CALIBRATION AND VALIDATION OF PMWIN MODFLOW WITH TANDO MUHAMMAD KHAN DISTRIBUTARY COMMAND AREA

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Abstract
Since Sindh is in the lower reaches of the Indus River, it is most vulnerable to a variety of upstream water development challenges. To overcome these challenges, HEC has launched the project "Sustainable Freshwater Management (LIB) for Irrigated Agriculture in the Lower Indus River Basin". Under the umbrella of this project, Muhammad Khan's distributary was selected as the study. The aim of this study is to Calibrate and validate PMWIN MODFLOW with Tando Muhammad Khan distributary command Area to highlight the groundwater potential. Documented pumping test data located in Muhammad khan distributary command area was simulated in PMWIN MODFLOW software to determine Sustainable usage of groundwater. For PMWIN MODFLOW the input data was obtained from distributary via pumping test and from already calculated data from various literatures. There were two tube-wells (head and tail); both were given no flow conditions in boundary conditions of mesh. The head values obtained at different intervals were used to calibrate and validate as well. Discharge was kept 70.5 m3/hour. The calibration was performed on a single time whereas for validation two simulated runs were generated. To verify the results, the root mean square deviation was calculated which states that the results are less than 10%. Time versus Hydraulic Head graphs presented to illustrate the conclusions graphically of the calibration and validation of the model.

1. Introduction

The freshwater resources, like water from precipitation and getting into streams, rivers, lakes, and groundwater, provide people with the water they have a day to measure. Water existing on the surface of the world is straightforward to see, and your view of the water cycle could be that rainfall fills up the rivers and lakes. But groundwater is critically important to life [1]. Groundwater is the water that is found in the spaces and splits of soil, rock and sand. It moves gradually through geologic formation of 'Aquifers' (soil, sand, and shakes). As the world's biggest circulated store of water, groundwater has a focal impact in continuing biological systems and empowering human variation to atmosphere fluctuation. The arranged significance of groundwater for worldwide water and food security will presumably reinforce under worldwide environmental change as more successive and serious atmosphere boundaries (dry seasons and floods) increment [2]. Sindh has been severely affected by the climate change because its seventy percent of its groundwater is saline. Out of 55 Million-acre feet (MAF) groundwater of Pakistan, the provinces of Punjab and Sindh have 35 MAF and 20 MAF respectively. In most of the areas of Sindh, groundwater is mixed with the canal water before it is utilized for the purpose of irrigation. In 1960, there were 20, 000 tube wells in Pakistan were about 20,000. Now, the number of tube wells is over a million. According to a report, "this immoderate and unplanned installation of tube wells has changed the hydro-salinity behavior of the Indus basin and groundwater is depleting in many canal commands and almost altogether urban settlements. Almost, 50% of Pakistan's total irrigation supply is given through groundwater abstractions. During the last decade, the rate of groundwater abstraction has risen to 60 km3, from the yearly recharge rate of 55 km3 [3]. Such a long overdraft has given birth to concerns of the sustainability of asset of the groundwater assets in the region. The use of tube-wells on a large scale is a key element or a role in changing the profile of Pakistan with respect to agriculture for an extended time. However, the noticeable increase in the uses of tubewells started in the 1960s when the irrigation system, on a large scale, without adequate drainage started to cause the issues of salinity and waterlogging [4]... According to the United States Geological Survey (USGS), MODFLOW (a finite-difference groundwater flow modeling program) allows you to develop a numerical representation of the hydrogeological environment at the field site which is under investigation. It very well may be arranged and cured by handy applications. On account of the structure and fixed information design, MODFLOW can be coordinated with geographic data frameworks (GIS) for groundwater asset the board. MODFLOW is a PC program that mathematically fathoms the three-dimensional groundwater stream condition for a permeable medium by utilizing a limited contrast strategy [5]. In the Sindh province, about 36% of the population consumes water that is contaminated with Arsenic. The presence of arsenic in water may cause hypertension, skin discoloration, keratosis, cardiovascular diseases, black foot disease, diabetes, and common deformities of the lungs, skin and bladder. Another test data shows that, 68% of the countryside inhabitants consume low quality portable water. Due to saline water, the occurrence of diseases related to stomach such as (vomiting, kidney, skin problems, and gastroenteritis, in the southern districts, of Sindh Province, Pakistan.)" [6]

2. Method

The Command Area of Tando Muhammad Khan has been chosen for this study. Head Regulatory coordinates are 25.2606634 N and 68.5789813 E. 59 cusecs is the discharge if the distributary and it off-takes from the right of main Rohri canal at RD-1038. The research region includes gross commanded area (GCA) of 22618 acres and a cultural command area (CCA) of 22213 acres. The distributary has 18 outlets of the distributary. The commencement of a distributary is located at coordinates 25.2417604° N and 68.579753° E, whereas the end is at 25.21235° N and 68.565833° E.

3. Observation of Data

To create a groundwater model with the MODFLOW we need the following data from the head and tail of our study area: • Depth of Impervious Layer. • Time. • Initial Hydraulic Head. • Horizontal Hydraulic conductivity. • Vertical Hydraulic conductivity. • Effective porosity. • Boreholes and observations. • Hydraulic conductivity. • Recharge. • Discharge. • Specific Yield. • Specific Storage. • Transmissivity.

Table 1: *Observation of Data*

Observation Well No.	Distance from the well (m)	Observation Well No.	Distance from the well (m)
1	7.70	1	18.90
2	18.50	2	39.30
3	39.40	3	62.20

4. *Groundwater Modeling with PMWIN*

A groundwater model is generated by choosing New Model from the software's File Menu. The model grid's dimensions are constructed by selecting Mesh Size from the Grid menu. Next, state the geometry of the model and regulate the model boundaries. Execute the flow simulation by taking MODFLOW and then opt for Run from the Models Menu. Upon finishing the flow simulation, you may utilize the modeling tools provided by PMWIN to evaluate the results. Data collected from the field now comes into account for the determination of the required parameters. These parameters are listed below:

Table 2: *Data Parameters*

Sr no.	Parameters	Sr no.	Parameters
1	Tube-well depth.	9.	Boreholes and Observation
2	Lithology of Underground Soil.	10.	Hydraulic Conductivity
3	Depth of Impervious Layer.	11.	Recharge
4	Time.	12.	Discharge
5	Initial Hydraulic Head.	13.	Specific Yield.
6	Horizontal Hydraulic conductivity.	14.	Specific Storage.
7	Vertical Hydraulic conductivity.	15.	Transmissivity
8	Effective porosity.		

Table 3: *Model's generated domains for head reach Tube-well spatially discretized*

Dimensions of Grid = 1000 m x 1000 m						
Number of columns = 25		Number of Rows = 25		Number of Stratums = 4		
Digits (Diagram arranged)	Size (m)	Number (From top to bottom)	Size (m)	numeral		Thickness (m)
1-12 and 20-25	40	1-12 and 20-25	40	1.	Semi confined strata	5.0572
13 and 19	13.34	13 and 19	13.34	2.	Sandy layer till top of strainer	28.469
14 and 18	4.45	14 and 18	4.45	3.	Formation thickness lower than bottom of strainer	-15

Table 4*: Model's generated domains for Tail reach Tube-well spatially discretized*

Dimensions of Grid = 1000 m x 1000 m					
Number of columns = 25		Number of Rows = 25		Number of Stratums = 4	
		Row		Stratum	
Digits (Diagram arranged)	Size (m)	Number (top to bottom)	Size (m)	Number	Thickness (m)
1-12 and 20-25	40	1-12 and 20-25	40	1. Semi confined strata	5.891
13 and 19	13.34	13 and 19	13.34	2. Sandy layer till top of strainer	0.204
14 and 18	4.45	14 and 18	4.45	3. Formation thickness lower than bottom of strainer	36.574
15-17	1.48	15-17	1.48	4. Formation thickness lower than bottom of strainer	-15

Table 5: *Input aquifer hydraulic Parameters Range* [7]

Aquifer		
Parameters	**Range**	**Data Source**
Horizontal Permeability (m/hr)	**1.3519 - 2.739 (JRS-57)** **1.2569 - 1.708 (JRS-60)**	**Present study calculated**
Vertical Permeability (m/hr)	**0.00275 - 0.26335 (For the Nawabshah Project Area)**	**GDC/BGS, 1990**
Porosity (dimensionless)	**0.002853 - 0.26335**	
Specific Storage (1/m)	**0.2 - 0.4** **.0000249 - 0.001206 (JRS-57)** **0.000014 - 0.000168 (JRS-60)**	**Present study calculated**
Semi-confining layer		
Horizontal Permeability (m/hr)	**0.08333 m/hr (Used for Design of Scavenger Wells in Nawabshah and Sanghar components)**	**GDC/BGS, 1990**
Vertical Permeability (m/hr)	**0.002853 - 0.26335**	
Porosity (dimensionless)	**0.3**	
Specific Yield (Fraction)	**0.2 – 0.25**	

Table 6: *Model domains' vertical discretization for Head reach and Tail reach tube-wells*

Layer No.	Thickness of layer (m)	Depth of layers bgl (m)	Elevation of top layer (m)	Elevation of bottom Layer (m)	Discharge of well in each layer (m^3/hr)
			Tail Tube-well site		
1	5.8915	5.8915	42.670	36.778	--
2	.204	6.0955	36.778	36.574	--
3	36.574	42.670	36.574	0	70.5
4	15	57.670	0	-15	---
				Total discharge (Qt)	70.5
			Head Tube-well site		
1	5.0572	5.0572	33.5262	28.469	--
2	28.469	33.5262	28.469	0	70.5
3	15	48.5262	0	-15	
				Total discharge (Qt)	70.5

5. RESULTS

Model calibration might be a transformative cycle in which progressive alterations and adjustments to the model depend on the aftereffects of past simulations [8]. The modeler must choose when enough alterations have been made to the parameters and measures sooner or later acknowledge the model as being satisfactorily adjusted (or maybe reject the model as being insufficient and look for different methodologies). The decision is mostly taken based on the combination of particular and neutral criteria. The accomplishment of the best fit between estimations of watched and figured factors is a regression strategy and can be assessed accordingly. That is, the remaining mistakes ought to have an imply that approaches zero and the deviations ought to be limited. Cooley (1977) talks about a few factual estimates that can be utilized to evaluate the dependability and "decency of fit" of groundwater flow models. The precision tests ought to be applied to however many dependent factors as possible.

In current study, The Simulation Periods for Head Tube-well were,

- 5 hours
- 6 hours
- 7 hours

Were assigned to the model for the Head tube-well head reach and in these stress periods there was continuous pumping.

The simulation periods for tail Tube-well were:

- 4.667 hours,
- 5.667 hours,
- 6.667 hours

Graphical illustration of the observed data calibrated with calculated data via PMWIND MODFLOW At both the beginning and end of the Muhammad Khan Distributary, the information is provided below:

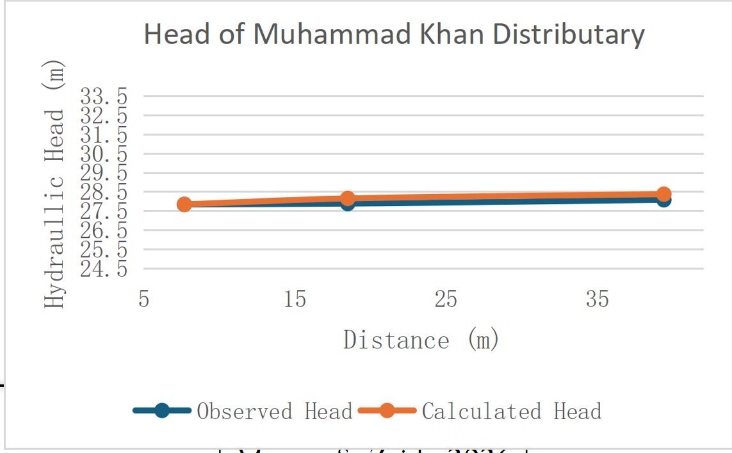

Figure 1: Total simulation period's division into stress periods for Head Tube-well

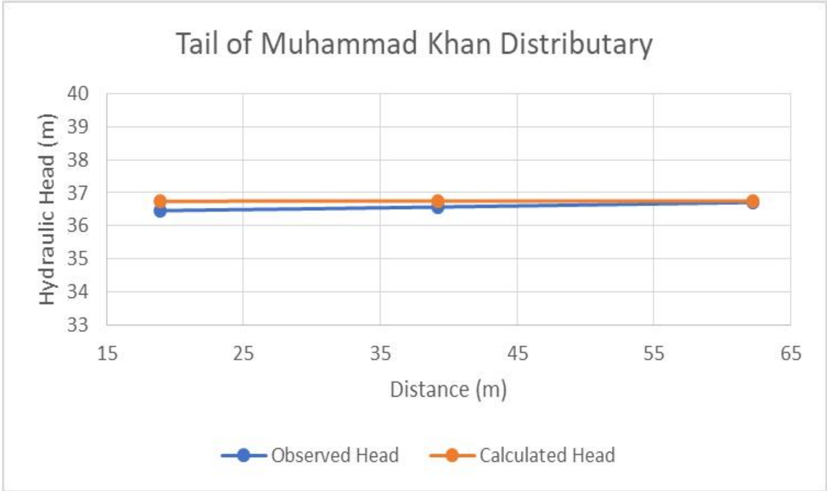

Figure 2: Hydraulic Head vs. Distance at 4.667 hours duration

Table 7: *Total simulation period's division into stress periods for Head Tube-well.*

STRESS PERIOD	INTERVAL OF STRESS PERIOD (HOUR)	TOTAL INTERVAL OF STRESS PERIODS (HOUR)	STATUS	AVAILABILITY OF RECORDS
1	5	5	Pumping	Available
2	6	11	Pumping	Available
3	7	18	Pumping	Available

Table 8: *Total simulation period's division into stress periods for Tail Tube-well*

STRESS PERIOD	INTERVAL OF STRESS PERIOD (HOUR)	TOTAL INTERVAL OF STRESS PERIODS (HOUR)	STATUS OF PUMPING	AVAILABILITY OF RECORDS
1	4.667	4.667	Pumping	Available
2	5.667	10.334	Pumping	Available
3	6.667	16.00	Pumping	Available

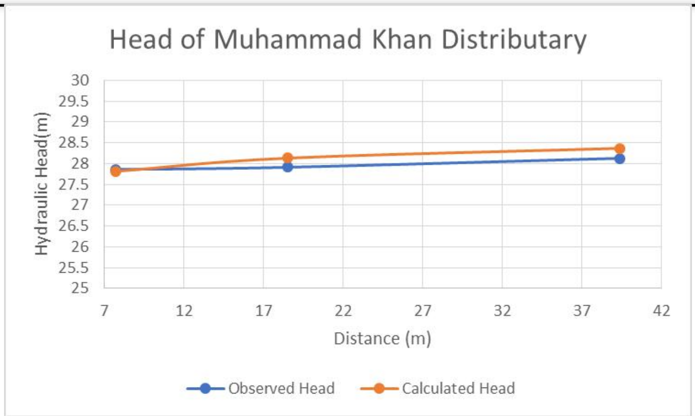

Figure 3: Hydraulic Head vs. Distance in 5 hours duration

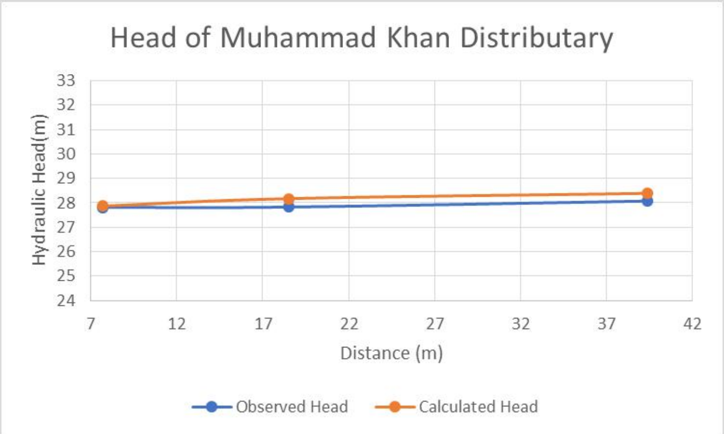

Figure 4: Hydraulic Head vs. Distance in 6 hours duration

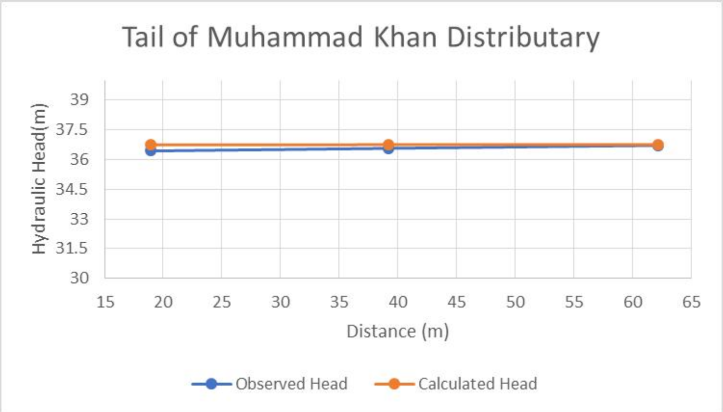

Figure 5: Hydraulic Head vs. Distance at 4.667 hours duration

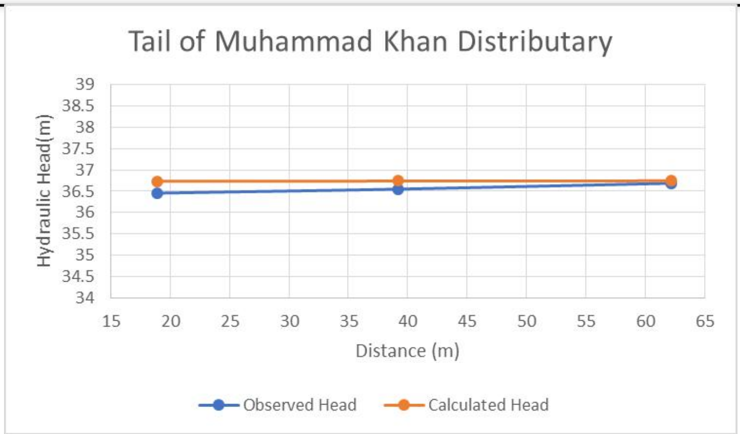

Figure 6: Hydraulic Head vs. Distance in 6.667 hours duration

Table 9: *Root mean square deviation values for the observed and simulated hydraulic*

Calibration Run	Validation Runs	
	Run-(1)	Run-(2)
	Head Tube-well	
0.070	0.0983	0.109
	Tail Tube-well	
0.0577	0.072	0.045

Above Table shows that the values of rms (root mean square vary from **0.0983 to 0.19** for Tube-well Head and **0.072 to 0.045** for Tube-well Tail. For the computation of accurate results the error margin should be less than 10%.

Hence, All the computed results using primary calculated values are less than 10%, which showing between observed and simulated hydraulic heads satisfactory matching, therefore the models of Muhammad khan distributary were successfully calibrated, for both head and tail reach tube-wells.

Table 10: *Hydraulic parameters after the calibration of layered aquifer system at Tail*

Hydraulic	Tail Tube-well			
	No. of Layers			
	1	2	3	4
Horizontal Permeability, K_h (mz/hr)	1.2	2.3	2.3	2.3
Vertical Permeability, K_V (m/hr)	0.2633	0.23	0.23	0.23
Specific Storage, S_s (1/m)	0.00015	0.00015	0.00015	0.00015
Actual Porosity, n	0.3	0.3	0.3	0.3
Exact yield, S_y	0.2	0.2	0.2	0.2

Table 11: *Hydraulic parameters after the calibration of layered aquifer system at Head*

Hydraulic Parameter	Head Tube-well		
	No. Layers		
	1	2	3
Horizontal Permeability, K_h (m/hr)	1.2	1.199	1.199
Straight up Permeability, K_V (m/hr)	0.002	0.0026	0.0026
Exact Storage, S_s (1/m)	0.00015	0.00015	0.00015
Effective Porosity, n	0.2	0.2	0.2
Exact yield, S_y	0.25	0.25	0.25

The calibrated hydraulic parameters of layered aquifer system for the command area of Seri distributary at Head and Tail reach is differ from the ranges which are mentioned by [7] the main reason of this difference is soil strata at the study area. There is sandy soil in the command area of Seri distributary.

6. CONLUSION

This research Activity was performed to Calibrate and Validate the PMWIN MODFLOW with Command Area of Tando Muhammad Khan distributary. The model was successfully calibrated and validated with the observed primary data of Muhammad khan distributary command area and the simulated results Via groundwater Modeling are showed in previous chapter of this thesis. Thus, the model have ability to reproduce the dynamic behavior of groundwater over simulation period. The values of horizontal hydraulic conductivity (K_H) determined for Head and Tail of Tube-well were 1.199 – 1.2 and 1.2 – 2.3 m/hour respectively whereas the values of Specific Storage (S_s) determined for Head and Tail of Tube-well which were from, 0.00015 m^{-1} and 0.025 – 0.85 m^{-1} respectively. The values of vertical hydraulic conductivity (K_v) determined for Head and Tail of Tube-well were 0.002 – 0.0026 & 0.23 – 0.2633 m/hour respectively, whereas the values of specific yield (S_y) determined for Head and Tail reach which were from, 0.01 – 0.25 m^{-1} and 0.25 m^{-1} respectively. The values of porosity (n) determined, and which were 3.0 for both Head and Tail Tube-well.

7. RECOMMENDATIONS

For local assessment of entire impact of Head and Tail Tube-wells, this calibrated model of Muhammad khan distributary can surely be used for sustaining water table and lateral movement of fresh plus saline groundwater interface. In the model we can determine the data from known weather data as input instead of generating the data on evapotranspiration as suggested by [9] for the purpose of getting more accurate results. Because of alteration in the geological strata from one region to another, the model's calibration can be accepted for other regions.

8. REFERENCES

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