{\partial t_w} \quad \text{..........(7)}$$

$$\nabla_x^2 h = \frac{QE}{q_E. \ \triangle x^2} \quad \frac{\partial V}{\partial t_E} \quad \text{..........(8)}$$

From these two equations, it is found that both systems are similar. The electrical units and the corresponding hydraulic units when connected by respective scale factors provide the necessary data for the construction of analogue model.

Considering the equation (1) for two dimensional flow of ground water in the finite-difference approximation form, the aquifer is subdivided into squares of equal areas, $\partial x.\partial y$. The sides of squares ∂x and ∂y, are equal and are of finite length, $\triangle x$, and $\triangle y$, respectively. The finite-difference grid and typical nodes for the ground water and the corresponding electrical system are shown in Figure 2 on next page.

Analogue models for simulating aquifers in three different areas of West Pakistan have been built. The geometric relationships have been mapped to a scale that forms similar configuration between the actual aquifers and the models. The electrical units of the models have been found from equations (7) and (8) that proportionally relate resistance to flow and storage capability in the analogous region. The models, therefore, consist of regular arrays of resisters and capacitors. The resister-capacitor network is characterized by junctions and discrete branches. Perforated masonite boards with holes on a one-inch square pattern have been used in the construction of network. The holes function as junctions or nodes. For two-dimensional flow problems and in internal parts of the analogue model, four resisters and a capacitor are connected to each node. The other ends of the capacitors have been connected to common ground of the electrical system.

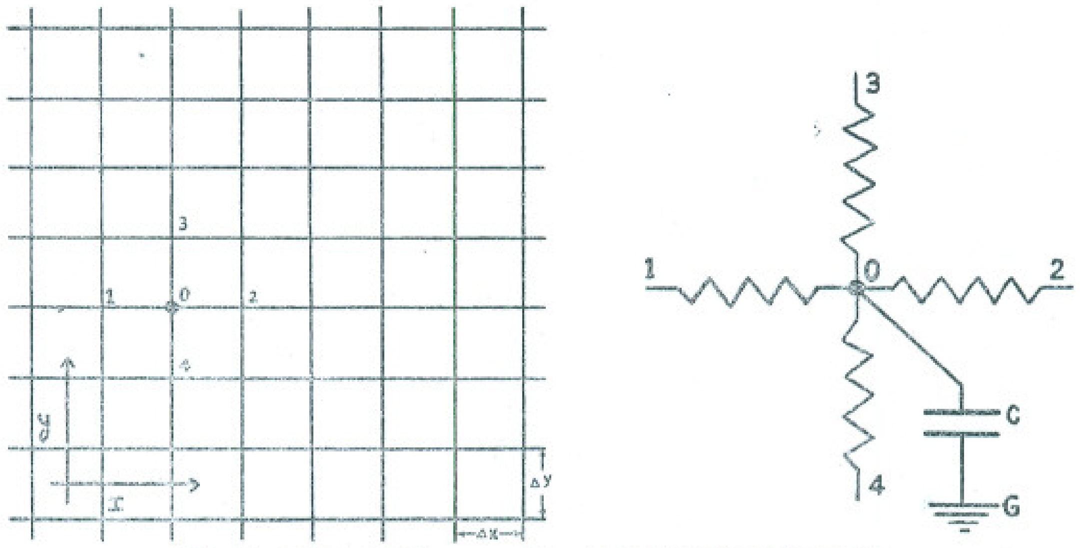


Fig. 2. Finite-Difference grid and Resister-Capacitor nets.

Once the electrical model consisting of regular array of resisters and capacitors is constructed analogous to hydrologic and geologic formations, all possible solutions can be obtained for different problems. The other necessary components required are excitation-response electronic apparatus, such as Wave-form generator, Pulse generators and Oscilloscope. The excitation-response equipment forces electrical energy in the proper time phase into the analogue model and measures energy levels within the energy dissipative resister-capacitor network. Oscilloscope traces *i.e.*, time-voltage graphs, are analogous to time-drawdown relationship. Recorded observation of time-voltage graph provides data for construction of a series of water level change maps. A normal set up of analogue computer is shown in Figure (3*a*, *b*, *c*).

ELECTRIC ANALOGUE ANALYSIS OF THE PROBLEM

It is recognized that the scientific management of the ground water is the key to permanent irrigation agriculture in West Pakistan. West Pakistan Water and Power Development Authority has prepared a long-range program for reclaiming the irrigated lands. The essential feature of the program is a proposed network of tubewells. Ground water withdrawal will serve the

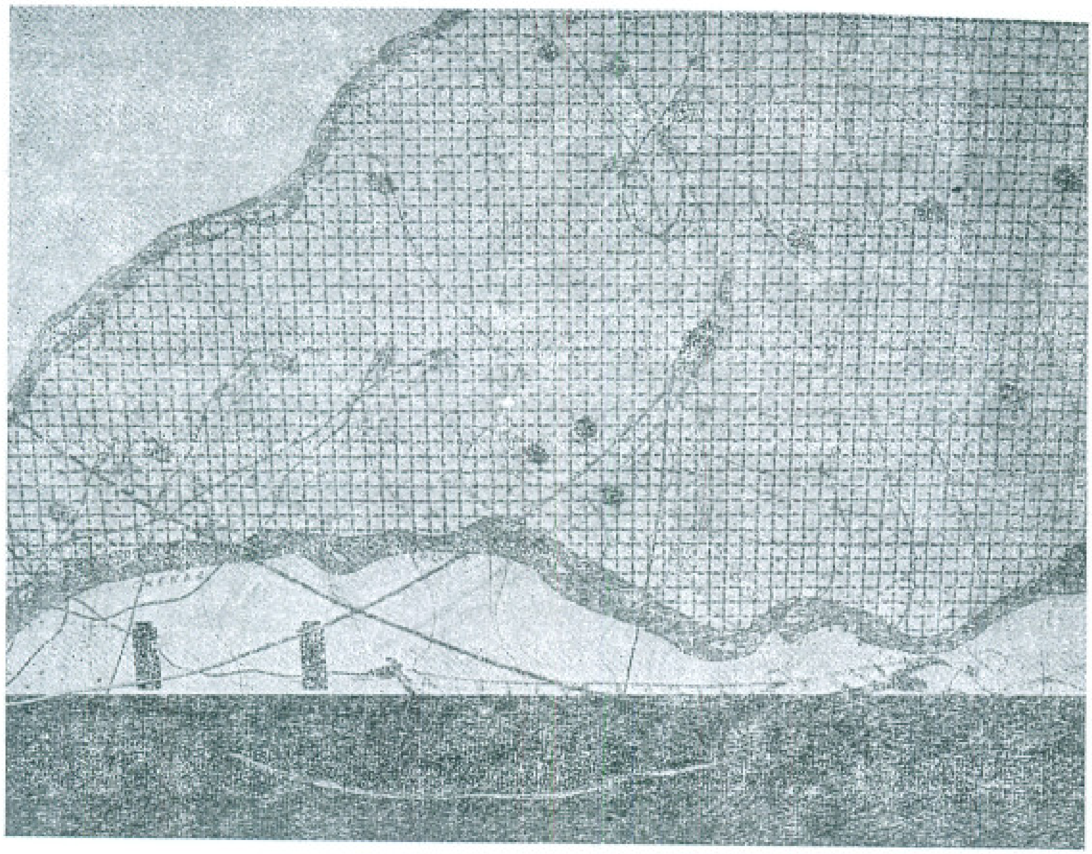


Fig. 3-2. Photograph showing the Electrical Model of Groundwater Aquifer of Chaj Doab (Capacitors are on back side of the Model).

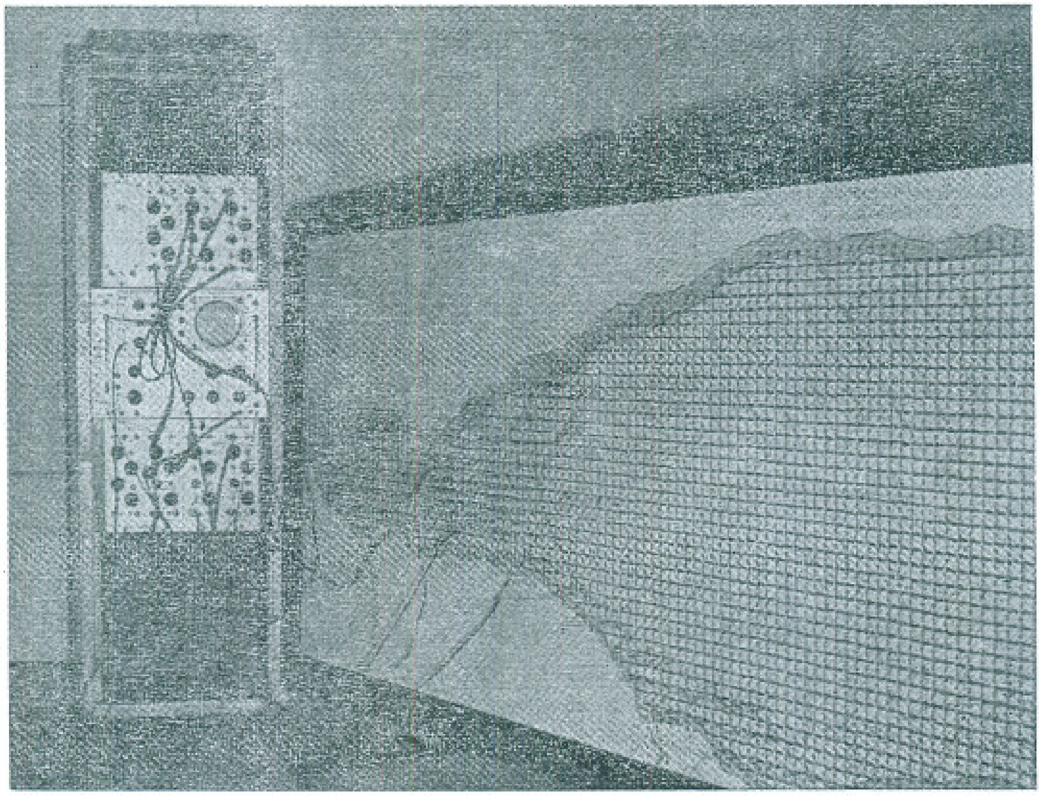


Fig. 3-*b*. Photograph showing a Computer Installation in operation on the Lower Thal Doab Model.

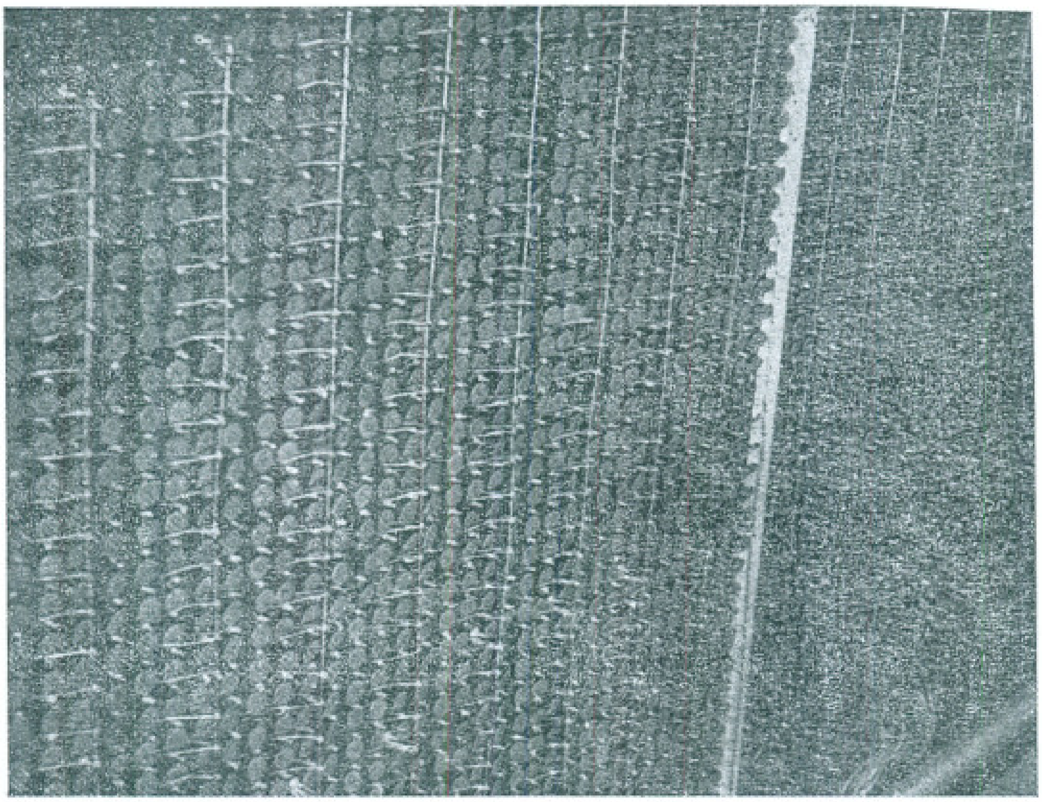


Fig. 3-c. Showing the arrangement of the Capacitors of Electric—Analogic Model for non-Steady State Conditions.

dual purpose of helping irrigation requirements, and providing subsurface drainage. It is, therefore, of high importance to forecast the feasibility of such a gigantic program for the most economic results. The economic effects most commonly understood are the changes in water level. In this connection, studies have been made using electric analogue computer to investigate the ground water system in Chaj Doab for delineating the cause of water-logging in the area and describing the magnitude of different hydrologic factors affecting the ground water system. The effect of pumping in Upper Rechna Doab and Lower Thal Doab Project areas under different hydrologic conditions have also been computed so as to help in knowing the extent of lowering of ground water levels in these areas under the conditions of study.

Studies on Chaj Doab Analogue Model

The study of steady-state conditions prior to canal irrigation and that of non-steady rise with time is prerequisite to evaluation of the hydrologic parameters of the flow system. Once the cause and effect relationship and the hydrologic factors involved are delineated, a new system may be superimposed on the existing conditions to identify the change expected.

Analysis of Steady-State Conditions. The ground water hydraulic system in the Chaj Doab was in a state of dynamic equilibrium under the natural environment that existed prior to the canal irrigation systems. Considered over a reasonably long period of time, recharge to the ground water reservoir balanced discharge and there was no evidence of long-term rise or decline of the water-table. This is illustrated in Figure 4. The general direction of ground water movement was diagonally away from the rivers and downstream towards the axis of Doab. The curving nature of ground water level contours indicates that any underflow from upstream areas plus recharge from local precipitation did not quite balance underflow downstream and evapotranspiration and the equilibrium was maintained by the recharge from the rivers to the groundwater. For the study of above steady state conditions following basic assumptions have been made.

1. The rivers were fully penetrating streams and were the recharge boundaries to the ground water system.

2. Evapotranspiration was the principal discharge source to maintain equilibrium conditions. The term evapotranspiration as used here is in fact the actual evapotranspiration minus the areal recharge due to precipitation which was considered to be a very minor source of recharge.

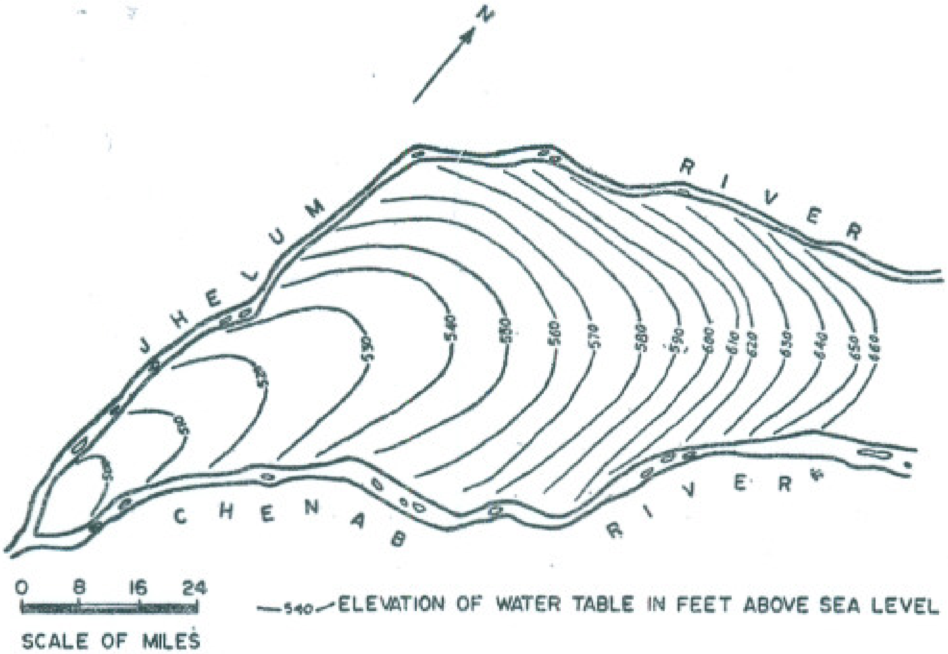


Figure-4 ACTUAL WATER-TABLE CONFIGURATION PRIOR TO CANAL IRRIGATION (CHAJ DOAB).

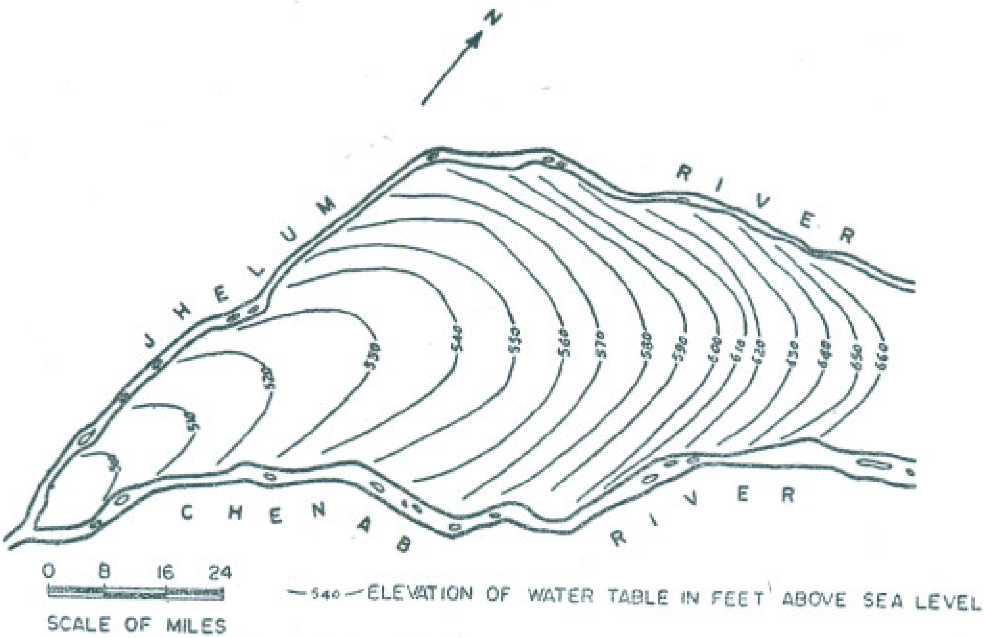


Figure-5 ANALOG-SIMULATED WATER-TABLE CONFIGURATION PRIOR TO CANAL IRRIGATION (CHAJ DOAB).

3. Recharge by underflow from the Upper reaches was considered negligible.

On the model, therefore, rivers, were simulated as constant potential boundaries with a gradient maintained according to the water levels in the rivers from upstream to downstream. Once this condition was established, the evapotranspiration on whole network of the model could be controlled. Fixed resisters were used vertically on the model network to simulate evapo-transpiration losses by imposing negative voltage across these resisters and the model network. Variable potentiometers were used to control the negative potentials on the evapotranspiration network for finer adjustments in order to duplicate the field conditions. The capacitors on the model for this study were kept open circuit as not to interfere with the steady state conditions.

The equipotential contours have been drawn (Figure 5), and are found to duplicate very closely the ground water level contours of the pre-irrigation period. On this map, the contours have been shown after assigning to the electrical potential values the corresponding water level values in accordance with the scale factors used. A comparison and similarity between Figures 4 and 5 is evident.

The negative voltage drop across each vertical resister and the corresponding nodal point on the model network was then determined. The current flowing through each vertical resister was calculated which corresponds to the rate of evapo-transpiration acting at that point. The evapo-transpiration rate values in terms of inches per year have been plotted and contoured in the map (Figure 6). It has been observed that these evapo-transpiration contours follow closely the depth to water-table contours of the pre-irrigation period. The analogue analysis yields that out of 568.4 million gallons per day as recharge rate from the rivers to the ground water, 567.2 million gallons per day were lost through evapo-transpiration and 1.2 million gallons per day discharged again from the ground water to the rivers at the point of confluence.

Analysis for Non-Steady-State Conditions. The hydrologic conditions, prevailing before the canal irrigation system, were changed by the introduction of canal irrigation. The superposition of the canal system introduced additional factors of recharge that resulted in a rise of the water-table in the area. Since 1901 when the lower Jhelum Canal System was opened, a general rise in water levels was observed. In 1915, Upper Jhelum Canal System was also introduced. Figure (7) shows the net effect from both systems for the change in water levels from pre-irrigation to 1960. The analysis of the problem involves knowledge of the degree of hydraulic connection of the rivers, time-sequence of canal

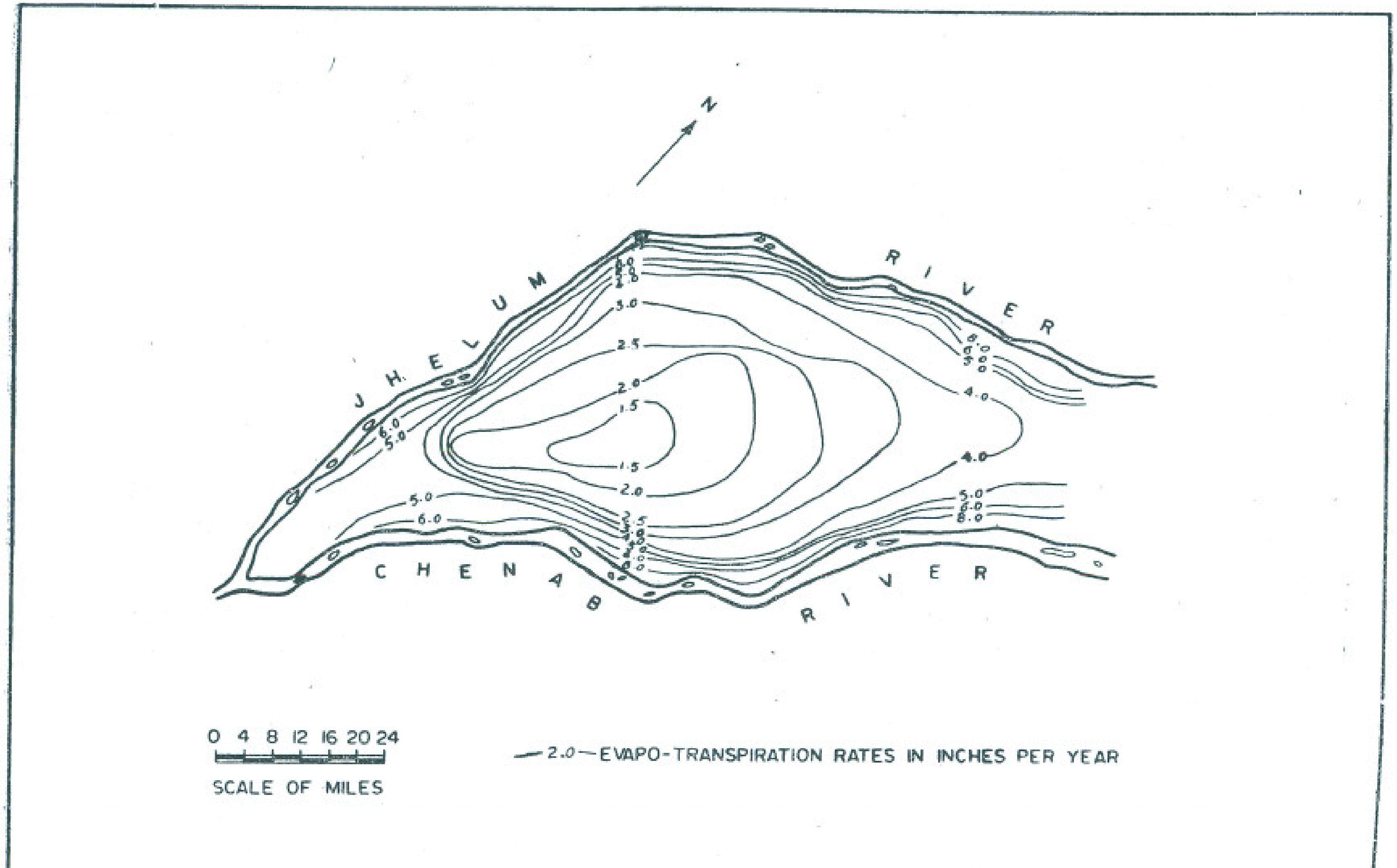


FIGURE: 6 MAP SHOWING EVAPOTRANSPIRATION OF PRE-IRRIGATION PERIOD FROM ANALOG ANALYSIS (CHAJ DOAB) construction, leakage from canal as a function of canal discharge, canal spacing density, and the effect of areal recharge owing to rainfall. There is no data available of most of these items and the analysis, therefore, is based on certain assumptions for analogue model study.

These assumptions are :—

1. A complete hydraulic connection between the rivers and aquifer was assumed and the level in the rivers was maintained at a constant head.

2. The transmissibility of the aquifer was considered to be uniform with an average value of 400,000 gallons per day per foot.

3. The specific yield was taken as 0.25.

4. Hydraulic connection between the canals and the aquifer was imperfect.

5. Initially the leakage from canal was assumed according to the size of a particular canal and its discharge.

6. The areal recharge was neglected. In fact, the evapotranspiration rate used in the present analysis were based on the previous analysis of steady-state conditions. These reflect the values of evapotranspiration rates minus the areal recharge.

7. Underflow of upper reaches of the Doab was considered to be negligible.

8. The sequence of the canal construction was followed. The canals were divided into segments and different recharges were imposed through various sections of the canals according to their sizes.

9. The initial conditions for the non-steady state were considered as a potential of zero in the network at zero time.

The analogue computer consisted of the passive resister-capacitor network, the power supply, wave form generator, pulse generators, power amplifiers and oscilloscope. Two pulse generators were used; one for the Lower Jhelum Canal System with the duration corresponding to 60 years, and the other for the Upper Jhelum Canal System starting 15 years after with a total pulse length corresponding to a 45 years' period. Resisters of different values to represent input recharge for different sections of the canals were used and were changed and adjusted as the situation demanded. Simulation of evapo-transpiration was based on the previous study of steady-state conditions. The diagram showing the experimental set-up is shown in Figure 9.

The transient state water level changes were observed on oscilloscope screen. The observations agreed very closely with those from field observation. Figure 8 shows the change map obtained from the analogue studies and this is comparable with that of observed field data (Figure 7). Typical hydrographs, as converted from the electrical components to the corresponding hydrologic equivalents, are shown in figure 10-*a*, *b*. These show the general type hydrographs for transient rise of ground water levels.

It has been found from this study that 1767 million gallons of water per day was the total leakage rate from the canals and that out of this 867 million gallons per day was the loss due to evapotranspiration. The net recharge rate to ground water system has been computed to be 900 million gallons per day.

Studies on Upper Rechna Doab Analogue Model

Upper Rechna Doab Project Area is one of a series of salinity control and reclamation projects in the Northern Zone of the Indus Plain designed to reclaim deteriorated lands, control subsurface drainage, and provide full supplemental irrigation water requirements by exploitation and management of ground water supplies.

The problem designed for the analogue study was to describe the decline and adjustment of the ground water-table as a function of time for the economic life of the project. For the purpose of analysing the problem, following parameters were used:

1. The analogue model was built using the value for storage coefficient as 0.25 and an average value of transmissibility of the aquifer as 400,000 gallons per day per foot.

2. The wells were spaced evenly on whole of the project area, and a net areal discharge was maintained at the rate of 1 foot per year.

3. Line-source recharge was maintained through the rivers and various canals. The line-source recharge was considered to be variable as a function of the decline in ground water levels in the Project Area. This effect was simulated in the model study by treating rivers, main canals and the link canals as constant head boundaries.

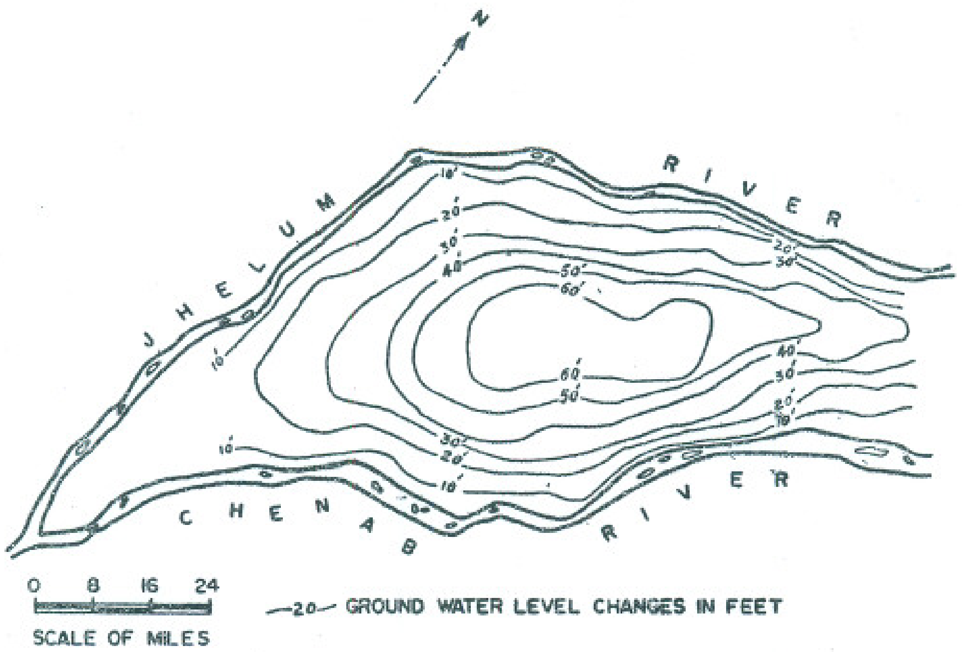


Figure-7 MEASURED CHANGES OF RISE IN GROUND-WATER LEVELS BETWEEN YEAR 1900 AND 1960 (CHAJ DOAB).

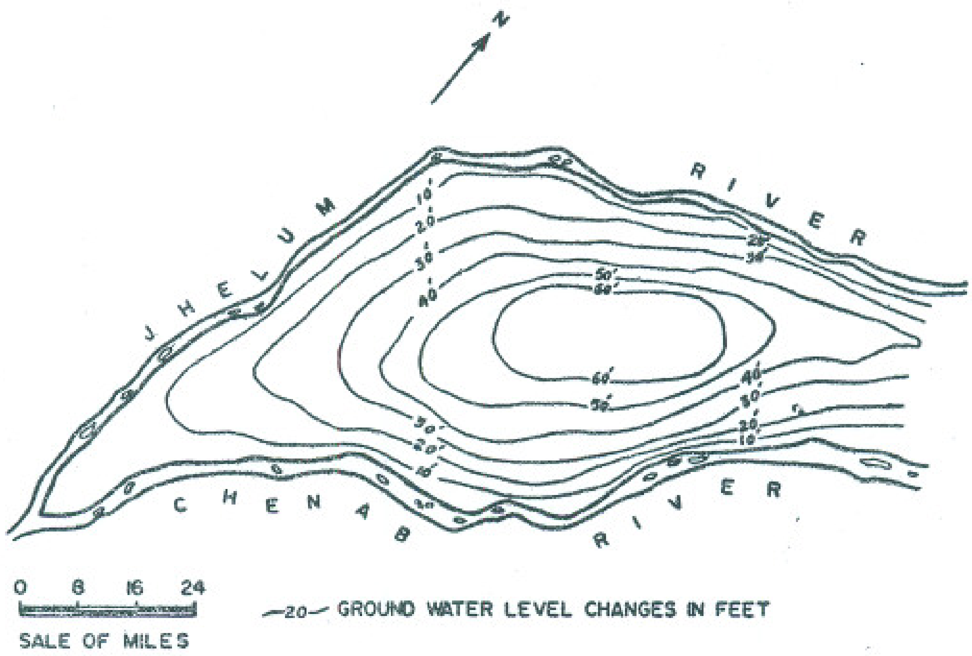


Figure-8 ANALOG-COMPUTED CHANGES OF RISE IN GROUND WATER LEVELS BETWEEN YEAR 1900 AND 1960 (CHAJ DOAB).

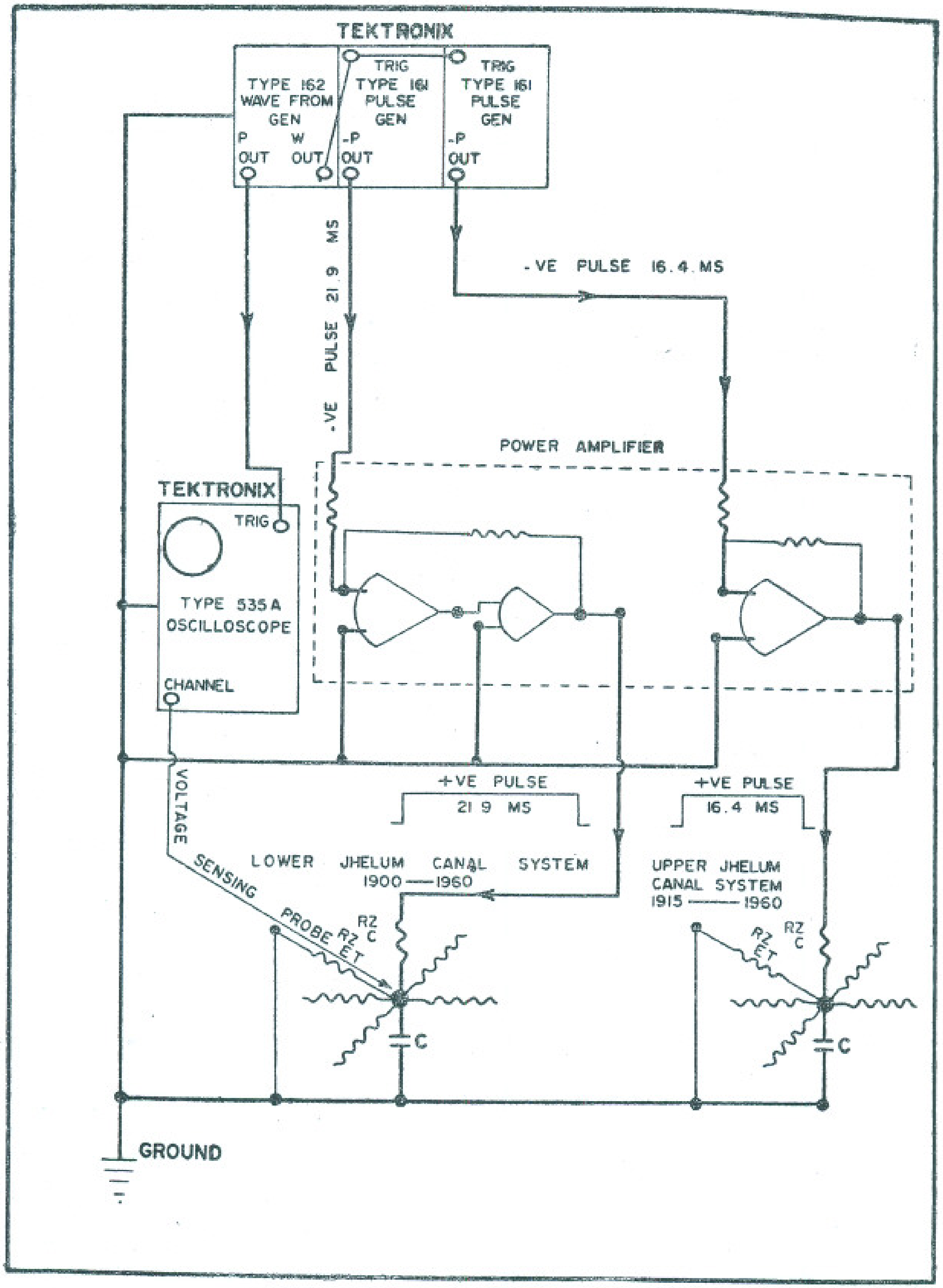
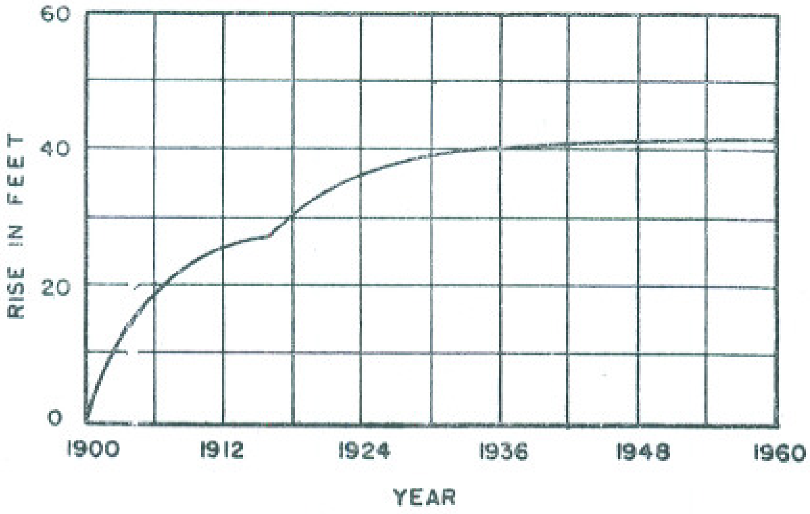
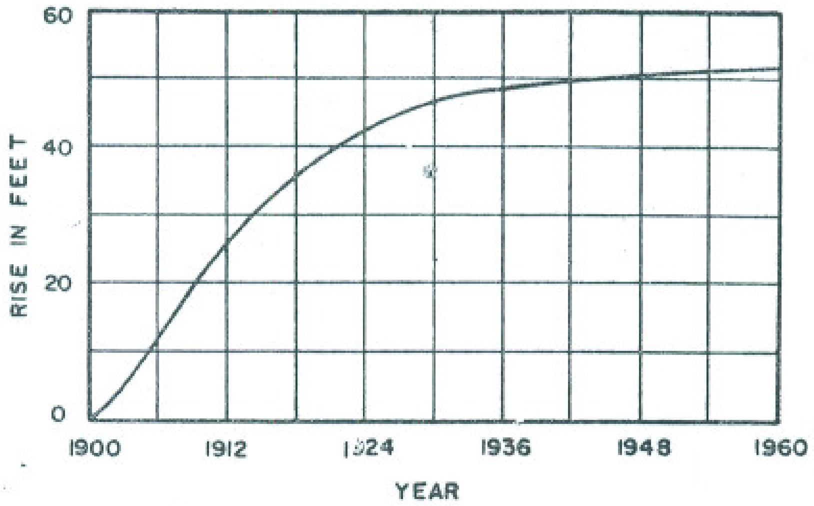


Fig. 9. Block diagram showing Components of Analog Computer for Non-steady State. (Chaj Doab)



(a) Showing effect of Upper Jhelum Canal System and its superposition on the alreadv existing Lower Jhelum Canal System.



(b) Showing typical rise in central portion of the Doab.

Figure-10 ANALOG-SIMULATED GENERAL TYPE HYDROGRAPHS FOR TRANSIENT RISE OF GROUND WATER LEVELS (CHAJ DOAB).

4. The initial conditions were considered as a potential of zero in the network at zero time.

The results of the analogue computer studies were obtained after the above-mentioned hydrologic conditions had been simulated using the necessary electronic apparatus. The projected decline in ground water level after 20 years of project operation have been obtained and are shown in Figure 11. Representative hydrographs from the analogue model studies for 50 years of project operation are also shown in Figures (12-*a*, *b*, *c*, *d*). Hydrograph (12-*a*) is a point located outside the project area boundary and shows that pumping in the project area shall also influence, to some degree, the ground water levels in the adjacent Central Rachna Doab Area. Hydrograph (12-*b*) shows the behaviour of ground water levels in a relatively small area bounded by four recharge sources; namely, Upper Chenab Canal, Mangtanwala Distributary, Qadirabad Link Canal and Ravi River. The drawdown of 10 feet at this point establishes just after 4 years and continues to be unchanged until 50 years of study. The hydrograph (12-*c*) is typical of the location at points midway from canals and the central points between them. The hydrograph (12-*d*), however, is a representative of high values of decline in ground water levels in the central points between big canals and at distance more than 10 miles away from the canals.

According to these data, drawdown of ground water levels will range from less than 10 feet in proximity to the line-sources of recharge to over 50 feet in areas remote from the rivers and link canals. It has been found that about 85 per cent of the unwatering will occur within the first 20 years. Moreover, the experimental hydrographs indicate that equilibrium conditions will be attained in proximity to the line-sources within 5 years and over most of the project area within 20 years. For practical purposes, equilibrium will be established over the entire project area within 40 to 50 years. Only in the areas of maximum drawdown will unsteady flow conditions persist after 50 years, and there the annual rate of decline will be insignificant.

Studies on Lower Thal Doab Analogue Model

Lower Thal Doab Project Area is another of a series of reclamation projects designed to raise the agricultural production of West Pakistan by providing drainage and supplemental water supplies through the use of tubewells. Present study has been made to determine the effect of pumping through tubewells on the ground water-table in the area. To evaluate the rate of decline in ground water table in the project area for the proposed project operation following hydrologic and geologic factors have been used :

1. The model study was made for two different values of transmis-

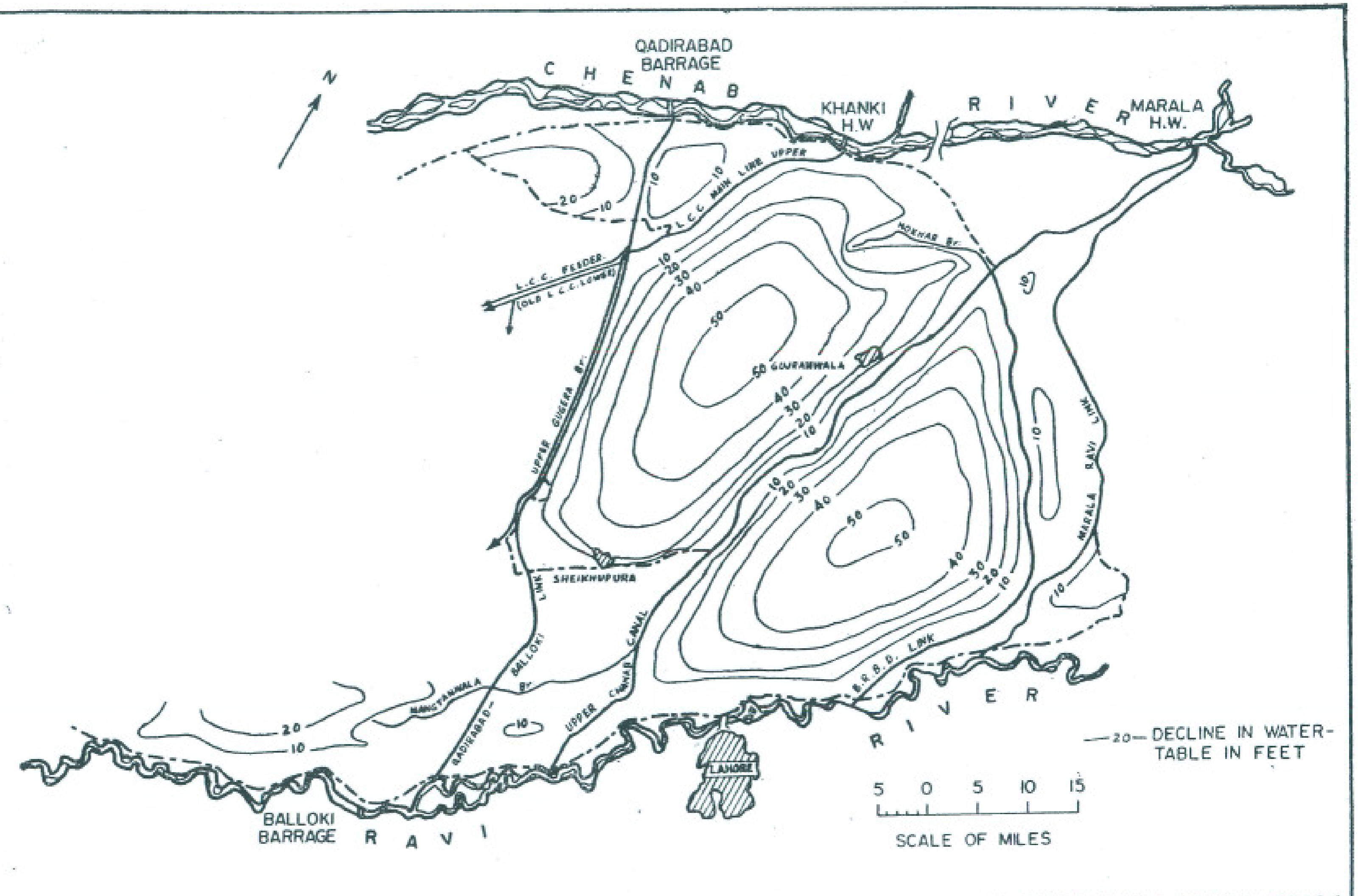
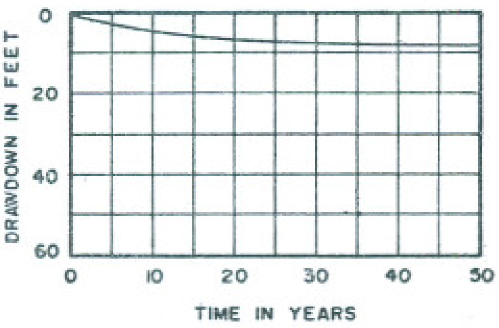
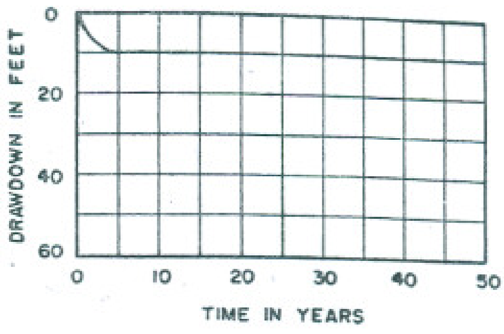


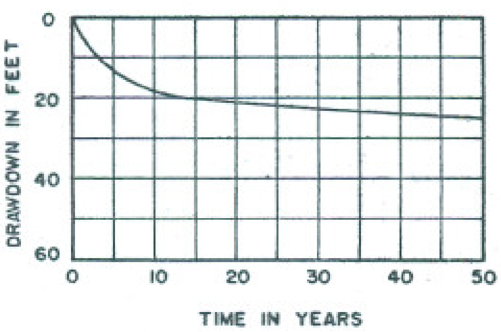
FIGURE: 11 ANALOG COMPUTED PROJECTED DECLINE IN WATER TABLE AFTER 20 YEARS OF PUMPING (UPPER RECHNA DOAB)



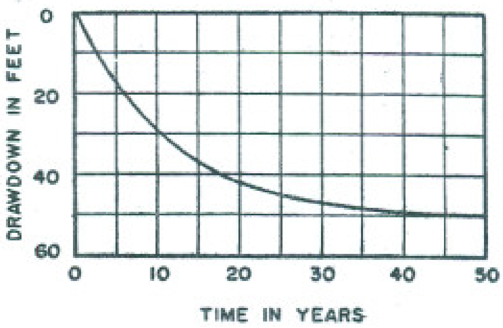
(a) Located outside the Project Area.



(b) Located in a place bounded by four recharge sources.



(c) Located mid-way from Canals and the central points between them.



(d) Located in the central points between big Canals and at distance more than 10 miles from the Canals.

Figure-12 ANALOG SIMULATED HYDROGRAPHS FOR 50 YEARS OF PROJECT OPERATION (UPPER RECHNA DOAB).

sibility. The two values of the average transmissibility of the aquifer used, were 440,000 gallons per day per foot and 800,000 gallons per day per foot. This has been done in order to know the behaviour of water table within these two extreme values of transmissibility.

2. The storage coefficient was assumed to be 0.20.
3. Rivers were maintained as constant head boundaries.
4. Line-source recharge of 0.226 million acre feet per year and 0.123 million acre feet per year was maintained through Muzaffargarh Canal and Rangpur Canal respectively.
5. Areal recharge influenced by the two canal systems was distributed differently in different areas of influence.
6. Tubewells were distributed evenly in the project area, except for a central part comprising 256 square miles where no tubewells were provided. No pumping was done in this central part, because the ground water underlying this area is highly mineralized. The rate of pumping in the project area was maintained at 2 feet per year.
7. The initial conditions were considered as potential of zero in the network at zero time.

Various recharge and discharge conditions were simulated on the model using five pulse generators. A general set-up of the experiment is shown in Figure (3-*b*). The decline in ground water levels as observed from this study has been contoured in Fgures (13-*a*, *b*) for 20 years of project operation. Figures (13-*a* and 13-*b*) show respectively the change in ground water levels for transmissibility values of 440,000 gpd/ft. and 800,000 gpd/ft. Hydrographs for high values of decline in ground water levels in the project area are given in Figures (14-*a*, *b*, *c*, *d*). The hydrographs (14-*a*) and (14-*c*) are those actually observed on the oscilloscope, while those in Figure (14-*b*, *d*) are the corresponding time-drawdown relationship.

The above studies indicate that the drawdown ranges between 5 feet to 25 feet and 5 feet to 15 feet for the transmissibility values of 440,000 gpd/ft. and 800,000 gpd/ft. respectively. Low drawdown is observed in proximity to the rivers and the unpumped central area of mineralized ground water. The influence of pumping on this unpumped area is clearly shown by zero drawdown contour in Figures (13-*a*, *b*). Higher values of drawdown occur in areas remote

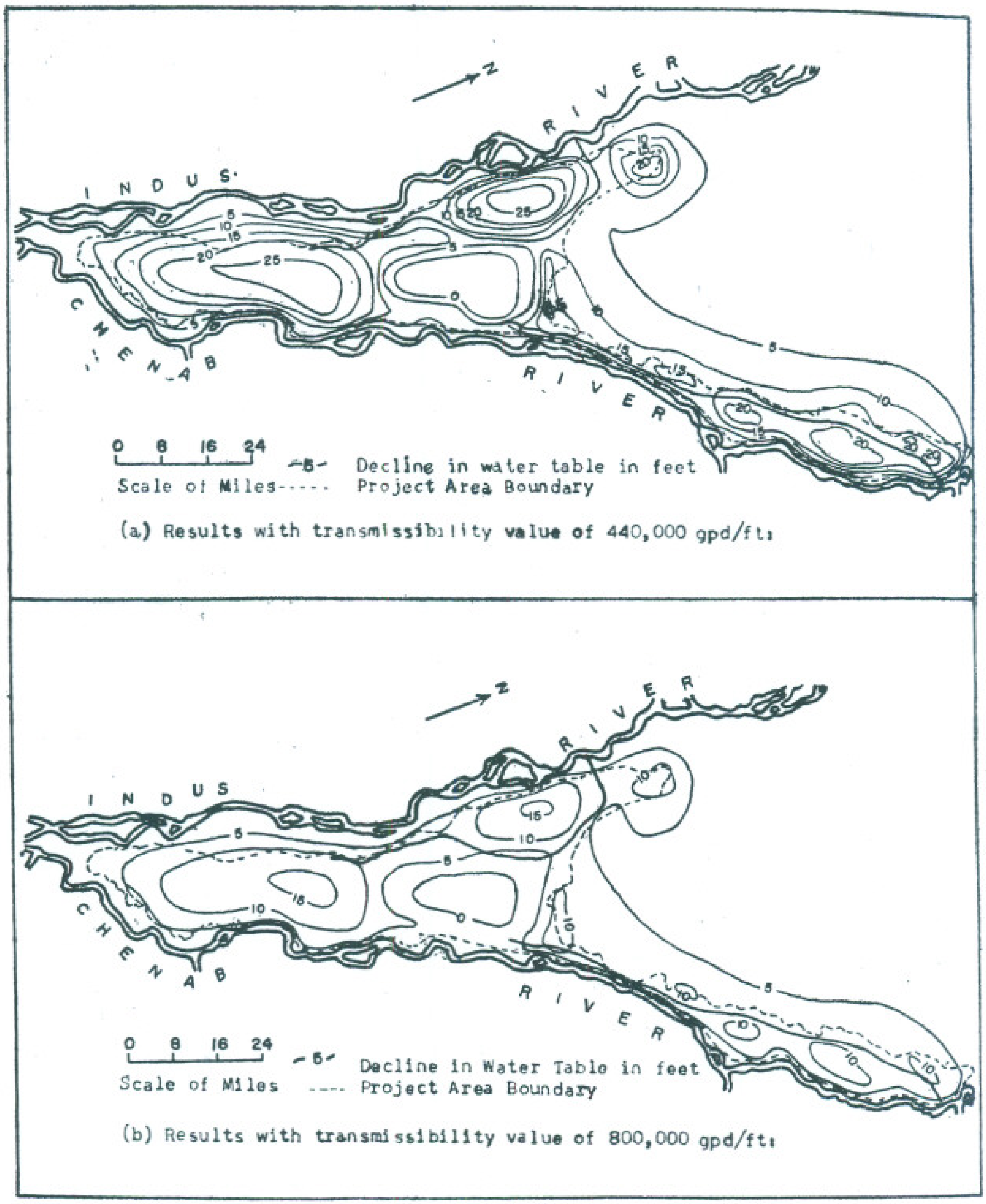
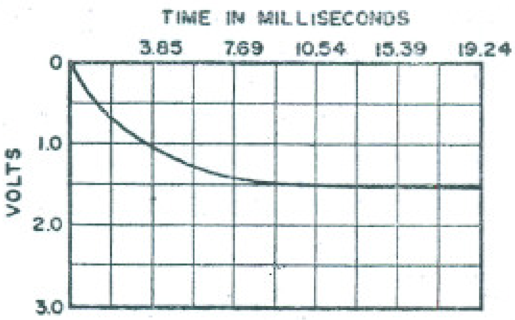
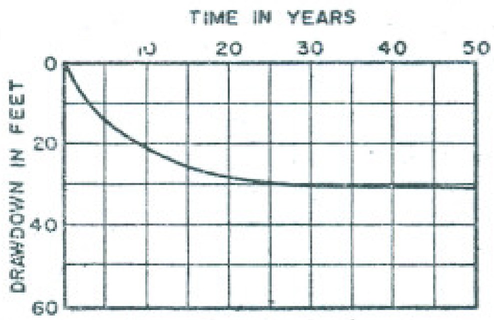


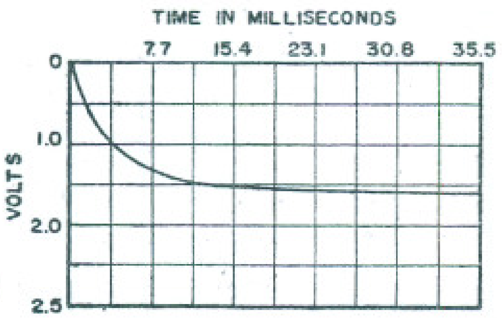
Figure-13 ANALOG COMPUTED PROJECT DECLINE IN WATER TABLE AFTER 20 YEARS OF PUMPING (LOWER THAL DOAB).



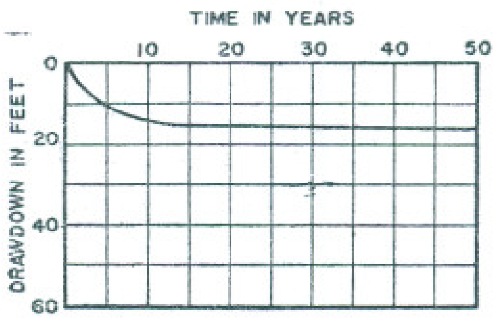
(a) Electrical Data taken from Oscilloscope (T = 440,000 gpd/ft).



(b) Hydrograph after conversion of electronic data into hydraulic data,(T = 440,000 gpd/ft:).



(c) Electrical Data taken from Oscilloscope (T = 800,000 gpd/ft:).



(d) Hydrographs after conversion of electronic data into hydraulic data (800,000 gpd/ft:).

Figure-14 HYDROGRAPHS FOR HIGH VALUES OF DECLINE IN GROUND WATER LEVELS AT THE SAME POINT (LOWER THAL DOAB).

to the rivers. Pumping the project area will also have an effect on the water-table of the adjacent Upper Thal Doab. The extent of influence in this part, under the conditions of present study, is evident from the contours in Figures (13-*a*, *b*). The above studies also reveal that the lowering of water-table under the proposed rate of pumping will not be very high. For reasonably assumed value of transmissibility of the aquifer, the lowering will be less than 25 feet anywhere in the project area after 20 years of continuous pumping.

CONCLUSIONS

On the basis of above investigations, the following conclusions are made:

1. During the pre-irrigation period of steady state conditions in Chaj Doab rivers were the major source of recharge to the ground water and to keep the hydraulic dynamic equilibrium the major discharge of ground water was by evapotranspiration. The evapotranspiration losses were greatest adjacent to the rivers where the water table was closest to the land surface. The configuration of the water-table in Chaj Doab was controlled by the pattern of evapotranspiration losses and the geometry of the Doab.

2. Seepage from the canal irrigation system is the source of rise in ground water levels in Chaj Doab and is the principal cause of subsurface drainage problems in the area. The seepage from the canals is a major component of ground water recharge. It is found that seepage from the canals is a function of the size and discharge in the canals.

3. The decline in ground water levels after 50 years of project operation of Upper Rechna Doab area will range from less than 10 feet in proximity to the line-sources of recharge to over 50 feet in areas remote from the rivers and main canals. It has been found that about 85 per cent of the dewatering will occur within the first 20 years. The equilibrium conditions will be attained in proximity to the line-sources within 5 years and over most of the project area within 20 years. For practical purposes, equilibrium will be established over the entire project area within 40 to 50 years. Only in the areas of maximum drawdown will the unsteady flow conditions persist after 50 years and there the annual rate of decline will be insignificant.

4. On the Lower Thal Doab model, the drawdown after a period of 20 years of continuous pumping has been observed to range from

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5 feet to 25 feet and 5 feet to 15 feet for the transmissibility values of 440,000 gpd/ft. and 800,000 gpd/ft. respectively. Low drawdown has been observed in proximity to the rivers and the unpumped central area of mineralized ground water. The pumping in the project area will have an influence on the ground water levels in this unpumped area and adjacent Upper Thal Doab. It is concluded that for a reasonably assumed value of transmissibility of the aquifer, the lowering of water-table will be less than 25 feet anywhere in the project area after 20 years of continuous pumping.

The conclusions of the present studies are based on certain basic assumptions and the reliability of the results depends, in part, upon the accuracy of these assumptions. Nevertheless, the studies made indicate clearly the effectiveness of the application of analogue computer in the study of ground water problems and in delineating the cause-effect relationships in problems of water-logging. Therefore, analogue, computers will, when used in conjunction with other available tools, greatly improve the analysis of ground water problems. With the aid of analogue computer, Analogue Model Section of Water and Soils Investigation Division is actively engaged in making quantitative appraisal of developed and undeveloped aquifers of West Pakistan.

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