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RESEARCH SUPPORT FOR
FORDWAH EASTERN SADIQIA (SOUTH)
IRRIGATION AND DRAINAGE PROJECT

SPATIAL AND TEMPORAL ASSESSMENT OF GROUNDWATER RECHARGE IN THE FORDWAH EASTERN SADIQIA (SOUTH) PROJECT AREA

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ABSTRACT

The subsurface drainage facilities in the development of the Indus Basin Irrigation System (IBIS) have been deferred causing the waterlogging and salinization of the soil profile especially in areas where the groundwater was saline. This study assesses the spatial and temporal groundwater recharge in such an area of the IBIS, Fordwah Eastern Sadiqia (South)-FESS Irrigation and Drainage Project area. Four years of groundwater monitoring data have been analyzed over the selected distributary commands to assess the water table behavior and the monthly net recharge, and to calculate the excess water removal requirements and the areal extents of waterlogging in the FESS Project area. The results of the study show that the water table in the area is in dynamic equilibrium with a slight rising trend. The months of March, August, and December exhibit peaks of net positive recharge over the distributary commands, thus, showing responsiveness of the water table and porous medium to irrigation and rainfall. The months of July and November also show positive net recharge. Initially an excessive amount of water per unit waterlogged area is to be drained in order to maintain a root zone depth of 1.5 meter, afterwards, the estimated monthly net positive recharge would be taken care of by the subsurface drainage facilities. A minimum of two-third of the FESS project area is under the influence of waterlogging suggesting implementation of subsurface drainage measure.

1 INTRODUCTION

Hydrologically, the annual discharge in arid areas is more than the recharge, and irrigation supplies are required for sound and sustainable agricultural development. The depth to water table is generally at a level that is un-harmful for crop growth and with the capacity to store the percolated/leached water without posing any problems for several years to come. Therefore, the development of arid and semi-arid areas for irrigated agriculture, generally, does not require simultaneous provision of drainage facilities. Deferring the drainage facilities can reduce the high initial cost of irrigated agriculture development in such areas. Subsurface drainage problems do not develop for a number of years after the beginning of irrigation, but arise as a direct result of irrigation. The recommendation is that in the planning stages, while the overall benefits of a proposed irrigation project are predicted for comparison with the project cost, the latter should include the ultimate drainage requirement and cost as a result of irrigation (Dumm, 1968).

The development of an irrigation system in arid areas causes the water table to fluctuate. The trend of water table fluctuation is generally cyclic and progressively upward from year-to-year due to imbalances of recharge and discharge. In an irrigated area, the groundwater hydrograph generally shows that the water table rises during irrigation and peaks after the last irrigation of the season, and then recedes during the non-irrigation period until irrigation for the next season/year commences. Significant rainfalls also show peaks in the groundwater hydrograph during the middle of the season. As the water table gets closer to the ground surface, the range of cyclic annual water table fluctuations and peaks become constant from year-to-year. This condition is usually defined as dynamic equilibrium. In such situations, the direct loss from the water table usually constitutes a considerable fraction of the total water supplied. That the loss from the water table up to a depth of two feet is equal to the evaporation from a free water surface has been reported; as the depth increases, the capillary upflow and associated evaporation become less and less (HTS/MMP, 1965). Also, in such situations, the water table or wetted condition prevails in the root zone; thus, water and nutrient uptakes are reduced due to the lack of free oxygen. The poor aeration also causes soil structure to deteriorate, a slow nitrogen mineralization process in the soil, and difficulty to ensure timely farming operations (Feddes, 1988). These factors are consequent to lower crop yields and greater losses.

The condition of dynamic equilibrium is associated with the transfer of salts as a result of capillary upflow and evaporation. The salts are deposited in the vadose zone either at or beneath the surface. On cultivated land, this process continues during fallow periods, but when irrigation restarts, the process is reversed and salts are flushed from the vadose zone. In the zones of relatively fresh groundwater, the effects of capillary upflow and evaporation become less, while salts accumulate in the surface layers in saline groundwater zones with the salinity decreasing sharply with depth. The build-up of soil salinity to a level that limits crop production and the type of crop results in the abandonment of cultivable lands and reduced farm returns.

The irrigated agricultural developments during the late nineteenth and early twentieth century in the arid and semi-arid areas of the Indus Basin Irrigation System (IBIS) deferred the drainage facilities. By the mid-twentieth century, the need for the provision of drainage facilities was inevitable due to waterlogging and salinization of irrigated lands. Since then, a number of water table and salinity control and reclamation schemes consisting of both, surface and subsurface drainage facilities have been implemented. Most subsurface drainage facilities comprised of vertical drainage, that is, installation of tubewells to lower the water table and associated salinization. In the areas of less saline groundwater, the tubewell drainage development also provided an additional source of water to supplement irrigation supplies, while highly saline drainage surplus in other areas increased the salinity in the IBIS. Horizontal subsurface drainage experiments pipes and ditches were also conducted within the IBIS, but did not become popular due to high costs. Net recharge and depth to water table, among other parameters / variables are essential and must be known when planning a vertical or horizontal subsurface drainage scheme for agricultural land drainage. Both vary considerably in space and time. The objective of this report is to study the water table behavior and to estimate net recharge for an arid to semi-arid area in the IBIS.

The scope of this report is limited to the assessment of fluctuations in ground water tables measured through a network of piezometers and to the calculation of the spatial and temporal net recharge and volume reduction required to control the water table for a study area.

Study Area

The study area is located in the Punjab Province of Pakistan and is part of the contiguous Indus Basin Irrigation System. The area is situated on the left bank of the River Sutlej bordering India to the East (Figure 1.1). This area receives perennial irrigation supplies through the Hakra Branch, the Sirajwah Distributary and the Malik Branch at the tail of the Eastern Sadiqia Canal offtaking from the Sulemanki Headworks on the Sutlej River. The Malik Branch and the lands served by the Mamun Distributary of the Hakra Branch, respectively, form the Northwestern and the Southern boundaries of the study area. Administratively, the area is located in the Bahawalnagar District that cover tehsils of Bahawalnagar, Harunabad and Chistian (NESPAK, 1992). Geographically, the area is situated between latitudes 29° 23' 45" and 29° 50' 16" North and longitude 73° 01' and 73° 16' 37" East. The real coordinates can be referenced to the Survey of Pakistan metric coordinated system gridded datum for Pak Zone 1. The datum for the area has been projected against the Lambert Conformal Conic Projection and corresponds to the Northing displacement from 590,000 m to 652,000 m, and the Easting displacement from 3,220,000 m to 3,266,000 m. The irrigation network in the study area covers a gross command area of 121,000 hectares and culturable command area of 105,000 hectares (NESPAK, 1992). The area is located in the cotton-wheat agro-ecological zone of the Punjab Province where conditions permit year-round cultivation. The annual cropping intensity is 129.3 percent (55.3 percent in Kharif), with wheat, cotton, sugarcane, fodder, and rice grown as major crops (NESPAK 1992).

Physiography

The area consists of both, alluvial and aeolian plains. The Sutlej River and former Hakra River constituted the active and abandoned alluvial flood plains. The rolling dune-covered aeolian plains are constituted by the Cholistan Desert. The topography of the area is generally flat with outcropping sand dunes. Natural drainage is lacking in the area. The natural surface level varies from 146 m to 163 m above mean sea level. The lands are sloping in the southwest direction. The topsoil is medium-textured and is underlain by thick sand and silt of several hundred meters. The occurrence of compact and calcareous silty/clay non-continuous layers at varying depths that restrict the groundwater flow to deeper layers and act as barriers is reported. The alluvial deposits are formed during recent and pleistocene ages (NESPAK, 1992). In the study area, sand dunes and ponds cover surface areas of 8,816 and 2,643 hectares, respectively.

Climate

The climate of the area is arid to semi-arid. The average annual rainfall in the area is 224 mm, with more than sixty percent of the amount occurring in the monsoon months of July, August and September. The annual reference evapotranspiration in the area is about 2,000 mm (Kahlown et al, 1998). May and June are the hottest summer months. The daily maximum temperature ranges between 42°C to 48°C during the summer season. The mild winter season starts in December and ends in February, with January being the coldest. The daily minimum temperature ranges between 12°C to 25°C during the winter season (WAPDA, 1988).

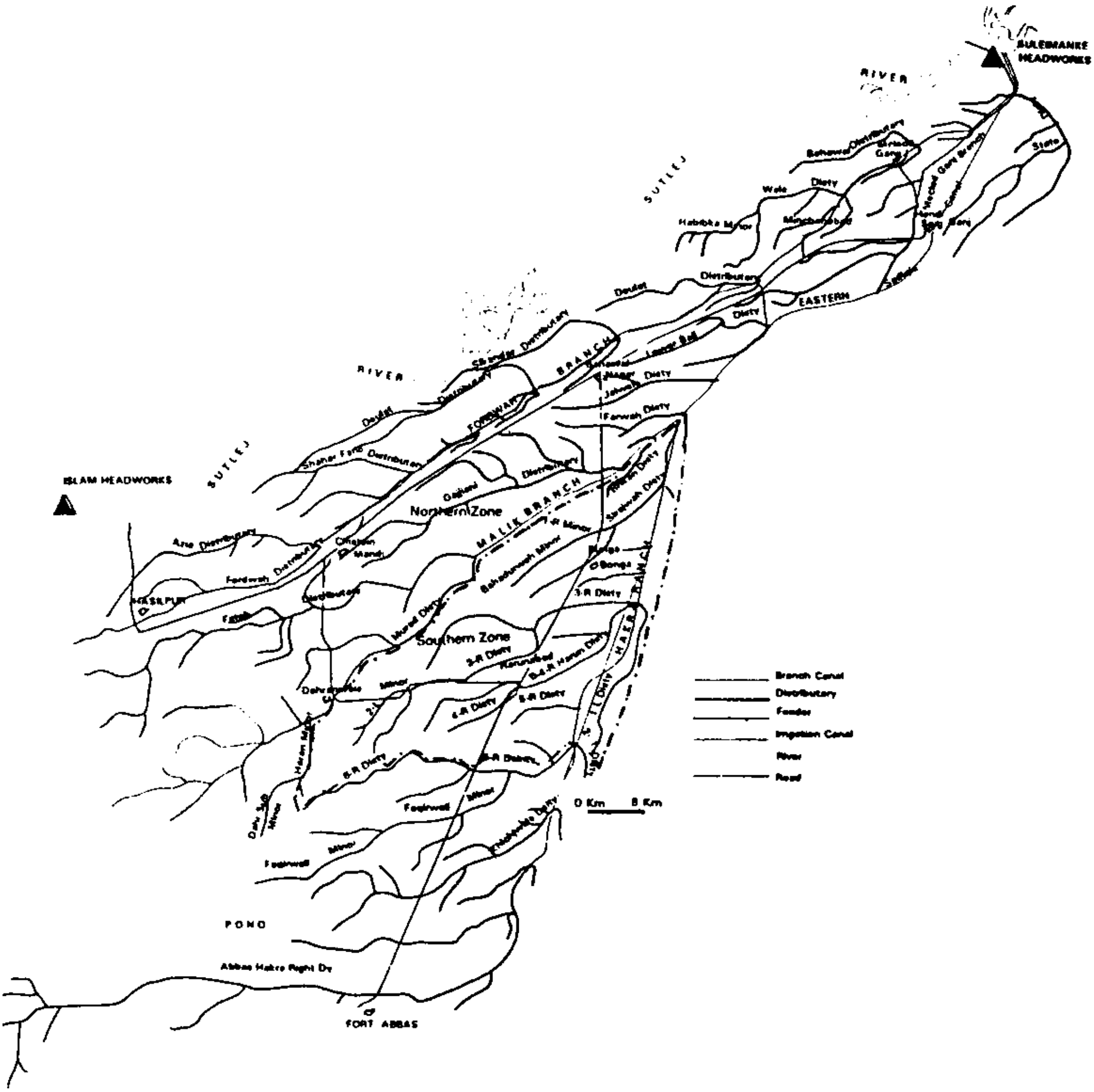

Figure 1.1. Layout of the Fordwah and Eastern Sadiqia Canals in Southeastern Punjab Province (WAPDA, 1994).

Irrigation System

Historically, the study area is part of the Sutlej Valley project for the development of irrigated agriculture. The lands were claimed from the Cholistan Desert by introducing the irrigation network of canals, distributaries, minors and watercourses. The Fordwah Canal and the Eastern Sadiqia Canal systems were constructed on the left bank of the Sutlej River during 1926-1932 to ensure perennial irrigation supplies to the area. The Sulemanki Headworks on the Sutlej River diverted the water to the canals. A result of the Indus Water Treaty in 1960 ceded control of river water in this part of the subcontinent to India, as well as the control of eastern rivers, including the Sutlej River. The continuation of irrigated agriculture in the areas of handed-over rivers has become possible through the construction of reservoirs on the western rivers and link canals. The Fordwah Eastern Sadiqia Canal System now receives supplies from the Mangla Reservoir on the Jehlum River through Rasul-Qadirabad, Qadirabad-Balloki, and Balloki-Sulemanki Link Canals.

The study area receives perennial irrigation supplies at the tail of the Eastern Sadiqia Canal through the Hakra and Malik Branches and Sirajwah and Girdhariwala Distributaries. The salient features of the irrigation network in the study area are shown in Table 1.1:

Table 1.1. The salient features of the irrigation network in the study area.

Channel	Offtake RD (km)	Gross Command Area (ha)	Culturable Command Area (ha)	Discharge (cumecs)	Length (km)	Number of water courses
Eastern Sadiqia Canal	Sulemanki Headworks	471995	393646	162.98	74.7	3460
Hakra Branch	74.7	250344	209348	76.69	89.2	1320
Bakushah Distributary	10.0	635	613	0.17	0.8	3
Sunder Distributary (1-R)	18.7	2073	2019	0.54	3.7	11
Dunga Distributary (2-R)	22.7	2737	2284	0.57	10.3	14
Khatan Distributary (3-R)	27.4	32859	28456	8.69	49.5	186
Qaziwala Minor (1-R/3-R)	16.8	7913	6790	1.87	18.0	46
Jourkanwala Minor (1-L/3-R)	38.4	3296	2593	0.76	10.3	19
Fazil Minor (2-L/3-R)	47.9	864	726	0.20	2.0	5
Harun Distributary (4-R)	27.4	20008	17931	5.35	34.2	129
Labhsingh Minor (1-RA/4-R)	7.1	2820	2459	0.62	6.7	16
Badruwala Minor (1-R/4-R)	22.0	5021	4298	1.22	15.4	32
Mubarik Distributary (1-L)	27.4	7633	5868	1.90	23.7	44
Baghsar Distributary (5-R)	45.5	4376	3797	1.02	23.7	25
Malik Branch	74.7	160299	133994	43.56	35.6	843
Bhukan Distributary	6.8	2173	1552	0.37	5.4	10
Murad Distributary	35.6	9066	8499	16.85	71.3	46
Haran Minor	71.3	1594	1256	1.95		9
Shadab Minor		381	363	0.10	1.6	2
Sirajwah Distributary	74.7	19901	17856	5.58	20.4	113
Najibwah Minor	20.4	3963	3834	1.10	17.2	27
Bahadurwah Minor	20.4	8241	7426	2.32	18.5	47
IR Minor		378	371	0.10	1.7	2
Girdhariwala Distributary	74.2	1632	1231	0.37	4.8	9

(Source: NESPAK, 1992, Ashraf and Khan, 1984).

Fordwah Eastern Sadiqia (South) Irrigation and Drainage Project

The developed intensive network of irrigation canals is a major water source for the fulfillment of the agricultural, industrial and domestic needs of the area of the Fordwah and Eastern Sadiqia Canal

Systems. Due to the deferred drainage infrastructure provision in the area, the irrigated agriculture caused negative environmental impacts in the form of waterlogging and salinity. The low-lying areas accumulated excess irrigation water, which caused an increase in the size and number of ponds, and became a permanent feature in the area. To plan drainage development in the area, the WAPDA identified a salinity control and reclamation project for the Fordwah Eastern Sadiqia Canal Commands (left bank of the Sutlej River-SCARP VIII) in 1966-67 during the Northern Indus Plain study by Tipton and Kalmbach Inc., consultant to WAPDA (NESPAK, 1992). A pilot project over an area of 31,509 hectares was implemented in 1970 in the Minchinabad area. A feasibility study for the identified project was carried out in 1977-78 by the NESPAK. The project boundaries were redefined in 1987 by the WAPDA, excluding the fresh groundwater areas and those covered by the Command Water Management Project. The new project is entitled "Fordwah Eastern Sadiqia Remaining", and is sub-divided into northern and southern zones. The integrated irrigation and drainage development works have been planned for each zone in phases. The first phase (1992-99) for the southern zone has been implemented for the provision of irrigation canal lining, interceptor-cum-subsurface drains, on-farm water management, surface drainage facilities, technical assistance and training. The monitoring of land and water conditions, field trials, research support and project preparation for the second phase have also been envisaged in the first phase. This study is part of the first phase, providing research support for the preparation of future projects. Hence, the coverage of this study is limited to the Fordwah Eastern Sadiqia (South)-FESS Irrigation and Drainage Project area.

2 GROUNDWATER SITUATION AND MONITORING

Geologically, the area is located within the flat Indo-Gangetic plain that forms the surface of an alluviated basin. The alluvial sediments in the basin were deposited in a structural depression from the Bay of Bengal to the Arabian Sea. The Himalayan Mountains on the North, the Sulaiman Hills on the West and the Aravali Hills on the East bound the present and ancestral flood plain of the Indus River and its principal tributaries. The alluvial material transported by the stream from uplands has accumulated in the subsiding basin to depths of several thousand feet. The floor of the basin is inferred as a highly irregular surface, suggesting that the relief on the bed rock surface may be several thousand feet deep and the alluvial deposits that fill the basin may vary considerably in thickness. The hydrogeological investigation indicated that highly porous to medium-grained sand saturated with water to within a few to a few tens of feet constituted the unconsolidated alluvial deposits underlying the Indus Plain. The thick sequence of unconsolidated sand, silt and clay deposits forming the alluvium range date from the Pleistocene to recent, and form a heterogeneous complex of discontinuous beds and lenses with limited vertical and horizontal extents. The alluvial deposits bounded by less permeable rocks of the structural basin form a huge groundwater reservoir (Kamal and Shamsi, 1965).

Lithological Studies

In the study area, groundwater investigations were first carried out by the Water and Soils Investigation Division (WASID) of WAPDA in 1958-59, by drilling six test holes to the depths of 600 to 900 feet. The investigation consisted of drilling bore holes, conducting aquifer tests, measuring water levels, collecting shallow and deep groundwater samples for chemical analyses, and collecting lithologic samples for physical and mechanical analyses and establishing the nature and extent of various lithological units. Based on these investigations, Kamal and Shamsi (1965) described the groundwater reservoir of the Bahawalpur Division, which include the study area, as comprising alluvial deposits consisting predominantly of fine to medium sand with rare silt, clay and gravel. The coarse sand and thick beds of clay are uncommon. Individual strata have limited the lateral and vertical extent. They characterized the alluvium as forming a single aquifer under water table conditions, despite the heterogeneous composition.

During the feasibility study of the SCARP-VIII in 1976, two test holes to the depth of 300 feet and thirty-two shallow test holes of 50 to 100 feet were drilled by NESPAK to supplement the WASID data for lithological information. The WAPDA obtained additional lithological information during 1985-86 by drilling twenty-two shallow test holes to depths of 100 to 150 feet while redefining the SCARP-VIII. All the lithological information is closely studied in this report for characterizing the subsurface to estimate the net recharge to the water table. The locations of test hole sites over the study area are shown in Figure 2.1.

Groundwater Quality

The groundwater quality in both, the shallow and the deep horizons tested during various lothological studies was found to be poor. The deep groundwater quality analysis for samples obtained from depths varying between 120 to 270 feet indicated the electrical conductivity of 19,000 mmhos/cm. The shallow groundwater quality analysis for samples from depths of 55 to 150 feet indicated an average electrical conductivity value of 12,900 mmhos/cm (NESPAK 1992).

Only along distributaries, minors and watercourses, groundwater tapped at very shallow depths by hand pumps and tubewells is of less saline quality, and can be used for irrigation purposes (NESPAK, 1992). The International Irrigation Management Institute Pakistan, also collected groundwater samples from pits, tubewells and hand pumps and analyzed for electrical conductivity as well (Aslam et al., 1999). They reported the quality of groundwater at varying depths range from 0.44 to 8.23 mmhos/cm. The groundwater development is very limited in the area, and only recently have some small tubewells been installed close to irrigation channels to supplement the irrigation water during peak crop water requirements.

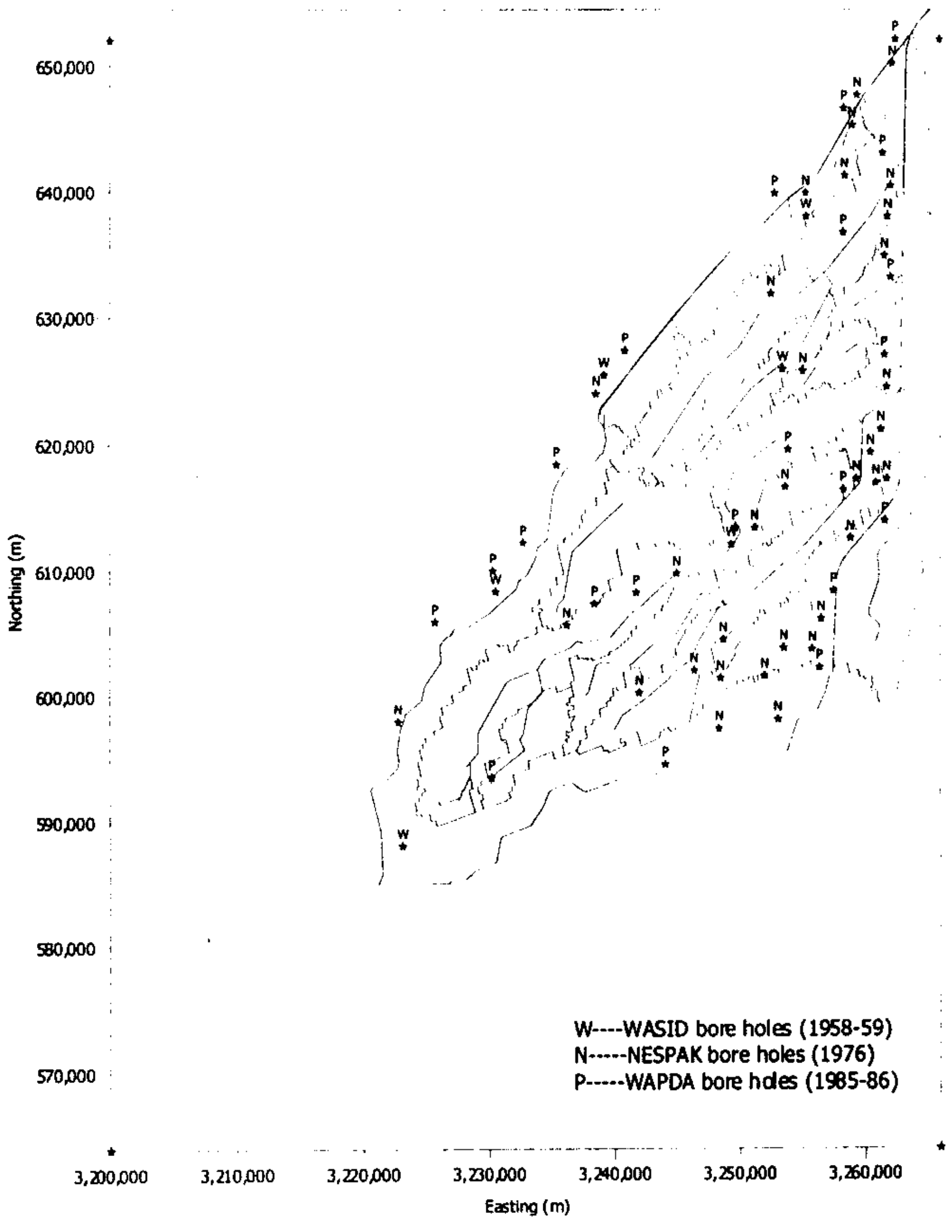

Figure 2.1. The locations of lithological bore hole sites over the study area.

Aquifer Tests

The characteristics of the alluvial aquifer in the study area have also been determined by conducting aquifer/pumping tests since the first hydrogeologic study by WASID. The values of aquifer constants were found commensurate with the observed lithology of the alluvium and were found suitable for installing tubewells of two to three cusecs (Kamal and Shamsi, 1965). The average porosity and specific yield during the laboratory analyses of sand samples from bore holes calculated values of 39 and 32 percent, respectively The values of 43 and 18 percent, respectively, were calculated for silty clay samples (Kamal and Shamsi, 1965).

The aquifer constants are subject to spatial variability; a series of aquifer tests to ascertain the alluvium characteristics of the study area for planning the drainage infrastructure developments has been carried out in 1988, 1991, 1992, and 1997. The locations of these aquifer test sites are shown in Figure 2.2. The results of two aquifer tests conducted by NESPAK-NDC in 1988 suggested the occurrence of an unconfined aquifer system with transmissivity values ranging from 1,200 to 1,500 square meters per day. Three additional aquifer tests in 1991 by NESPAK also suggested an unconfined aquifer with transmissivity values varying between 700 and 950 square meters per day (Javed, 1998). The preliminary results of two aquifer tests in 1992 by the Hydrogeology Directorate, WAPDA, indicated a semi-confined aquifer system with a transmissivity value of 450 square meters per day and storativity value of 0.0001 (Javed, 1998).

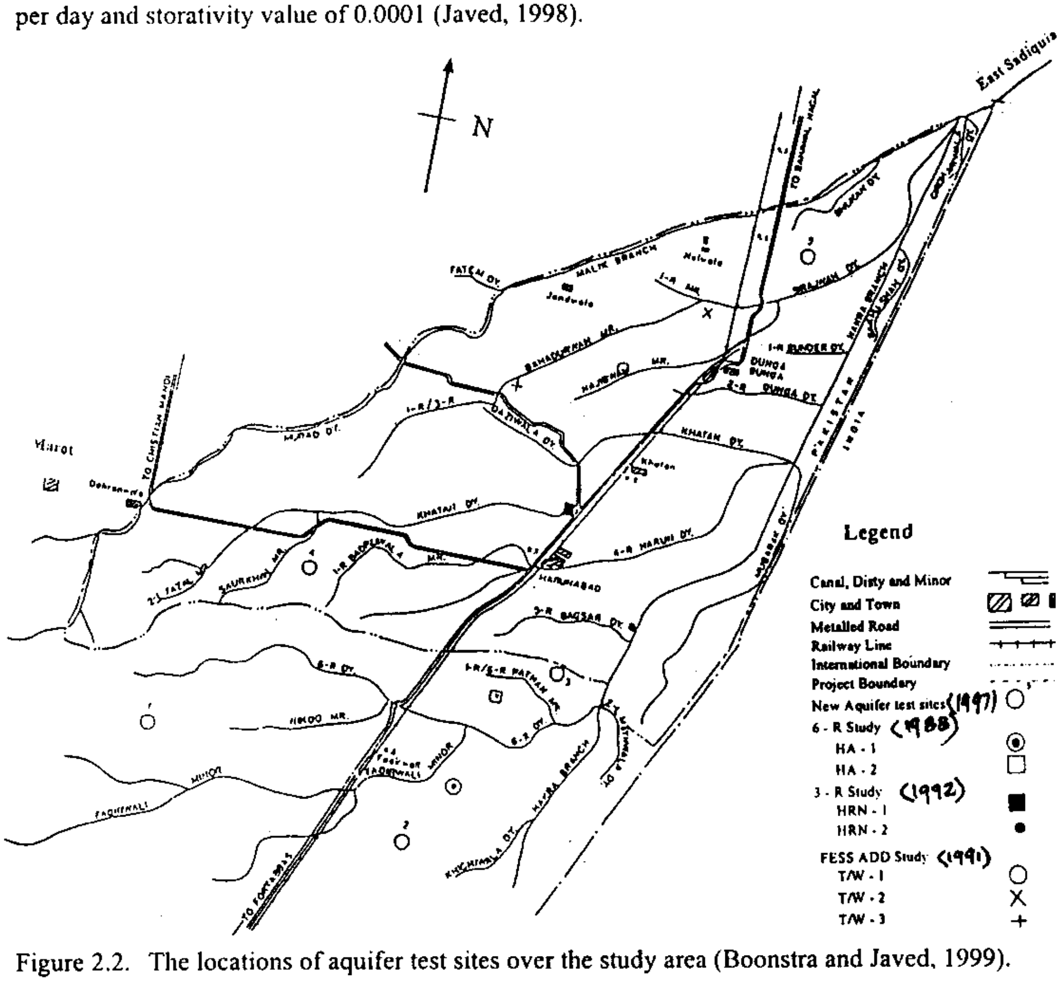

Figure 2.2. The locations of aquifer test sites over the study area (Boonstra and Javed, 1999).

The Hydrogeology Directorate carried out five tests in the study area in 1997. These tests characterized the aquifer as consisting of unconsolidated alluvial deposits, with groundwater under water table conditions, and with the upper ten-meter layer composed of less permeable clay and silty clay. The aquifer test data were analyzed using the United Nations' Groundwater Software for Windows (GWW); the transmissivity values estimated vary between 517 to 3,261 square meters per day, and the coefficient of storage ranges between 3.8E-7 and 6.5E-4 (Ismail and Mohiuddin, 1997).

Boonstra and Javed (1999) reanalyzed the aquifer test data of all the above-mentioned tests using SATEM: Selected Aquifer Test Evaluation Methods, a microcomputer program, to update the transmissivity map and to estimate the thickness and specific yield values of the aquifer for the groundwater modeling of the study area. They discarded the test data of one site each from the aquifer test sites in 1988, 1992 and 1997 because large variations of transimissivity values resulted from time-drawdown, time-recovery and residual-drawdown analyses of data. The lack of time-recovery data in one case caused concern regarding the accuracy of data. They summarized the results of nine aquifer tests suggesting the unconfined aquifer of 100-meter thickness, with transmissivity values ranging from 684 to 1,806 square meters per day for the study area. The specific yield values are estimated on the lower side. They suggested adjusting and adopting a single value of specific yield for the study area during the calibration of the groundwater model.

Groundwater Modeling Study

The International Waterlogging and Salinity Research Institute (IWASRI) is conducting a groundwater modeling for the study area using the Standard Groundwater Model Package (SGMP), a finite element model for the simulation of groundwater basins, developed by Boonstra and DeRidder (Sufi et al., 1998). The purpose of the modeling study using the groundwater balance approach is to predict the effects of anti seepage measures implemented under the first phase of the FESS project, on the regional water table and the reduction in the extent of areas in need of drainage. The study is under progress and preliminary modeling results have identified the nodal areas under urgent need of drainage, as well as predicted the future water table behavior under assumed impacts of anti seepage measures (Sufi et al., 1998).

Groundwater Monitoring

Before the introduction of irrigation developments in the commands of the Fordwah Eastern Sadiqia Canal system, the groundwater table was very deep and at some places the depth to water table was more than one hundred feet. The water table remained at the same level for a long time due to natural equilibrium conditions. To bring the maximum area under canal commands, the alignments of channels were kept on ridges as per recommendations of the irrigation command survey. Additional water through the irrigation network and unconsolidated alluvial deposits of sand underlying the study area caused deep percolation of excess water. The natural equilibrium of the groundwater table status was disturbed due to the new dimension of percolated water. The average rise in groundwater is estimated to be vary between 30 to 50 cm annually (WAPDA, 1988).

Kamal and Shamsi (1965) reported that the program of measuring water levels was initiated as early as the 1920s in the areas commanded by the Fordwah Eastern Sadiqia Canals, in view of the anticipated rise in groundwater levels after the inception of canal irrigation in the region. The depth to water table survey by the Planning Division (Water) Central, WAPDA, for the assessment of groundwater conditions was carried out in 1987. The estimate was that 57 percent of the study area underlies a water table within 1.5 meter depth, 34 percent within 3 meters and 8 percent more than 3 meters. The area under water was estimated as 1 percent (WAPDA, 1988).

The first phase of the FESS project included the monitoring of land and water conditions of the project area. The SCARP Monitoring Organization was entrusted with the installation, replacement, and monitoring of groundwater levels on a monthly basis. The network of piezometers in the study area, and extending in the south and south-west directions, is laid down considering the spatial discretization requirement of the groundwater modeling study by IWASRI (Minhas, 1998). Accordingly, a network of 125 piezometers were installed in the irrigated areas between the Hakra and Malik Branch canal systems, constituting 80 internal and 45 external nodes, respectively, that describe the nodal areas and boundaries of the modeled area. The nodal network divides the area into 21 sections, and each contains four to six piezometers perpendicular to the groundwater flow (Sufi et al., 1998). The piezometers consist of shallow bottom-perforated plastic or metal pipes with graded gravel envelopes. The depth to water table measurements are taken manually by a marked tape and electrical sounder or 'plopper' (makes a sound upon striking the water surface). The locations of piezometers are shown in Figure 2.3. This study also uses the depth to groundwater table data monitored for the nodal network of piezometers, for the spatial and temporal assessment of groundwater recharge.

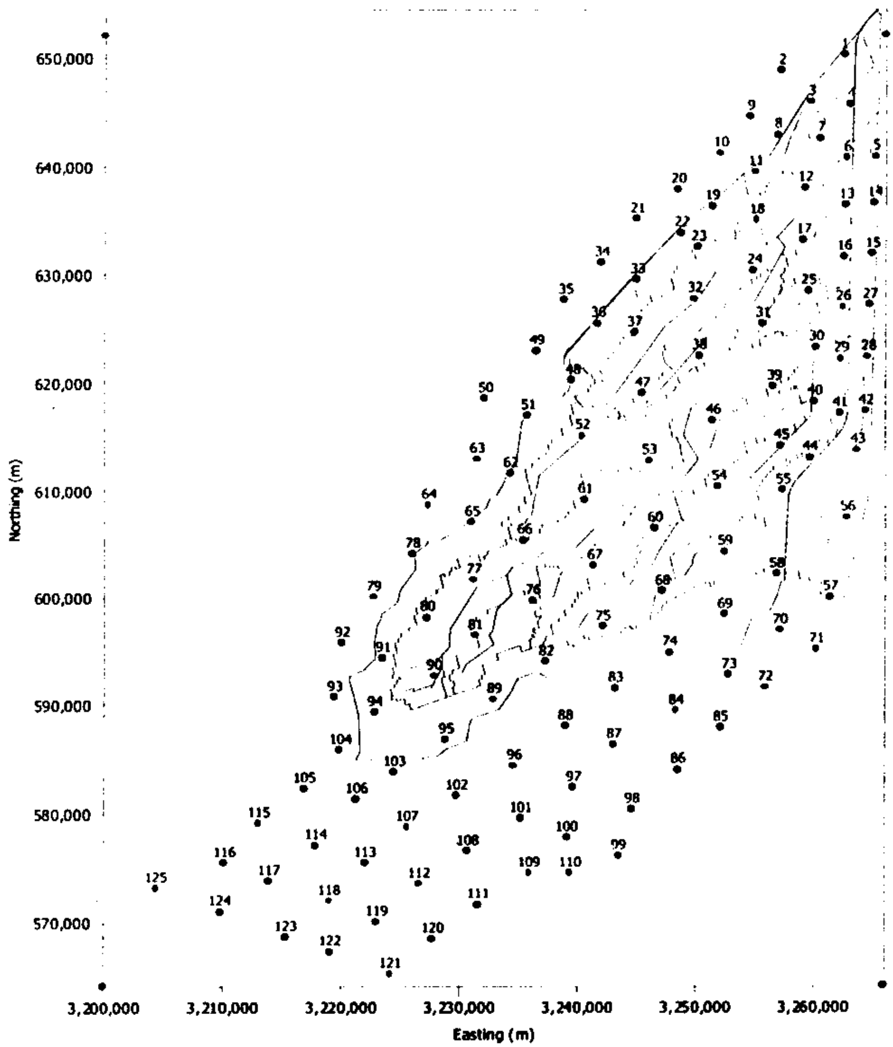

Figure 2.3. The nodal network of piezometers in the study area.

3 METHODOLOGY AND ANALYSES

The monthly depth to water table data collected by the SCARP Monitoring Organization through a network of piezometers over the study area and surroundings have been utilized in this study to describe the behavior of water table, monthly recharging pattern, and delineation of areas requiring subsurface drainage. The depth to water table data for each month represents a unique surface of the water table over the study area. The basic idea of this study is to generate and compare the surfaces of the water table for subsequent months to determine recharging and discharging areas, and net recharge flux to the study area during the month of interest. The water table surface is generated using a grid-based contouring and three-dimensional surface plotting graphics program, SURFER for Windows, developed by Golden Software, Inc (1996). A 100-meter square grid mesh is laid over the study area and the grid cell value is generated using a proven and popular geostatistical technique, Kriging (Golden Software, Inc., 1996).

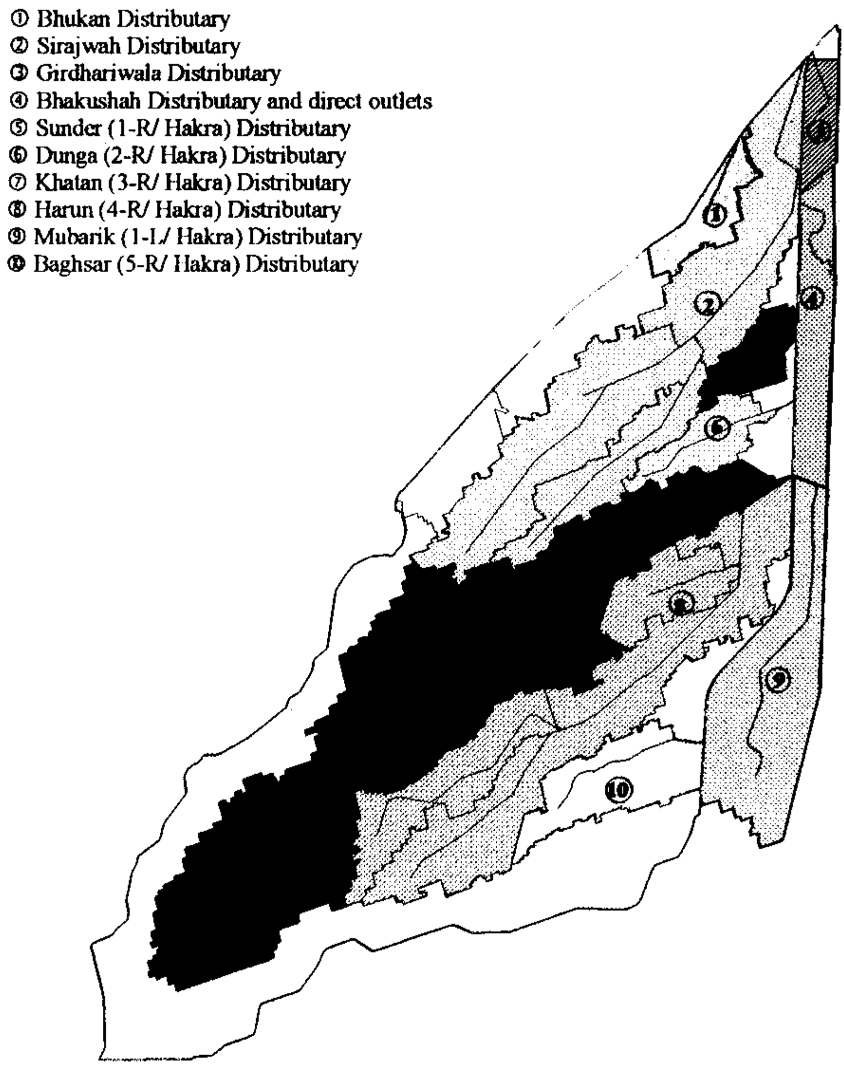

Figure 3.1. The spatial consideration for the groundwater analysis of the study area.

Dividing the area into distributary commands exposes the spatial consideration for purposes of analysis. Ten complete distributary commands are considered for analysis of the area, as shown in Figure 3.1. Throughout this report, the names of the distributaries have been used. Table 1.1 may be used for referring to the code names given to some distributaries. The irrigation needs of the remaining areas are met through the direct outlet commands of the Hakra and Malik Branches and partial commands of the Mamun Distributary (6-R Hakra), Murad Distributary and Shadab Sub-minor. The command area of a distributary is delineated by digitizing and combining the command area maps of all the outlets, obtained from the Punjab Irrigation Department, on the distributary. Thus, spatial consideration in this study makes it unique and different from other studies. The temporal consideration for the study relies upon the availability of groundwater monitoring data for the network. This study covers the analysis for a period of four years, from May 1994 to April 1998 covering eight cropping seasons (Kharif-May to October and Rabi-November to April).

Water Table Fluctuation

Eighty-seven out of the network of 125 piezometers are located in and in proximity to the study area. The maximum depth to water table fluctuation in a piezometer in the study area for the period of analysis is 213 cm, while the minimum is 67 cm. The average fluctuation in a piezometer of the study area is calculated as 132 cm. Thus, the groundwater system in the study area is dynamic due to these large fluctuations over the period of analysis.

The hydrograph of a typical piezometer (ID # 45, NSL 157.23 m, Northing 614,144m, Easting 3,257,214m) in the study area is shown in Figure 3.2. A statistical analysis of the depth to water table observations shows significant variations and responsiveness to the hydrologic conditions and irrigation practices. The water table fluctuates within a depth of 45 and 142 cm, showing the waterlogged situation for the critical root zone depth of 150 cm. A slight rising trend of water table (3.6 cm per year) occurs over the period of study. The capillary upflow and evaporation phenomena (the loss from the water table) are quite operative and the water table is under the dynamic equilibrium, with the mean depth of 108 cm over the period of analysis. The sharp crests, especially in the monsoon months, followed by troughs, indicate that the capillary upflow and evaporation phenomena constitute a large fraction in the groundwater balance for the area.

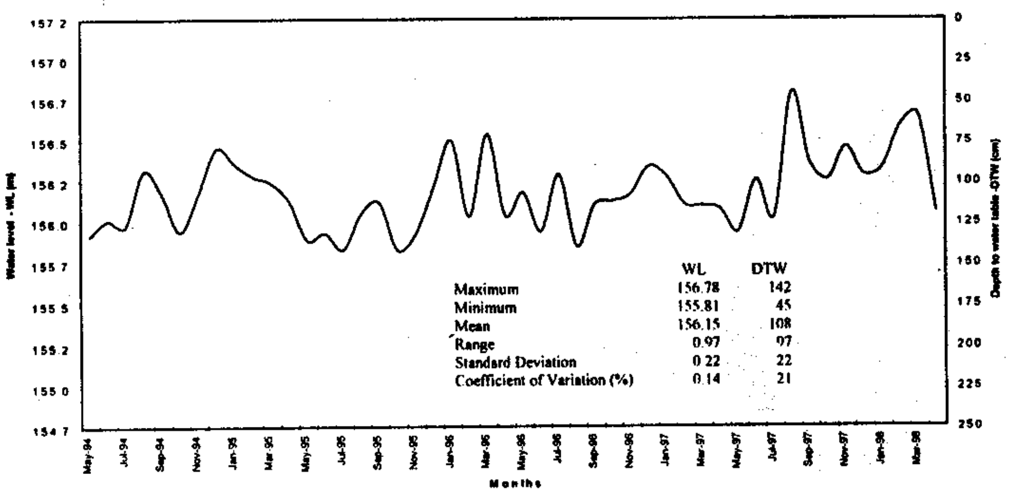

Figure 3.2. The hydrograph of a typical piezometer in the study area.

The fluctuation of the water table over the area during the study period is analyzed in terms of comparing average water table elevations during the month of May. The selection of the month of May is arbitrary. The trend of water table behavior is shown in Figure 3.3. The water table is rising over the three-year period from May 1994 to May 1997. The average water table has risen by 42 cm, 5 cm and 19 cm during May 1994-95, May 1995-96 and May 1996-97, respectively, with a mean rise of 22 cm per year.

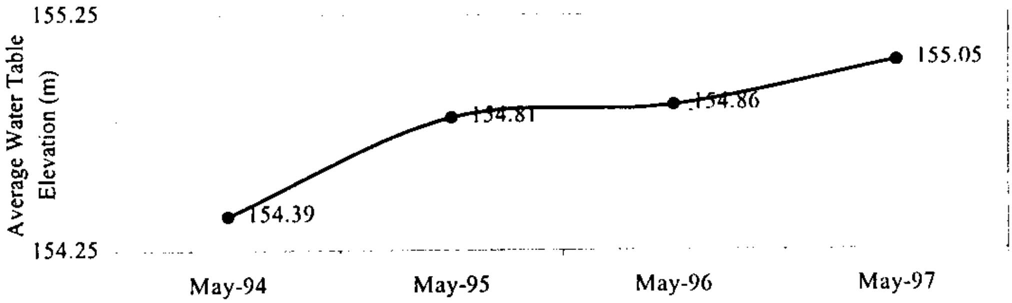

Figure 3.3. The trend of average water table elevation during May.

The piezometric network data is statistically analyzed to determine the tendencies in natural surface levels, water levels and depths to water table over the distributary command. The maximum, minimum and mean water levels and depths to water table are calculated for a particular month and are averaged out for the study period. Table 3.1 summarizes these values at distributary command level. The Sunder Distributary offtaking from the Hakra Branch in the head reach depicts that the water table remained close to the natural surface level over the command. On average, the water table remained at a depth of 64 cm in the Sunder Distributary, causing waterlogged conditions. The Mabarik distributary shows the best conditions with an average water table at 162 cm, while varying between 119 and 214 cm when keeping the root zone aerated during the study period. The Baghsar Distributary shows the largest variation of 174 cm between the average minimum and maximum depths to water table over the command.

Table 3.1. The average maximum, minimum, and mean natural surface elevation, water table elevation and depth to water table for distributary commands during the study period.

Distributar Command	Numbers of Piezometer	Natural Surface Elevation			Water Table Elevation			Depth to Water Table		
		Max (m)	Min (m)	Mean (m)	Max (m)	Min (m)	Mean (m)	Max (m)	Min (m)	Mean (m)
Baghsar	3	155.28	152.65	154.35	154.23	152.49	153.32	1.86	0.12	1.03
Bakhushah	8	162.74	160.23	161.84	161.44	160.27	160.99	1.60	0.40	0.85
Bhukan	5	162.54	160.00	161.20	160.78	159.92	160.48	1.28	0.36	0.67
Dunga	5	161.15	156.87	159.70	158.94	157.66	158.62	2.04	0.62	0.96
Harun	16	161.15	149.71	156.03	155.23	154.55	154.94	1.48	0.83	1.11
Khatan	28	161.15	147.37	153.38	152.14	151.26	151.83	2.13	1.22	1.54
Mubarik	10	160.60	155.28	158.10	156.95	155.97	156.52	2.14	1.19	1.62
Sirajwah	20	162.54	154.91	159.37	158.86	158.01	158.61	1.36	0.49	0.75
Sunder	4	161.78	159.76	160.99	160.61	159.60	160.35	1.40	0.39	0.64

Sixteen piezometers of the network are in and in close proximity to the Harun Distributary. The depth to water table situation is not so bad, as the water table varies between 83 and 148 cm below the ground with an average of 111 cm. The results of simple statistical analysis over the study area are quite encouraging, with average depth to water table varying between 54 and 442 cm and with a mean value of 192 cm.

Direction of Groundwater Flow and Temporal Variations

The ground surfaces in the study area exhibit a flat terrain. The general fall of the land is in south and southwest directions. The groundwater levels are obtained by deducting the depths to water table from the natural surface levels. The groundwater levels are shown in the form of contour maps (Figure 3.4). The average groundwater levels at the end of the Rabi (April) and Kharif (October) seasons show that the direction of groundwater flow generally follows the ground slope. The sharp curvatures of the groundwater levels in the eastern portion of the study area follow the course of the Hakra Branch that represent seepage from the branch canal.

The average depths to water table contours at the end of the Rabi and Kharif seasons are depicted in Figure 3.5. In the upper reaches and the vicinity of the Hakra and Malik Branches, the depths to water table contours are closed and of small magnitude, thus, forming mounds of groundwater in such areas. The upper portion of the study area has water tables closer to the natural surface than the lower portion of the study area. Since the upper portion transmits large volume of water supply to the area, therefore, a proportionately large amount of water seeps to the water table. Generally, the depth to water table contours in the month of October show a deeper trend than for April. Hence, during the Rabi season, more water is contributed to the water table than during the Kharif season. The higher summer temperatures are the cause of accelerated capillary upflow and evaporation phenomena, and therefore, the occurrence of rapid loss from the water table in the area during Kharif season.

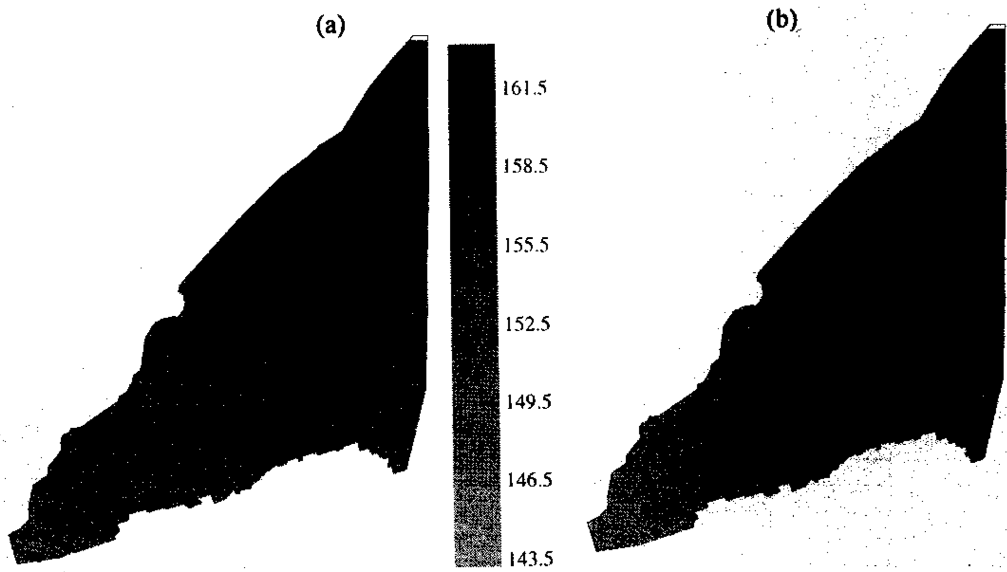

Figure 3.4. The contours of average groundwater levels (m) during the months of (a) April (b) October in the study area.

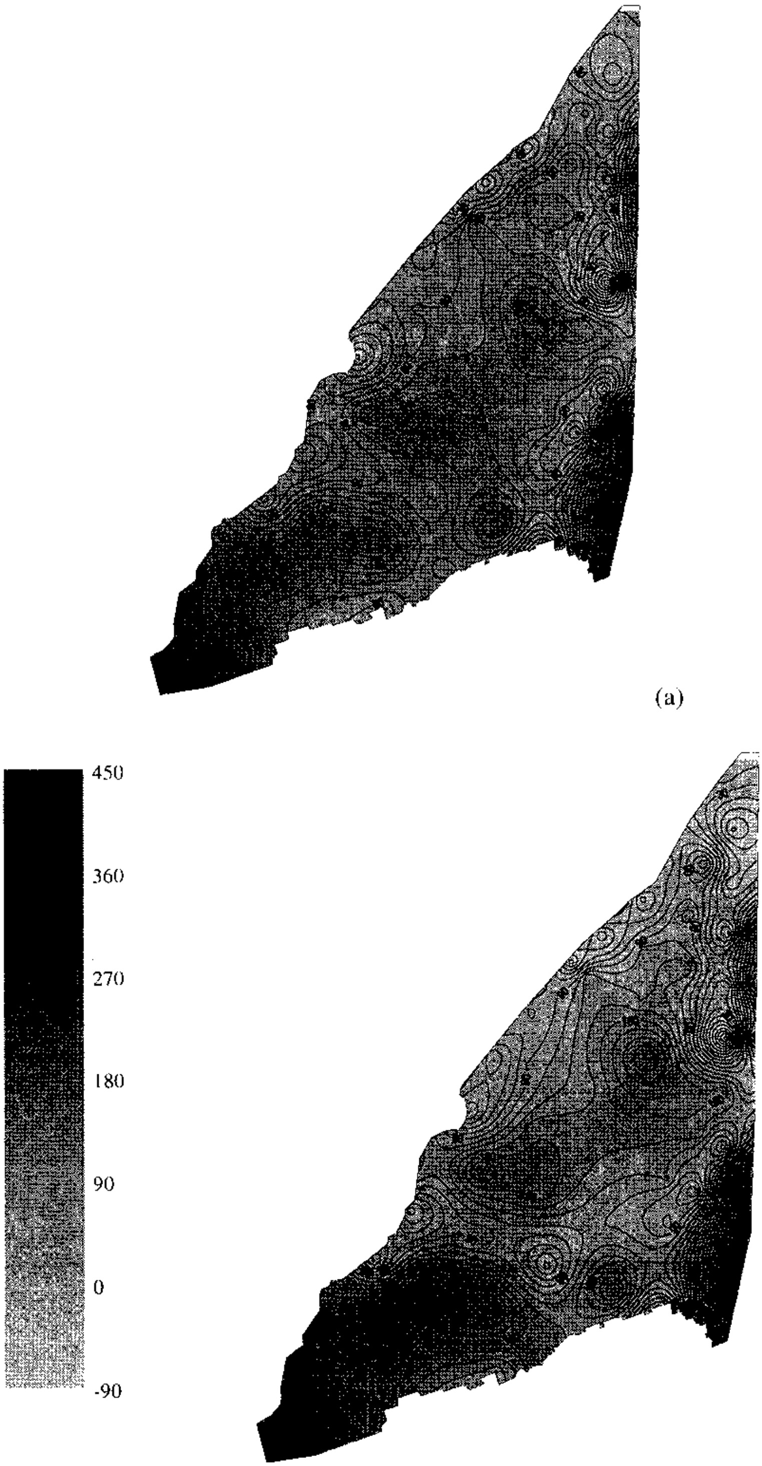

Figure 3.5. The contour of average depth to water table (cm) during the months of (a) April (b) October in the study area.

Temporally, the average monthly fluctuations in the depth to water table have also been analyzed at the distibutary command level. Table 3.2 shows temporal variations of the groundwater elevations above mean sea level and the depth to water table in the Harun Distributary command area, and Annex I contains similar information for other distributaries. The deepest water table is found in the month of June, while December exhibits the shallowest. The largest variation, of 47 cm, in depth to water table is found in the month of July. An appraisal of Annex I indicates that the depths to water table reach maximum values during the summer months of May, June or July in various distributary commands.

Table 3.2. The average monthly maximum, minimum, and mean water table elevations and depths to water table in the Harun Distributary.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water Table Elevation (m)												
Maximum	155.06	155.12	155.19	154.99	154.86	154.91	155.15	155.09	155.09	155.00	155.15	155.23
Minimum	154.94	154.88	154.95	154.92	154.57	154.55	154.67	154.82	154.88	154.83	154.83	154.97
Mean	155.01	154.99	155.07	154.96	154.77	154.75	154.81	154.99	154.97	154.94	154.95	155.07
Depth to Water Table (m)												
Maximum	1.12	1.17	1.10	1.14	1.45	1.48	1.38	1.21	1.15	1.19	1.20	1.08
Minimum	0.99	0.94	0.86	1.06	1.19	1.14	0.91	0.97	0.96	1.05	0.90	0.83
Mean	1.05	1.07	0.99	1.10	1.28	1.30	1.23	1.05	1.08	1.11	1.10	0.97

Recharge and Discharge Behavior

The water table behavior is further analyzed in terms of recharge and discharge (build-up and lowering) over the study area and period. This consisted of the generation of the water table surface during the month of interest, and then subtracting the generated water table surface of the preceding month. Accordingly, the positive results show the build-up of water table, while negative results show the lowering of the water table during the month of interest. The recharge and discharge behavior of the water table over the Harun Distributary (Table 3.3) and other distributaries (Annex II) have been studied.

Table 3.3. The monthly water table fluctuations (build-up, lowering and net change in mm) for the Harun Distributary for the study period.

Year	Water Table	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1994-95	Build-up		45	263	245	119	186	105	195	154	212	86	37
	Lowering		95	35	109	73	133	193	67	178	149	148	83
	Net Change		-50	228	136	46	53	-87	128	-25	62	-62	-46
1995-96	Build-up	23	33	159	411	53	156	146	184	116	75	243	135
	Lowering	222	198	49	13	297	190	172	31	72	200	88	195
	Net Change	-200	-165	110	399	-244	-34	-26	152	44	-125	155	-60
1996-97	Build-up	44	120	359	162	59	225	116	230	188	114	96	68
	Lowering	109	89	75	186	395	7	335	58	156	163	54	32
	Net Change	-64	31	284	-24	-335	217	-218	172	32	-49	41	36
1997-98	Build-up	94	172	32	372	70	116	300	193	72	108	187	0
	Lowering	166	92	258	43	126	122	92	151	165	103	132	286
	Net Change	-73	80	-226	329	-55	-6	208	42	-94	5	55	-286
Average	Build-up	54	93	203	297	75	171	167	200	132	127	153	60
	Lowering	166	118	104	88	222	113	198	77	143	154	106	149
	Net Change	-112	-26	99	210	-147	57	-31	124	-11	-27	47	-89

During the months of July, August, November, December and March the water table build-up is more than the lowering over almost every distributary command for the same period, thus, positive net recharge during the month. The Harun Distributary exhibits a maximum water table build-up of

411 mm during August 1995, followed by 297 mm lowering in September 1995 that shows the responsiveness of the water table and soil medium to monsoonal rains and high summer temperatures. The maximum average build-up (297 mm) and lowering (222 mm) of the water table occur during the months of August and September, respectively, over the Harun Distributary command.

In order to show the extents of recharge and discharge areas over the commands of the distributaries on a monthly basis, maps are prepared to represent these areas. Figure 3.6 shows the extents of average recharge (shaded) areas for the month of interest over the Harun Distributary command. Similar figures have been prepared for other distributaries in the study area (Annex III). The unshaded areas show the discharge areas and no change areas. The map of the Harun Distributary shows that recharge area does not occur in the month of May. Hence, it can be said the water made available during the month of May is fully utilized along with the water table contribution to the root zone. Similarly, minimal areas received recharge during the months of February, April and September, representing the maximum utilization of available water, as well as, water table contribution to meet crop irrigation demands. The maps for the months of August and July are showing that the complete distributary command is receiving recharge. Similarly, the maps for the months of November, December and March show larger areas of recharge. The inference is that the water availability (rainfall and irrigation) is more than the water utilization during these months, and that excess water is increasing the extents of recharge in areas.

Net Recharge Fluctuation

The monthly net recharge fluxes to the study area at the distributary level are evaluated to determine the volume reduction required for the water table control. The distributary-wise lithological information is appraised to determine the water yielding or drainable porosity values. A fence diagram showing the lithology over the Harun Distributary command is shown in Figure 3.7, while those of other distributaries are in Annex IV. The subsurface lithology of the Harun Distributary command consists of alternate layers of fine and coarse-grained clay, silt and sand. The bore hole near the Harun Distributary head regulator is showing a single thick layer of clay, while other bore holes show heterogeneity in vertical extent. The comparison of the bore holes' litholology shows a heterogeneous nature spatially, and therefore, different layers have limited lateral extents. However the top three meters, or less, over the distributary command is mostly composed of silt and sand. Also, the soils encountered over the command area have shown a weighted permeability value of 1.52 m/d, the corresponding specific yield (Sy) value is 14 percent as per a general relationship developed between permeability and specific yield by L.D. Dumm (1968) and others, and used by the United State Bureau of Reclamation (Luthin, 1978).

The monthly net recharge for a distributary is calculated by multiplying the net change value of the water table during the month of interest and the specific yield value for the distributary. The monthly net recharge fluctuation for the Harun Distributary and others are given in Table 3.4, and graphically shown in Figure 3.8. The fluctuations in net recharge correspond to the behavior of the water table.

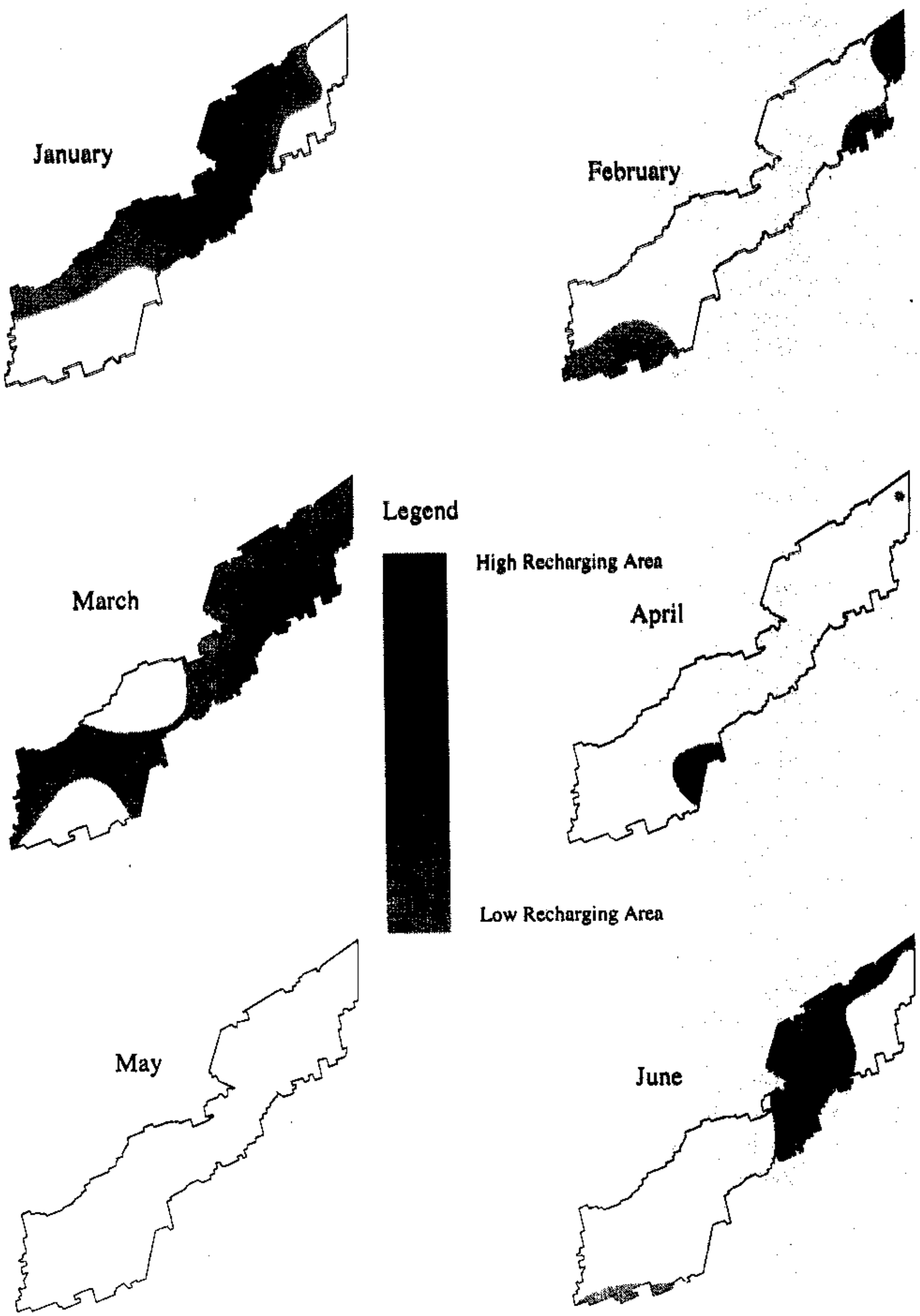

Figure 3.6. The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Harun Distributary command.

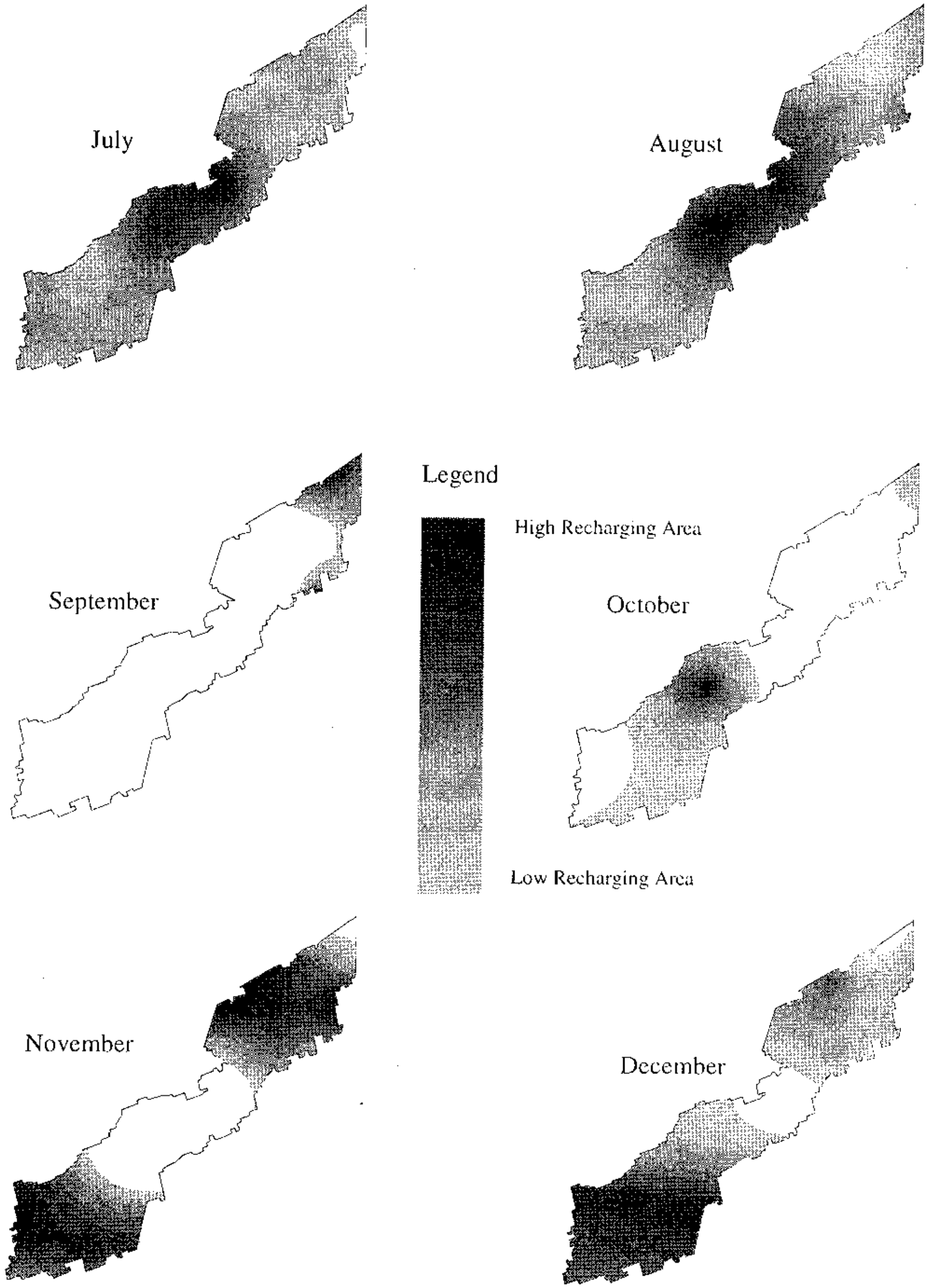

Figure 3.6 (contd.).The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Harun Distributary command.

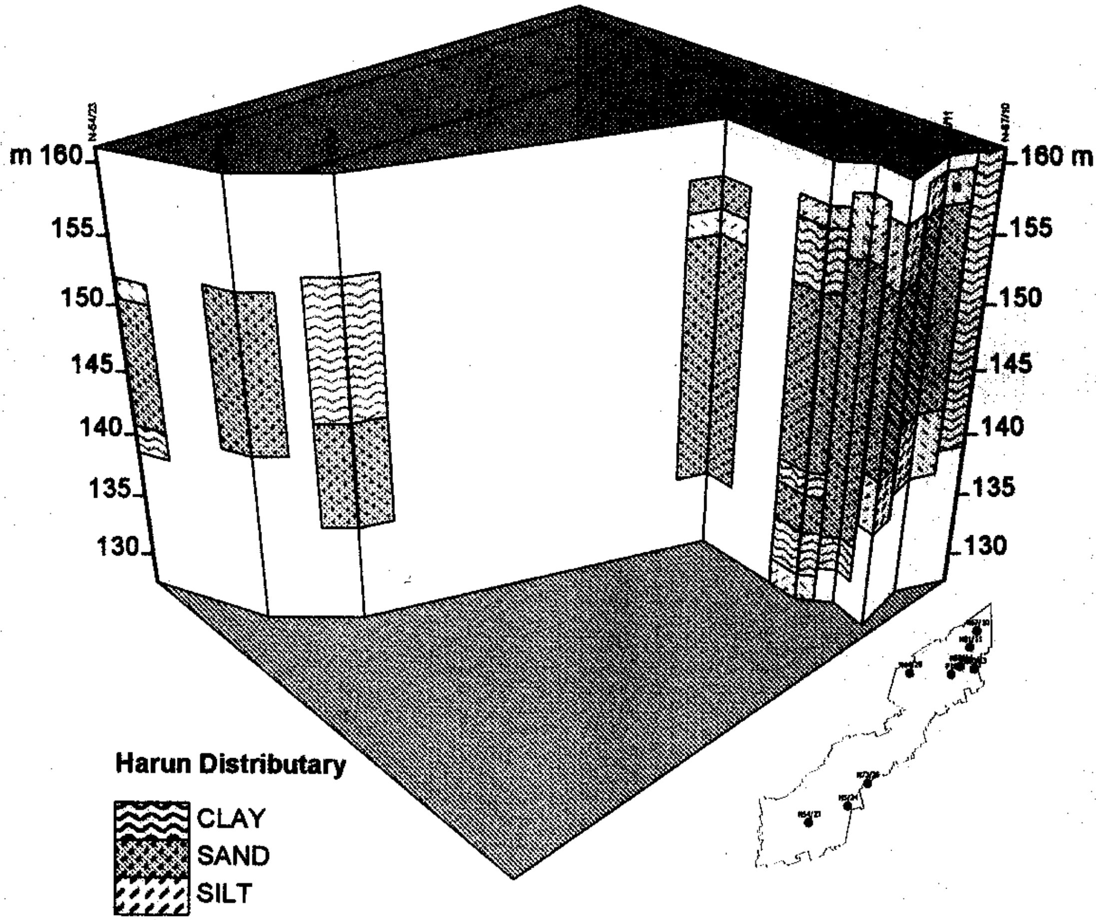

Figure 3.7. The subsurface lithological fence diagram over the Harun Distributary command.

Table 3.4. The estimated specific yield values and average monthly net recharge fluctuations, in mm of water, for different distributaries.

	K (m/d)	Sy (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Baghsar	1.23	13	3	-13	14	-7	-12	-2	11	27	-11	-4	2	13	20
Bakushah	1.44	14	-30	5	14	-11	-12	13	5	52	5	-10	-20	3	13
Bhukan	1.45	14	-22	-12	33	-4	-10	-8	-3	18	10	-17	12	20	16
Dunga	2.14	17	-9	-12	30	-16	-13	11	5	49	8	-55	41	7	46
Girdhariwala	1.13	13	-21	-22	27	-4	-22	-1	-5	59	15	-32	-14	25	7
Harun	1.52	14	-1	-4	7	-12	-16	-4	14	29	-21	8	-4	17	13
Khatan	1.81	15	3	-12	9	-11	-3	-7	14	21	-20	-13	11	23	15
Mubarik	1.31	13	-10	-4	25	-5	7	-9	-1	27	3	-16	9	7	31
Sirajwah	1.79	15	-1	-15	24	-12	-2	-10	9	28	-5	-17	16	25	41
Sunder	1.72	15	-33	14	13	-20	-1	8	1	35	0	-20	13	13	23
FESS Area	1.64	15	-6	0	13	-6	-20	-6	8	21	-11	-8	5	20	10

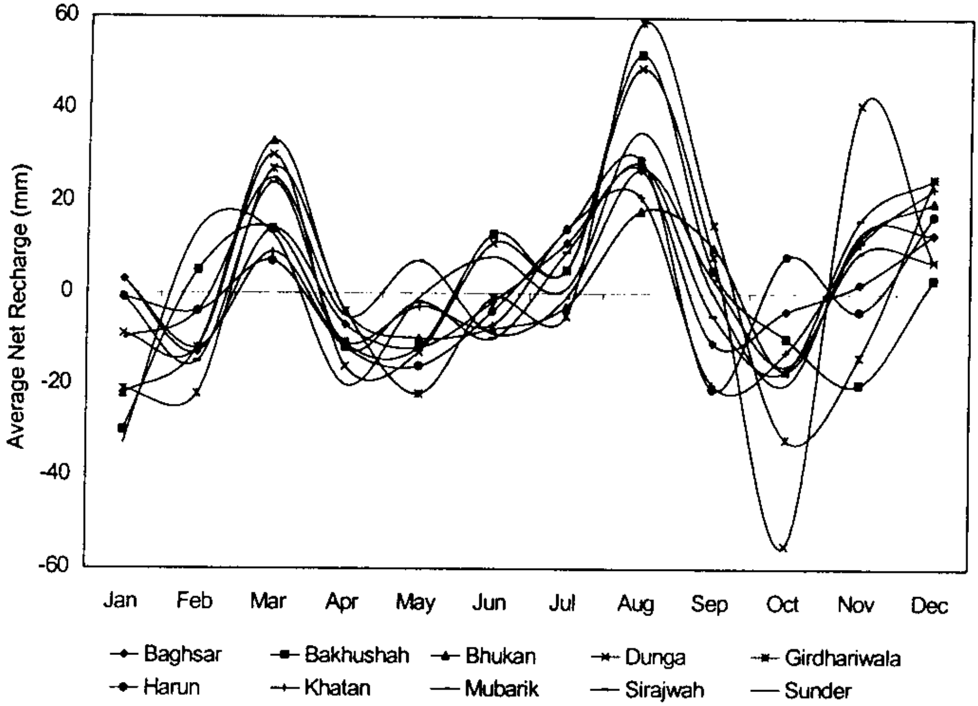

Figure 3.8. The average net recharge fluctuations for the distributaries in the study area.

4 GROUNDWATER ASSESSMENT

The assessment of net recharge over the study area is conducted in order to determine the area and volume of water required to be removed from the root zone for optimum cropping and yield. The average monthly water levels over every distributary command are calculated from the groundwater monitoring data obtained from the network of 125 piezometers. A critical depth of 1.5 m for the root zone is established for the assessment of drainable surplus. This depth provides aerated conditions for most of the crops grown in the area, and an allowance for capillary rise from the water table. The targeted surface of groundwater elevation is prepared by subtracting target depth from the natural surface levels. The design of the subsurface drainage system in the area is to be based on the amount of excess water within the targeted depth.

The estimation of excess water to be removed from the root zone, the delineation of areas and contours showing water levels above the root zone depth of 1.5 m, and the estimation of the areal extent of water levels within the depth to water table category of 0-50 cm, 50-75 cm, 75-100 cm, 100-125 cm, and 125-150 cm, at the distributary level for each month are described in the following paragraphs.

Excess Water Assessment

The difference between the average water levels during the month of interest and the targeted water elevations over a distributary command represents the amount of excess water in that month if the former is higher. This difference is the height of the water table to be lowered/drained to maintain an adequate root zone environment. The corresponding height of water to be drained is obtained by applying the specific yield estimated for the distributary. Table 4.1 summarizes the amount of excess water to be removed from the root zone of a distributary on a monthly basis. Values are the average height of the water table in areas where water table is above the target level.

Table 4.1. The average monthly recharge reduction required, in mm of water, from different distributaries in the study area for water table control.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baghsar	56	47	55	54	34	36	36	55	48	42	44	55
Bakhushah	66	80	92	80	63	72	73	114	116	113	94	91
Bhukan	142	113	164	160	127	118	117	138	149	130	144	167
Dunga	84	99	94	74	64	70	72	102	75	100	97	97
Girdhariwala	179	158	185	181	151	148	144	203	218	190	176	201
Harun	72	61	67	52	34	31	39	68	54	49	52	66
Khatan	71	62	67	53	42	32	41	57	44	43	47	64
Mubarik	35	35	49	44	31	27	28	39	43	41	43	47
Sirajwah	118	93	113	101	80	71	77	100	91	80	95	121
Sunder	110	126	137	118	96	101	101	138	138	117	131	144

Over the Harun Distributary command, the closest depth to water table in the waterlogged areas is occurring during the month of January, and hence, showing maximum drainage requirement (72 mm per hectare of excess water from the waterlogged areas are to be removed). In the study area, the largest excess water removal is required in the Girdhariwala Distrbutary, amounting to maximum of 218 mm per hectare during the month of September. The estimates of excess water removal from Girdhariwala Distributary are on the higher side, and must be used with caution as the coverage of the distrubtary command by the piezometer network is limited when compared to others. The Mubarik Distributary is showing the lowest requirement for drainage. A graphical comparison of recharge reduction required per unit area among the distributaries for every month is provided in Figure 4.1. A minimum average water table height of 27 mm and a maximum average water table height of 218 mm of drainable surplus occur in the study area during a one-month period.

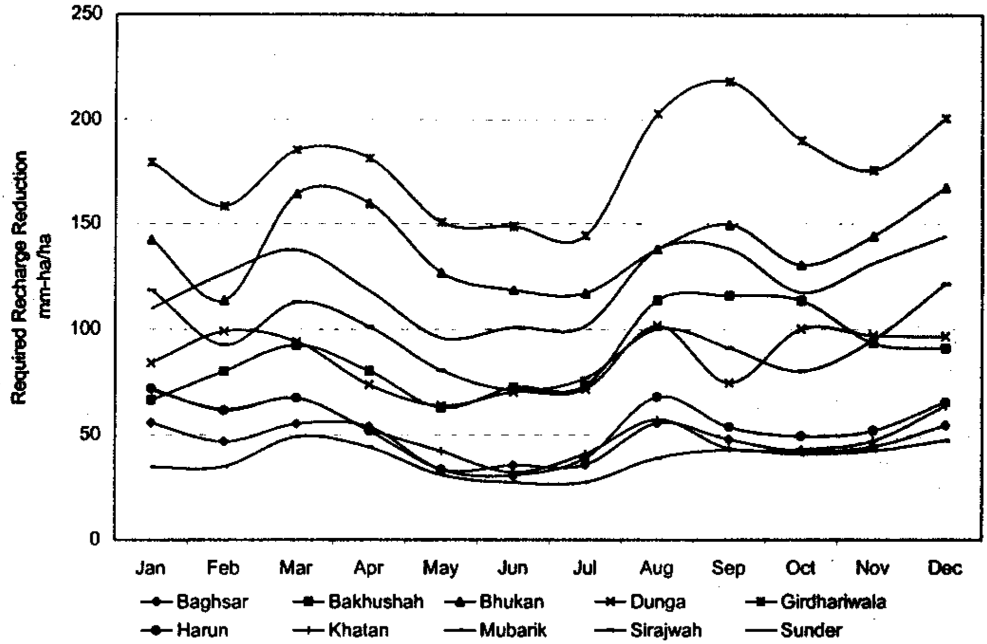

Figure 4.1. The average monthly recharge reduction required from different distributary commands in the study area for water table control.

Delineation of Areas Requiring Subsurface Drainage

One of the objectives of this study is to identify areas persistently requiring subsurface drainage facilities for maintaining a root zone conducive to crop growth. This has been achieved by plotting the difference of the average water levels during the month and the target water level over the distributary command. Figure 4.2 shows the average monthly contours of water levels above the critical root zone depth of 1.5 m in the Harun Distributary command area. Similar contour maps for other distributaries are shown in Annex V. Figure 4.2 illustrates that the maximum area of the Harun Distributary is waterlogged during the months of March and December (94%), while it is minimum in the month of June.

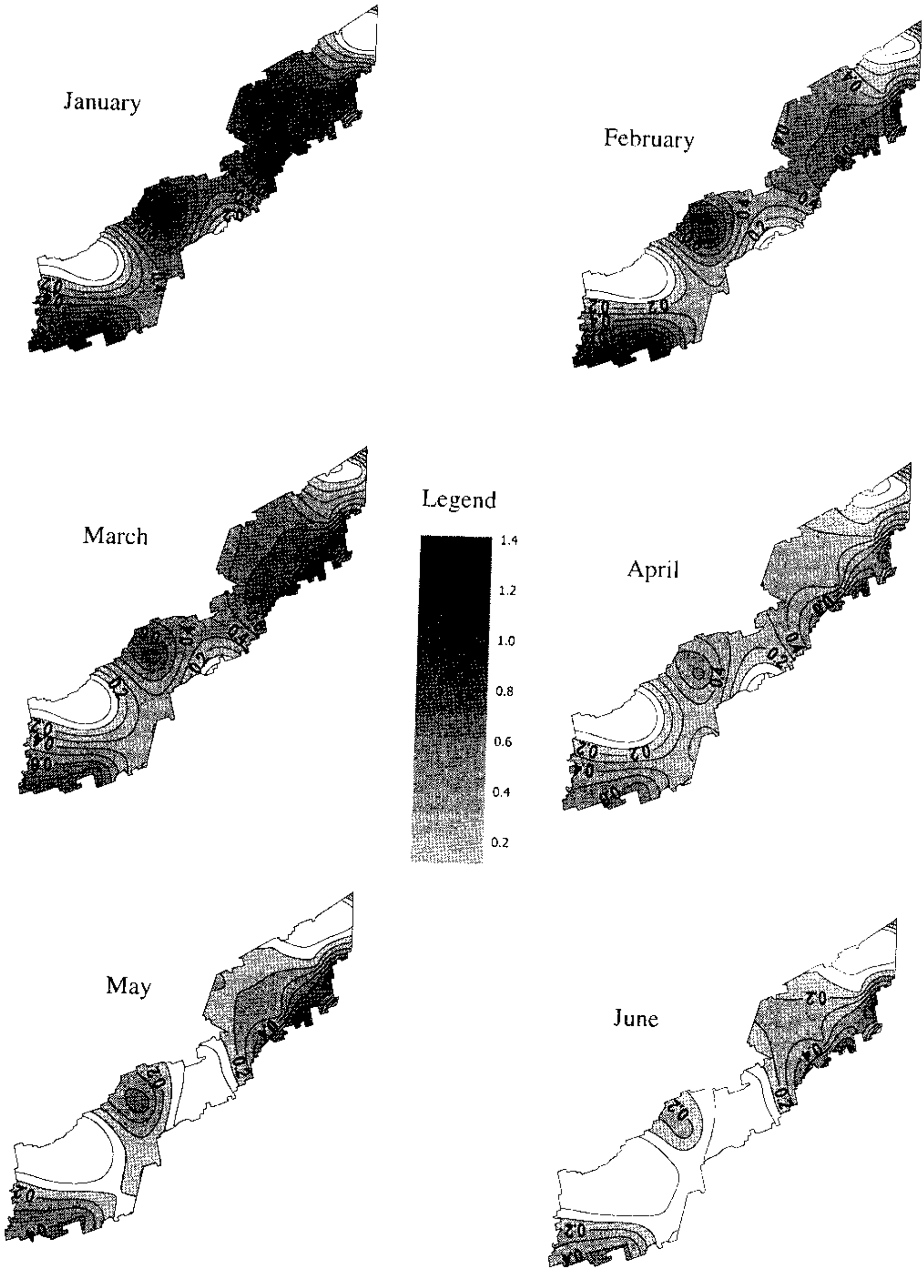

Figure 4.2. The average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in Harun Distributary command.

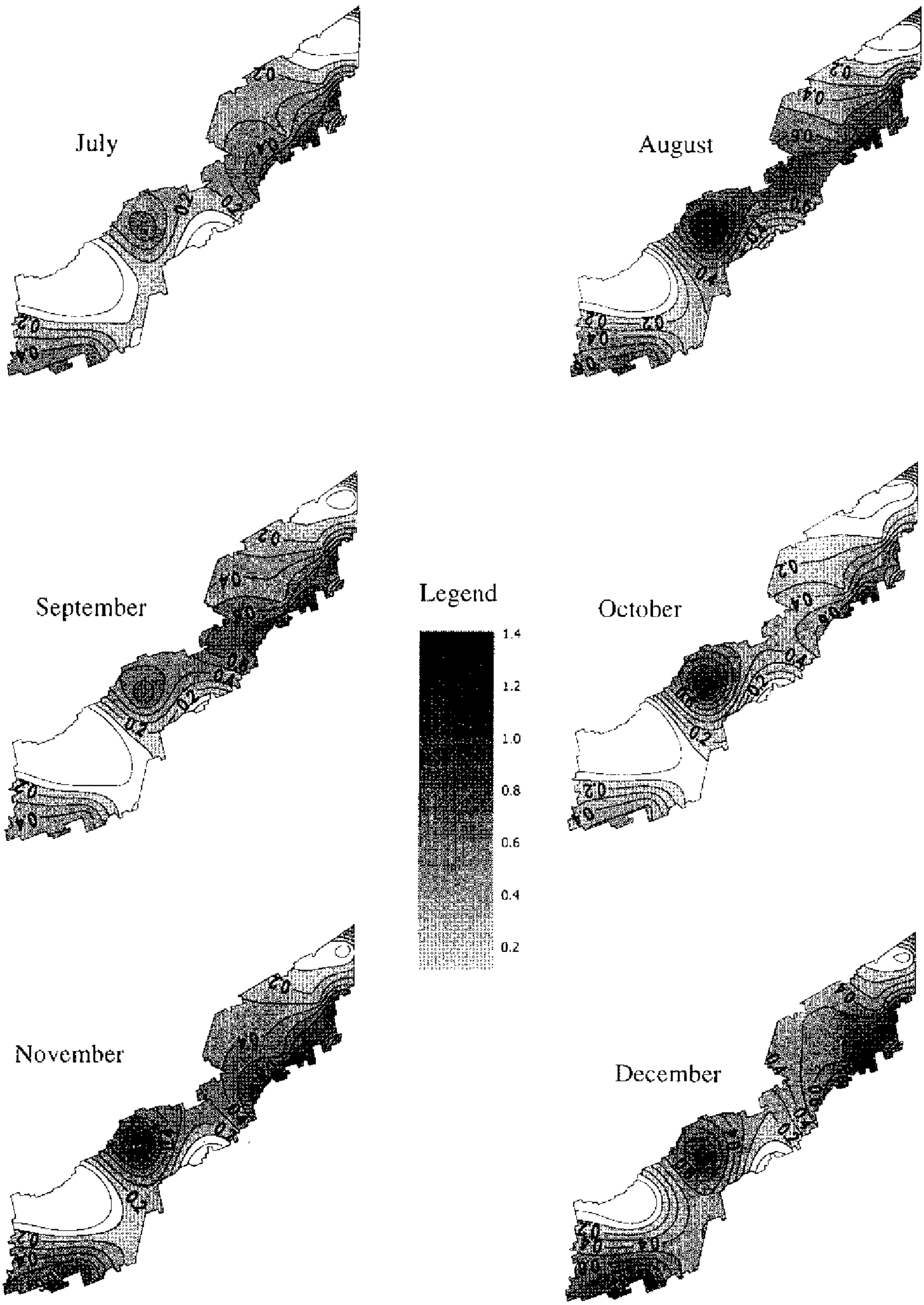

Figure 4.2 (contd.). The average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in Harun Distributary command.

Waterlogged Area Assessment

To check the severity of shallow water table conditions in the area, the critical root zone depth is divided into five categories of depth to water table (DTW) for the purpose of this study. The categories represented DTW of 0-50 cm, 50-75 cm, 75-100 cm, 100-125 cm and 125-150 cm for the assessment of waterlogged areas. Areas of different DTW categories in the Harun Distributary command are given in Table 4.2 on monthly basis. For other distributaries in the study area, Annex VI contains the similar information.

Table 4.2. The average monthly areas under different DTW categories over the Harun Distributary command.

	0-50 cm		50-75 cm		75-100 cm		100-125 cm		125-150 cm		Total (0-150)	
Month	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Jan	0	0	1177	6	9559	46	5938	28	2494	12	19167	92
Feb	0	0	886	4	5604	27	9058	43	3534	17	19082	92
Mar	109	1	1212	6	7882	38	7169	34	3174	15	19546	94
Apr	35	0	273	1	3399	16	10762	52	4609	22	19078	91
May	0	0	54	0	712	3	4995	24	9831	47	15591	75
Jun	0	0	12	0	560	3	4083	20	9043	43	13698	66
Jul	0	0	25	0	892	4	8410	40	7413	36	16740	80
Aug	27	0	1520	7	7440	36	5568	27	3718	18	18273	88
Sep	6	0	352	2	4294	21	7085	34	5258	25	16995	82
Oct	74	0	797	4	3781	18	5804	28	6638	32	17094	82
Nov	5	0	348	2	3983	19	8212	39	5654	27	18202	87
Dec	13	0	1443	7	6711	32	7675	37	3757	18	19598	94

Most areas over the Harun Distributary command have DTW between 75 to 150 cm. The maximum waterlogged conditions (94 percent of the area) are observed during the months of December and March, while the month of June shows the smallest area (66 percent) affected with a high water table. A maximum of 7 percent of area is affected by waterlogging over the year, with water tables within a 75cm depth.

The assessment of the study area also shows a similar trend, as that depicted in Table 4.3. In the month of June, two-thirds of the study area is under the effect of waterlogging. A maximum of 28 percent of the study area is showing a water table within a 75 cm depth below the ground level in the month of December. The extents of areas covered by each category of DTW in the month of June over the study area are required to identify problematic locations. For the purpose, areas encroaching upon a root zone depth of 1.5 meters in the form of water levels above and below this depth are shown. Figure 4.3 shows the extents of areas under different categories. Water levels above 1.5 meters show ponding situations in those locations. These are the most critical areas, where the subsurface drainage problem persists even though the natural discharges are at a maximum and the intervention of a subsurface drainage system is required to keep the root zone environment suitable for optimum cropping and yield. The overlays of sand dune and ponded areas are delineated in order to show the limitation of monitoring data in the study area.

Table 4.3. The average monthly areas under different DTW categories over the study area.

	0-50 cm		50-75 cm		75-100 cm		100-125 cm		125-150 cm		Total (0-150)	
Month	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Jan	8509	7	21206	17	35470	29	23414	19	12569	10	101168	82
Feb	6944	6	14090	11	27005	22	33999	27	15209	12	97247	79
Mar	14869	12	16309	13	29273	24	28887	23	13092	11	102430	83
Apr	10816	9	12053	10	22487	18	37962	31	17806	14	101124	82
May	4088	3	8762	7	20386	16	25006	20	30166	24	88409	71
Jun	3744	3	8194	7	16208	13	22907	19	31937	26	82989	67
Jul	5079	4	10850	9	16826	14	28207	23	29253	24	90215	73
Aug	13812	11	16134	13	22866	18	26935	22	17163	14	96910	78
Sep	12587	10	11042	9	17526	14	30042	24	24359	20	95555	77
Oct	10518	9	9671	8	16818	14	23896	19	24979	20	85883	69
Nov	10691	9	14570	12	19103	15	29099	24	22328	18	95791	77
Dec	15653	13	18436	15	26894	22	27555	22	14017	11	102555	83

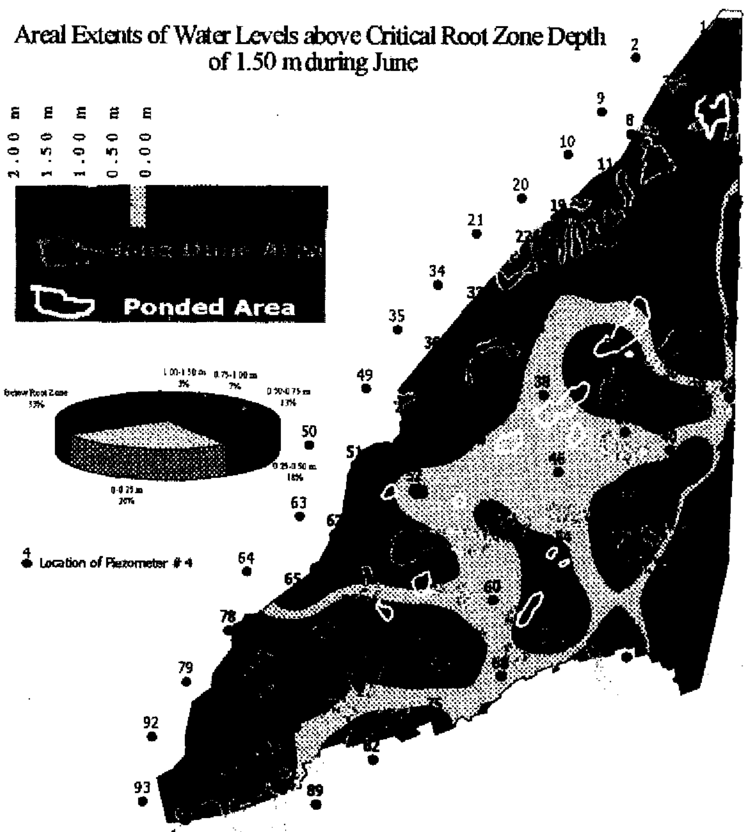

Figure 4.3. The areal extents of water levels above critical root zone depth of 1.5 m during June over the study area.

REFERENCES

Ashraf, M and M. A. Khan. 1984. Irrigation Directory Punjab, Planning and Investigation Organization, Planning Division, Water and Power Development Authority, Lahore, Pakistan.

Aslam, M., A. Hameed., A. Hussain and M. Tabassam. 1999. Soil salinity-sodicity and land use suitability in the Fordwah Eastern Sadiqia (South) irrigated area, International Irrigation Management Institute, Pakistan, Report No. R-81.

Boonstra, J. and I. Javed. 1999. Result of aquifer tests analyses of Fordwah Eastern Sadiqia (South) Project, Bahawalnagar, International Waterlogging and Salinity Research Institute, WAPDA.

Dumm, L.D. 1968. Subsurface drainage by transient-flow theory. Journal of the Irrigation and Drainage Division, Proceedings of the ASCE, 94(IR4) 505-519.

Feddes, R.A. 1988. Effects of drainage on crops and farm management, Agriculture Water Management, 14 (1988) 3-18, Elsevier Science Publishers B.V., Amsterdam, Netherlands.

Golden Software Inc. 1996. Surfer for Windows Version 6. User's Guide Contouring and 3D Surface Mapping. 809 14^{th} Street, Golden, CO80401-1866,USA.

Hunting Technical Services Ltd and Sir M.MacDonald & Partners (HTS/MMP). 1965. Lower Indus Report, Physical Resources-Groundwater, Volume 6, Supplement 6.1.3, 4 & 5. West Pakistan Water and Power Development Authority.

Ismail, M and S.M. Mohiuddin. 1997. Grounwater Studies for Fordwah Eastern Sadiqia (South) Project, Hydrogeology Directorate, WAPDA.

Javed, I. 1998. Groundwater development and management at Fordwah Eastern Sadiqia (South) Project, Bahawalnager, Punjab, Pakistan, A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirement for the degree of Master of Science, McGill University.

Kahlown, M. A., M. Iqbal, G. V. Skogerboe, and Saeed ur Rehman. 1998. Waterlogging, salinity and crop yield relationships, Fordwah Eastern Sadiqia (South) Irrigation and Drainage Project, MREP Report No. 233 and IIMI Report No. R-73, MONA Reclamation Experimental Project, WAPDA and International Irrigation Management Institute, Pakistan.

Kamal, M. T. and R. A. Shamsi. 1965. Geohydrology of the Bahawalpur project area, West Pakistan, WASID, WAPDA, Bulletin No. 10.

Luthin, J. N. 1978. Drainage Engineering, Robert E. Krieger Publishing Company, Huntington, N.Y.

Minhas, R. Z. U. 1998. Monitoring of land and water conditions, in the Proceedings of workshop on research and results and Phase-II planning of Fordwah Eastern Sadiqia South Project, Editors M.M. Alam, M. Ilyas, and M. N. Bhutta, IWASRI, WAPDA.

NESPAK. 1992. Fordwah Eastern Sadqia (South) Phase-1 Irrigation and Drainage Project, PC-1 Proforma, Lahore, Pakistan.

Sufi, A.B., M.F.K. Niazi, I. Ahmed, and I. Javed. 1998. Groundwater modeling for identifying drainage needs in FESS, in the Proceedings of workshop on research and results and Phase-II planning of Fordwah Eastern Sadiqia South Project, Editors M.M. Alam, M. Ilyas, and M. N. Bhutta, IWASRI, WAPDA.

WAPDA. 1988. PC-I Proforma-Fordwah Eastern Sadiqia Phase-II (Southern Unit, SCARP-VIII), Planning Directorate (Water) Central.

ANNEXURES

Annex-I. Average Monthly Minimum, Maximum and Mean Water Table Elevations and Depths to Water Table.

Table I.1. The average monthly minimum, maximum and mean water table elevations and depths to water table in Baghsar Distributary.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water Table Elevation (m)												
Maximum	153.48	153.50	153.59	153.48	153.34	153.35	153.51	153.62	154.23	153.93	153.40	153.61
Minimum	153.19	153.03	153.18	153.30	152.93	152.99	153.08	152.49	152.99	153.07	152.97	153.22
Mean	153.37	153.33	153.41	153.40	153.18	153.18	153.22	153.18	153.51	153.42	153.26	153.40
Depth to Water Table (m)												
Maximum	1.16	1.32	1.17	1.05	1.42	1.36	1.27	1.86	1.36	1.28	1.38	1.13
Minimum	0.87	0.85	0.76	0.87	1.01	1.00	0.84	0.73	0.12	0.42	0.95	0.74
Mean	0.98	1.02	0.95	0.95	1.17	1.17	1.13	1.17	0.84	0.94	1.09	0.95

Table I.2. The average monthly minimum, maximum and mean water table elevations and depths to water table in Bakushah Distributary.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water Table Elevation (m)												
Maximum	160.94	161.01	161.19	161.03	161.03	161.04	161.21	161.44	161.37	161.41	161.21	161.21
Minimum	160.71	160.85	160.94	160.89	160.27	160.72	160.63	161.07	161.05	160.92	160.89	160.86
Mean	160.81	160.93	161.07	160.97	160.74	160.81	160.86	161.21	161.27	161.17	161.05	161.06
Depth to Water Table (m)												
Maximum	1.12	0.99	0.90	0.94	1.60	1.14	1.24	0.78	0.79	0.92	0.98	1.01
Minimum	0.90	0.83	0.65	0.80	0.81	0.80	0.63	0.40	0.47	0.43	0.62	0.63
Mean	1.03	0.91	0.77	0.86	1.11	1.03	0.99	0.64	0.58	0.68	0.80	0.78

Table I.3. he average monthly minimum, maximum and mean water table elevations and depths to water table in Bhukan Distributary.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water Table Elevation (m)												
Maximum	160.54	160.54	160.73	160.63	160.60	160.59	160.69	160.78	160.56	160.54	160.59	160.78
Minimum	160.47	160.07	160.48	160.53	160.06	159.92	159.95	160.28	160.48	160.30	160.42	160.57
Mean	160.51	160.31	160.63	160.59	160.41	160.36	160.35	160.49	160.53	160.40	160.51	160.65
Depth to Water Table (m)												
Maximum	0.68	1.07	0.66	0.61	1.14	1.28	1.25	0.92	0.71	0.90	0.77	0.61
Minimum	0.60	0.60	0.41	0.52	0.54	0.55	0.45	0.36	0.58	0.60	0.56	0.36
Mean	0.63	0.84	0.51	0.55	0.75	0.80	0.81	0.67	0.62	0.75	0.65	0.51

Table I.4. The average monthly minimum, maximum and mean water table elevations and depths to water table in Dunga Distributary.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water Table Elevation (m)												
Maximum	158.72	158.76	158.81	158.76	158.64	158.60	158.94	158.83	158.92	158.78	158.91	158.85
Minimum	158.65	158.53	158.70	158.64	157.66	158.06	157.89	158.53	158.54	158.30	158.49	158.60
Mean	158.68	158.63	158.75	158.69	158.33	158.40	158.48	158.69	158.76	158.59	158.71	158.72
Depth to Water Table (m)												
Maximum	0.91	1.02	0.86	0.91	2.04	1.63	1.81	1.17	1.02	1.26	1.09	1.10
Minimum	0.83	0.80	0.75	0.80	0.92	0.96	0.62	0.73	0.64	0.88	0.65	0.71
Mean	0.88	0.93	0.81	0.86	1.26	1.19	1.11	0.91	0.83	1.00	0.89	0.87

Table 1.5. The average monthly minimum, maximum and mean water table elevations and depths to water table in Khatan Distributary.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water Table Elevation (m)												
Maximum	152.09	151.96	152.07	152.00	151.96	151.87	152.14	152.04	151.96	151.84	152.01	152.13
Minimum	151.88	151.74	151.96	151.84	151.34	151.26	151.48	151.53	151.54	151.50	151.57	151.80
Mean	151.96	151.88	152.01	151.92	151.73	151.66	151.75	151.86	151.75	151.67	151.81	151.95
Depth to Water Table (m)												
Maximum	1.49	1.62	1.40	1.52	2.05	2.13	1.90	1.85	1.84	1.88	1.82	1.58
Minimum	1.27	1.40	1.29	1.36	1.40	1.50	1.22	1.33	1.40	1.52	1.35	1.23
Mean	1.40	1.49	1.35	1.45	1.64	1.71	1.62	1.50	1.62	1.70	1.56	1.42

Table 1.6. The average monthly minimum, maximum and mean water table elevations and depths to water table in Mubarik Distributary.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water Table Elevation (m)												
Maximum	156.61	156.57	156.92	156.77	156.83	156.67	156.65	156.88	156.95	156.82	156.76	156.88
Minimum	156.39	156.38	156.46	156.45	156.04	155.97	155.97	156.23	156.19	156.09	156.14	156.26
Mean	156.48	156.48	156.65	156.62	156.45	156.38	156.37	156.60	156.58	156.48	156.55	156.61
Depth to Water Table (m)												
Maximum	1.76	1.77	1.69	1.69	2.06	2.14	2.13	1.88	1.92	2.01	1.97	1.84
Minimum	1.54	1.58	1.23	1.37	1.31	1.48	1.49	1.26	1.19	1.33	1.38	1.27
Mean	1.67	1.66	1.50	1.53	1.69	1.76	1.77	1.54	1.55	1.66	1.59	1.53

Table 1.7. The average monthly minimum, maximum and mean water table elevations and depths to water table in Sirajwah Distributary.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water Table Elevation (m)												
Maximum	158.82	158.70	158.83	158.71	158.78	158.58	158.86	158.85	158.82	158.70	158.76	158.86
Minimum	158.61	158.42	158.59	158.61	158.01	158.08	158.28	158.44	158.49	158.35	158.46	158.69
Mean	158.70	158.54	158.73	158.67	158.48	158.43	158.49	158.68	158.64	158.52	158.63	158.76
Depth to Water Table (m)												
Maximum	0.74	0.94	0.76	0.75	1.36	1.29	1.09	0.92	0.88	1.01	0.90	0.66
Minimum	0.53	0.66	0.52	0.64	0.57	0.77	0.50	0.51	0.53	0.66	0.59	0.49
Mean	0.66	0.81	0.62	0.68	0.87	0.93	0.87	0.68	0.71	0.84	0.73	0.59

Table 1.8. The average monthly minimum, maximum and mean water table elevations and depths to water table in Sunder Distributary.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water Table Elevation (m)												
Maximum	160.25	160.58	160.53	160.41	160.51	160.35	160.51	160.59	160.59	160.61	160.57	160.57
Minimum	160.13	160.25	160.32	160.20	159.60	160.06	159.91	160.34	160.29	160.01	160.26	160.42
Mean	160.19	160.39	160.45	160.31	160.13	160.22	160.25	160.50	160.50	160.38	160.43	160.49
Depth to Water Table (m)												
Maximum	0.86	0.75	0.67	0.80	1.40	0.93	1.08	0.65	0.71	0.99	0.73	0.57
Minimum	0.75	0.42	0.46	0.58	0.48	0.65	0.49	0.41	0.41	0.39	0.43	0.43
Mean	0.80	0.61	0.55	0.68	0.87	0.77	0.74	0.50	0.50	0.61	0.56	0.50

Annex-II. Monthly Water Table Fluctuations (Build-up, Lowering and Net Change in mm).

Table II.1. The monthly water table fluctuations (build-up, lowering and net change in mm) for the Baghsar Distributary for the study period.

Year	*Water Table*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*
1994-95	*Build-up*		75	87	231	184	41	73	51	231	69	31	8
	Lowering		29	9	0	59	88	86	101	0	116	87	64
	Net Change		46	77	231	124	-47	-13	-50	231	-47	-56	-56
1995-96	*Build-up*	6	0	288	292	5	47	115	176	68	0	317	44
	Lowering	127	172	66	0	67	247	257	0	48	172	0	128
	Net Change	-121	-172	223	292	-62	-200	-141	176	20	-172	317	-84
1996-97	*Build-up*	10	94	337	118	0	100	95	247	75	0	94	36
	Lowering	80	12	54	0	235	79	120	85	111	127	28	0
	Net Change	-70	82	283	118	-235	21	-25	162	-35	-127	66	36
1997-98	*Build-up*	85	78	0	215	6	134	252	135	0	17	118	0
	Lowering	173	102	260	32	165	44	8	37	119	57	14	117
	Net Change	-88	-23	-260	183	-159	89	243	99	-119	-40	104	-117
Average	*Build-up*	34	62	178	214	49	80	134	152	94	22	140	22
	Lowering	127	79	97	8	132	115	118	56	69	118	32	77
	Net Change	-93	-17	81	206	-83	-34	16	96	24	-97	108	-55

Table II.2. The monthly water table fluctuations (build-up, lowering and net change in mm) for the Bakushah Distributary for the study period.

Year	*Water Table*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*
1994-95	*Build-up*		383	9	476	186	45	24	93	97	246	119	11
	Lowering		10	100	0	0	247	189	106	259	100	66	96
	Net Change		373	-92	476	186	-202	-164	-13	-161	146	53	-86
1995-96	*Build-up*	0	164	235	436	37	192	228	115	50	114	188	38
	Lowering	261	113	117	0	256	276	278	52	223	107	87	226
	Net Change	-261	51	118	436	-220	-85	-50	63	-173	7	101	-188
1996-97	*Build-up*	104	127	219	236	33	19	14	101	0	146	98	167
	Lowering	70	42	20	0	149	125	182	74	317	132	45	20
	Net Change	33	85	199	236	-117	-107	-169	27	-317	15	54	147
1997-98	*Build-up*	59	83	133	350	341	146	0	95	27	151	212	0
	Lowering	87	230	209	0	53	36	200	87	244	178	15	189
	Net Change	-29	-146	-76	350	288	110	-200	8	-217	-27	196	-189
Average	*Build-up*	54	189	149	374	149	100	67	101	44	164	154	54
	Lowering	139	99	112	0	115	171	212	80	261	129	53	133
	Net Change	-85	91	37	374	34	-71	-146	21	-217	35	101	-79

Table II.3. The monthly water table fluctuations (build-up, lowering and net change in mm) for the Bhukan Distributary for the study period.

Year	*Water Table*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*
1994-95	*Build-up*		23	122	314	312	0	141	226	51	126	164	76
	Lowering		187	79	74	28	251	89	0	166	37	13	171
	Net Change		-164	43	240	284	-251	52	226	-116	88	151	-94
1995-96	*Build-up*	13	0	44	386	0	0	160	130	73	0	606	24
	Lowering	76	182	23	0	187	244	0	52	143	475	0	86
	Net Change	-57	-182	21	386	-187	-244	160	78	-70	-475	606	-62
1996-97	*Build-up*	42	168	121	0	163	70	102	101	90	0	332	157
	Lowering	150	14	42	327	14	69	52	70	241	334	39	0
	Net Change	-108	154	78	-327	149	1	51	32	-151	-334	292	157
1997-98	*Build-up*	84	31	0	255	131	75	104	237	0	363	40	0
	Lowering	126	81	232	31	101	81	20	0	298	0	138	120
	Net Change	-43	-50	-232	224	30	-6	84	237	-298	363	-98	-120
Average	*Build-up*	46	55	72	239	152	36	127	174	53	122	285	64
	Lowering	118	116	94	108	83	161	40	30	212	212	48	94
	Net Change	-69	-61	-22	131	69	-125	87	143	-159	-89	238	-30

Table II.4. The monthly water table fluctuations (build-up, lowering and net change in mm) for the Dunga Distributary for the study period.

Year	*Water Table*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*
1994-95	*Build-up*		447	0	851	141	160	66	124	57	251	144	80
	Lowering		9	306	0	0	41	142	76	33	203	161	82
	Net Change		437	-306	851	141	119	-76	48	24	49	-17	-2
1995-96	*Build-up*	0	30	131	159	0	0	333	164	106	103	384	0
	Lowering	184	98	73	0	307	293	0	0	108	219	0	278
	Net Change	-184	-67	58	159	-307	-293	333	164	-2	-116	384	-278
1996-97	*Build-up*	54	78	375	43	45	54	613	61	64	133	139	83
	Lowering	79	64	0	60	16	729	24	144	276	206	52	22
	Net Change	-25	14	375	-17	29	-675	589	-83	-212	-73	87	61
1997-98	*Build-up*	53	58	221	156	505	115	218	63	128	149	254	0
	Lowering	81	174	240	4	178	550	96	16	161	293	0	158
	Net Change	-27	-116	-19	152	327	-436	122	47	-33	-144	254	-158
Average	*Build-up*	36	153	182	302	173	82	308	103	89	159	230	41
	Lowering	114	86	155	16	126	403	66	59	145	230	53	135
	Net Change	-79	67	27	286	47	-321	242	44	-56	-71	177	-94

Table II.5. The monthly water table fluctuations (build-up, lowering and net change in mm) for the Girdhariwala Distributary for the study period.

Year	*Water Table*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*
1994-95	*Build-up*		96	0	711	169	0	0	6	92	162	39	0
	Lowering		0	65	0	0	165	200	36	81	184	44	40
	Net Change		96	-65	711	169	-165	-200	-31	11	-22	-5	-40
1995-96	*Build-up*	0	34	24	619	0	0	127	36	0	54	371	0
	Lowering	242	81	122	0	212	79	0	0	208	356	0	177
	Net Change	-242	-47	-98	619	-212	-79	127	36	-208	-302	371	-177
1996-97	*Build-up*	20	36	322	87	297	61	0	23	0	27	201	162
	Lowering	77	47	0	133	0	61	202	11	252	197	0	0
	Net Change	-57	-10	322	-45	297	0	-202	12	-252	-170	201	162
1997-98	*Build-up*	0	15	0	544	217	75	0	777	0	20	266	0
	Lowering	204	74	302	0	0	806	155	34	203	192	0	68
	Net Change	-204	-59	-302	544	217	-731	-155	743	-203	-172	266	-68
Average	*Build-up*	7	45	86	490	171	34	32	210	23	66	219	40
	Lowering	174	51	122	33	53	278	139	20	186	232	11	71
	Net Change	-168	-5	-36	457	118	-244	-107	190	-163	-166	208	-31

Table II.6. The monthly water table fluctuations (build-up, lowering and net change in mm) for the Khatan Distributary for the study period.

Year	*Water Table*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*
1994-95	*Build-up*		88	263	209	92	83	152	274	133	133	87	42
	Lowering		129	30	88	73	114	116	152	53	115	52	138
	Net Change		-41	233	121	19	-31	36	122	79	18	35	-96
1995-96	*Build-up*	28	92	75	312	29	63	174	258	114	36	207	53
	Lowering	118	152	45	0	310	267	20	26	60	155	84	153
	Net Change	-90	-60	30	312	-280	-204	154	232	54	-119	122	-100
1996-97	*Build-up*	93	85	334	79	61	115	131	246	95	20	54	139
	Lowering	110	118	36	119	264	178	181	67	194	94	72	78
	Net Change	-16	-32	298	-40	-202	-63	-50	178	-100	-74	-17	61
1997-98	*Build-up*	157	136	42	272	109	96	190	239	120	28	128	0
	Lowering	103	202	225	106	173	135	30	152	82	182	37	149
	Net Change	54	-66	-183	166	-64	-39	161	88	38	-154	90	-149
Average	*Build-up*	93	100	179	218	73	89	162	254	115	54	119	58
	Lowering	110	150	84	78	205	174	87	99	98	136	61	130
	Net Change	-17	-50	94	140	-132	-84	75	155	18	-82	58	-71

Table II.7. The monthly water table fluctuations (build-up, lowering and net change in mm) for the Mubarik Distributary for the study period.

Year	*Water Table*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*
1994-95	*Build-up*		72	0	124	121	89	72	149	328	130	102	45
	Lowering		122	44	0	0	106	82	35	170	189	85	58
	Net Change		-50	-44	124	121	-17	-9	114	159	-59	17	-13
1995-96	*Build-up*	0	0	50	226	0	0	231	58	64	107	232	0
	Lowering	75	90	45	0	81	271	0	0	156	139	0	93
	Net Change	-75	-90	5	226	-81	-271	231	58	-93	-33	232	-93
1996-97	*Build-up*	45	71	126	151	44	35	93	105	53	126	126	121
	Lowering	76	57	0	19	61	69	32	103	265	136	24	3
	Net Change	-31	14	126	132	-17	-34	61	2	-212	-11	102	117
1997-98	*Build-up*	316	0	53	400	132	25	99	105	49	65	416	0
	Lowering	49	159	166	54	75	209	110	69	216	99	0	163
	Net Change	267	-159	-113	346	57	-184	-11	35	-167	-34	416	-163
Average	*Build-up*	120	36	57	225	74	37	124	104	124	107	219	41
	Lowering	67	107	64	18	54	164	56	52	202	141	27	79
	Net Change	53	-71	-7	207	20	-127	68	52	-78	-34	192	-38

Table II.8. The monthly water table fluctuations (build-up, lowering and net change in mm) for the Sirajwah Distributary for the study period.

Year	*Water Table*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*
1994-95	*Build-up*		148	213	332	128	77	158	323	201	123	111	53
	Lowering		109	110	126	110	123	142	8	112	173	44	116
	Net Change		39	104	207	18	-47	16	316	90	-50	66	-64
1995-96	*Build-up*	61	21	80	300	8	40	219	205	137	118	279	20
	Lowering	141	102	60	0	295	293	50	22	144	259	0	147
	Net Change	-79	-81	20	300	-287	-254	169	183	-7	-141	279	-127
1996-97	*Build-up*	47	97	273	185	148	81	164	117	95	128	150	90
	Lowering	98	53	0	180	89	225	78	64	150	164	150	17
	Net Change	-51	44	273	4	59	-143	86	53	-55	-36	0	73
1997-98	*Build-up*	208	12	84	305	211	188	217	208	113	102	296	0
	Lowering	115	273	236	68	143	201	58	84	158	276	0	201
	Net Change	93	-261	-152	237	68	-12	159	123	-44	-173	296	-201
Average	*Build-up*	105	70	163	280	123	96	189	213	137	118	209	41
	Lowering	118	134	101	93	159	211	82	44	141	218	49	120
	Net Change	-13	-64	61	187	-36	-114	107	169	-4	-100	160	-80

Table II.9. The monthly water table fluctuations (build-up, lowering and net change in mm) for the Sunder Distributary for the study period.

Year	*Water Table*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*
1994-95	*Build-up*		574	0	359	236	60	48	157	0	367	0	0
	Lowering		0	400	0	0	247	33	26	257	50	116	109
	Net Change		574	-400	359	236	-187	15	132	-257	317	-116	-109
1995-96	*Build-up*	0	52	189	253	0	0	304	192	95	70	296	0
	Lowering	160	169	15	0	221	343	0	0	212	132	0	296
	Net Change	-160	-118	174	253	-221	-343	304	192	-117	-62	296	-296
1996-97	*Build-up*	64	100	221	107	0	41	135	92	0	208	83	96
	Lowering	32	17	0	70	80	63	94	66	279	80	145	9
	Net Change	32	83	221	37	-80	-22	41	26	-279	128	-62	87
1997-98	*Build-up*	114	0	91	295	137	73	78	45	103	155	219	0
	Lowering	6	318	68	0	69	52	100	37	342	175	0	209
	Net Change	108	-318	23	295	68	21	-23	8	-239	-20	219	-209
Average	*Build-up*	59	181	125	254	93	43	141	122	50	200	150	24
	Lowering	66	126	121	17	92	176	57	32	273	109	65	156
	Net Change	-7	55	5	236	1	-133	84	89	-223	91	84	-132

Annex III. Extents of Average Monthly Recharge and Discharge Areas.

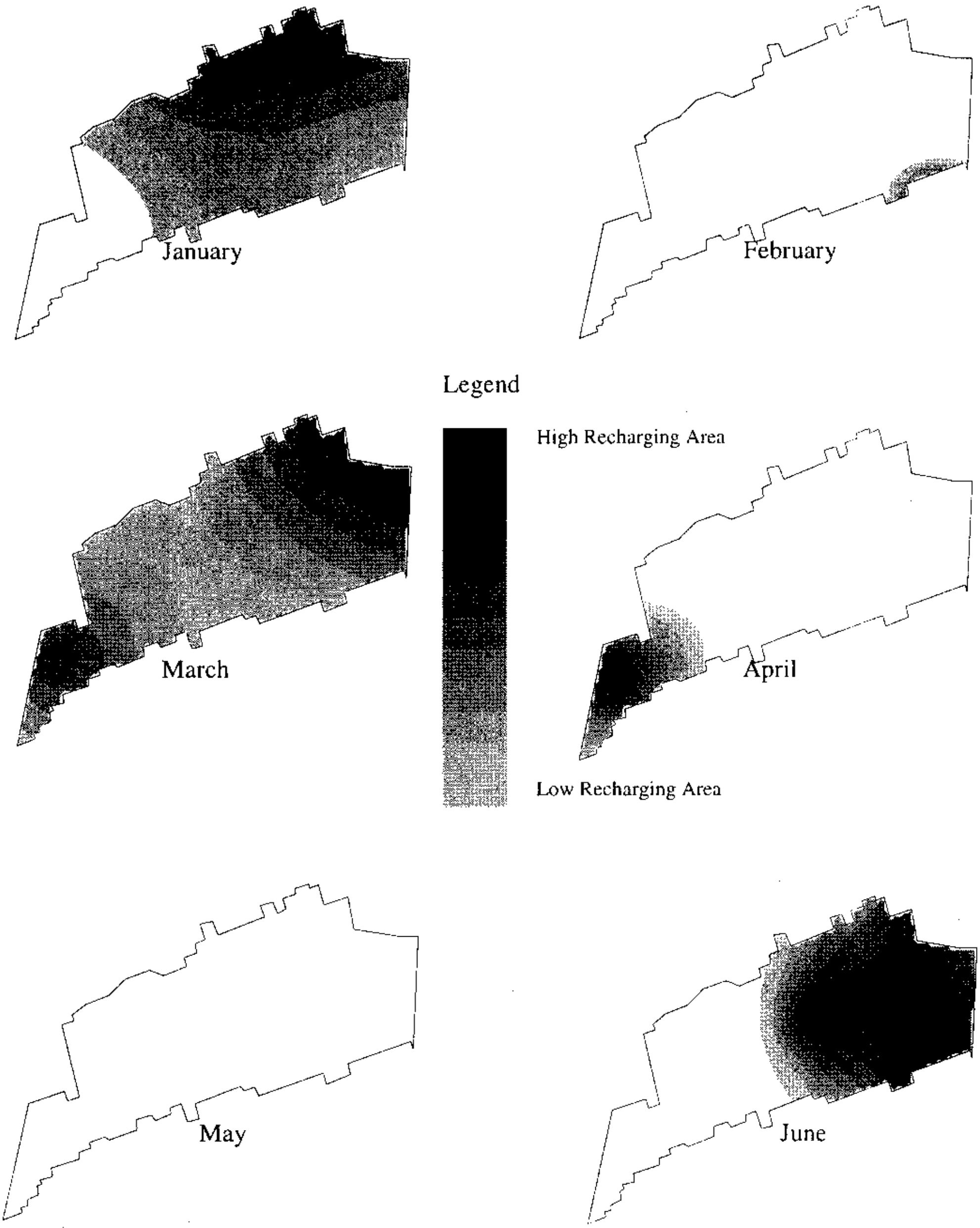

Figure III.1. The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Baghsar Distributary command.

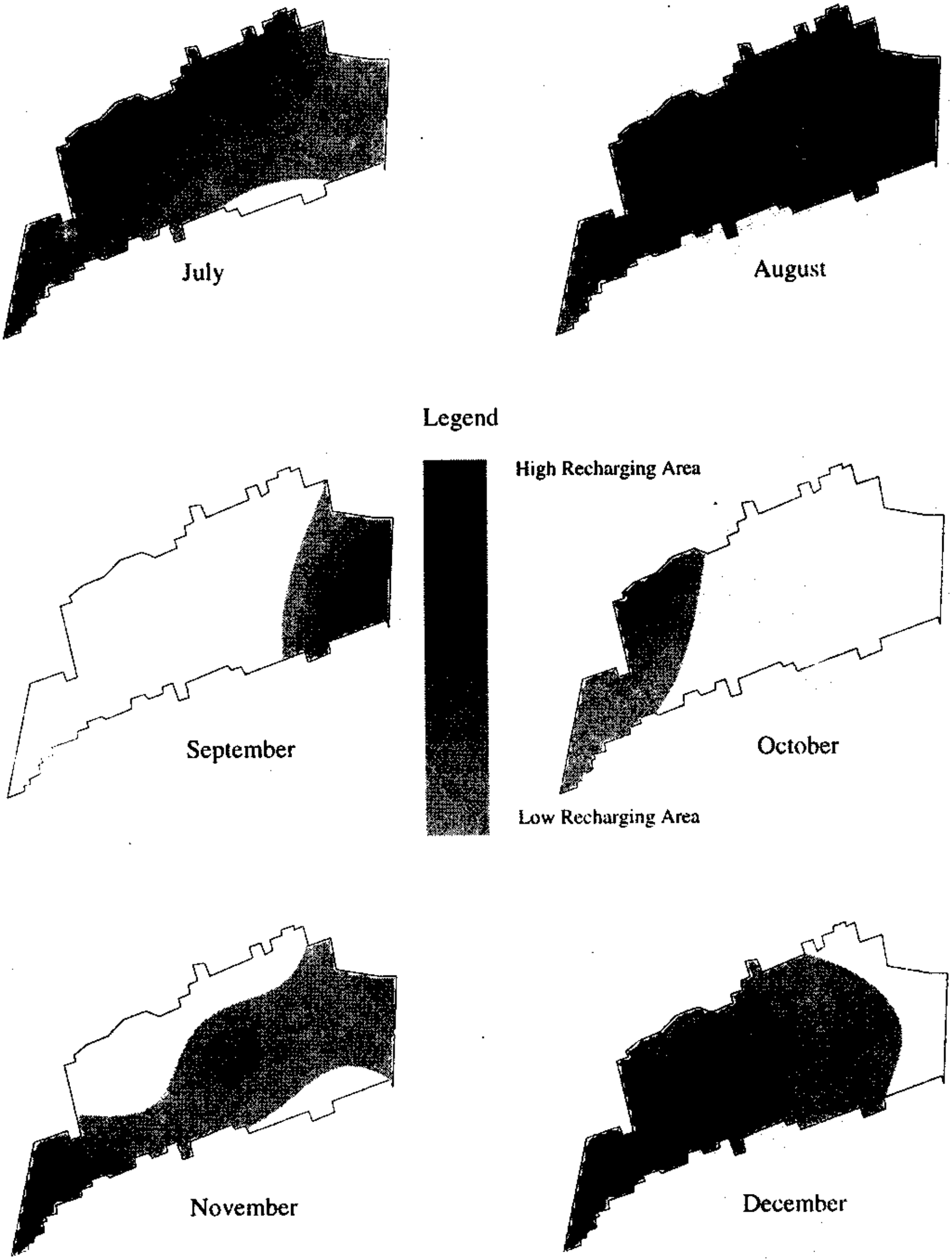

Figure III.1 (contd.). The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Baghsar Distributary command.

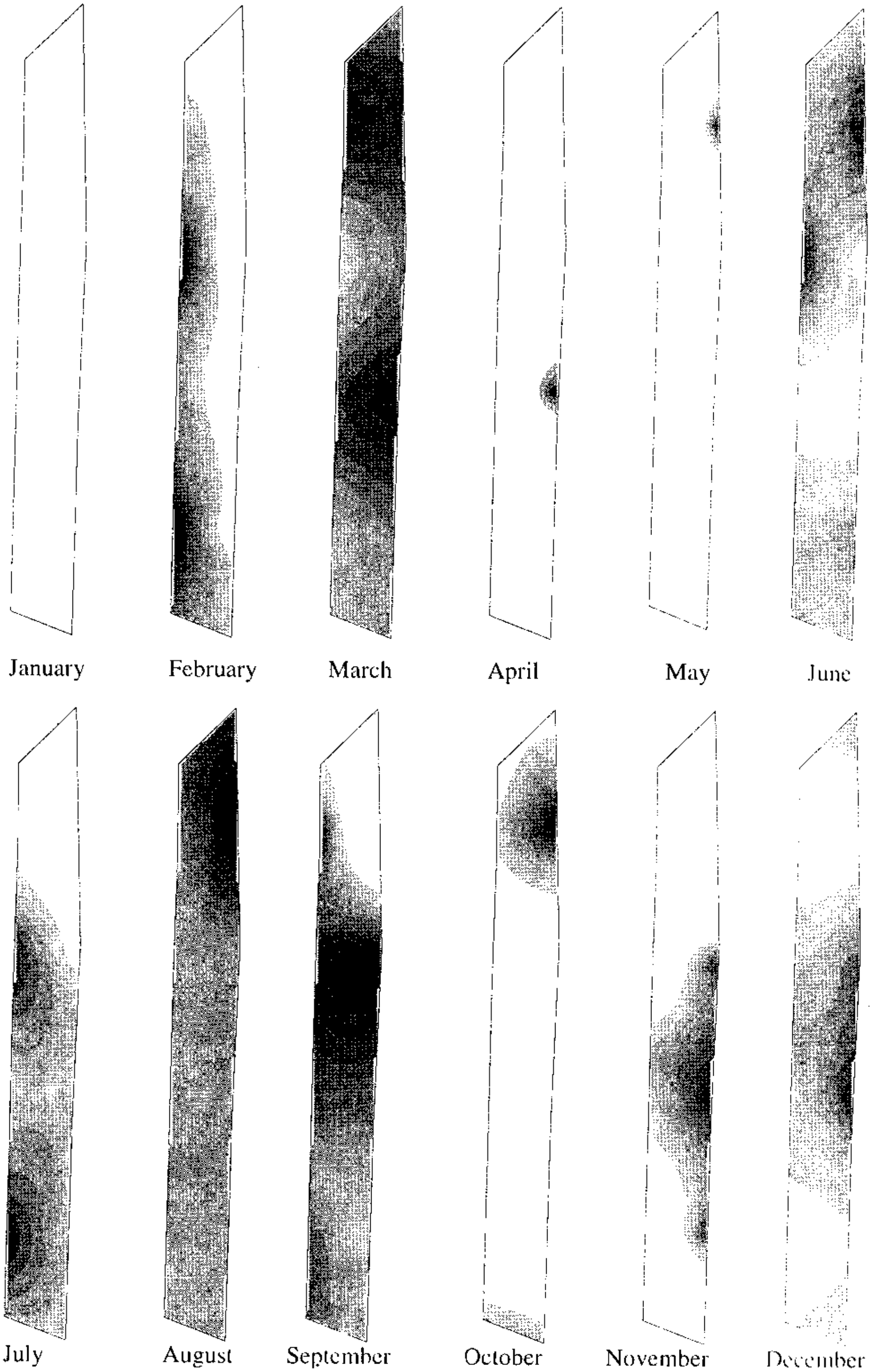

Figure III.2. The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Bakushah Distributary command (including Hakra Branch's Direct Outlet commands).

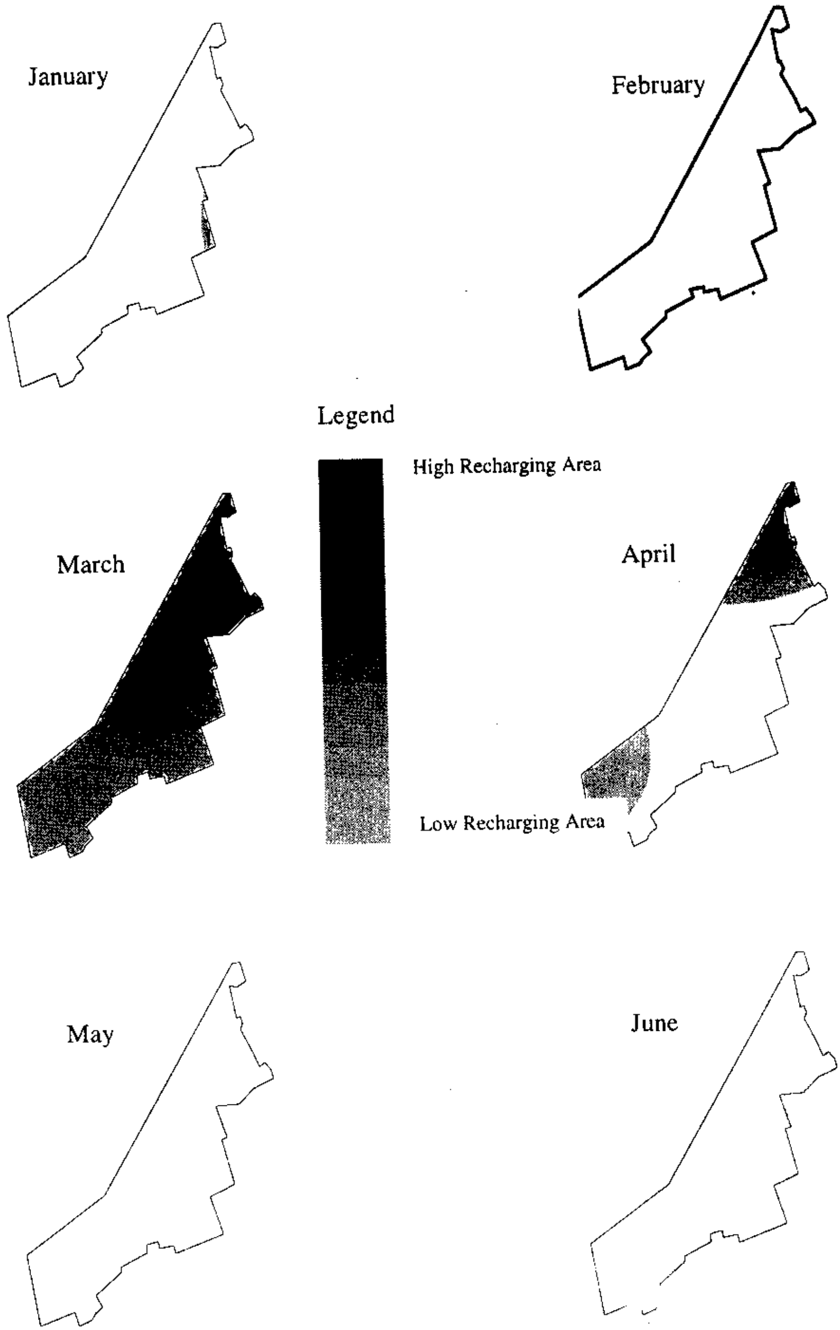

Figure III.3. The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Bhukan Distributary command.

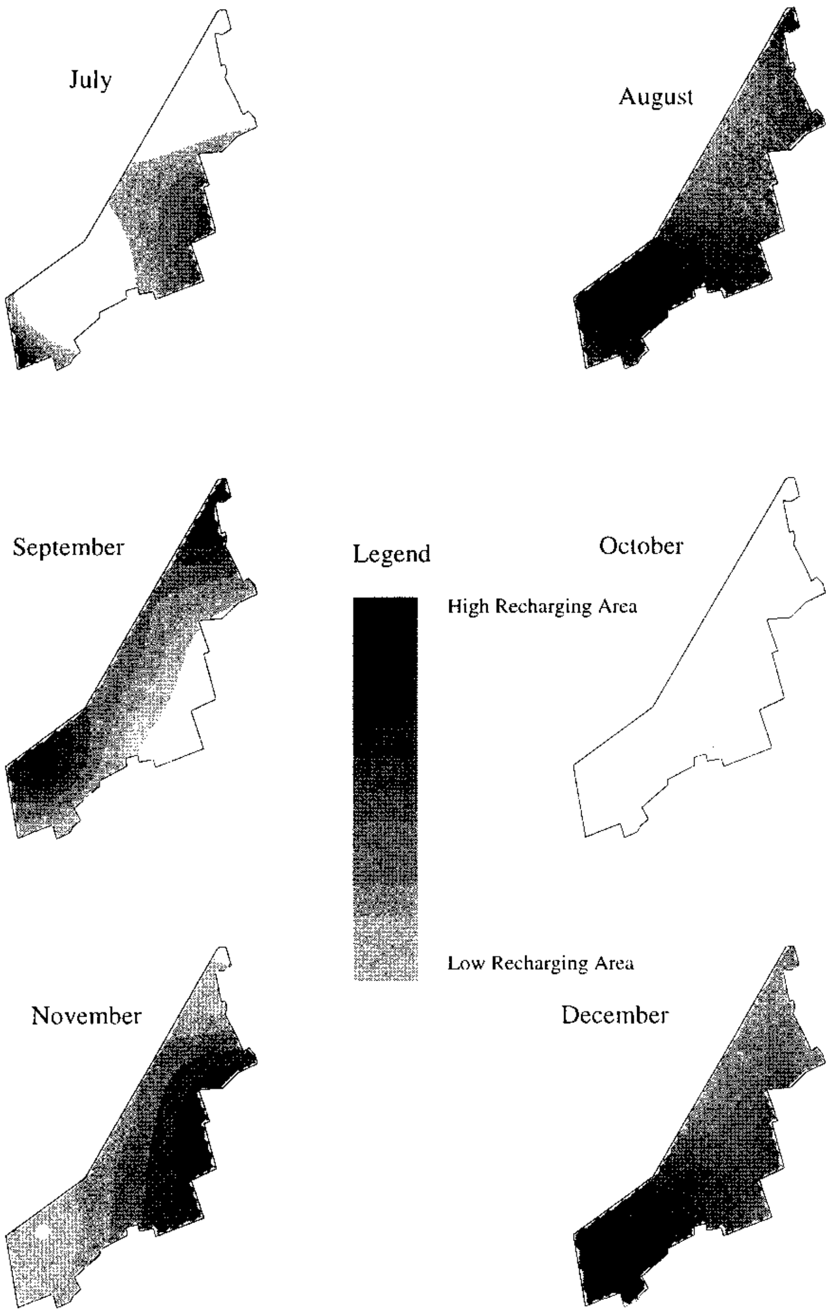

Figure III.3 (contd.). The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Bhukan Distributary command.

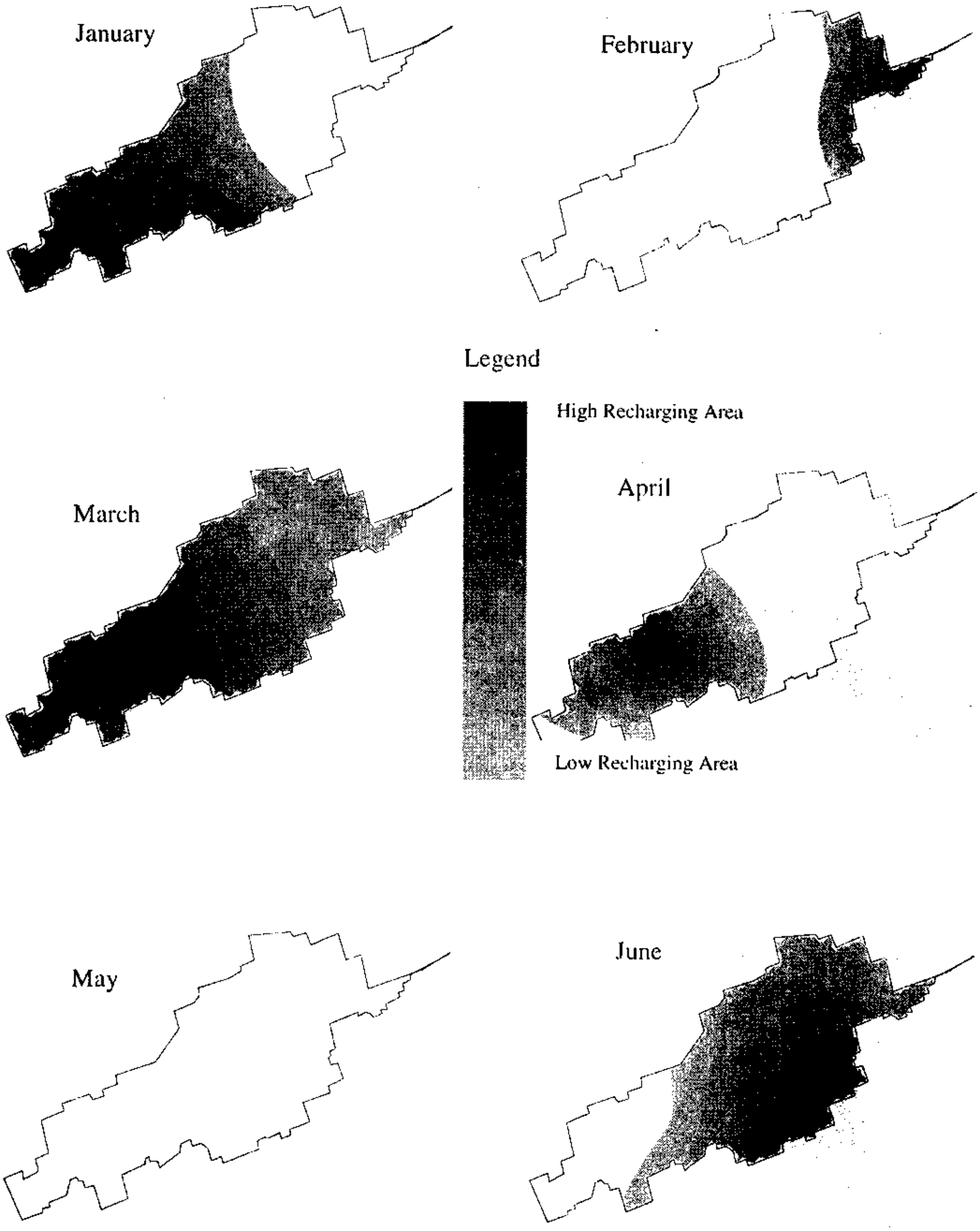

Figure III.4. The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Dunga Distributary command.

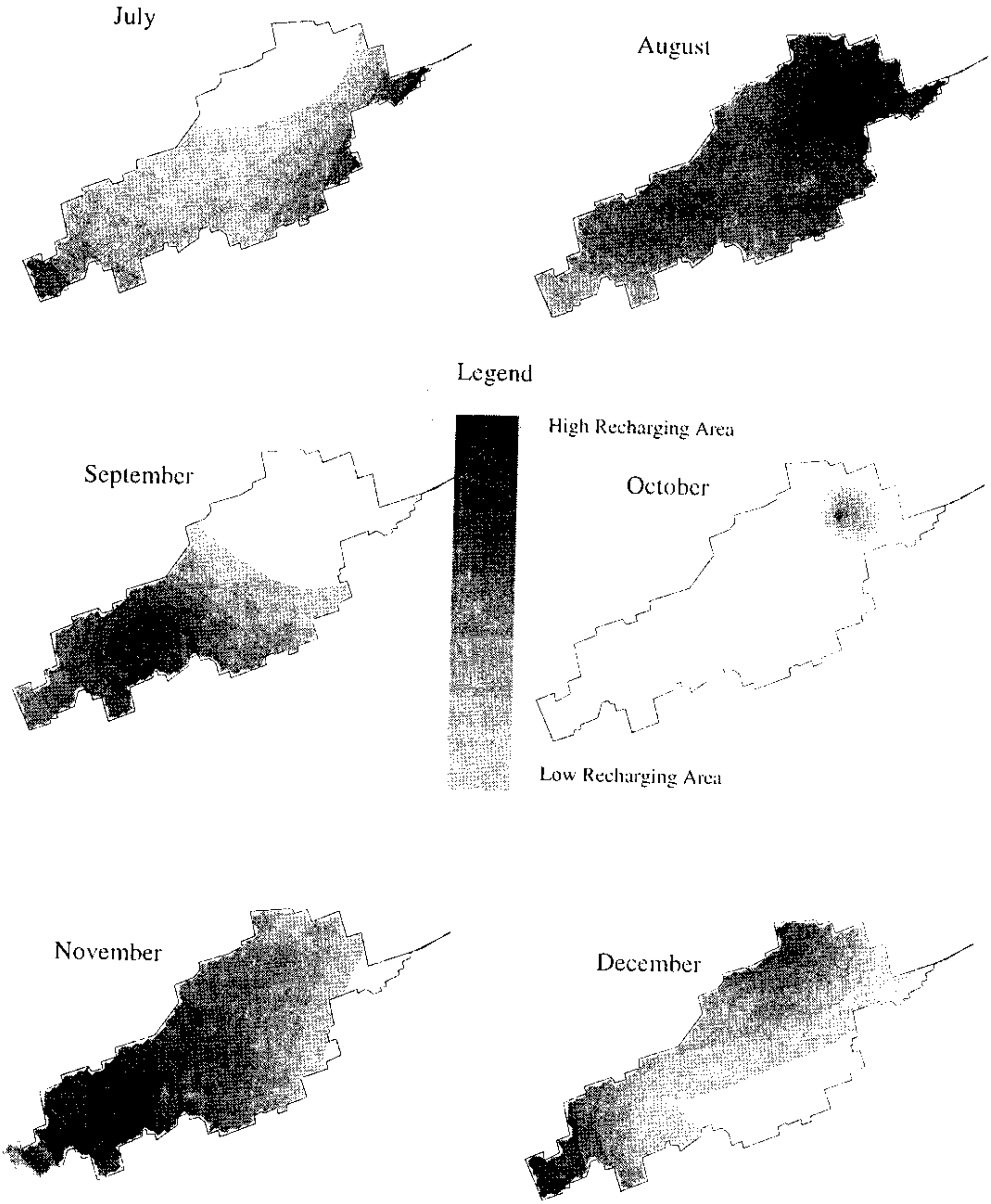

Figure III.4 (contd.). The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Bhukan Distributary command.

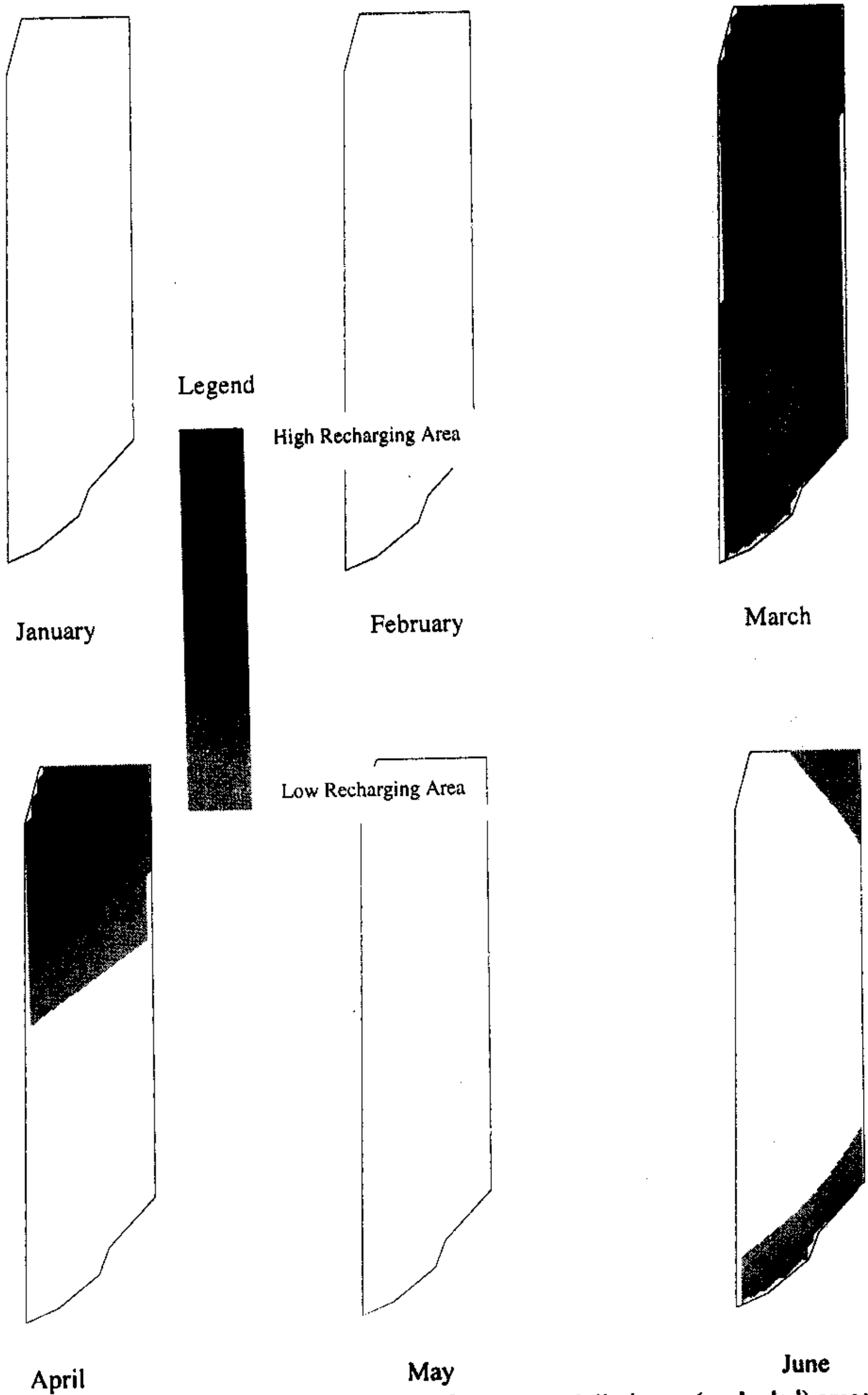

Figure III.5. The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Girdhariwala Distributary command.

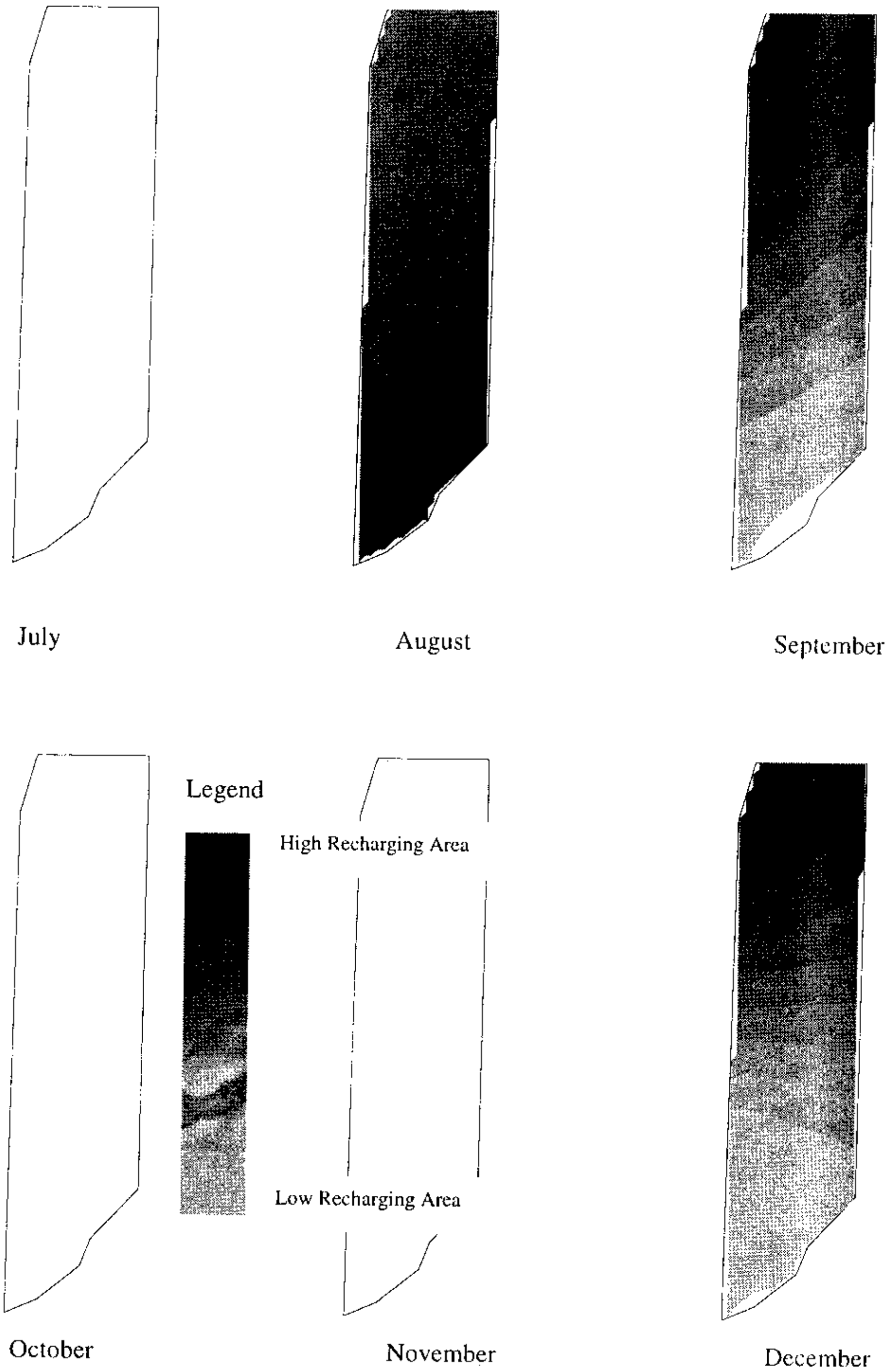

Figure III.5 (contd.). The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Girdhariwala Distributary command.

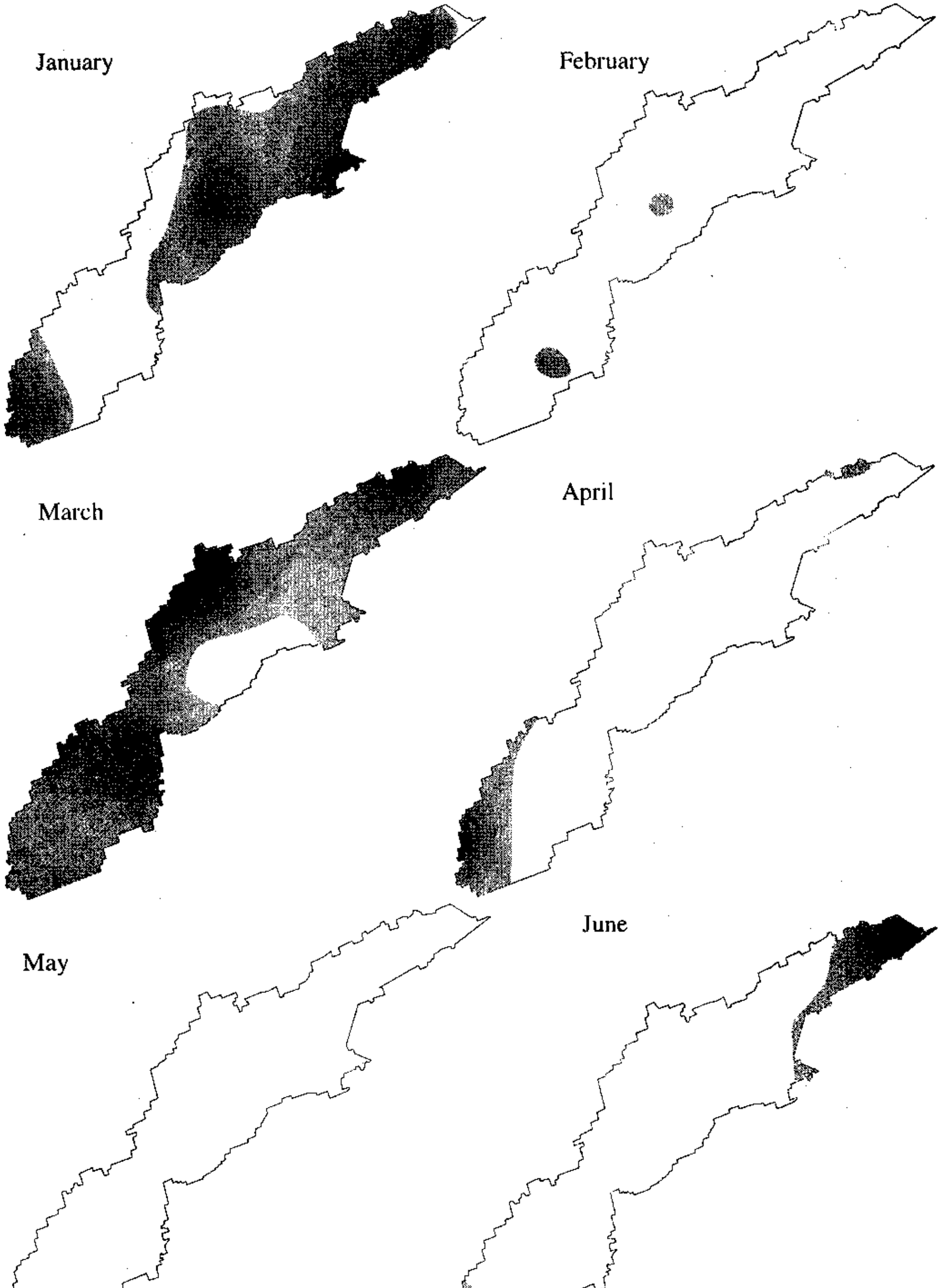

Figure III.6. The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Khatan Distributary command.

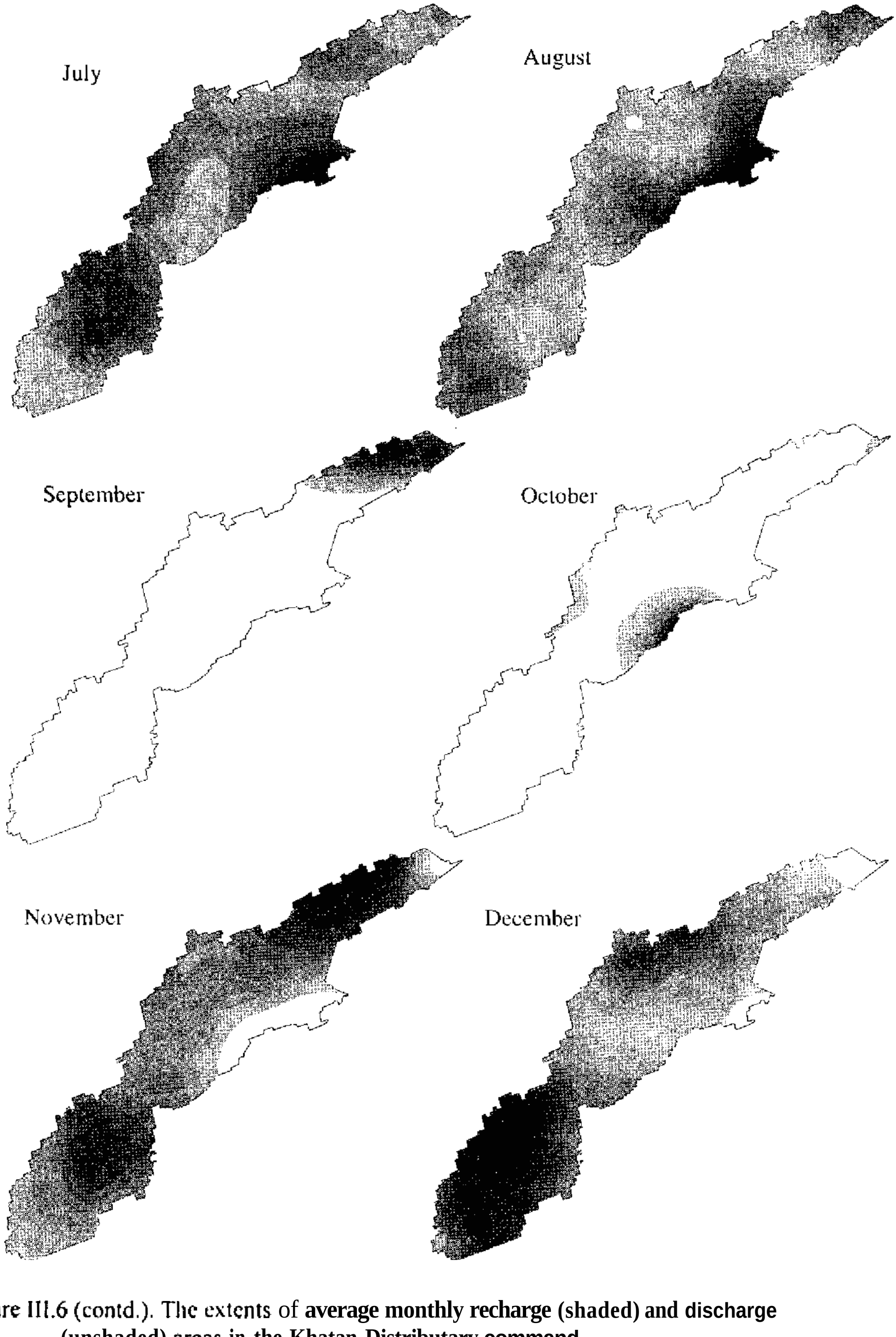

Figure III.6 (contd.). The extents of **average monthly recharge (shaded) and discharge (unshaded) areas in the Khatan Distributary command.**

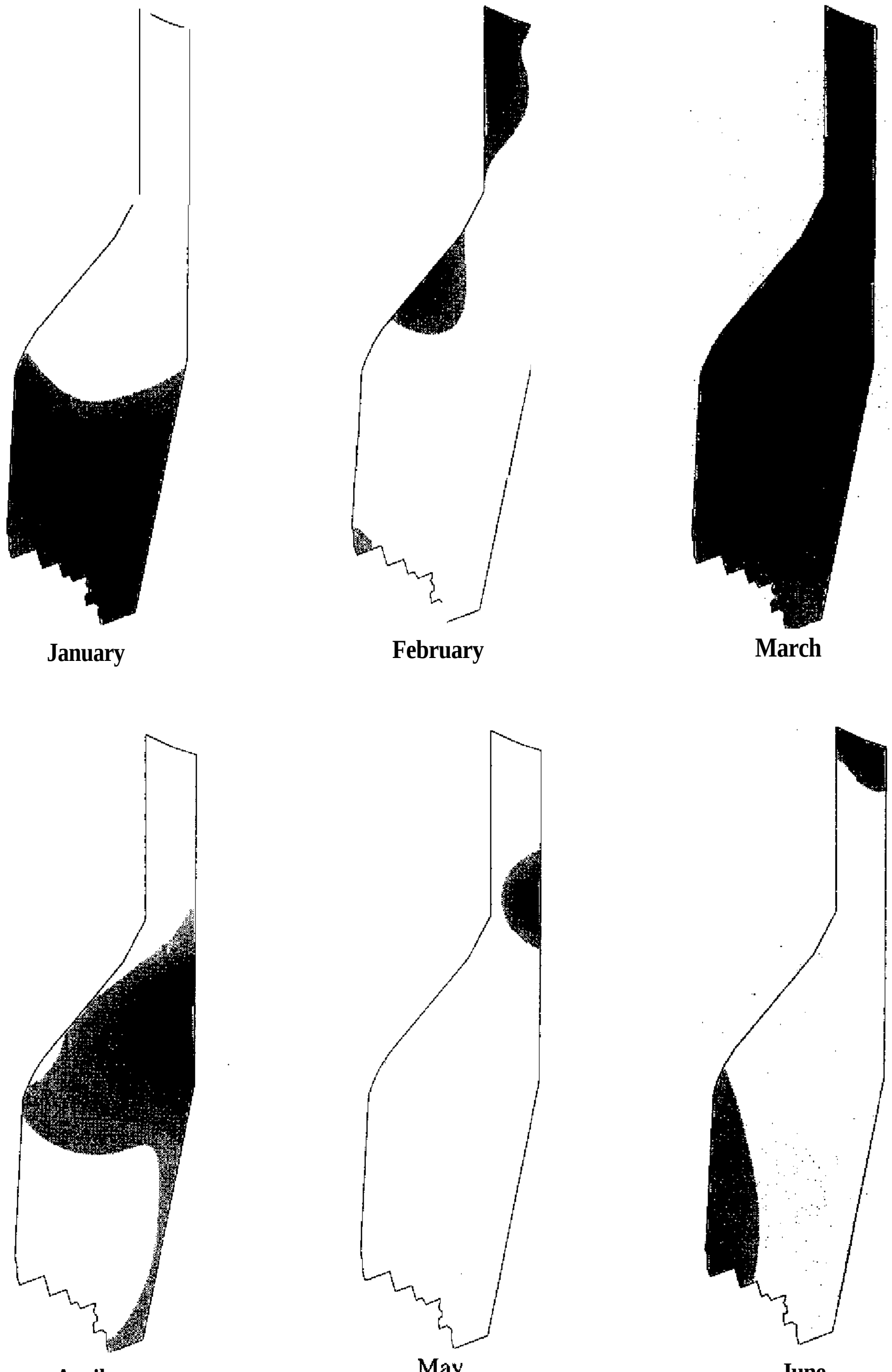

Figure III.7. The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Muharik Distributary command.

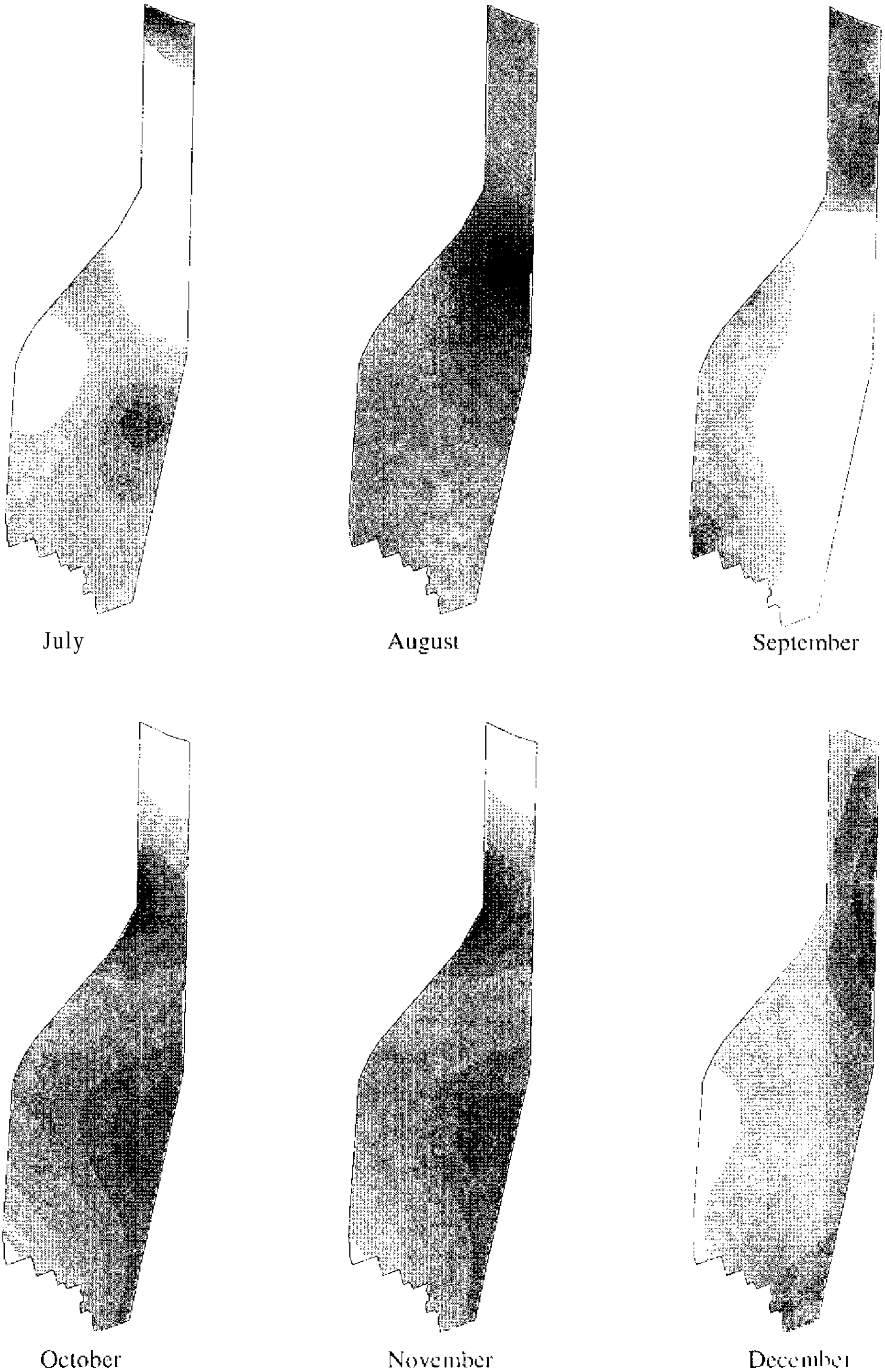

Figure 111.7 (contd.). The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Mubarik Distributary command.

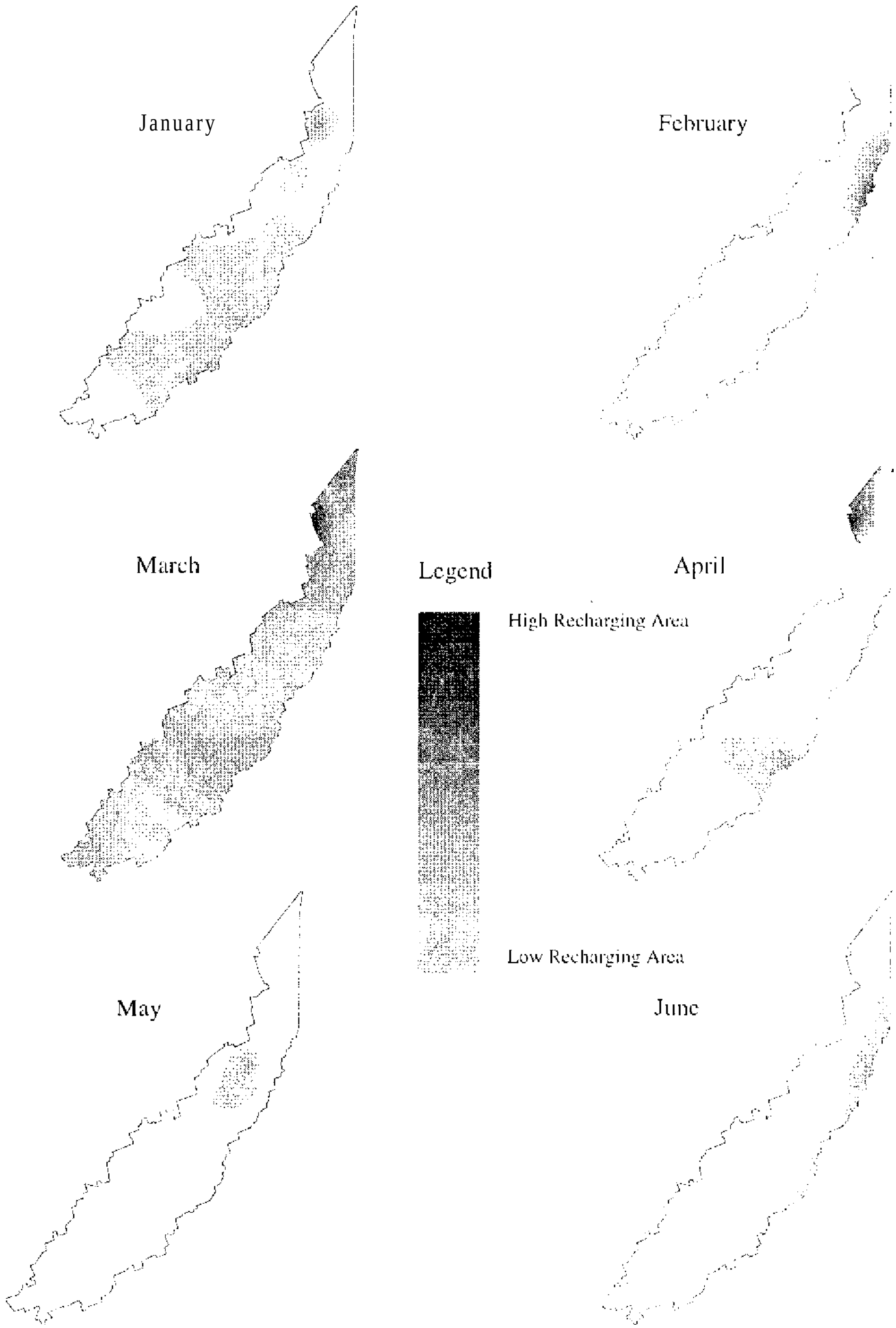

Figure III.8. The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Sirajwah Distributary command.

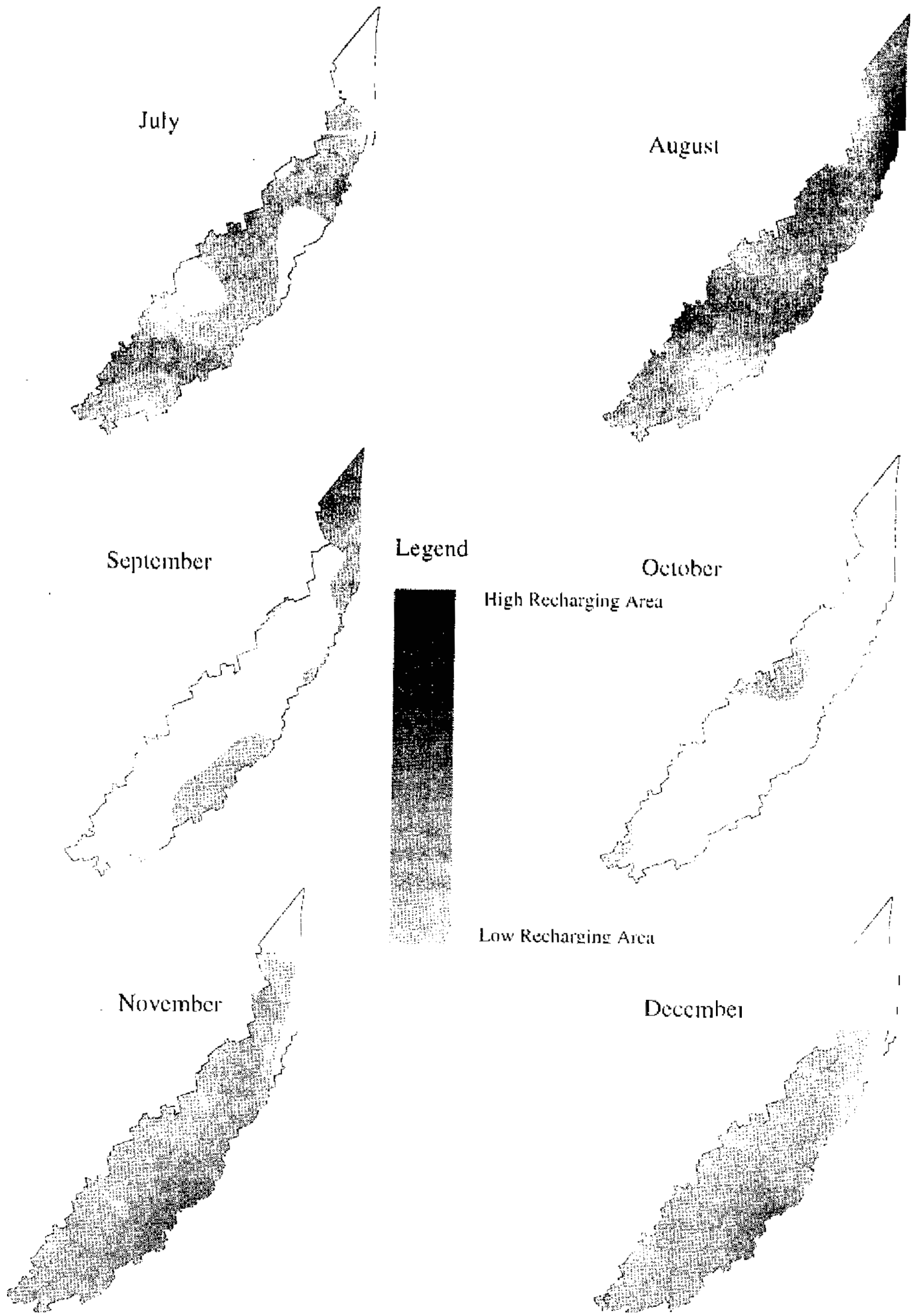

Figure III 8 (contd.). The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Sirajwah Distributary command.

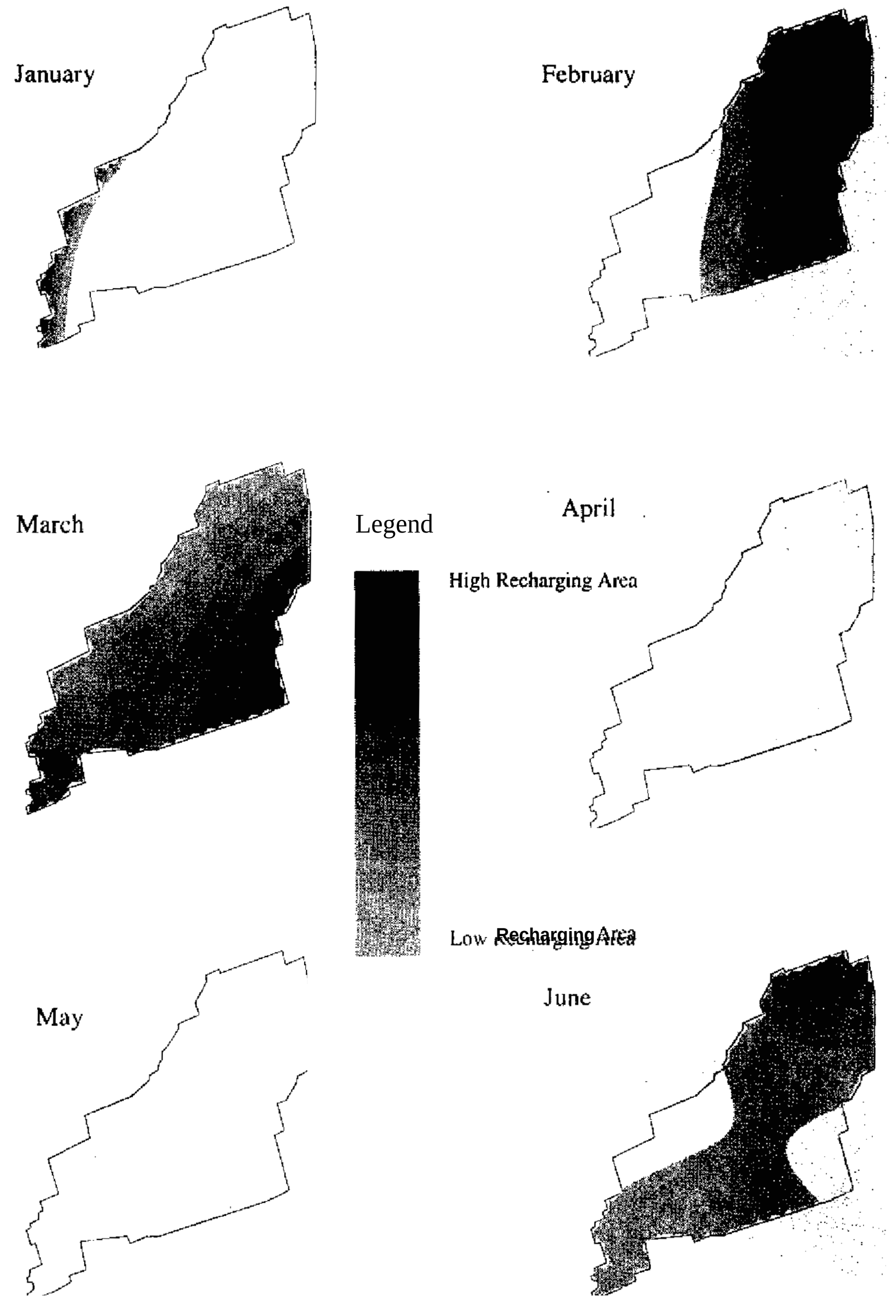

Figure III.9. The extents of average monthly recharge (shaded) and discharge (unshaded) areas in the Sunder Distributary command.

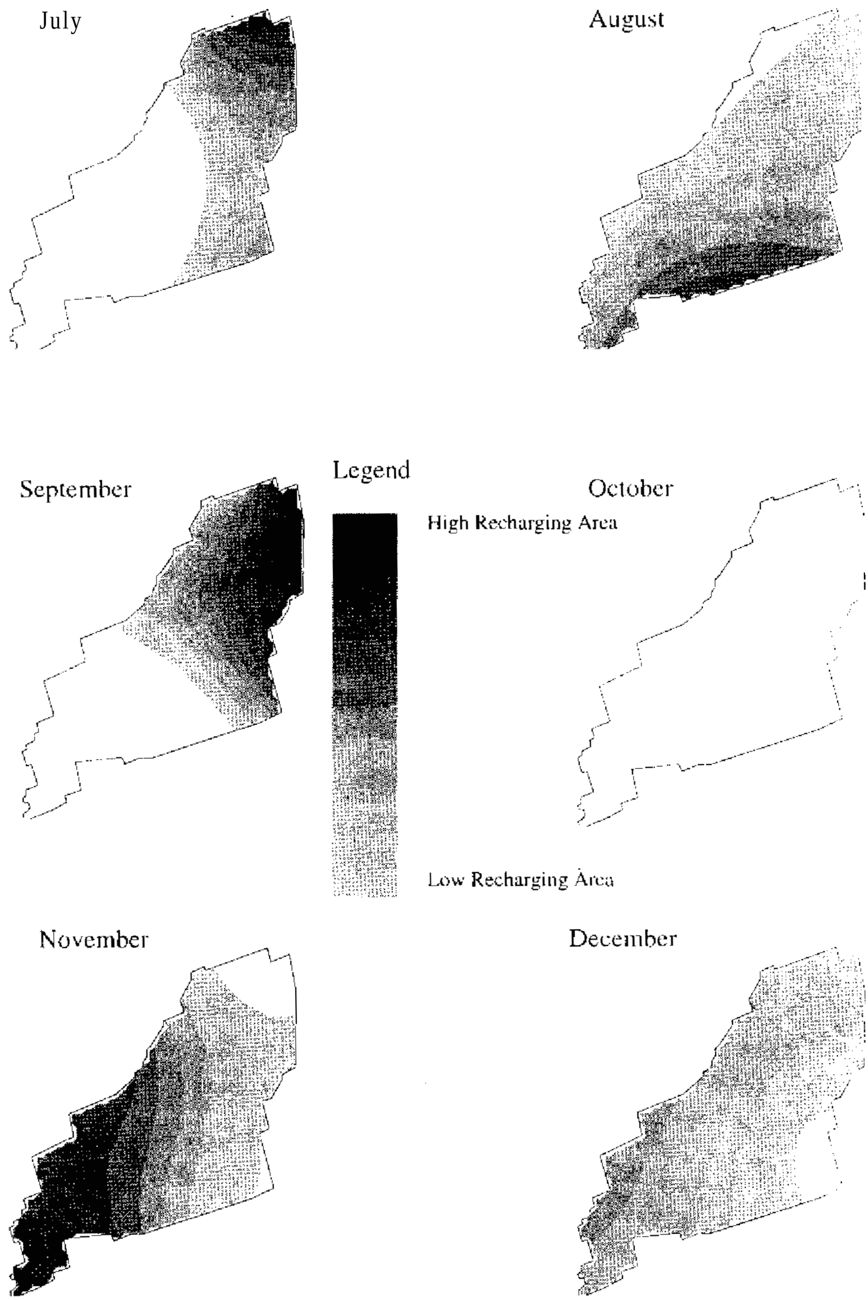

Figure III.9 (contd.). The **extents of average monthly recharge (shaded) and discharge (unshaded) areas** in **the Sunder Distributary command.**

Annex IV. **Subsurface Lithological Fence Diagram.**

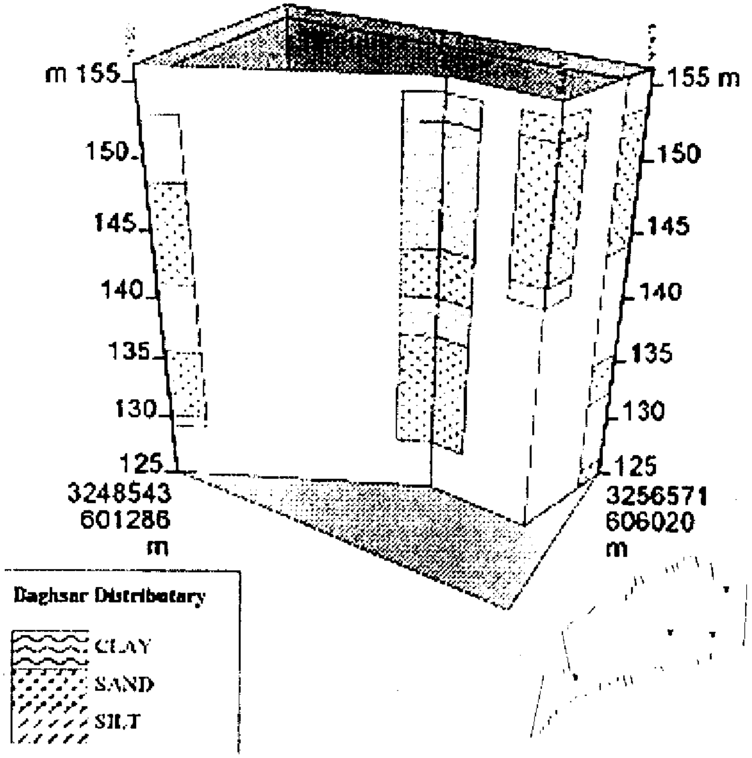

Figure IV.1. The subsurface lithological fence diagram over the Baghsar Distributary command.

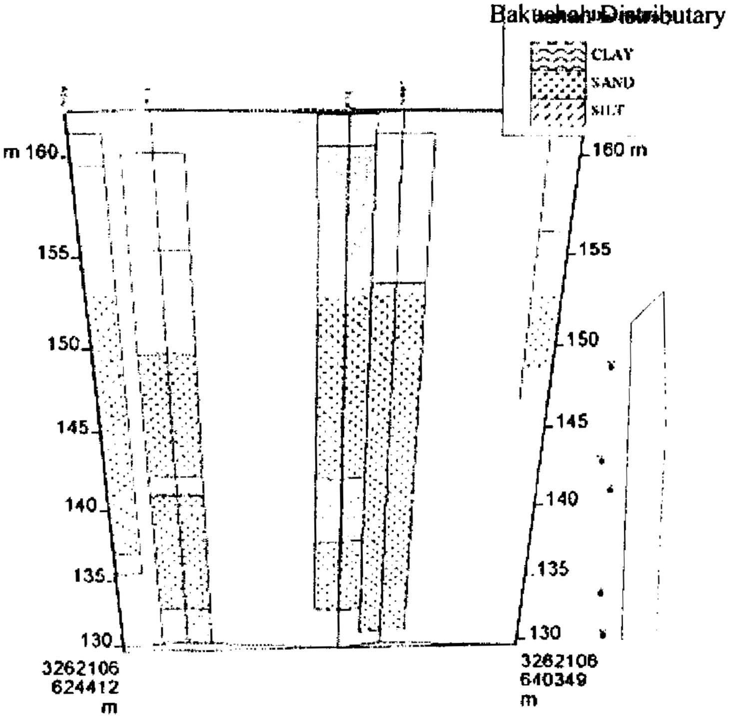

Figure IV.2. The subsurface lithological fence diagram over the Bakushah Distributary command.

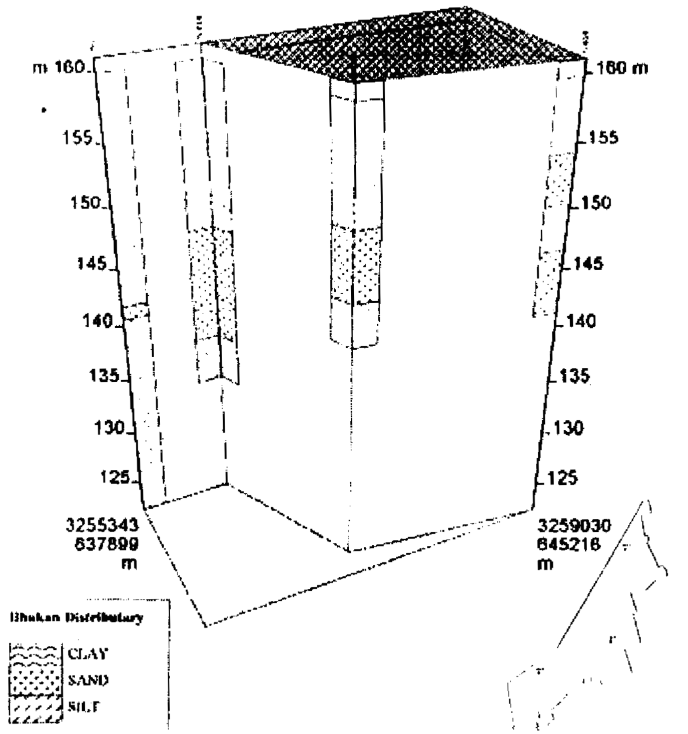

Figure IV.3. The subsurface lithological fence diagram over the Bhukan Distributary command.

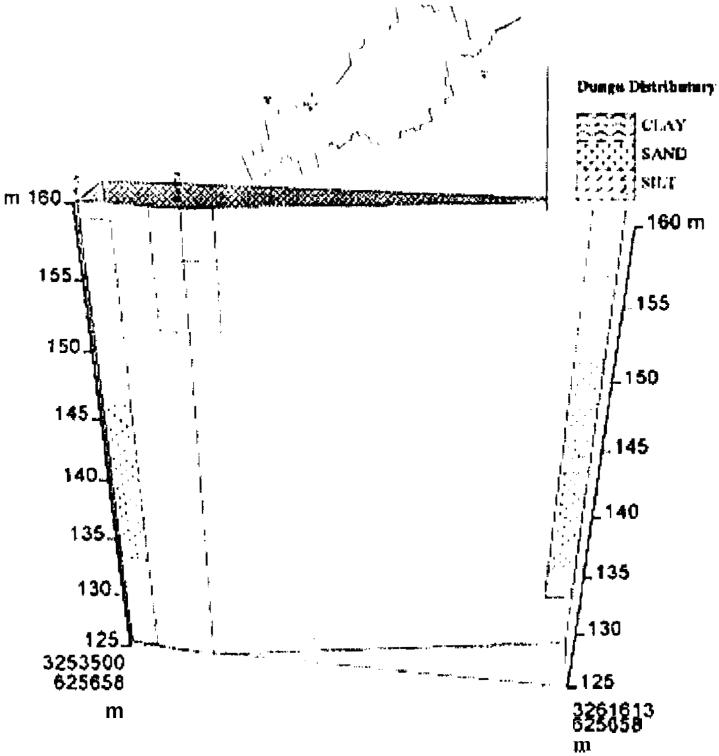

Figure IV.4. The **subsurface lithological fence diagram over the Dunga Distributary command,**

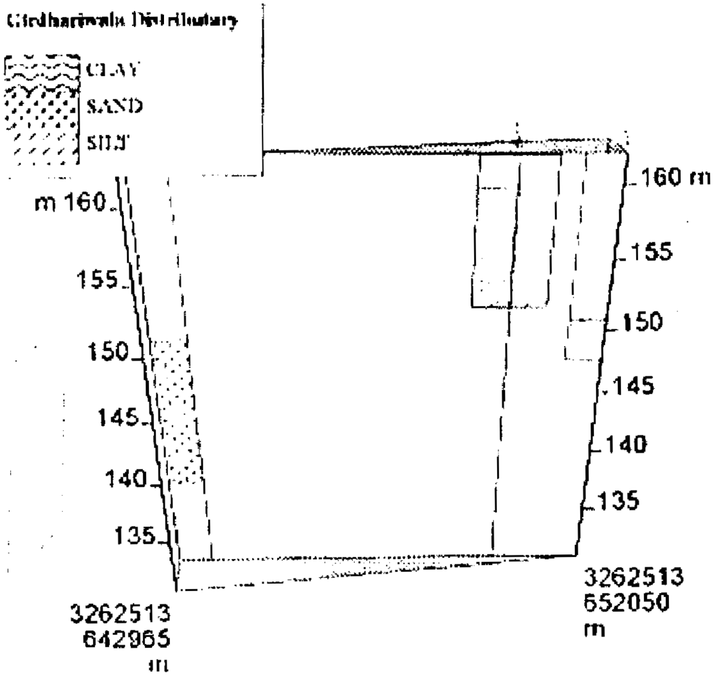

Figure IV.5. The subsurface lithological fence diagram over the Girdhariwala **Distributary** command.

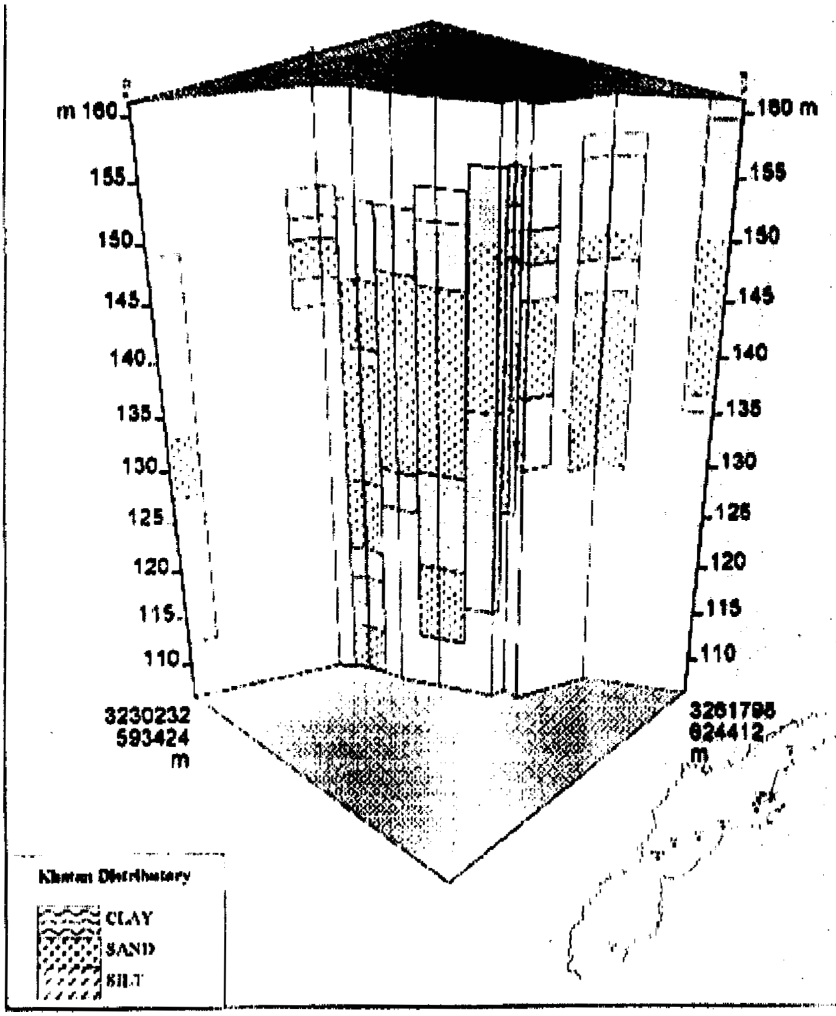

Figure IV.6 The subsurface lithological fence diagram over the Khatsn Distributary command.

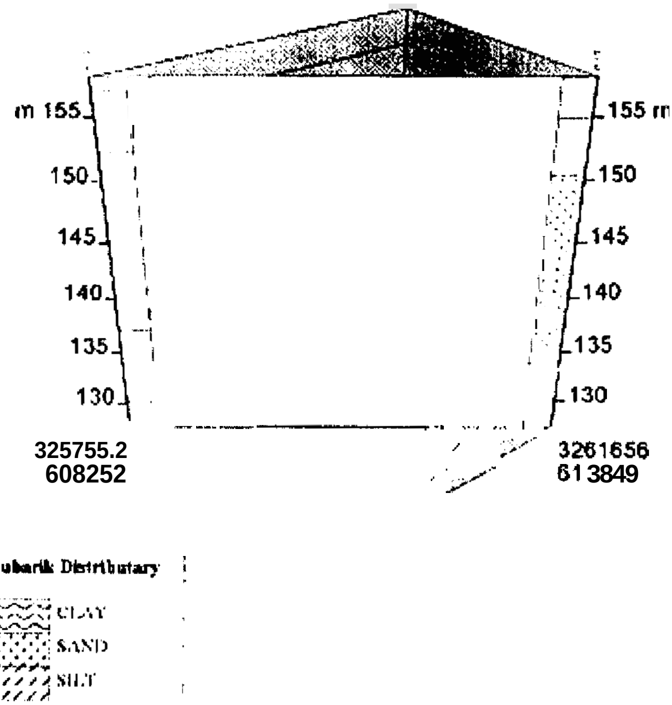

Figure IV.7. The **subsurface lithological fence diagram over** the **Mubarik Distributary** command.

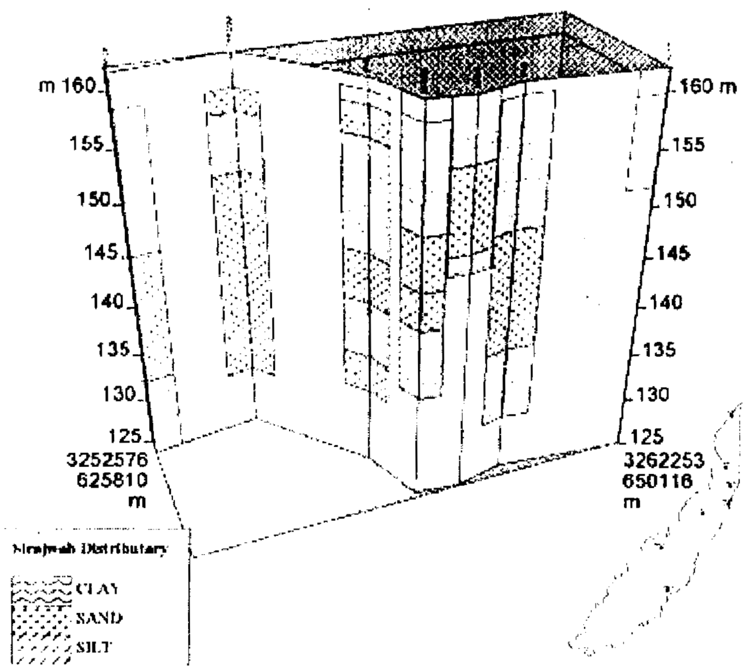

Figure IV.8. The **subsurface lithological fence diagram over the Sirajwah Distributary command.**

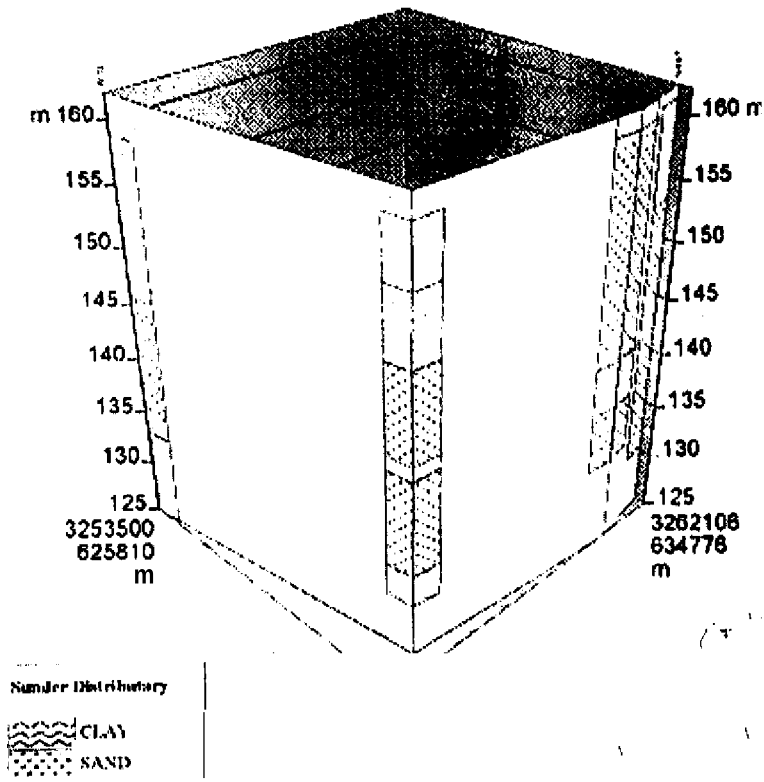

Figure IV.9. command.

Annex V. Average Monthly Contours of Water Levels above the Critical Root Zone Depth of *1.5* meters.

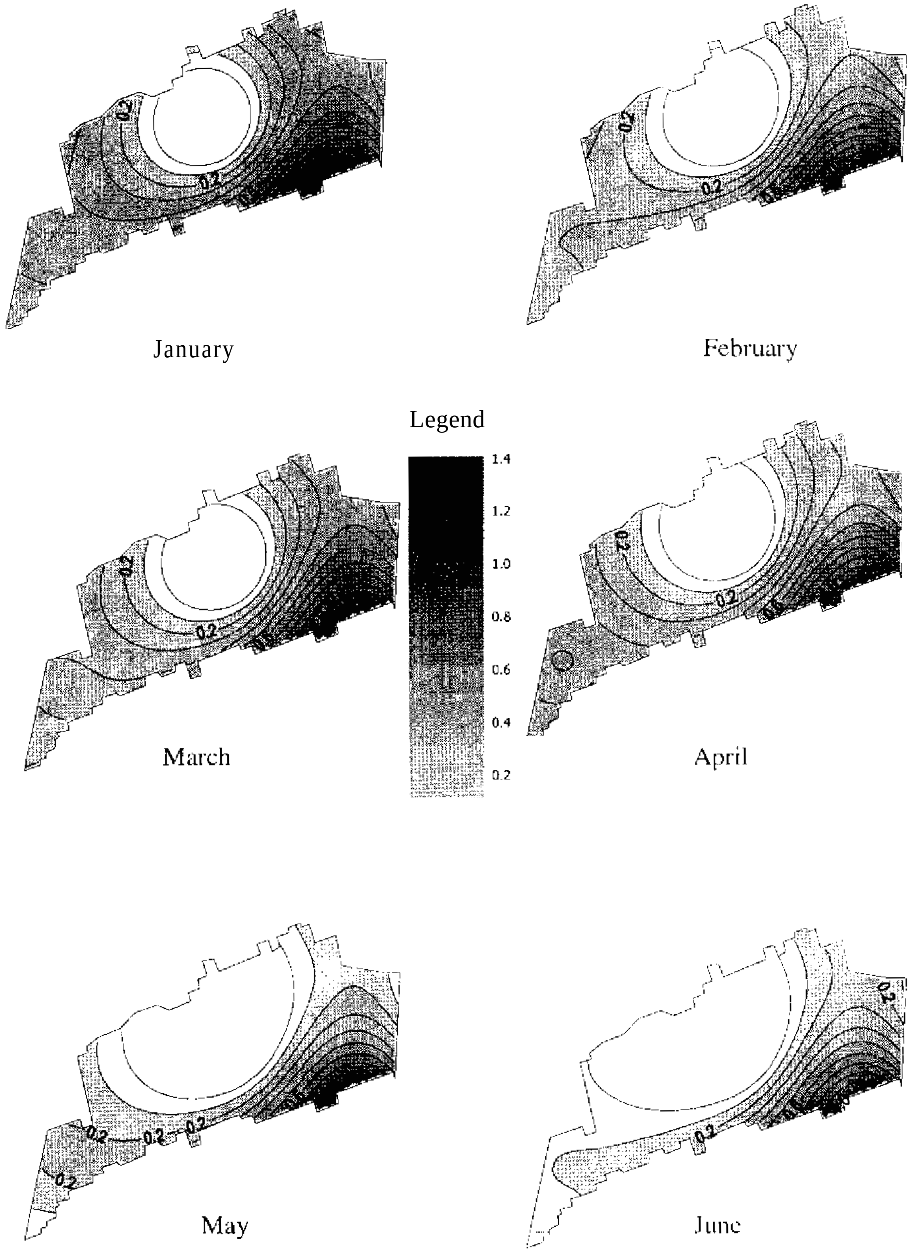

Figure V.1. **he average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in the Baghsar Distributary command.**

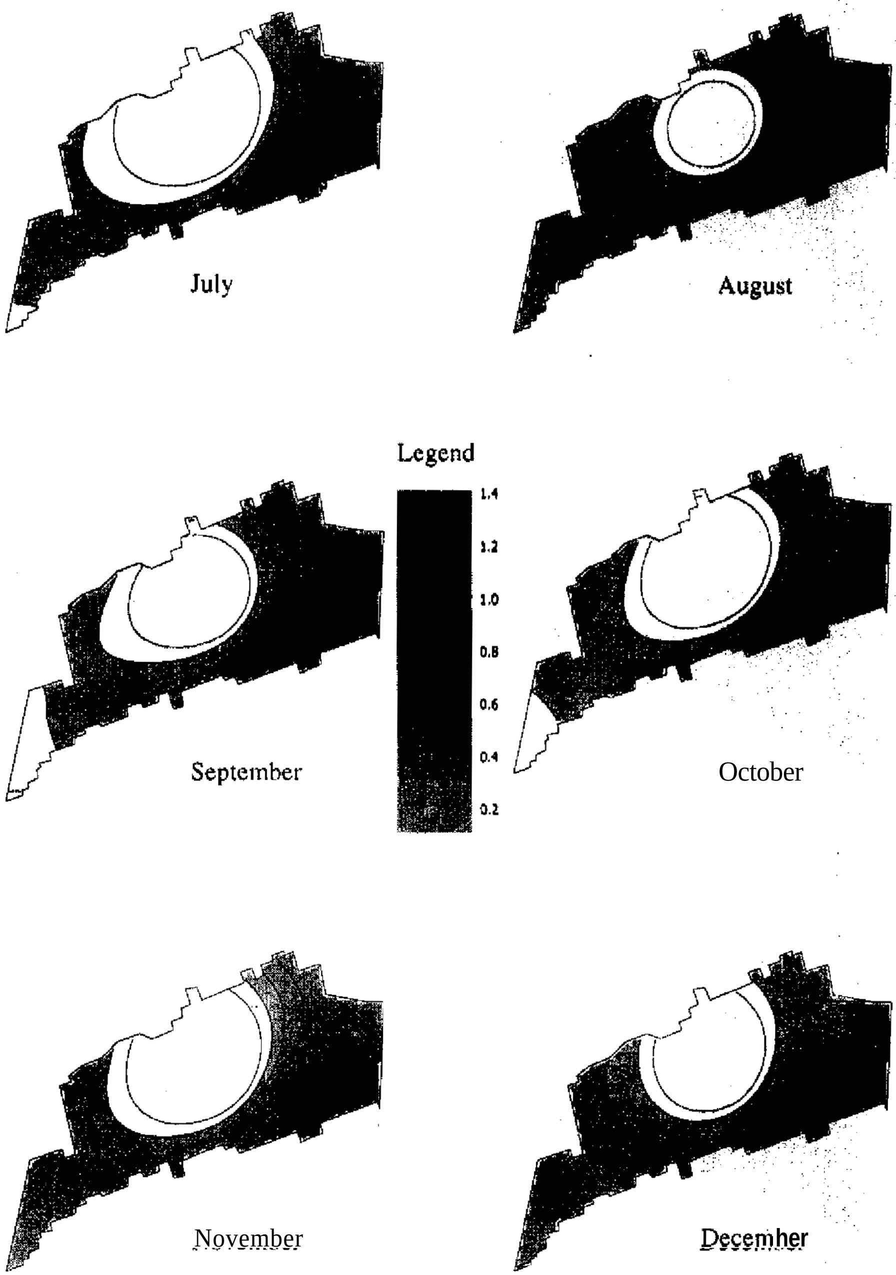

Figure V.1. (contd.). The average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in the Baghsar Distributary command.

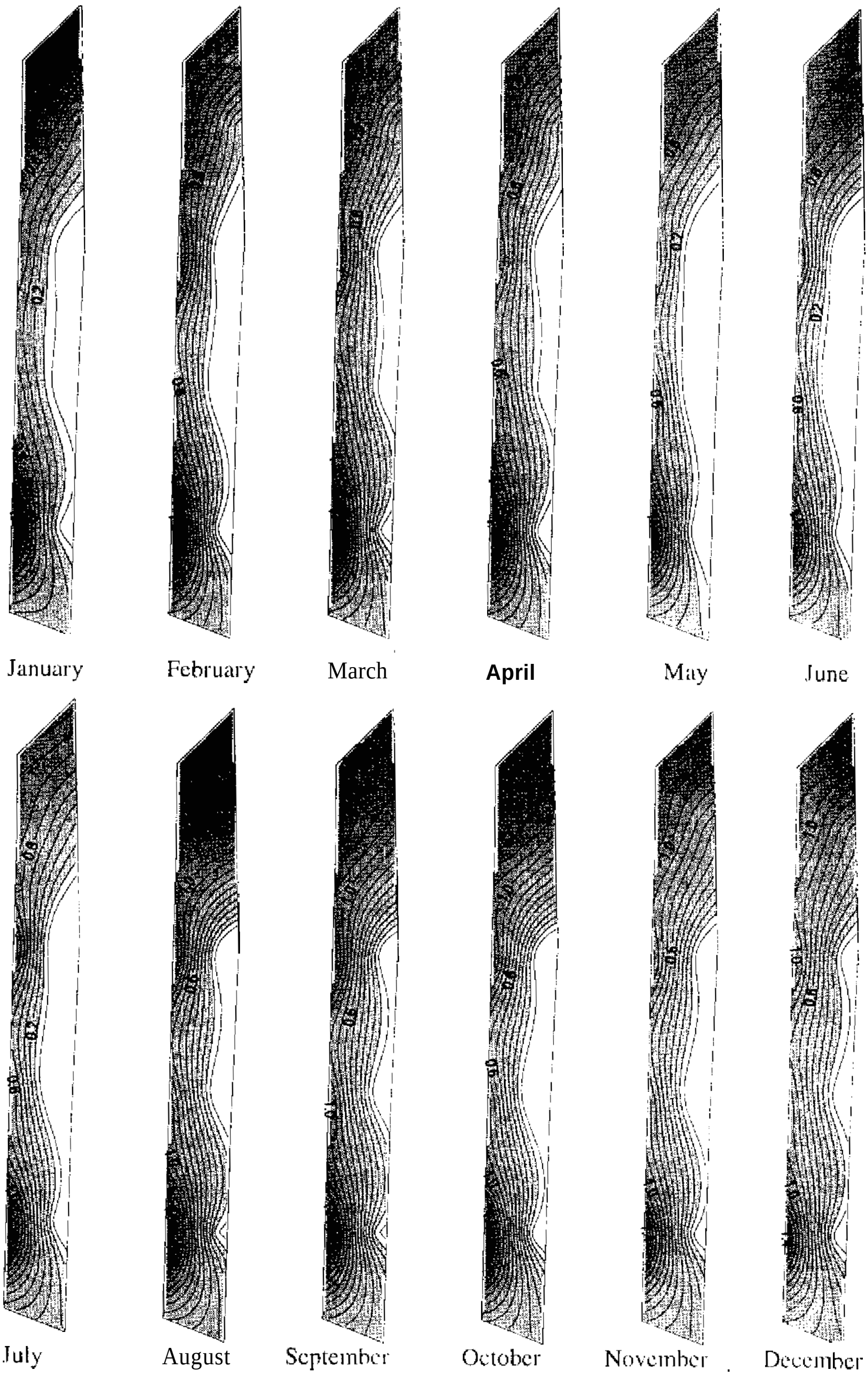

Figure V.2. The **average monthly contours of water levels (m) above** the **critical root zone depth of 1.5 meters in the Bakushah Distributary command.**

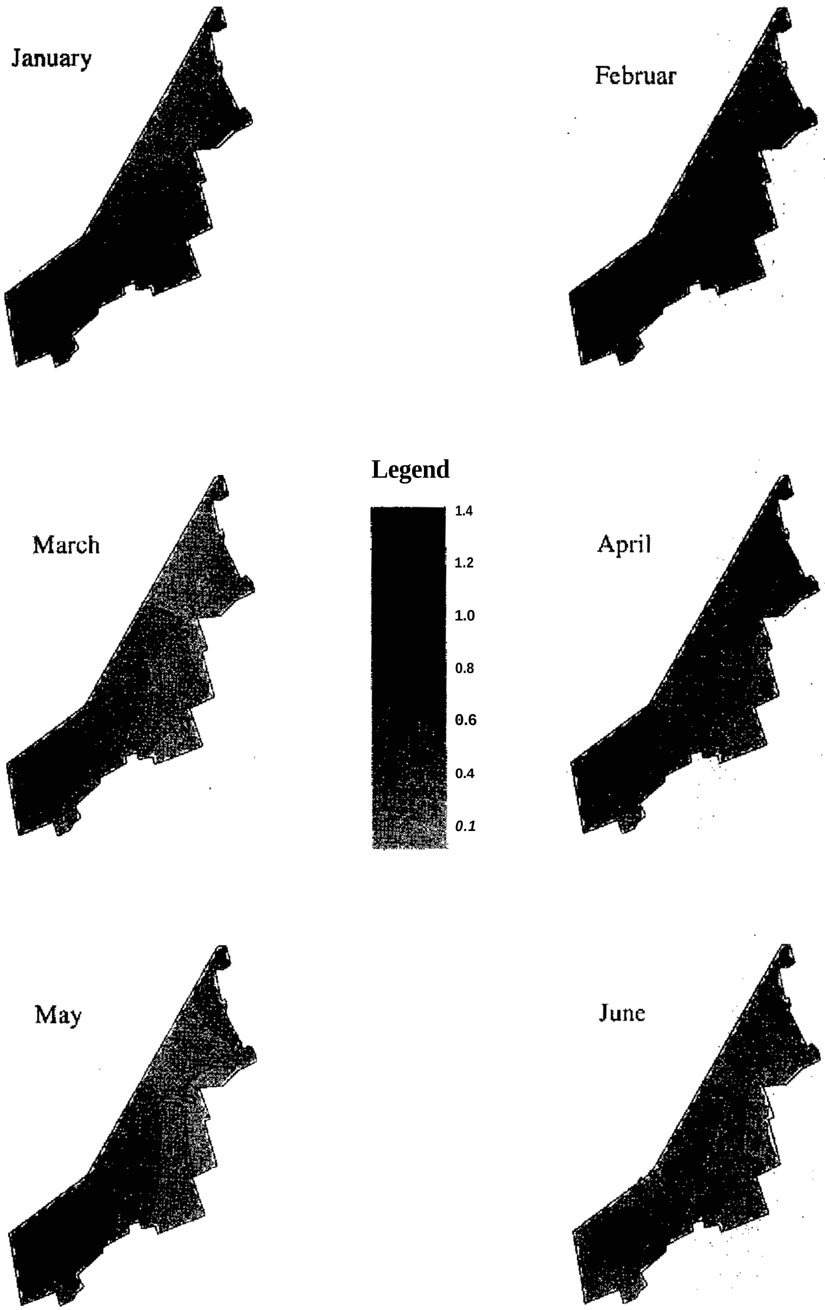

Figure V.3. The average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in the Bhukan Distributary command.

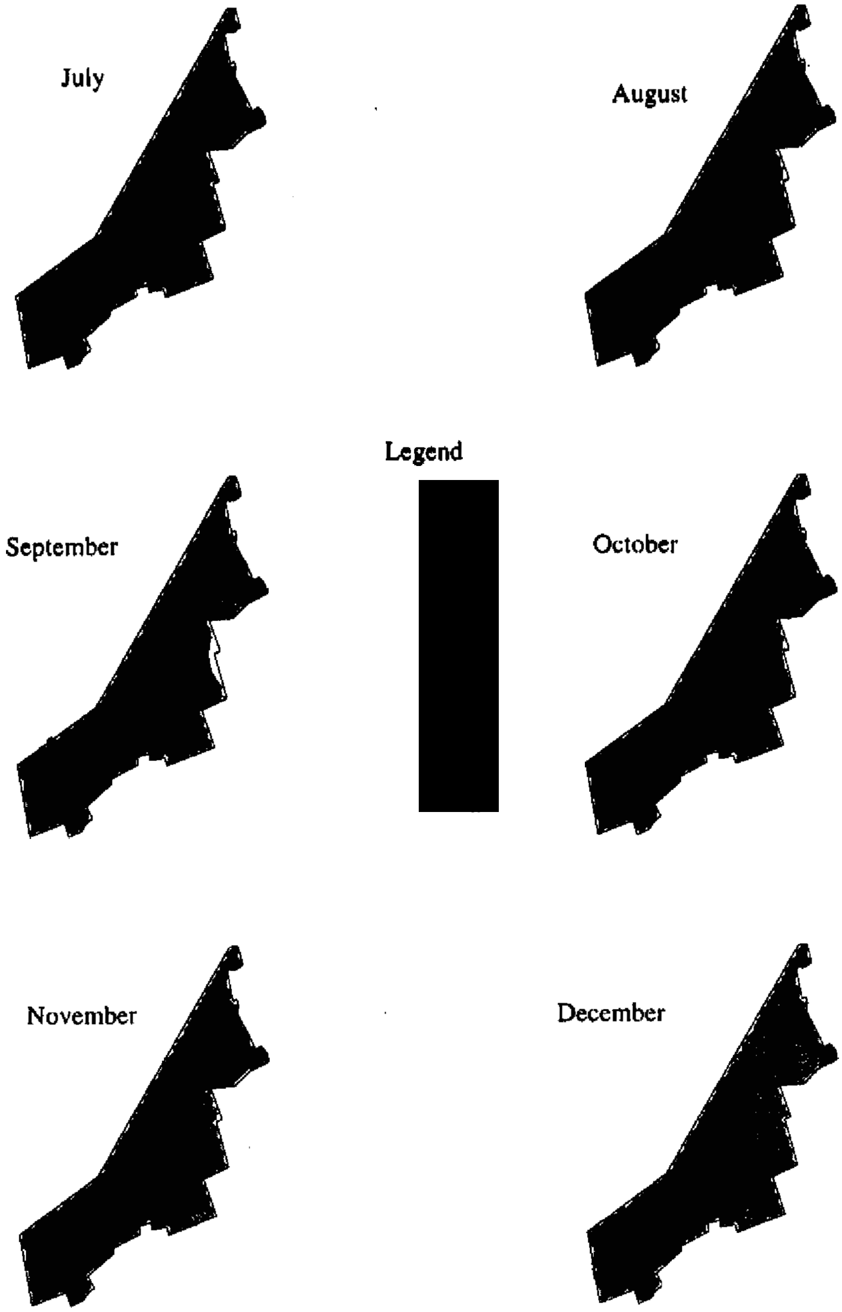

Figure V.3 (contd.). The average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in the Bhukan Distributary command.

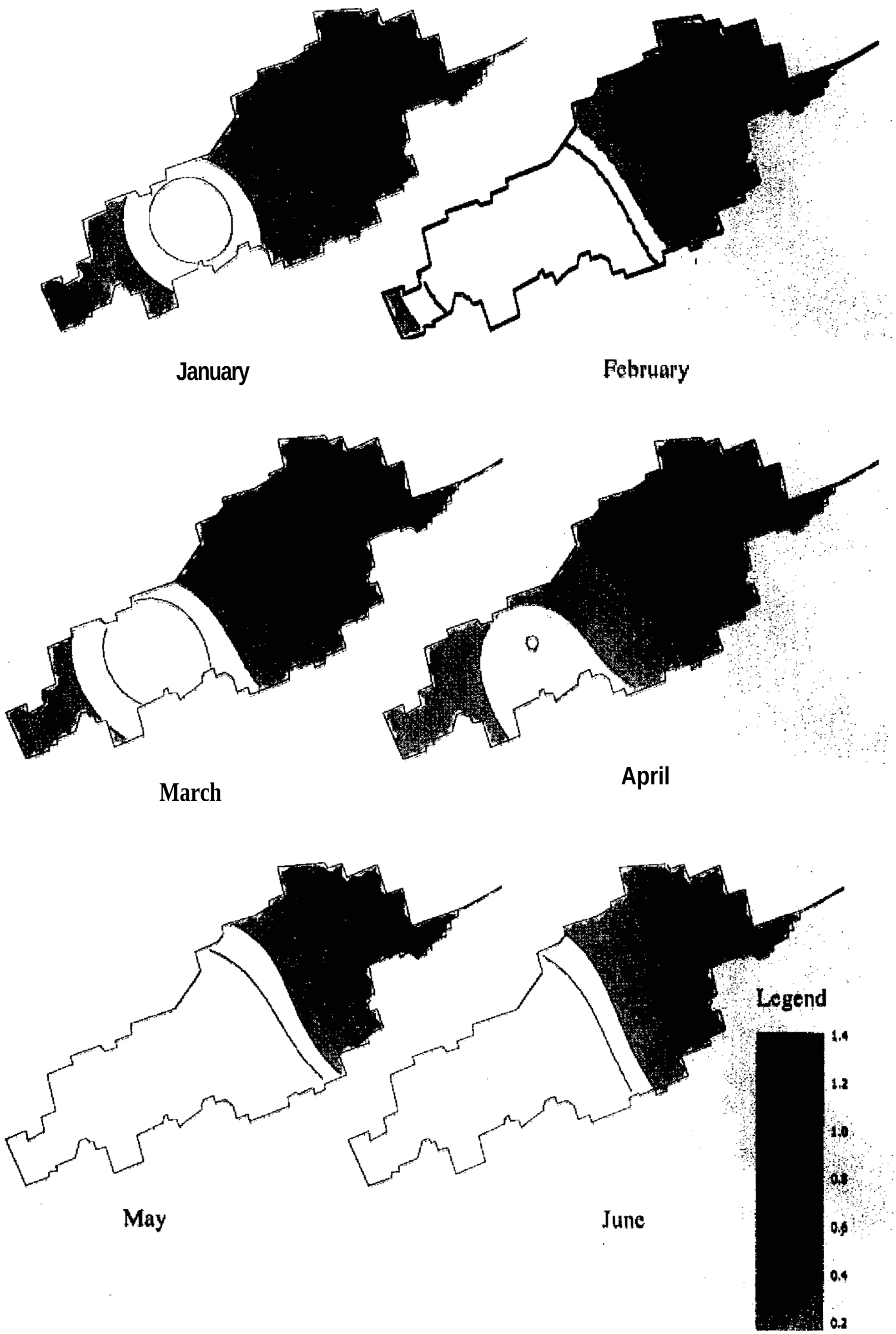

Figure V.4. The average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in the Dunga Distributary command.

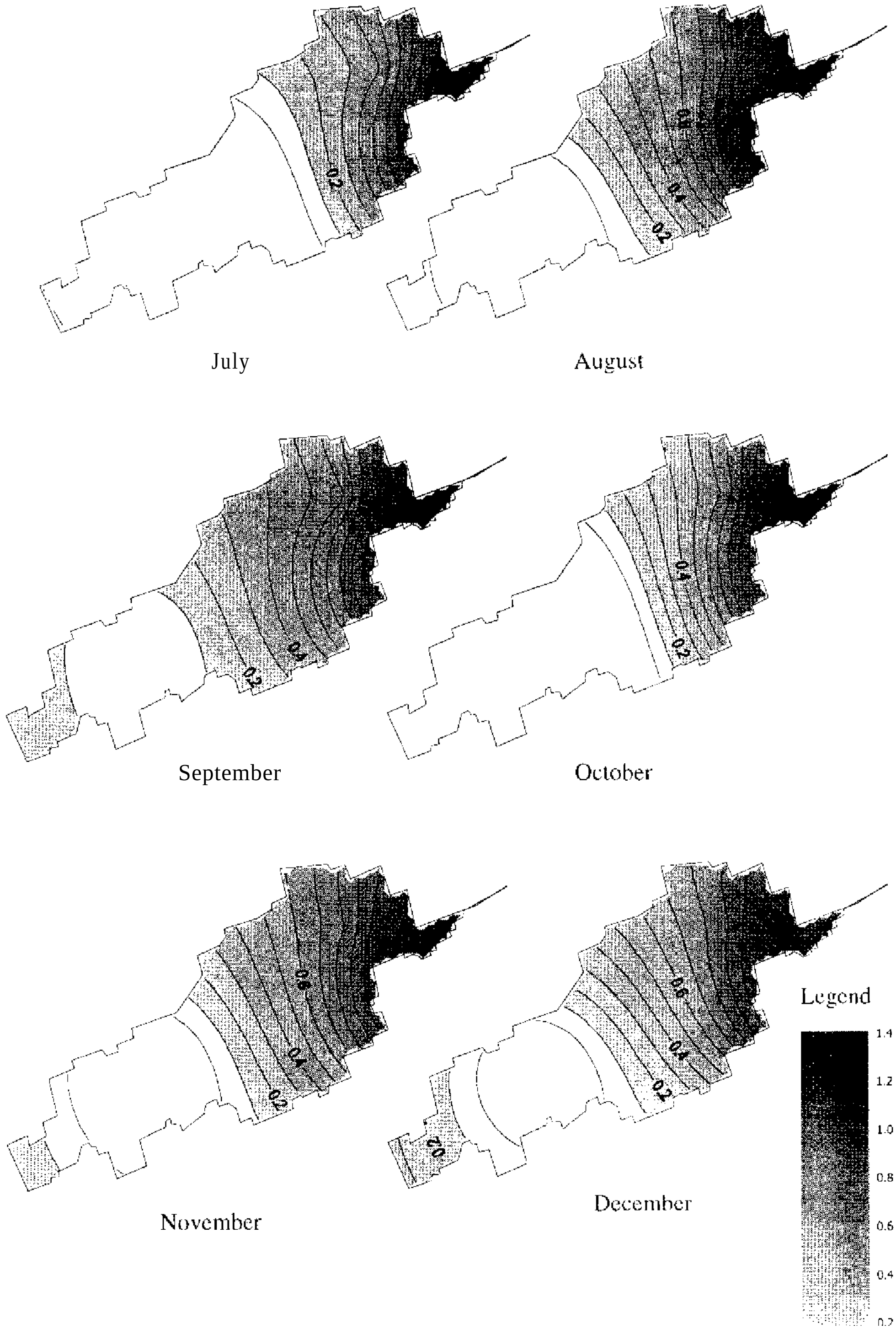

Figure V.4. (contd.). The **average** monthly **contours of water levels (m) above the critical** root **zone depth of 1.5 meters in the Dunga Distributary command.**

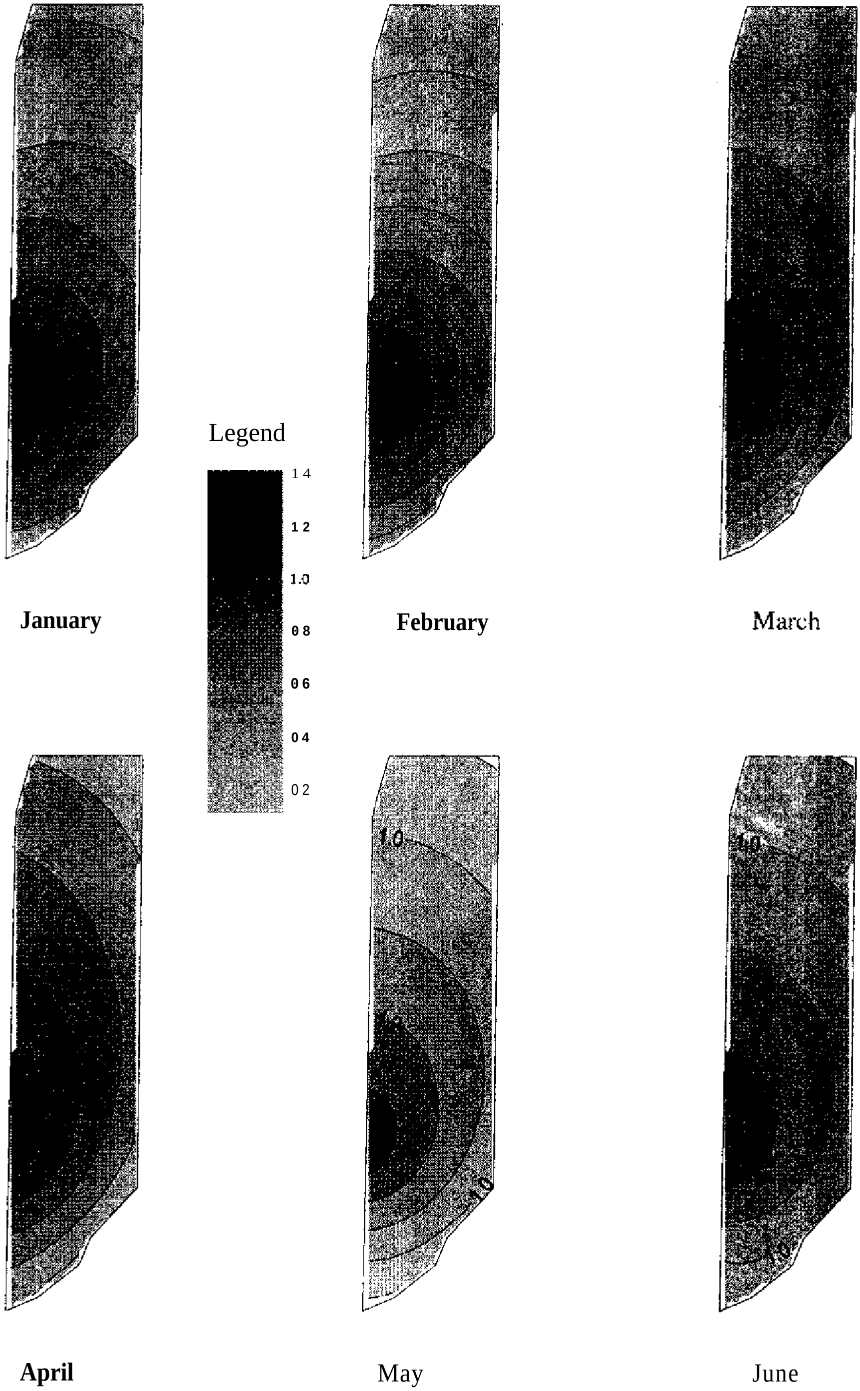

Figure V.5. The average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in the Girdhariwala Distributary command.

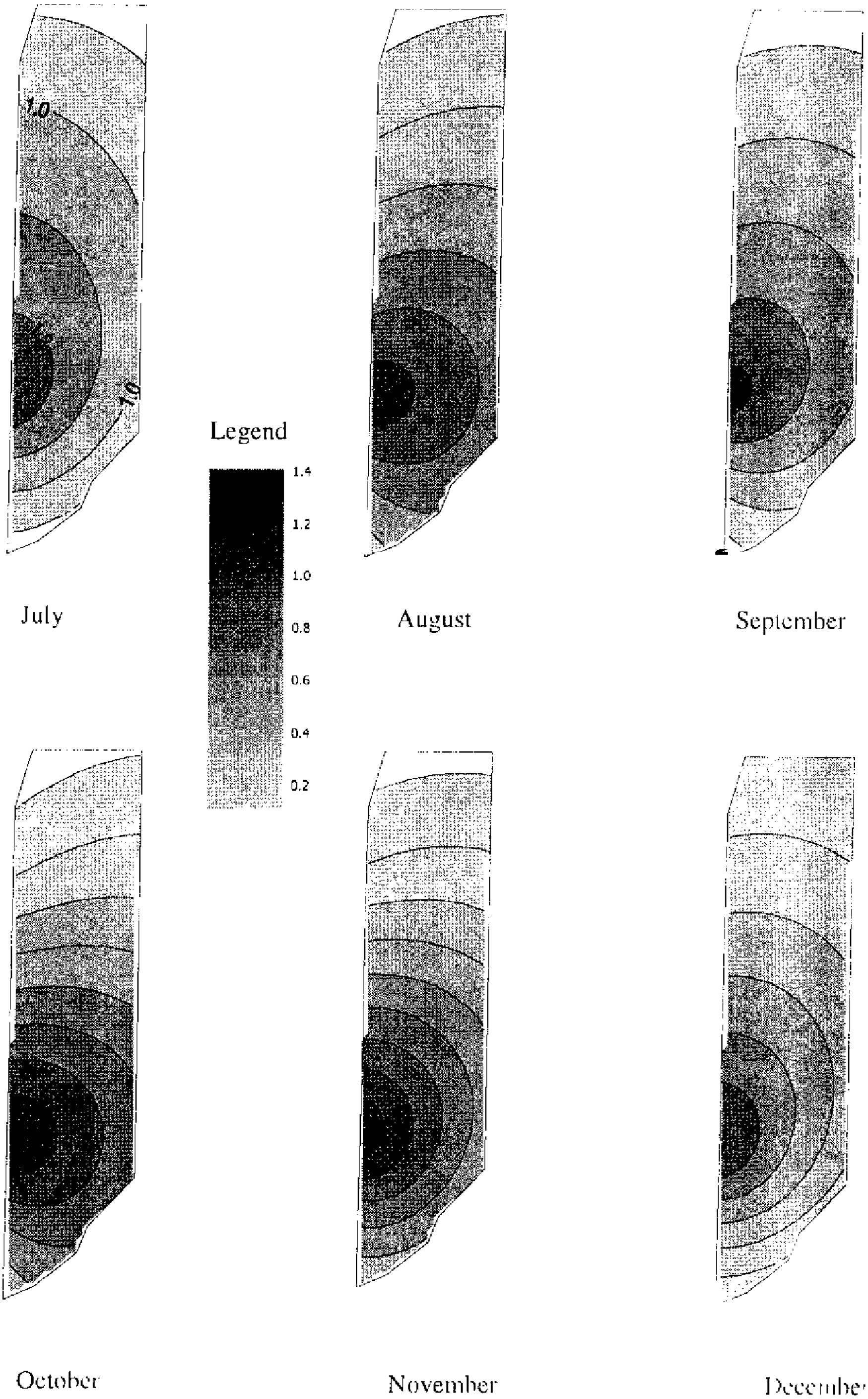

Figure V.5. (contd.). The average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in the Girdhariwala Distributary command.

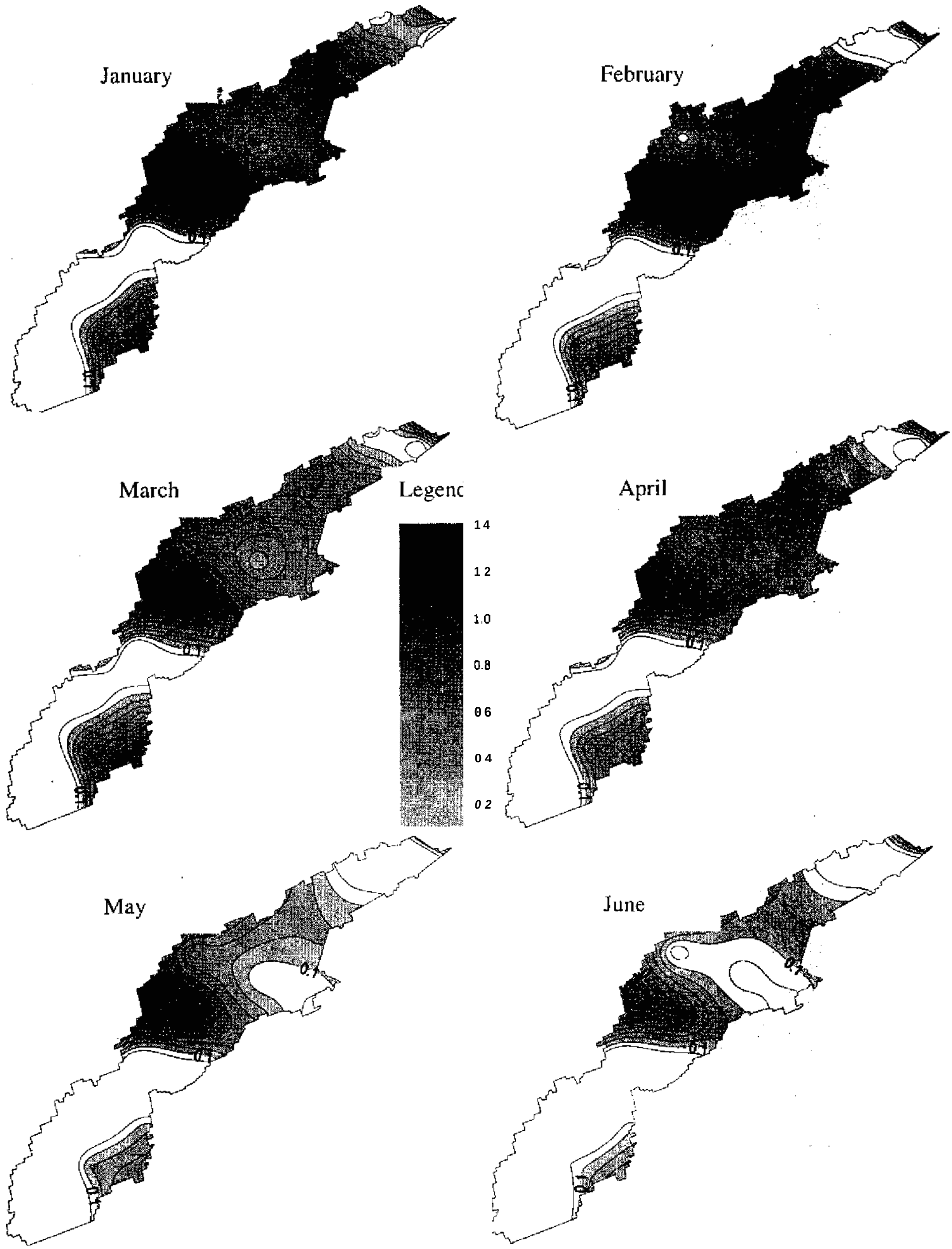

Figure V.6. The average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in the Khatan Distributary command.

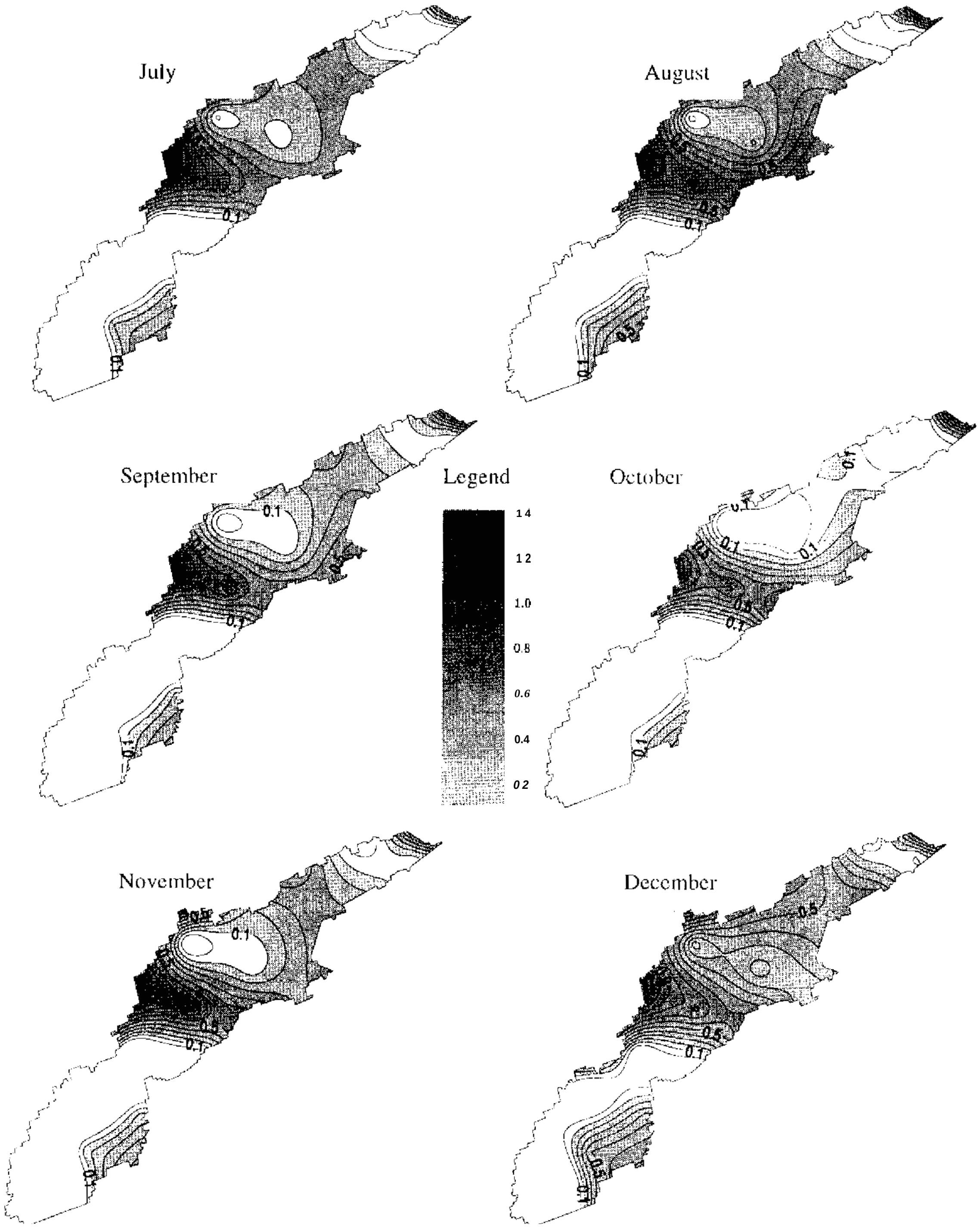

Figure V.6. (contd.). The average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in the Khatan Distributary command.

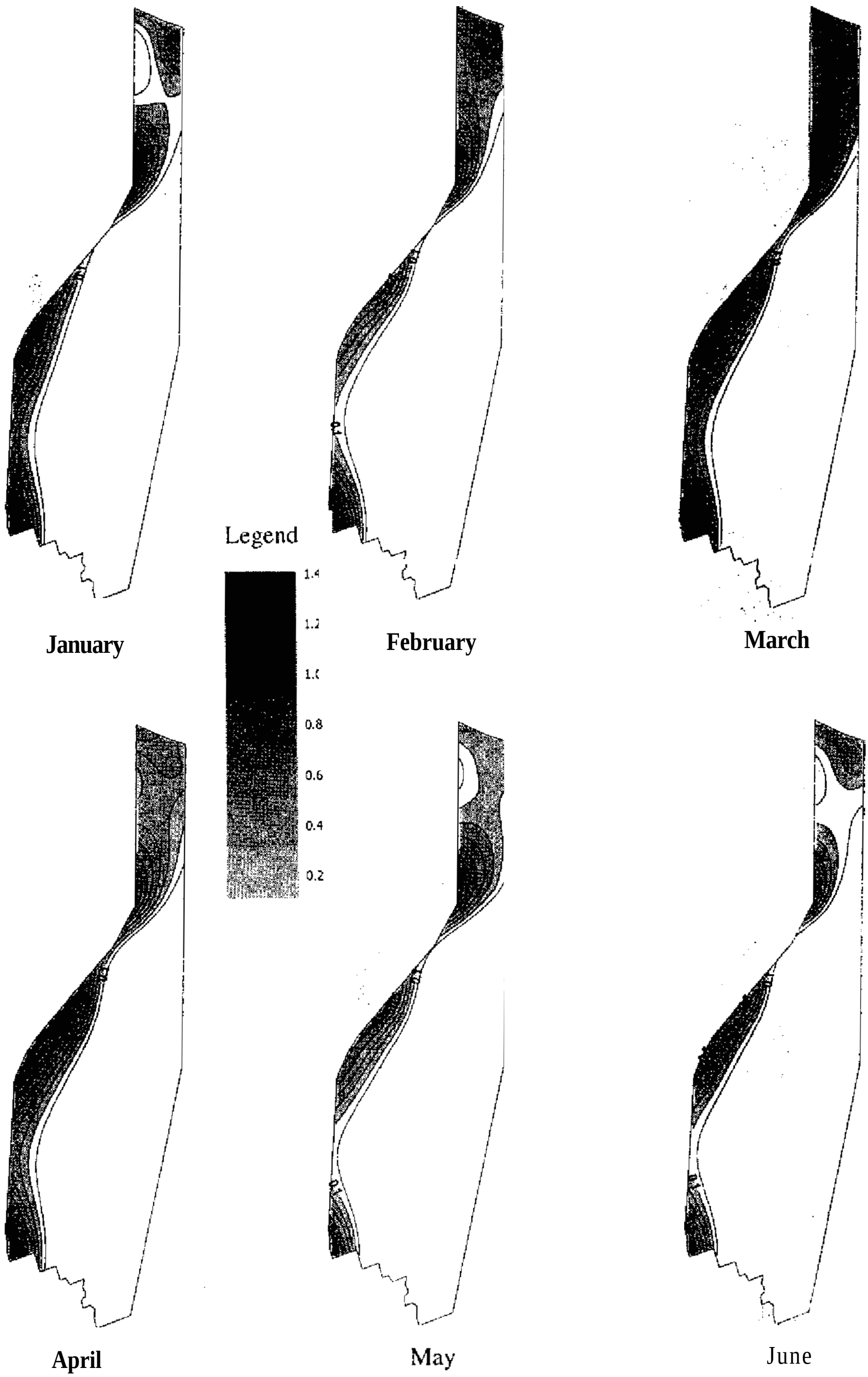

Figure V.7. The average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in the Mubarik Distributary command.

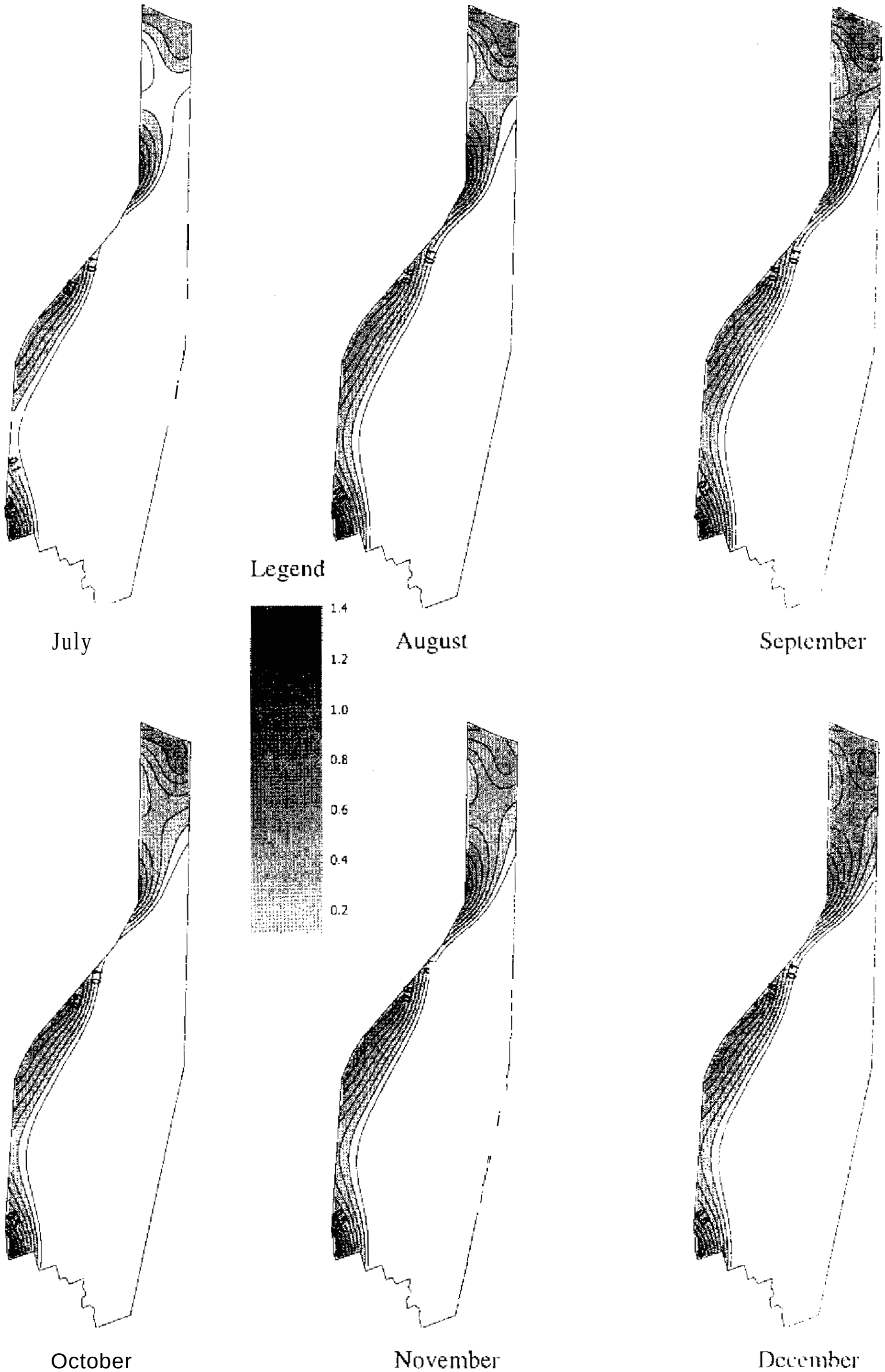

Figure V.7. (contd.). **The average monthly contours of water levels (m) above the critical root zone depth** of 1.5 **meters in the Mubarik Distributary command.**

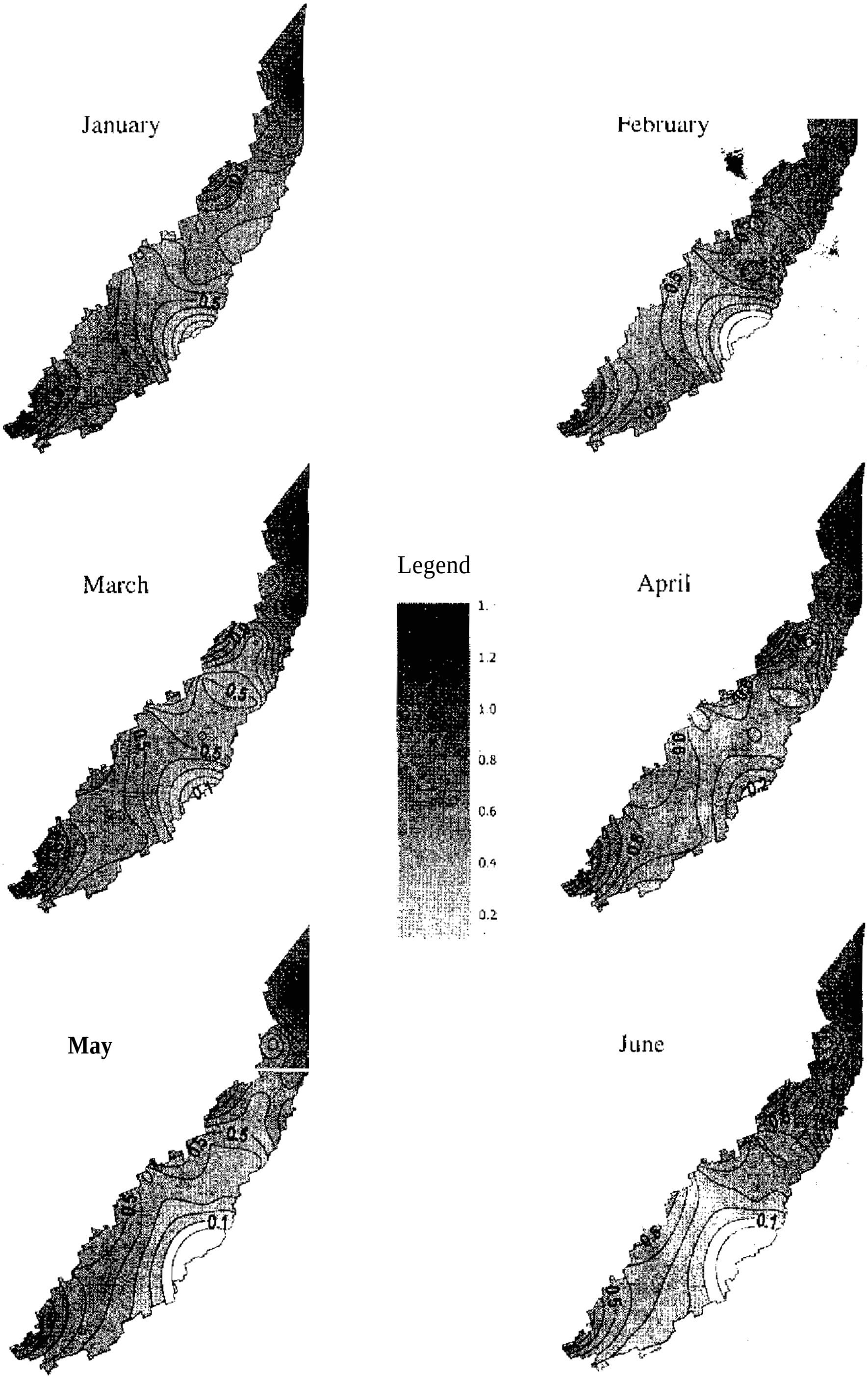

Figure V.8. The average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in the Sirajwah Distributary command.

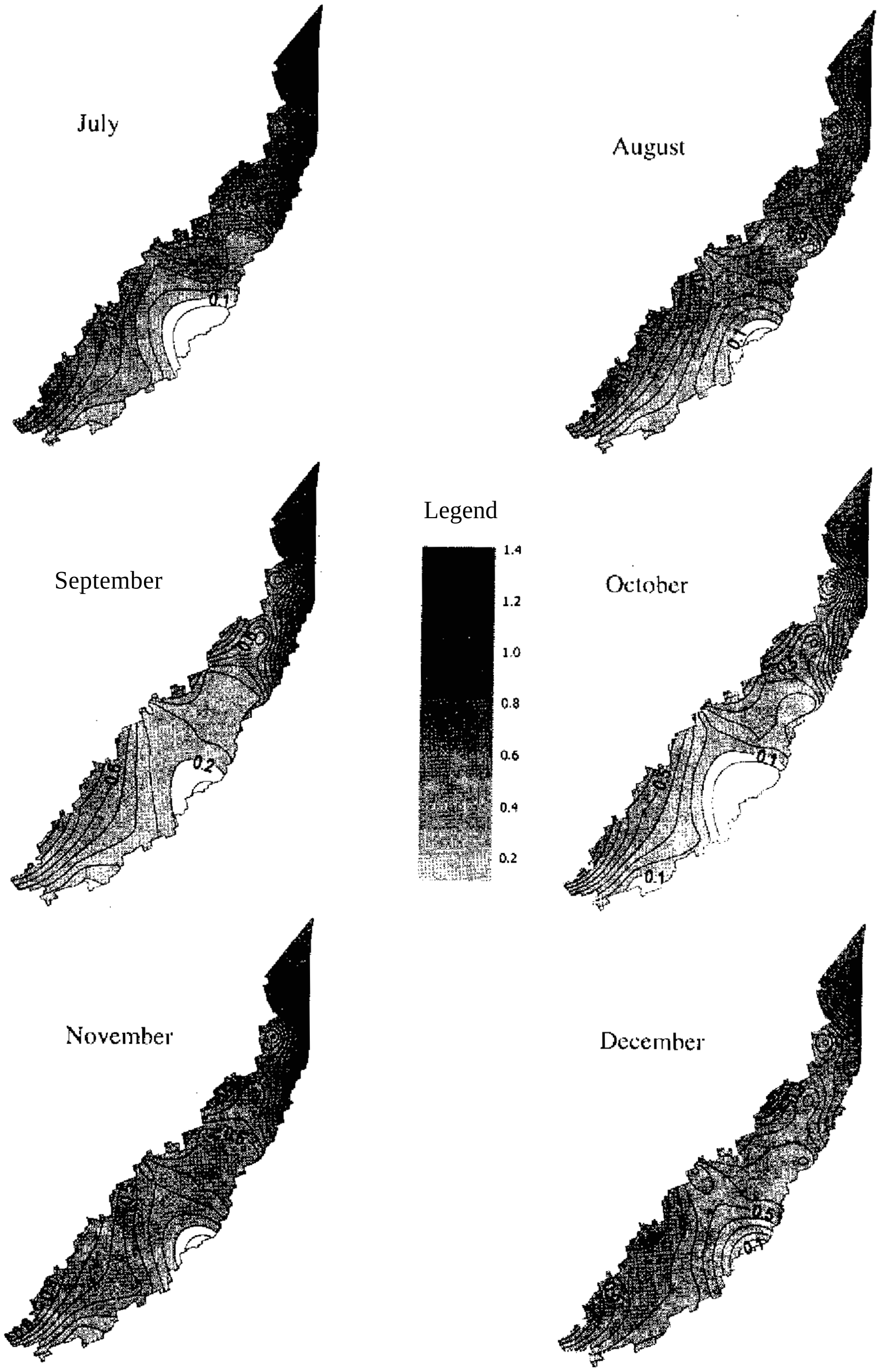

Figure V.8. (contd.). The average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in the Sirajwah Distributary command.

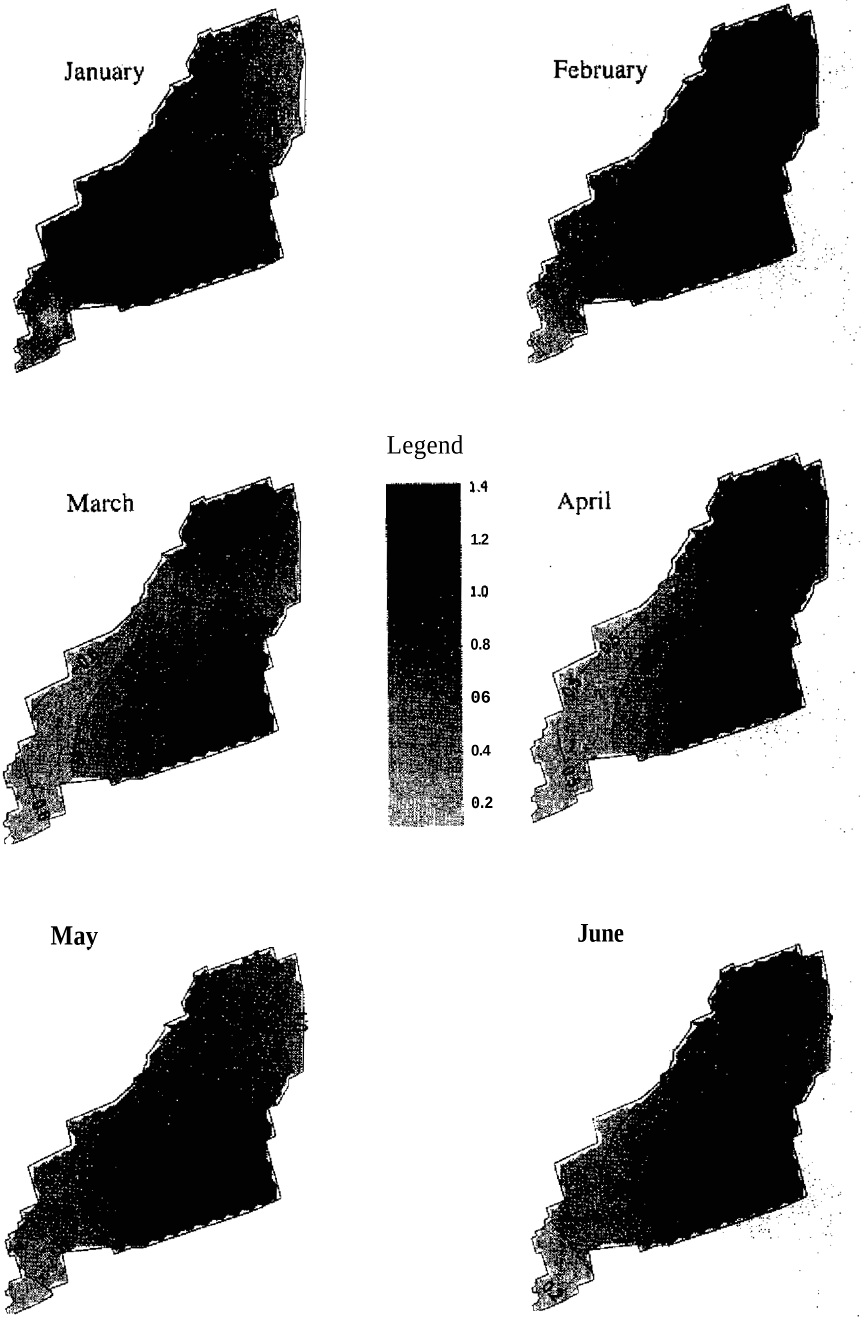

Figure V.9. **The average monthly contours of water levels (m) above the critical root zone depth of** 1.5 **meters in the Sunder Distributary command.**

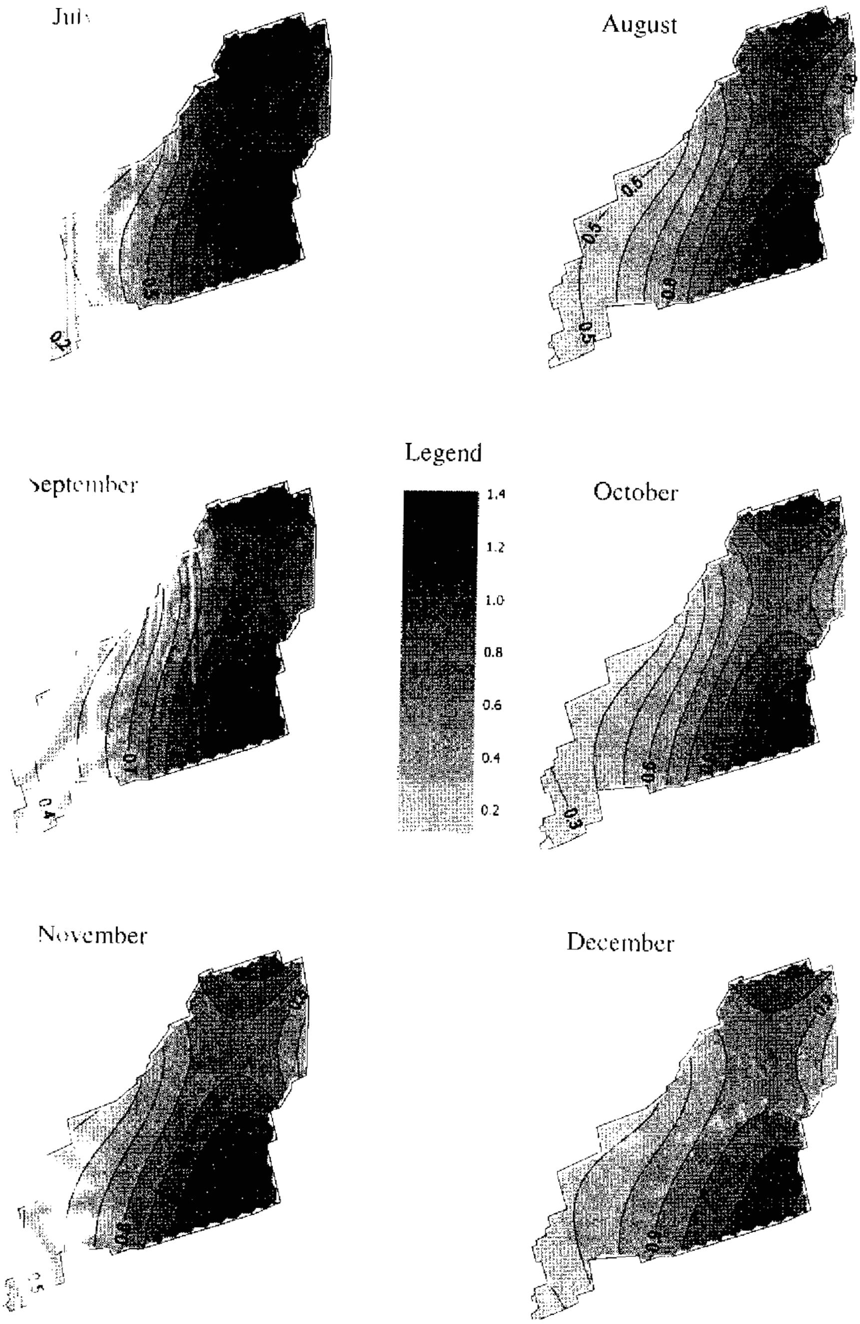

Figure V.9. (contd.). The average monthly contours of water levels (m) above the critical root zone depth of 1.5 meters in the Sunder Distributary command.

Annex VI. Average Monthly Areas under Different DTW Categories.

Table VI.1. The average monthly areas under different DTW categories **over** Baghsar Distributary **command.**

	0-50		50-75		75-100		100-125		125-150		Total (0-150)	
Month	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Jan	88	2	233	5	479	t1	21051	47	906	20	3811	X5
Feh	88	2	204	5	348	8	1659	37	1275	28	3573	80
Mar	127	3	246	5	457	10	1885	42	995	22	3711	83
Apr	03	2	224	5	443	10	1824	41	1010	22	3594	80
May	0	0	103	2	251	6	466	10	2092	47	2913	65
Jun	8	0	143	3	290	6	548	12	1759	39	2748	61
Jul	8	0	147	3	298	7	672	15	2068	46	3193	71
Aug	117	3	248	6	468	10	2191	49	915	20	3940	88
Sep	156	3	251	6	458	10	884	20	1804	40	3553	79
Oct	84	2	187	4	326	7	884	20	1855	41	3336	74
Nov	79	2	193	4	347	8	853	19	1822	41	3295	73
Dec	80	2	204	5	620	14	1741	39	940	21	3585	80

Table VI.2. The average monthly areas under different DTW categories over Bakushah Distributary command.

	0-50		50-75		75-100		100-125		125-150		Total (0-150)	
Month	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Jan	211	5	388	10	581	15	1210	30	988	25	3378	85
Feb	252	6	560	14	832	21	905	23	685	17	3234	81
Mar	573	14	664	17	904	23	840	21	582	15	3562	89
Apr	323	8	559	14	894	22	981	25	726	18	3482	87
May	30	1	347	9	636	16	944	24	906	23	2863	72
Jun	47	1	569	14	765	19	875	22	733	18	2989	75
Jul	95	2	444	11	922	23	948	24	685	17	3094	78
Aug	1120	28	609	15	744	19	663	17	475	12	3611	90
Sep	1213	30	696	17	754	19	623	16	459	12	3746	94
Oct	1098	28	534	13	688	17	606	15	497	12	3423	86
Nov	596	15	679	17	867	22	788	20	573	14	3504	88
Dec	516	13	755	19	1007	25	840	21	615	15	3732	93

Table **VI.3.** The average monthly areas under different **DTW** categories over Bhukan Distributary command.

	0-50		50-75		75-100		100-125		125-150		Total (0-150)	
Month	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Jan	698	33	1081	52	316	15	0	0	0	0	2095	100
Feb	331	16	658	31	828	40	278	13	0	0	2095	100
Mar	1553	74	542	26	0	0	0	0	0	0	2095	100
Apr	1265	60	829	40	0	0	0	0	0	0	2095	100
May	157	8	1411	67	527	25	0	0	0	0	2095	100
Jun	12	1	1315	63	768	37	0	0	0	0	2095	100
Jul	0	0	1253	60	841	40	0	0	0	0	2095	100
Aug	444	21	1578	75	73	3	0	0	0	0	2095	100
Sep	952	45	1049	50	93	4	0	0	0	0	2095	100
Oct	384	18	1152	55	554	26	5	0	0	0	2095	100
Nov	697	33	1356	65	42	2	0	0	0	0	2095	100
Dec	1421	68	673	32	0	0	0	0	0	0	2095	100

Table VI.4. The average monthly areas under different DTW categories over Dunga Distributary command.

	0-50		50-75		75-100		100-125		125-150		Total (0-150)	
Month	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Jan	61	3	320	14	527	23	528	23	654	28	2089	90
Feb	145	6	232	10	354	15	337	14	387	17	1455	62
Mar	225	10	295	13	394	17	433	19	637	27	1983	85
Apr	109	5	219	9	452	19	575	25	973	42	2328	100
May	24	1	58	2	152	6	354	15	465	20	1052	45
Jun	34	1	72	3	223	10	428	18	450	19	1208	52
Jul	45	2	80	3	218	9	420	18	468	20	1232	53
Aug	207	9	248	11	397	17	390	17	417	18	1659	71
Sep	147	6	209	9	403	17	611	26	963	41	2334	100
Oct	135	6	191	8	281	12	352	15	312	13	1271	54
Nov	173	7	283	12	412	18	394	17	482	21	1745	75
Dec	210	9	346	15	367	16	408	17	568	24	1900	81

Table VI.5. The average monthly areas under different DTW categories over Girdhariwala Distributary command.

	0-50		50-75		75-100		100-125		125-150		Total (0-150)	
Month	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Jan	1557	100	0	0	0	0	0	0	0	0	1557	100
Feb	1091	70	466	30	0	0	0	0	0	0	1557	100
Mar	1557	100	0	0	0	0	0	0	0	0	1557	100
Apr	1557	100	0	0	0	0	0	0	0	0	1557	100
May	1192	77	365	23	0	0	0	0	0	0	1557	100
Jun	1195	77	362	23	0	0	0	0	0	0	1557	100
Jul	1025	66	532	34	0	0	0	0	0	0	1557	100
Aug	1557	100	0	0	0	0	0	0	0	0	1557	100
Sep	1557	100	0	0	0	0	0	0	0	0	1557	100
Oct	1493	96	64	4	0	0	0	0	0	0	1557	100
Nov	1243	80	314	20	0	0	0	0	0	0	1557	100
Dec	1557	100	0	0	0	0	0	0	0	0	1557	100

Table VI.6. The average monthly areas under different DTW categories over Khatan Distributary command.

	0-50		50-75		75-100		100-125		125-150		Total (0-150)	
Month	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Jan	105	0	2546	8	8222	25	9624	29	4696	14	25194	76
Feb	34	0	2102	6	3982	12	11786	35	5499	16	23403	70
Mar	337	1	2315	7	5866	18	11752	35	5118	15	25387	76
Apr	47	0	825	2	3223	10	12702	38	7585	23	24382	73
May	0	0	266	1	2594	8	6306	19	10925	33	20091	60
Jun	0	0	144	0	1574	5	3186	10	12899	39	17803	53
Jul	31	0	465	1	1786	5	5852	18	12586	38	20720	62
Aug	77	0	1191	4	4885	15	8534	26	7464	22	22150	66
Sep	0	0	369	1	2519	8	8205	25	10499	31	21592	65
Oct	9	0	366	1	2731	8	4248	13	8550	26	15903	48
Nov	112	0	818	2	2803	8	8290	25	9784	29	21807	65
Dec	381	1	1564	5	6308	19	11510	35	5777	17	25539	77

Table VI.7. **The average monthly areas under different** DTW **categories over Mubarik Distributary command.**

	0-50		50-75		75-100		100-125		125-150		Total (0-150)	
Month	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Jan	1	0	31	0	228	2	811	9	1527	16	2598	27
Feb	2	0	31	0	126	1	857	9	1386	15	2401	25
Mar	6	0	108	1	515	5	1537	16	1010	11	3177	33
Apr	2	0	89	1	453	5	1249	13	1370	14	3164	33
May	0	0	1	0	156	2	658	7	1619	17	2435	26
Jun	0	0	5	0	63	1	518	5	1503	16	2090	22
Jul	0	0	5	0	63	1	554	6	1410	15	2031	21
Aug	2	0	34	0	309	3	1030	11	1523	16	2898	31
Sep	9	0	50	1	398	4	1125	12	1409	15	2992	32
Oct	1	0	28	0	375	4	880	9	1272	13	2555	27
Nov	1	0	31	0	373	4	1159	12	1295	14	2859	30
Dec	0	0	44	0	507	5	1431	15	996	11	2979	31

Table VI.8. **The average monthly areas under different** DTW **categories over** Sirajwah **Distributary command.**

	0-50		50-75		75-100		100-125		125-150		Total (0-150)	
Month	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Jan	2798	14	6424	31	9603	47	1413	7	275	1	20513	100
Feb	1633	8	3283	16	7382	36	6522	32	1343	7	20163	[illegible]
Mar	3986	19	2717	13	9695	47	3564	17	551	[illegible]	20513	100
Apr	2802	14	2356	11	7473	36	7542	37	340	2	20513	100
May	1455	7	1563	8	5945	29	8534	42	2258	11	19756	96
Jun	1342	7	1533	7	3613	18	9110	44	3828	19	19426	95
Jul	1184	6	2286	11	4804	23	8270	40	3084	15	19628	96
Aug	3113	15	3611	18	5082	25	6839	33	1761	[illegible]	20406	[illegible]
Sep	2943	14	1858	9	4677	23	8277	40	2758	[illegible]	20513	100
Oct	2500	12	1430	7	3465	17	6858	33	4610	[illegible]	18863	[illegible]
Nov	2622	13	2869	14	5913	29	7340	36	1672	[illegible]	20415	100
Dec	3787	18	5579	27	8582	42	2059	10	497	2	20503	100

Table VT.9. The **average monthly areas under different DTW categories over Sunder Distributary** command.

	0-50		50-75		75-100		100-125		125-150		Total (0-150)	
Month	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Jan	0	0	449	23	1385	72	101	5	0	0	1936	100
Feb	183	9	1034	53	663	34	56	3	0	0	1936	100
Mar	388	20	1011	52	535	28	1	0	0	0	1936	100
Apr	146	8	805	42	858	44	127	7	0	0	1936	100
May	6	0	390	20	979	51	492	25	0	0	1867	96
Jun	0	0	554	29	879	45	463	24	41	2	1936	100
Jul	30	2	708	37	617	32	511	26	71	4	1936	100
Aug	552	29	776	40	493	25	114	6	0	0	1936	100
Sep	752	39	540	28	367	19	277	14	0	0	1936	100
Oct	275	14	776	40	458	24	411	21	16	1	1936	100
Nov	337	17	940	49	596	31	63	3	0	0	1936	100
Dec	492	25	1088	56	356	18	0	0	0	0	1936	100

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