

**ASSESSMENT OF GROUNDWATER DEVELOPMENT POTENTIAL
IN DISTRICT NOWSHERA USING GROUNDWATER MODELING**

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ABSTRACT

Outside the canal irrigated areas of the Indus Plain, the groundwater is no longer a limitless resource it once was. The reason being that increasing population with passage of time demands increasing water supplies with varying rates at various locations governed by socioeconomic setup of the area. Drastic variability in respect of topography, soil strata and hydrogeology of the Nowshera district covering an area of about 1700 Km² is responsible for vast variation in groundwater availability at various locations. In order to comprehend this complexity of groundwater hydrology, various field investigations were carried out by Hydrogeology Directorate of WAPDA including 1134 electrical probes, 25 test holes, 10 aquifer tests. To estimate future groundwater development potential in different parts of the area, the district area was divided into sub-areas. Groundwater Vistas (GV5) finite difference groundwater model (MODFLOW) was applied to develop 2-D groundwater model for the study area. During model calibration it was found that rainfall recharge to groundwater varies quite drastically across the area. The reasons being variable surface slope, soil strata and natural drainage pattern in the area. Water balance for each subarea as calculated by the model was used to estimate the availability of groundwater for future development. The groundwater approach proved quite useful for estimation of further groundwater development potential in different areas of the district. The results indicate that about 69 cusecs development potential is still available with quite varying rates across the district.

1. INTRODUCTION

The district Nowshera is situated in the center of North-West Frontier Province. It covers an area of about 1700 Km² between latitude 33° 42' to 34° 09' and longitude 71° 41' to 72° 15' (Figure 1). Groundwater generally occurs under watertable conditions with a few local exceptions. Depth to watertable generally varies from 13 to 50 meters below ground level in barani areas whereas it is within 10 m in canal irrigated areas.

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The occurrence of groundwater particularly in barani areas is controlled by climatic and hydro-geologic conditions. Rainfall is the main source of groundwater recharge. Deep percolation from fields and stream losses at various stages of flow coupled with varying properties of the upper soil strata and the underground aquifer are responsible for varied availability of groundwater across the district.

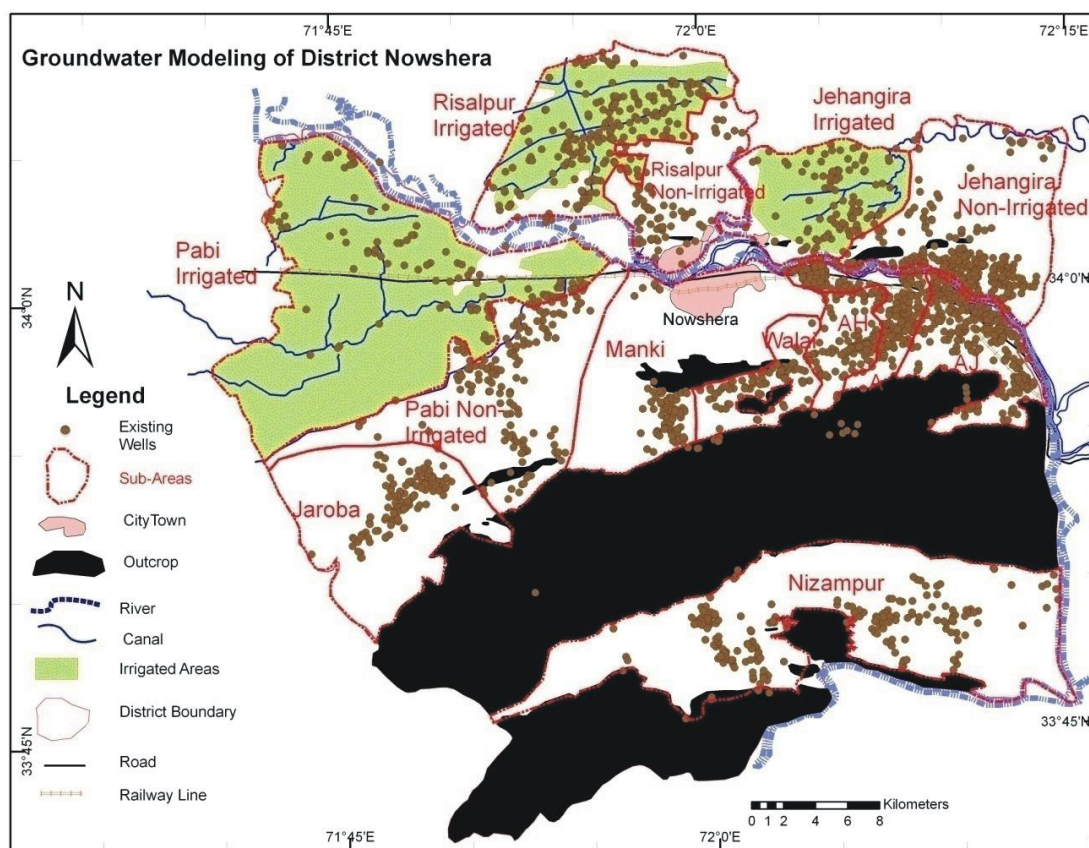


Figure 1: Already installed open/tube wells, sub-areas and other surface features in the area.

The movement of groundwater generally follows the topography which greatly varies particularly in central and southern parts. Groundwater elevation contours for the month of March 2008 in district Nowshera are shown in Figure 2. From this contour map it is clear that groundwater is being discharged to River Kabul in Northern parts of the district and to River Indus in Southern part.

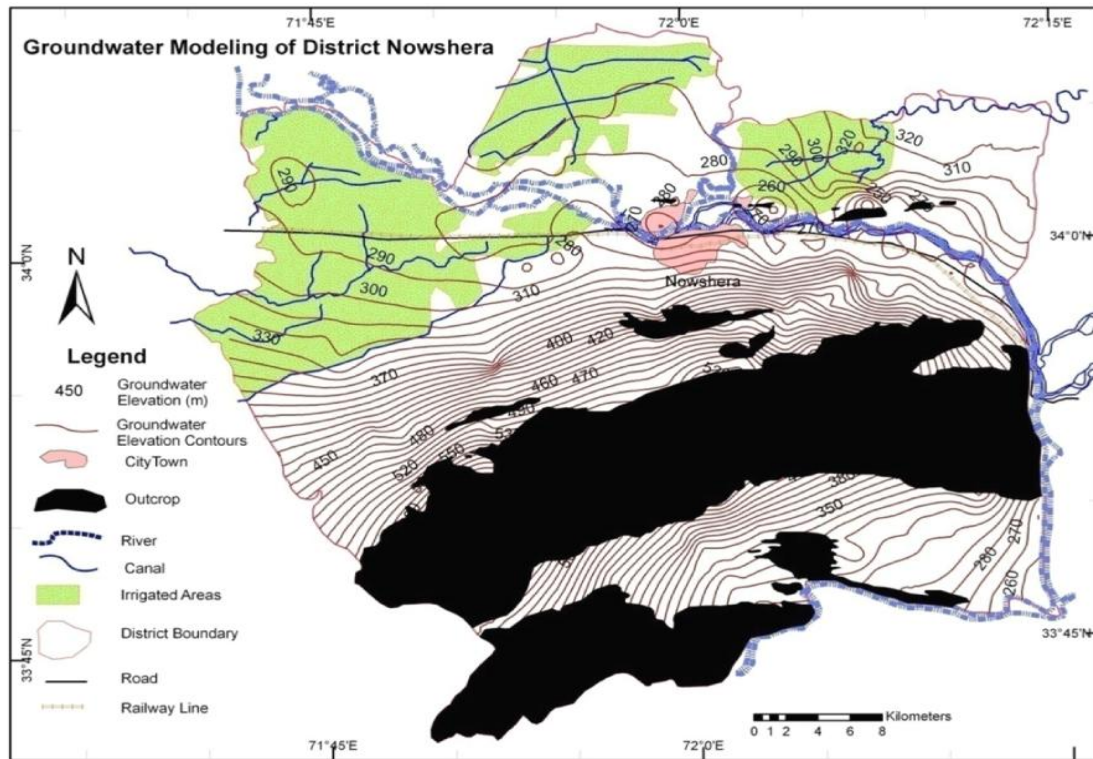


Figure 2: Groundwater elevation contours (m) for the month of March 2008.

1.1 Existing Groundwater Pumping

A substantial amount of groundwater is being abstracted for different uses in the area through water wells. The total amount of abstraction from the area through water wells via the field survey of 2265 water wells has been estimated as 322442 m³/d (132 cusecs).

1.2 Sources of Water in District Nowshera

1.2.1 Rainfall

The average annual rainfall at Risalpur and Cherat during 1988-2007 is 684 and 585 mm respectively. The area receives maximum rainfall i.e. about 60% in the months of February, March, July and August. It is thought that winter rains contribute relatively more to groundwater recharge than monsoon rains which are in form of thunder storms and have more runoff (WAPDA, 2008).

1.2.2 Groundwater

The groundwater is available mostly at the optimum depth for economical exploitation for various uses by the local inhabitants. The shape of groundwater table generally follows the surface topography. The discharge from the groundwater reservoir in the project area occurs mainly through existing water wells and outflow to rivers and evapo-transpiration where the

watertable is near to the ground surface particularly in areas adjacent to the rivers.

The depth to groundwater along the Kabul and Indus rivers and in canal irrigated areas in western part is generally less than 10 m while it is more than 30 m for areas at higher elevations. The watertable in the district rises during rainy season (July and August) and declines during dry season (October to December) when the groundwater abstraction is higher (WAPDA, 2008b).

1.2.3 Canal supplies

In Northern and Western parts of the area the canal irrigated land is 20628 hectares and served by irrigation channels 136856 m long. An appreciable amount of water is percolating to groundwater from irrigation application and channel loses.

2. GROUNDWATER MODEL DEVELOPMENT

Nowshera district of North West Frontier Province (NWFP) was modeled with the main objective to find out the remaining potential for groundwater development in the area particularly for areas having rainfall as the only source of groundwater recharge. The district map which is also the study area is shown in Figure 1 with different surface features as canal irrigation system, River Kabul in the upstream joining with River Indus at Khairabad along with distribution of existing production wells.

The Natural Surface Elevation (NSL) varies steeply in the Southern part of the district. Due to steep surface slopes leading to steep groundwater slopes, very fine grid i.e. 200 meters spatial resolution was superimposed on this area for the purpose of discretizing the aquifer for groundwater modeling. A steady state 2-D (single layer) groundwater model was developed. The main objective of groundwater modeling of the area was to assess the available groundwater development potential in different parts of the district, in addition to the pumpage being done at present.

2.1 Geographical Information System (GIS):

To handle such a large area for the purpose of groundwater modeling, accurate hydrologic surface features are required along with Natural Surface Elevations (NSL). For this purpose, satellite images covering the whole area (year 2007) having 10 meter spatial resolution were used. The different surface features of hydrologic importance such as rivers, canals and irrigated areas were digitized from these images using ArcGIS software.

Boundary of the district was digitized in AutoCAD from the already available district map. It was geo-referenced in GIS and superimposed on the satellite image with the same reference coordinate system. From the satellite image the canal system was digitized keeping in view the district map for cross reference. The Kabul River in upper part and the River Indus in lower part was also digitized in the same

wells were displayed in GIS software (ArcGIS) using their Lat/Long coordinates along with their data. The groundwater elevations data was imported in SURFER 8 for preparing groundwater elevation and depth contour maps for the month of March 2008. This contour map was then imported in ArcGIS to superimpose on the already developed map having surface features with it. This provided a good picture to judge the groundwater flow patterns in the area. From these contours, one can see that the groundwater is flowing into the river, both in Northern and Southern parts of the district. At the same time there is hardly any possibility of the river recharging the groundwater except only in the adjoining areas and that too during high river stage.

2.2.3 Natural ground surface elevations

To represent the top layer of the model, fairly accurate natural surface elevations (NSL) were needed. For this purpose, the Shuttle Radar Topography Mission (SRTM, 2000) data available on the internet was downloaded and used after screening for removing spikes and dips i.e. removing errors in the data. The data consists of average elevation of the pixel (90m by 90m) in the raster format. The data was converted to point format with 200 m resolution and was imported in the groundwater model to serve as the NSL in the top layer of the groundwater model.

3. MODEL DESIGN AND SURFACE HYDROLOGIC FEATURES

The hydro-geological investigations carried out in the District revealed that the aquifer is heterogeneous and its depth ranges from 33 to more than 200 m. Sub-surface strata varies rapidly across the area with respect to type of rocks present, lateral and vertical permeability, storage coefficient and specific yield. Therefore keeping in view the availability of the data, a two dimensional model was applied, consisting of unconfined groundwater flow. In the water table aquifers, the water is derived from storage by drainage of pores, expansion of water and compaction of aquifer matrix. The governing equations incorporating Dupuit-Forchheimer assumptions applicable to such a situation for unsteady groundwater flow are as below;

$$\frac{\partial}{\partial x} \left(K_x h \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_y h \frac{\partial h}{\partial y} \right) - R = S_{ya} \frac{\partial h}{\partial t}$$

For steady state situation i.e. with no change in storage in the aquifer over the time period considered in the above equation reduces to;

$$\frac{\partial}{\partial x} \left(K_x h \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_y h \frac{\partial h}{\partial y} \right) = 0$$

Where $R = R(x, y, z, t)$ is the recharge volume per unit aquifer volume at the point (x, y, z) at time t and have dimensions of T^{-1} , h = potential over the flow domain and K_x, K_y = hydraulic conductivity in the x and y directions. However the

variability in hydraulic conductivity was taken into account using zones having same value of conductivity both for x and y directions.

3.1 Model Design

Groundwater Vistas (GV5) finite difference groundwater modeling software was used to develop the groundwater model for the District Nowshera. Groundwater Vistas (GV) provide a unique groundwater modeling environment for Microsoft Windows which couples a powerful model design system with comprehensive graphical analysis tools. GV is a graphical design system for MODFLOW and other similar models, such as MODPATH and MT3D. GV displays the model design in both plan and cross-sectional views using a split window (both views are visible at the same time). Model results are presented using contours, shaded (color coded) contours, velocity vectors, and detailed mass balance analyses is possible for any area of interest (ESI, 2007). An area of 54.2 Km in East-West direction and 43.0 Km in North-South direction was selected for groundwater modeling covering the whole district but leaving the rock outcrop area in Southern direction. The model domain was discretized using a cell size of 200 m in both directions resulting in 58265 total cells. This resulted in a regular mesh of 215 rows and 271 columns. Out of these, 25829 cells falling out of the district boundary and under outcrop area were declared as no flow cells.

Pump out tests conducted in the project area by Hydrogeology Directorate of WAPDA, are well spread and show that the aquifer is very much complex and non-homogeneous. To simplify the situation, a one layer model was developed with different aquifer depths in different areas mostly ranging from 120 m to 200 m. The top elevation of the model area was obtained from SRTM data as mentioned earlier. The bottom elevation of the aquifer was obtained by subtracting 150 m from the model at respective cells and then adjusted for above mentioned aquifer thicknesses in different areas according to test holes data and newly installed tube wells by the department.

3.2 Boundary Conditions for the Model

Different surface features of hydrologic importance were digitized in GIS software to act as reference map for the modeling software. The following boundary conditions were required for the model.

- a) **Irrigation channels losses:** The irrigation canals upto distributary level i.e. distribution channels of Hazar Khani, Kabul and Warsak canals along with their distribution channels lying on Western side of Kabul River and distribution channels of Swat canal and Keshgi and Zarda branch systems etc. on the Northern side of the Kabul River were digitized from the Sattelite image using ArcGIS software and imported in Groundwater Vistas Model as background map. These line source of recharge were added in the groundwater model in the form of recharging wells. The recharge at any location depended upon the wetted perimeter of the channel at that location. The data of wetted perimeter of the irrigation channels at appropriate locations as provided by NWFP Irrigation and Power Department was used.

- b) **Recharge from field application and rainfall:** Recharge from the top surface in the form of rainfall in barani areas and seepage losses from the watercourses and field irrigation application in irrigated areas were added to the model. For this purpose different recharge zones were specified in the model area. Rainfall losses were also added to irrigation application losses and were added at constant rates as depth units per time (m/day). For this purpose three irrigation recharge zones were digitized from the satellite image. The recharge rate was finalized to a value of 0.0005 meter per day in irrigated areas. Rainfall in the district is being measured at two station i.e. Resalpur and Cherrat. Twenty percent of this rainfall (as a starting value) was taken as being recharged to groundwater in areas without irrigation. This recharge rate was adjusted finally to the following values i.e. 0.0003125, 0.000375, 0.00039 and 0.00044 m/day, in different recharge zones during model calibration as shown in Figure 4.

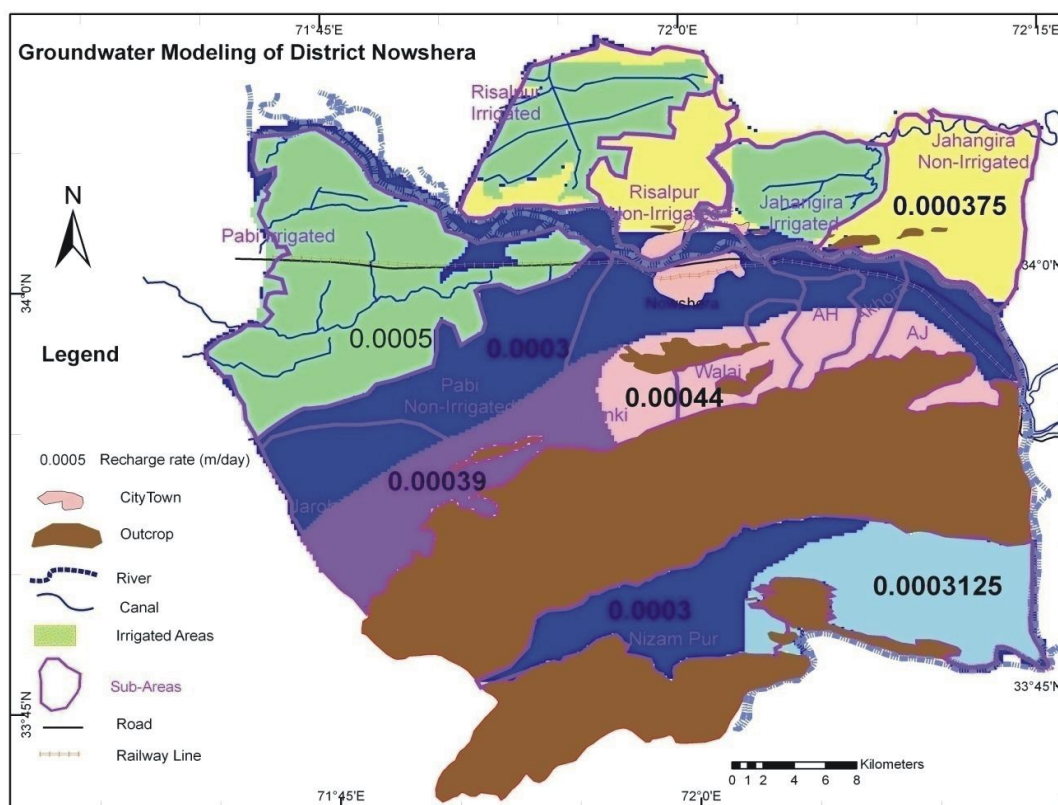


Figure 4: Different recharge zones with recharge values ranging from 0.0003 to 0.0005 m/day depending upon irrigated, barani and near to outcrop areas.

- c) **No Flow areas:** Geological outcrop areas falling in the model area was digitized and declared as no flow cells so that groundwater flow does not take place in these outcrop areas.
- d) **Existing Tubewells:** Existing water wells falling in the model area were required to be installed along with their estimated pumping volumes in the

model for proper calibration. For this, GPS coordinates of all the tubewells collected by Hydrogeology department along with the estimation of groundwater being pumped by these wells in different sub-areas were used. These sub areas are not separate hydrologic units but framed out only to facilitate the field work by the department. The GPS coordinates were used to display these wells in GIS as shown in Figure 1.

The estimated pumping for these nine sub-areas was fed in the model at appropriate locations where existing tubewells were pumping groundwater. These wells were fed in the form of well package discharging @ of 200 to 306 m³/day (0.0816 to 0.125 cfs) at steady state without any closure time. Thus a lesser number of pumping wells were installed as compared to the actual existing number and at the same time pumping at less rate but with out any break. The total estimated pumping in these sub-areas was, however equal to the actual pumpage as collected from the field.

- e) **Evapotranspiration:** The total pan evaporation of 1.735 m per year takes place in the area. The same rate of evapotranspiration i.e. 0.00475 meter per day was applied to each model cell with an extinction depth of 3.048 m (10 ft). If the watertable in any cell is below this depth from the NSL no evaporation takes place from the watertable, otherwise the evaporation is calculated by the model by a built in function which exponentially reduces the rate to zero when watertable is more than 10 ft depth. Usually the groundwater is deep at most of the places in the district. Only the cells mostly adjacent to the river have shown evapotranspiration taking place during model simulation.

4. MODEL CALIBRATION

Calibration is the process by which the independent variables (parameters and fluxes) of a model are adjusted, within reasonable limits to produce the best match between the simulated and measured data (usually from groundwater level monitoring). This process involves refining hydraulic properties and boundary conditions of the model to achieve the desired degree of correspondence between the model simulation and observations of the groundwater flow system. Because actual fluxes like tubewell discharges in the area were collected through a detailed field survey, so these tubewell discharges were not changed during calibration. The remaining parameters like hydraulic conductivity, aquifer thickness, rainfall and irrigation recharges were adjusted until the model simulated contour map well matched with the actual groundwater elevation contour map of March 2008. The model was run several times, and during the process the boundary conditions and parameter values were adjusted until fairly accurate agreement was found between field observed watertable and the corresponding model simulated values. In total 128 targets consisting of observed water levels were added to the model for calibration purposes. The following calibration parameters were achieved in this process:

$$\text{Residual Mean} = -0.039,$$

Residual Standard Deviation = 2.08,
 Residual Sum of Squares = 113.03,
 Absolute Residual Mean 1.49, Minimum Residual = -5.6,
 Maximum Residual = 4.3.

5. RESULTS OF SIMULATIONS

The groundwater model was run on steady state basis. Model simulated groundwater elevations calculated by the model exported in GIS shape format and displayed in GIS map of the district are shown in Figure 5. The Groundwater Vistas modeling environment has the capability to display the simulation in a number of formats. Using this ability of the software, mass balance results were obtained from the model on whole model area as well as sub-area basis. The results are discussed in detail as below.

5.1 Groundwater Elevation Contours:

In the existing situation on steady state basis the model has simulated groundwater elevations at each model cell. The watertable elevation contour map based on steady state situation in the area is shown Figure 5.

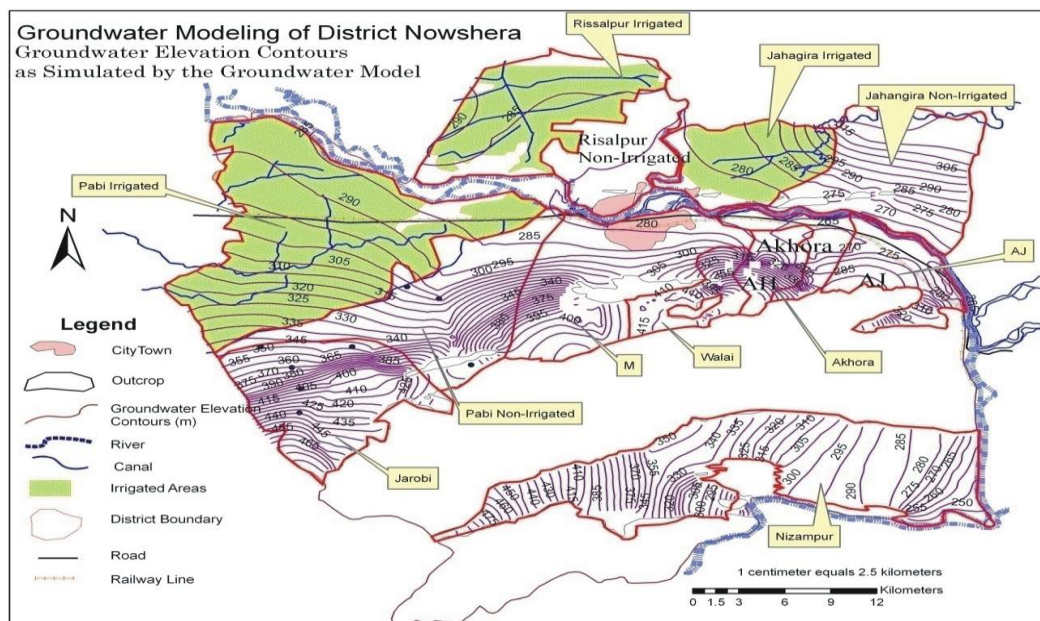


Figure 5: Groundwater elevation contours (m) as simulated by the model showing existing steady state situation along with division of sub-areas in red color boundary.

This figure has been exported from the groundwater model software. The groundwater elevation contours show that the canal system in the area has a major contribution to groundwater recharge from the surface in irrigated areas. This fact is revealed by the downward curvature of the contours at these locations. At the

same time a relatively higher rate of groundwater pumpage is causing the contours to have an upward curvature.

The groundwater Vistas software can provide model simulation results in many different ways according to the requirement. However, the water balance on the whole model domain basis and on sub-areas basis i.e. tubewell abstraction areas on steady state basis was obtained from the model.

5.2 Water Balance for the Whole Model Domain:

The Table 1 gives the overall water balance of the model area simulating the existing steady state situation.

Table 1: Water balance for the whole model domain.

Description	Inflow (m ³ /day)	Outflow (m ³ /day)
Recharge (rainfall + irrigation losses)	484592.1	0.0
ET	0.0	62170.8
River	54223.6	237051.0
General Head Boundary	64876.6	4116.0
Canal seepage losses	22086.7	0.0
Existing production wells	0.0	322442.8
Total	625779.0	625780.6

**Inflow means:* flow coming into the model domain.

**Outflow means:* flow going out from model domain.

As given in Table 1 above, the model simulation of the groundwater flow of the area has shown that the largest outflow from the groundwater in the area is towards the River Kabul and Indus in the model area i.e. @ 237051 m³/day (96.8 cfs). The second outflow is in the form of evapotranspiration in areas where watertable is within 10 feet depth. These areas are mostly in the form of narrow strips along the river with lower Natural Surface Elevations (NSL), and also in irrigated areas with shallow groundwater depth. This evapotranspiration takes place @ 62170.7 m³/day (25.39 cfs). So this part of groundwater flow i.e. available for development is only along the rivers and in irrigated areas which may already be using groundwater more or less equal to the requirement of the area, so this outflow is considered to be mostly available in areas where it may not be required. The third outflow is the current groundwater abstraction @ 322442.8 m³/day (131.69 cusecs).

So, only two types of outflows from the model area can be captured and that also not to the full extent. These are the groundwater flows towards river Kabul and Indus and the evapotranspiration taking place in areas with watertable near to the ground surface.

5.3 Water Balance on Sub-area Basis:

In order to be more site specific for future potential of groundwater development, the water balance was obtained for sub-areas (as defined earlier) used for current tube well abstraction estimates by the department. The water balance for these areas is given in Table 2.

Table 2: Water balance for different sub-areas of the model domain as simulated by the steady state groundwater model developed for the Nowshera District.

Sub-Area	Inflow Components (m ³ per day)					Total Inflow	Outflow Components (m ³ per day)					Total Outflow	Error %
	Adjoining Areas	Canal Seepage	River	GHB	Surface Recharge		Adjoining Areas	Well Pumpage	Outflow to River	ET	GHB		
Nizampur	0	0	2331.0	0	61609.5	63940.5	0	23562	38892.2	1487.9	0	63942.2	-1.62
Akora-Jehangira	3808.3	0	7547	0	16186.8	27542.1	2179.7	24098	1161.6	103.4	0	27542.9	-0.76
Akhora	16568.5	0	5246.5	0	9056	30871.0	3713	26112	1025.2	20.3	0	30870.5	0.55
Akora-Havai	5250	0	0	0	8547.2	13797.2	3595.2	10202	0	0	0	13797.2	0.02
Walai	1011.6	0	0	0	11321.6	12333.2	4097.4	8236	0	0	0	12333.4	-0.14
Manki Sharif	9414.3	0	1375.4	0	37954.4	48744.1	20281.6	7344	21118.5	0	0	48744.1	0.02
Pabi Non-Irrig	51584.9	742.3	123	0	36400.4	88850.6	45150.2	37638	5944.4	117.9	0	88850.5	0.07
Jarobi	6231.5	0	0	0	35950.8	42182.3	25352.3	16830	0	0	0	42182.3	-0.05
Pabi Irrigated	63314.8	9609.7	5439.4	0	114760	193123.9	43093.1	36144	59349.5	54537.2	0	193123.8	0.08
Risalpur Irrigated	4682.0	4881.9	395.91	35182	50956	96097.9	21778.7	57586.21	14214.9	1599.1	919	96098.0	-0.05
Risalpur Non-Irrig.	20910.5	600	3209.2	0	22202	46921.7	18769.6	6864.6	20583.0	704.3	0	46921.6	0.08
Jehangira Irrigated	38187.8	2290.4	9538.6	0	30991.2	81007.9	27157.3	21114	32636.8	99.8	0	81007.9	-0.02
Jehangira Non-Irrig.	14988.4	3444.3	3957.7	29695	39720	91805	36125.97	45900	6581.8	0	3197	91804.9	0.13

In order to conclude and recommend groundwater development potential in the sub-areas the outflows from Table 2 which can be tapped for future development are summed in Table 3. Out of this total groundwater development potential 50% is considered to be available for future development for most of the sub-areas. The same has been mentioned in the last column of Table 3. It may be observed from Table-3 that the maximum development potential is 23.26 cusecs for sub-area Pabi irrigated area followed by Nizampura sub-area with exploitable potential of about 8.0 cusecs. The lowest value of development potential is 0.42 cusecs for Akhara Sub-area.

Table 3: Groundwater Development Potential in different sub-areas of the District.

Sub-Areas	Area (m ²)	Existing Pumpage (m ³ /day)	Existing outflows which can be taped (only Italic & Bold has been summed up in Column 8) (m ³ /day)				Available potential (m ³ /day)	Proposed development potential (50% of Column 8) (ft ³ /sec)
			Groundwater Exchange (Outflow-Inflow)	Outflow to adjoining areas	Out flow to River	ET		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)= (4)+(5)+(6)+(7)	(9)
Nizampur	204,589,558	23562	0	0	38892.24	1487.92	38892.24	7.94
Akora-Jehangira	45,549,896	24098	-1628.5	2179.7	1161.65	103.44	1161.65	0.47 *
Akhora	25,436,637	26112	-12855.5	3713	1025.17	20.32	1025.17	0.42 *
Akora-Havai	23,828,945	10202	-1654.8	3595.2	0	0	3595.2	1.47 *
Walai	29,581,942	8236	3085.7	4097.4	0	0	3085.7	0.63
Manki Sharif	116,687,653	7344	10867.3	20281.6	21118.5	0	31985.8	6.53
Pabi Non-Irrig.	117,861,578	37638	-6434.7	45150.2	5944.4	117.98	5944.4	1.21
Jalozai/Jaroba	104,147,374	16830	19120.8	25352.3	0	0	19120.8	3.91
Pabi Irrigated	223,257,456	36144	-20221.6	43093.1	59349.46	54537.2	113886.6	23.26
Risalpur Irrig.	102,524,844	57586.21	17096.8	21778.7	14214.96	1599.16	31311.8	6.40
Risalpur Non-Irrigated	59,269,521	6864.6	-2140.9	18769.6	20583	704.39	20583	4.20
Jehangira Irrigated	63,520,587	21114	-11030.5	27157.3	32636.87	99.82	32636.87	6.67
Jehangira Non-Irrig.	103,742,285	45900	21137.6	36125.97	6581.8	0	27719.4	5.66
Total							330948.6	68.78

This total development potential in all the district sub-areas sums up to 68.78 cfs. However this additional development in one area may affect the groundwater in the adjoining areas, particularly this will be the situation in case of Akora-Jehangira, Akora, Akora-Havai, Manki Sharif and Walai areas. Keeping in view this interaction of groundwater between these areas, outflows in some of the areas i.e. Akhora and Akhora-Havai were not taken into account while calculating groundwater potential for these areas.

SUMMARY AND CONCLUSIONS

Due to relative abundance of surface water resources and the fragmented nature of the landscape, reliance on groundwater in NWFP province has generally been lower in past. The local government of District Nowshera has taken a passive

* In these three cases, 100 % of column 8 has been adopted to be available for future development. It is assumed here that outflows from adjoining areas will compensate for this bit higher development.

attitude towards groundwater development/management with the result that local population started groundwater development on its own. But the problems that local community is facing with in the installation of tube wells is the lack of credible information about the aquifer properties and water availability at local scale. However, recently the local government entrusted the work of hydro-geological investigations for estimation of groundwater development potential to WAPDA. In order to comprehend hydro-geology of the area, various field investigations were carried out by Hydro-geology Directorate of WAPDA consisting of 1134 electrical probes, 25 test holes, 10 aquifer tests. In order to tackle the second part i.e. to estimate groundwater development potential in the district a steady state 2-D (single layer) groundwater model was developed. Data regarding aquifer parameters, irrigation system, existing annual groundwater pumpage and groundwater table observations well distributed in the district were used for calibration of the model. The project area was divided into sub-areas and water balance for each was obtained from the model in order to estimate further groundwater development for each sub-area. Following conclusions are drawn from the work;

- Movement of groundwater generally follows the topographic configuration of the area and generally it is north to south in northern part and south to north in central part towards Kabul river, whereas it is north west to south east towards Indus river in southern part with some local variations.
- The groundwater in the project area is recharged mainly by precipitation and seepage from canal irrigation in irrigated areas. Rainfall is however the only source of recharge for un-irrigated areas. The subsurface inflow from adjoining areas is taking place only from northern side of the District across the Kabul River.
- The total recharge to the groundwater (including minor contributions from Kabul and Indus Rivers) in the area as determined by groundwater model is 625779 m³/d (255 cusecs).
- The total groundwater abstraction from the area, at present, has been estimated as 132 cusecs by field survey.
- The available groundwater potential has been estimated as 330949 m³/d (135 cusecs) out of which about 50% i.e. 168373 m³/d (68.78 cusecs) is proposed for future groundwater development on District basis in order to avoid mining of the precious resource.
- Rainwater harvesting and other recharge measures can play a significant role in enhancing the groundwater potential for sustainable development in the area particularly the barani areas. The local government can take up the construction of check dam structures at appropriate locations after a thorough study of surface water hydrology of the area. These activities will reduce surface runoff to Kabul/Indus Rivers, reduce pressure on groundwater exploitation and increase rainfall recharge to groundwater reservoir of the area.

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