PAKISTAN
WATER AND POWER DEVELOPMENT AUTHORITY

DIGITAL GROUNDWATER FLOW MODEL OF MOENJODARO MONUMENTS PROJECT AREA

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LAHORE

AUGUST, 1993

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ABSTRACT

Digital Computer simulation is one of the most effective and economical techniques which is commonly applied to study the groundwater problems. The present study for the Preservation of Moenjo daro Monuments Project area was referred to Analog Model Laboratory of Scarps Monitoring Organization, WAPDA, by the Authority of Preservation of Moenjodaro Monuments, to evaluate and predict the future response of six No. additional tubewells, suggesting most effective locations in Project area. For this purpose a Finite Difference Model aquifer simulation programmed by S.P. Larson and others was designed to achieve this objective. The Digital Model Study based on this programme comprises a digital net-work constructed on a square grid pattern due to the simplicity of the problem. The model study of Moenjodaro monuments project area carried out in this laboratory consists of two stages. In the first stage, the model is calibrated for the historic period April, 1986 to April, 1990 on the basis of available geohydrological input data supplied by the referring Agency. The results of the computer simulations indicate that a drawdown of 4 feet can be achieved with the installation of 6 no. additional tubewells with the pump utilization factor of 16 hours daily or 66 percent. The computer results indicate that model is very sensitive to the tubewell pump age in the project area. Moreover, the alternative of putting 6 no. additional tube wells on river Indus side is relatively more Effective than the proposal of installing 4 No* tubewells on river Indus side and 2 No, tubewells on Dadu canal side. In second stage the model is calibrated for September, 1986 to September, 1990 in place of April, 1986 to April, 1990. Computer model results a year after calibration, simulating 7 additional tubewells including old tubewell No.14 on river Indus side indicate a drawdown of 8 feet. It is the place to mention that the change in the calibration period was made keeping in view the fact that water levels are generally higher in the month of

September/October after the Monsoon and flood season. The fluctuation in water levels are more during these months as compared to the month of Apri1.

Furthermore once developed the Moenjodaro Monuments Project area model can be used to simulate different schedules of the planned tubewells. If the mean annual pumping rate will be for example 50% of the installed capacity, the resulting ground water table can be predicted easily by performing a simulation Run. Thus the present Digital Model of Monuments area may serve as an excellent tool for the future management and preservation of Moenjodaro Monument Project area.

INTRODUCTION

1.1. BACKGROUND

About. 300 kilometer north of Karachi lie the immense ruins of Moenjodaro. More than four thousand years ago it was one the most important cities of a flourishing riverine civilization located in the Indus Valley. Excavations, since 1922 have unearthed a remarkable well organized settlement. Growth of the latest irrigation system in the area has endangered the site of Moenjo Daro. The ruins of Moenjo Daro excavated so far are in very bad condition. Because of the rise in water table and the effects of salt crystallization near the surface, baked bricks of these priceless remains are rapidly deteriorating to check this deterioration of bricks, the Authority for the Preservation of Moenjo Daro is taking suitable steps at various levels.

The first step towards the solution of this problem is to lower the water table to a depth from which the salts may not rise to the surface by capillary action. At the time of excavation water table was reported to be at 25 feet below the ground level. The present water table varies between 5 to feet during summers and winters. This rise in water table can be attributed to the introduction of perennial irrigation from Sukkur Barrage.

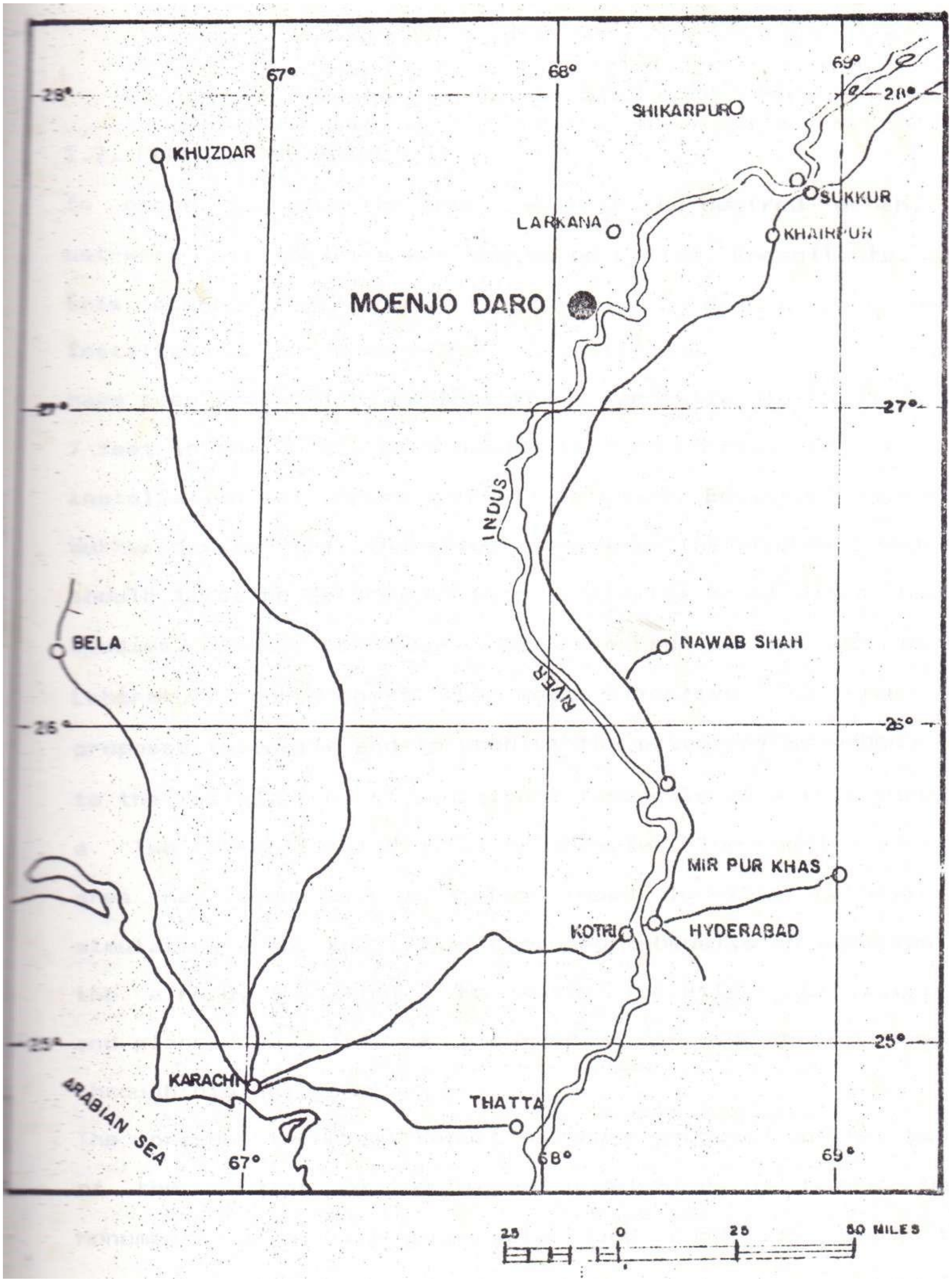


FIGURE:- I MAP SHOWING LOCATION OF MOENJODARO.

1.2.PURPOSE AND SCOPE

In order to lower the water table to the desired depth, net—work of tubewells was suggested by the Consultants. This connection 27 No. wells of 3 cusecs capacity each were installed in two phases and now additional 6 No. tubewells have been proposed to control the water tab1e fluctuation **7** feet in the Moenjodaro Monuments Project Area. Before installation of these tubewells, Chief Engineer (Water), Sukkur decided that the effectiveness of the proposed scheme should first be determined through Digital Groundwater Model Studies. Thus the study was referred to Analog Model Laboratory to suggest the. Most effective location proposed tubewells and to predict the extent of drawdown due to the installation of additional tubewells. For this purpose a "Two Dimentional Digital Groundwater Flow Model" of area has been designed and developed in this Laboratory, simulating 6 No. additional proposed tubewells in addition to the already installed 27 No. wells. The effect of existing and planned tubewells was observed on the groundwater system through digital simulations.

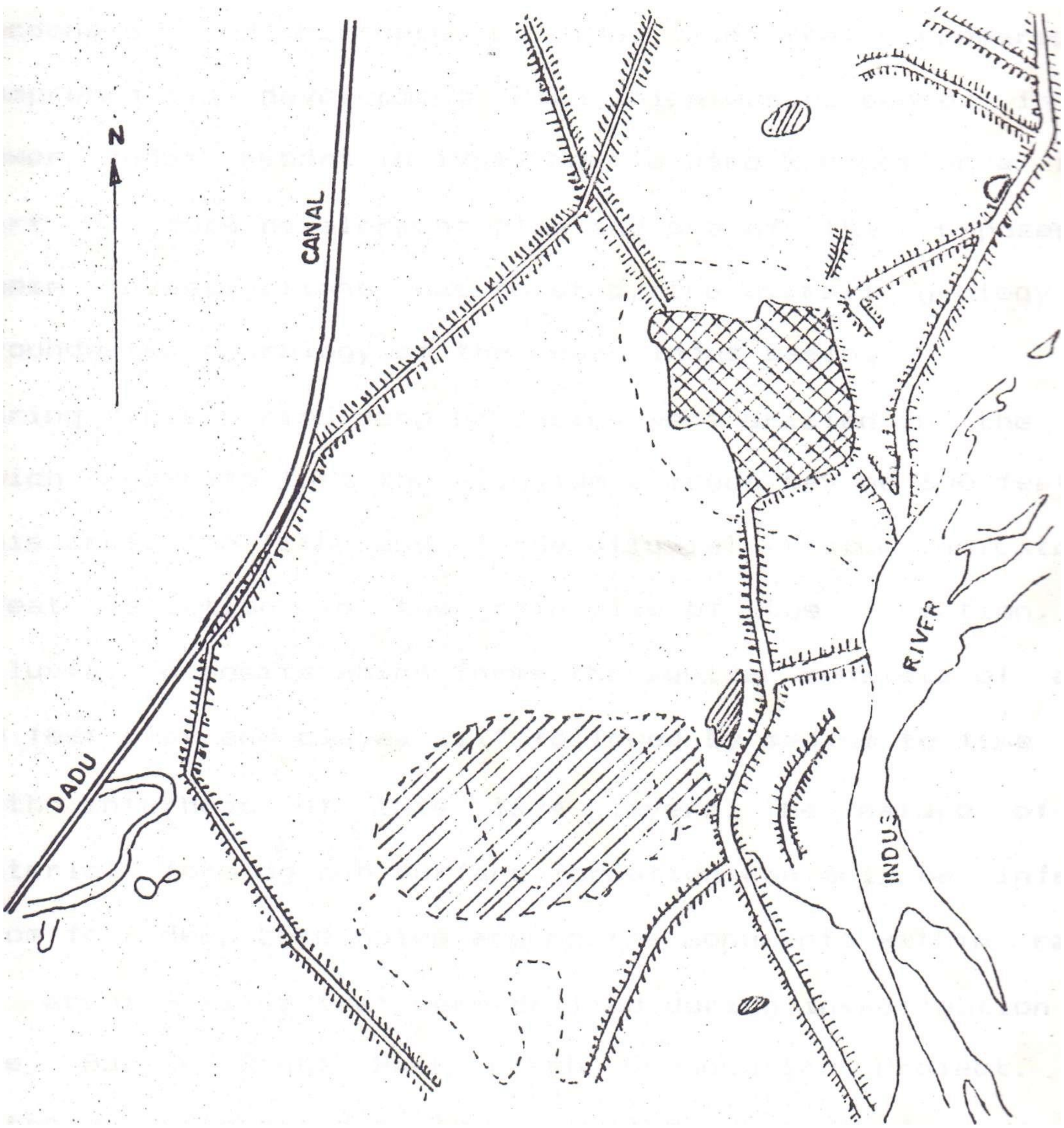
The present technical report has been prepared on the basis of the findings of the Digital Model Study of Moenjo Monuments area. The groundwater flow conditions with given tubewells discharge, space recharge from rice irrigated fields and induced seepage from Dadu canal and river Indus has been computed with this model. This report gives description of 5 No. computer simulations performed in this Laboratory along with the interpretation presented in 13 No.

1.2. LOCATION AND EXTENT

The Moenjo Daro Monuments Project area is located on the right bank of river Indus about 200 miles north of Karachi (shown in Figure 1). The monuments are situated in a part of the Indus valley where the surface level varies between 151 to 154 feet above mean sea level. The level of the mounts vary considerably. A perennial canal called the Dadu canal having capacity about 1500 cusecs flows some two miles in the west of monuments. This canal is a part of Sukkur Barrage irrigation system. The total project area of the Moenjo Daro monuments is about 0.37 sq. miles.

1.3. CLIMATE

The climate of the area can be classified as hot and arid. The hottest month is June with mean monthly temperature of o 115 F. January is the coldest month with mean monthly o temperature of 78 F. The average. rainfall around Moenjo Daro is less than 5 inches, most of which occurs during the months of July and August. In the arid climate of Moenjo Daro area rainfall has practically no influence on the water table. Due to the hot and dry climate, evaporation is very high.



LEGEND

EXISTING MONUMENTS

POSSIBLE EXTENTION OF RUINS

RIVER

BUND

VILLAGE

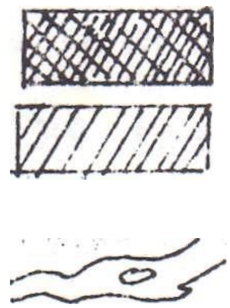


FIGURE:- 2 SITE PLAN OF MOENJODARO ARCHEAOLOGICAL SITES.

1.5. GEOLOGY AND HYDROGEOLOGY

In the lower Indus Basin sub surface investigations were initiated by Hunting Technical Services Ltd. and Sir Macdonald and Partners in 1962 and they prepared a comprehensive development Plan which was presented in the lower Indus Report in 1966- Moenjo Daro Project area is a of this development plan and one of the purposes of investigations was to study the overall geology and groundwater hydrology of the Lower Indus Basin.

During this period deep boreholes were drilled .in the area indicate that the alluvium extends beyond 600 feet in this area. The lithology of the alluvial stratum indicates a variation in the grain size of the formation. The alluvial deposits which forms the aquifer consists of about 30 feet clay and clayey silt followed by medium to fine sand interbreeds of this clayey layers. The nature of the material forming sub surface formation can only be inferred from four deep bore holes around the monuments within radius about 6 miles that were drilled during investigation for Sukkur Right Bank Fresh Groundwater Project. The lithology indicated by these we11s shows sand of more than feet thickness overlain by top clay layers of thickness ranging from 12 to 24 feet.

DIGITAL MODEL TECHNIQUE

2.1. INITIAL CONDITIONS

Water levels from mean sea level and ground surface elevation plotted from the values supplied by the referring agency, to groundwater table was computed from the difference ground surface and water level elevations. Thus water elevation in April/September, 1986 were taken as initial condition at each node for computation of water level elevation for the subsequent year. All the values of water is and surface levels were interpolated at each node with respect to mean sea level.

The values of Transmissivity and Storage Coefficient suggested by the Referring Agency and also available from the literature was used as 0-405 cubic foot per second per foot 0.14 respectively. These values have been distributed uniformly over the each node in the model grid. These, values Transmissivity and Storage Coefficient are shown in the computer listing as appended (Annexture-1)

2.2. BOUNDARY CONDITIONS

The finite difference grid (Fig-3) was extended beyond the boundaries of the project area in all directions to impose boundary conditions. River Indus formed the boundary the south and Dadu canal in the north of the model area. These two boundaries were assumed as constant recharge boundaries to the model. In the East and West the grid was extended sufficient far off from the boundaries of the project area to assume no influence boundary conditions. Since no flow is assumed to occur across these boundaries, Transmissivity values were maintained as zero on the last row of the model area.

2.3. RECHARGE AND WITHDRAWAL AT EACH NODE

Input to or output from groundwater storage from the following sources was computed for each node. The following components were considered.

i) Seepage from river Indus.

ii) Seepage from Dadu canal and outlets.

iii) Infiltration in the field from farm irrigation.

iv) Infiltration from rainfall (if any).

v) Pump age.

vi) Evapotranspiration.

The recharge to or abstraction from groundwater storage equals to sum of recharge from river, seepage from canal, return flow from farm irrigation and recharge from precipitation minus pump age and evapotranspiration.

2.4. MODEL AREA

The model area is the area which is covered by the digital model. It encloses the project area besides other adjoining area making effective contribution. The model area was needed to be extended to locations where boundary condition can be defined such as no flow boundaries/physical boundaries etc. This model was designed in a way that the assumed boundary conditions may not have any direct influence inside the model The model area has been extended in the north—west up Dadu canal and in the south-east up to river Indus which considered as physical boundaries. Both the physical boundaries have been simulated as constant recharge line Sources. In the north-east and south-west, boundary conditions chosen about 2 miles away on each side of the project area as no flow boundaries.

2.5. FINITE DIFFERENCE NET WORK

After defining the model area and model boundaries aquifer stem is discretized into cells using one of the two methods Block-centered formulation or the Point-centered formulation. In both systems, the aquifer is divided into square grids to fit the geometry of the model area. In the point—centered formulation the nodes are located at the intersection points and in the Block—centered formulation, nodes are taken at the Centre of the cells. The spacing depends upon the availability of the hydraulic properties of system, which are generally uniform over the extent of the cell.

Fig: 3 shows the Finite Difference Net—work of Moenjodaro Monuments digital groundwater model designed with 21 rows and columns, thus forming 546 Block—centered nodes- The model net—work covers an area of 19.59 sq. Miles out of which project area is about 0.37 sq. Miles. Each net-work node is 1000 feet wide and 1000 feet long (Fig: 3) It is assumed that the hydrological input parameters are uniform within each nodal area.

COMPUTER SIMULATIONS AND DISCUSSIONS

3.1. SIMULATION RUN NO. l (CALIBRATION OF THE MODEL)

The model was calibrated to obtain a good match between the observed and computed water table elevations. In this process hydrological input parameters as disc us Bed above were adjusted until a good fit was obtained.

This simulation run was carried out to calibrate this Digital 3round Water Flow Model of the project area by developing a groundwater model where some parameters are not well known, therefore, during calibration the unknown parameters have adjusted to a reasonable extent to achieve the better - etching between the model computed and observed contours. For this reason the importance of the field monitoring data regarding water levels is significant to meet the purpose of useful model calibration.

The observed contours for April, 1990 and model computed results for the same period are illustrated in Fig: 4 and Fig: 5.These two illustrations indicate some reasonable match of water levels. This model calibration was obtained with good deal of efforts by attempting different model simulations by varying the rate of pump age in the project area. The overall monitored pump age had to be reduced by 10% to achieve the presented model calibration indicating thereby that the given field pump age was on the higher side besides other uncertainties in the scanty field measurements. Based on this achieved status of model calibration, the following prognostic simulations were attempted for a period of one year after model calibration.

3.2. SIMULATION RUN NO. 2.

This prognostic computer simulation' was conducted to simulate the proposed alternative of installing 6 No. tubewells at different given locations on river side as shown in the illustration No.6. These tubewells are in addition to the already working 27 No. wells in the Moenjodaro monuments project area. The computed contours showing depth to water table by simulating 6 No. tubewells on river side are displayed in Figs No. 6. It is intended to control the existing water table variation of 5 to 7 feet in summer and winter seasons so as to maintain a uniform water table at 32 feet below ground level throughout the year. In this prognostic simulation, .it is assumed that the existing tubewells may work with their present pumping efficiency along with proposed 6 No. wells with pumping efficiency of 66 percent (i.e.16 hours daily). According to the model simulation this alternative can help to lower the water table by 4 feet in the central region of the monuments area within a period of one year. In other words the depth to water table in the following April may reach to 40 feet instead of 36 feet in the central region of the monuments under 66 percent pump uti1ization factor.

3.3. SIMULATION RUN NO. 3

This computation run was performed to evaluate the influence of the second proposed alternative on the groundwater system by installing 4 No. tubewells at different locations on the side of river Indus and 2 No. tubewells on the Dadu canal side as shown in the illustration No. 7. However other assumption of 27 No. existing tubewells and related hydrological parameters were kept the same as in the previous simulation run No- 2. The results of this prognostic simulation run are plotted and presented in Figs No.7 the analysis of the computer results reveals that this configuration of 6 No. tubewells may help to lower the water table in the central region of the monuments up to 40 feet but the configuration and area of depth to water table contour appear to change and reduce with this alternative. It is observed that the area showing depth to water table of 40 feet is decreased as compared to the previous simulation. Therefore, results achieved with the proposed alternative-1 seems relatively more promising.

3.4. SIMULATION RUN NO. 4

This digital simulation was performed to calibrate the Digital Groundwater Flow Model for the new historic period. The idea to run this simulation was developed due to the fact that fluctuation in water levels .in the area is more after the floods etc., in the river Indus. Water level heads in the river are increased and thus increasing the recharge to the Area. Moreover, the referring Agency has also requested to run the model simulating 7 No. wells in the outer ring in place of 6 No. additionally proposed wells. The process of model calibration was repeated again for the new historic period. In practice, the calibration of groundwater model is frequently accomplished by adjusting the input hydrological parameters (aquifer properties, sources , sinks, boundary and initial conditions) to reasonable extent. Calibration is a time consuming and tricky process in which simulated input parameters are adjusted to achieve the field observations. Many computer simulations have to be performed to arrive at the desired field conditions. Figs No.8 shows the depth to water table contours observed in the field for September, 1990 and contours shown in Fig.No9 are the computed results for the same period. The agreement between the field and numerical model response is very encouraging. This comparison shows that a reliable model has been obtained. It is pertinent to mention here that some uncertainty may occur during the calibration process. This can be attributed to the scanty field data relating to groundwater heads, surface level etc. in the model area when an account is taken of the approximations and assumptions which have to be made to represent the field behavior.

3.5. SIMULATION RUN NO.5

Once the model is calibrated for the historic period by obtaining the best fit between the field measurements and computed results, .it can be employed for predictive studies. This digital simulation was performed to observe the effect of 7 No. proposed tubewells in addition to the already working 26 No. wells in place of 6 No. proposed wells. The additional one No. well bearing No. 14 is to be replaced from inner circle to the new location to the second circle as shown in Fig No.10. All other recharge/discharge hydrological parameters were kept the same. It is observed from the computed results that with the addition of these proposed tubewells the water table will further drop by 6 feet thereby reaching at the depth of 36 feet. However, a very small pocket of 38 feet contour of depth to water table .is also noticed but that is very small. Moreover, it is observed from the depth to water table contours that the declining trend is more towards the river side. It can be attributed to the local effect of the additional proposed tubewells. Therefore, to keep the balance in the water table contours within the monuments it is suggested that whenever in future tubewells be installed, these should be proposed just on the opposite side of these wells.

Reference:- For water table elevation maps please see Figure Nos.11 to 15.

4. CONCLUSIONS AND RECOMMENDATIONS

1. The results of Digital Model Studies reveal that 7 No. tubewells, if located on river side, may prove more effective(Fig-6 & 10) as water table may drop down by another 4 to 8 feet within one year period, if all the tubewells work as per design.
2. Water level contours depicted in Figure-7 do not suggest any prominent improvement with the location of two tubewells towards Dadu canal and four tubewells on river side.
3. The analysis of the model simulations indicates that the Project area is more sensitive to the tubewell pump age thus, it needs very careful 1 and frequent monitoring.
4. Installation of seven proposed wells are recommended on river side as shown in Figure-10.
5. In order to maintain the water table at a constant depth, it is adviseable to run some of the wells only in summer to intercept the fluctuation of 5 to 7 feet caused by floods in the river Indus and rain in the area.
6. To monitor the position of depth to water table accurately more piezometers in the model area should be installed (as shown in Figs 3) as the controls available in the area are not sufficient.
7. Tubewells with low discharges or defective screens need immediate rehabilitation as it badly effects the efficiency of the project.
8. It has been observed that rice cultivation is still a source of recharge to the area. Farmers should be encouraged to switch over to new crops by giving them some incentives.

NOTE:- MAPS CAN BE PROVIDED ON DEMAND.