

Predicting the impact of riverbed excavation on the buried depth of groundwater table and capillary water zone in the river banks-taking Xinfeng hydropower station as an example

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Abstract. In order to obtain a larger water level drop for power generation, Xinfeng hydropower station proposed to dig 0~3m depth under the riverbed of downstream. This will affect the burial depth of the groundwater level and capillary water zone on both sides of the river and the nearby resident life and agriculture production. In this study, a three-dimensional groundwater numerical model was set using GMS software to predict the flow field changes after the downstream of riverbed was deepened in Xinfeng hydropower station. Simulation results showed that groundwater level near the bank will greatly decline, affecting water consumption of local residents. Because of the local developed canal system and abundant irrigation water amount, riverbed excavation barely affects agriculture production when increasing the irrigation water volume and frequency.

1. Introduction

Xinfeng hydropower station is located in Hezhou City, Guangxi Province, China. The Guiling river passes through it from northeast to southwest. The river banks are terraces surrounded by low hills. The elevation of the terraces are in the range of 101 to 113m and that of the riverbed are in the range of 99.8 to 102.5m. According to the geological tectonic units, our study area is located in the southeast wing of the Guangxi ϵ -type structural system. The details of regional structure of the research area are shown in Figure 1.

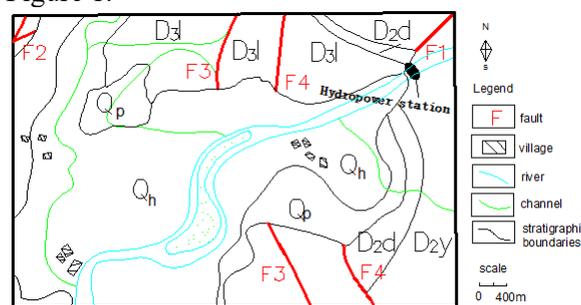


Figure 1. Regional geological structure map.

The groundwater in the study area are porous and bedrock fissure water. The aquifer is mainly recharged by precipitation, irrigating infiltration and canal system leakage. However, the latter two are very limited because the terraces surface are covered with silty clay with poor permeability. The regional groundwater direction in the study area is from both sides to the river.

2. Hydro-geological test

2.1. Steady flow pumping test

The profile illustration on both sides are shown in Figure 2.

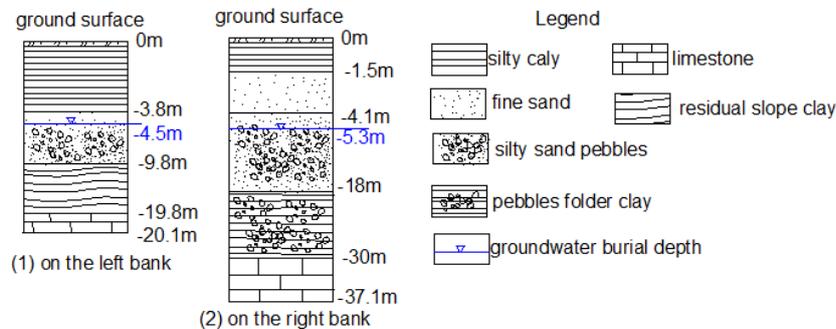


Figure 2. The profile illustration on both sides.

The hydraulic conductivities are calculated by Dupuit-Thiem equation^[5]. Calculation parameters are listed in table 1 and table 2.

$$h^2 - h_w^2 = \frac{Q}{\pi K} \ln \frac{r}{r_w} \quad (1)$$

Where h is the thickness of the aquifer in the observation hole (m); h_w is the thickness of the aquifer in the pumping hole (m); Q is the stable pumping flow (m³/s); K is hydraulic conductivity (m/d); r is the distance between the pumping hole and observation hole(m). r_w is the radius of the pumping hole(m).

Table 1. Pumping test data and derived hydraulic conductivities on the right bank.

Pumping hole		groundwater level	Hydraulic
Steady ground-water level drawdown (m)	Steady pumping flow (L/min)	drawdown in No.1 observation hole (m)	conductivity (m/d)
1.5	49.9	0.06	1.441
2.0	55	0.08	1.555
3.0	61.3	0.12	0.915
6.0	78.1	0.12	0.561
12.0	88.32	0.12	0.397

Table 2. Pumping test data and derived hydraulic conductivities on the left bank.

Pumping hole		groundwater level	Hydraulic
Steady water level drawdown (m)	Steady pumping flow (m ³ /d)	drawdown in No.4 observation hole (m)	conductivity (m/d)
1.33	38.54	0.02	2.93
2.83	27.07	0.05	1.173
6.33	27.41	0.07	0.78

2.2. Test pits

Plastic limit and moisture content intersection method was used to determine the burial depth of the capillary water^[1]. Near the pumping test holes, test pits were dug to collect soil samples to analyze w , w_p and I_p . The samples information are shown in table 3 and table 4.

Table 3. Variation of water content in soil profile on the right bank.

depth (m)	w(%)	w _p	I _p	Soil name	Saturation
0.2	19.9	20.6	15.2	Hard silty clay	unsaturated
0.3	22.3	21.3	15.1	Hard plastic silty clay	saturated
0.6	24.1	23.4	15.7	Hard plastic silty clay	saturated
0.8	23.7	23.3	14.3	Hard plastic silty clay	saturated
0.9	24.3	22.1	15.3	Hard plastic silty clay	saturated
1.2	25.8	23.6	15.8	Hard plastic silty caly	saturated

From table 3, it was found that the capillary water in the right bank is about 5m above the groundwater table using the plastic limit and moisture content intersection method.

Table 4. Variation of water content in soil profile on the left bank.

depth(m)	w(%)	w _p	I _p	Soil name	Saturation
0.2	21.0	22.5	15.6	Hard silty clay	unsaturated
0.3	17.7	20.6	14.6	Hard silty caly	saturated
0.4	21.2	23.0	15.2	Hard silty clay	saturated
0.6	19.6	20.1	16.5	Hard silty clay	unsaturated
0.8	21.9	20.4	16.0	Hard plastic silty clay	unsaturated
0.9	18.9	18.4	16.6	Hard plastic silty clay	saturated
1.2	21.0	21.6	15.9	hard plastic silty clay	unsaturated
1.6	18.4	19.7	14.8	Hard plastic silty clay	unsaturated

Based on the principle of plastic limit and moisture content intersection method^[1], the pit hasn't been dug into the capillary zone. Fig.2 showed that, the water-bearing media is coarse grained soil and pebble is accounted for 40~70%. That means, the capillary water rising height in this media is almost zero^[1-4].

3. Numerical Simulation

3.1. Mathematical model

The groundwater flow model of the study area can be established by the following equations (HJ610-2011) :

$$\begin{cases}
 \frac{\partial}{\partial x} \left[K_x \frac{\partial h}{\partial x} \right] + \frac{\partial}{\partial y} \left[K_y \frac{\partial h}{\partial y} \right] + \frac{\partial}{\partial z} \left[K_z \frac{\partial h}{\partial z} \right] + W = \mu_s \frac{\partial h}{\partial t} & (x, y, z \in \Omega) \\
 h(x, y, z, t) = h_0(x, y, z) & (x, y, z \in \Omega), t = 0 \\
 h \Big|_{B_1} = h_1(x, y, z, t) & (x, y, z) \in B_1, t \geq 0 \\
 k \frac{\partial k}{\partial n} \Big|_{B_2} = q(x, y, z, t) = 0 & (x, y, z) \in B_2, t \geq 0
 \end{cases} \quad (2)$$

Where h is groundwater head (m); K_x, K_y, K_z are hydraulic conductivity along x, y, z direction respectively(m/d); B_1 is the specified head boundary (the first kind of boundary); B_2 is the barrier boundary (the second boundary); h_1 is the river water level(m); W is the source and sink intensity(d⁻¹); Ω is seepage area; μ_s is water storage rate(m⁻¹) and its empirical value is 0.0008.

3.2. Fixed conditions

The initial water level is monitored on January 15, 2015. The Guiling river is set as the specified head boundary, the all-around low hills watershed are set as barrier boundary. The top of vertical boundary was determined with elevations using IDW interpolation. The thick and slightly weathered limestone was served as the bottom boundary in vertical direction^[6-8].

3.3. Mesh generation

The planar grid was divided into 100 rows and 100 columns, and the vertical profile was divided into three layers.

3.4. Zones

Partition of rainfall infiltration and the hydraulic conductivity zones are shown in Figure 3 and Figure 4, and the inserted tables show values of infiltration coefficients and hydraulic conductivity coefficients.

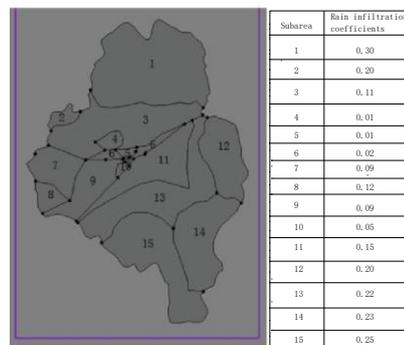


Figure 3. Partition map of rainfall infiltration coefficients and their values.

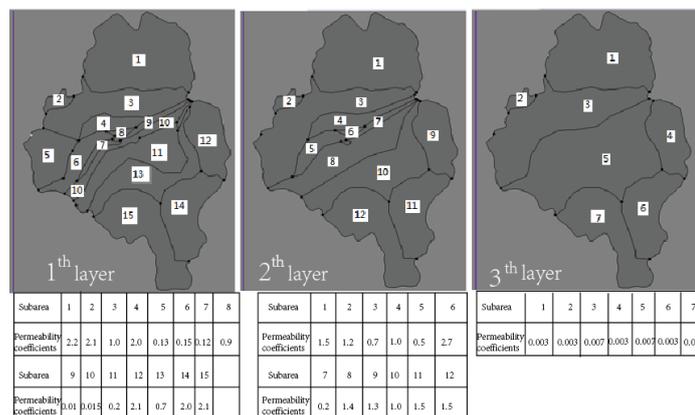


Figure 4. Partition map of permeability coefficients and their values.

3.5. Model identification and verification

Monitoring data of the groundwater level from 6 wells and 2 drilling were used in this model. The observation period was ranged from January to September 2015. The observed and calculated water level at different time were shown in table 5 and table 6 respectively. The identification and verification effect are shown in Figure 5 and Figure 6 respectively.

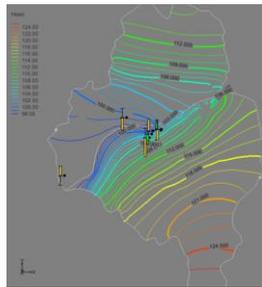


Figure 5. Model fitting effect (June 9~11, 2015).
 (The green bars indicate perfect fitting and the yellow bars indicate fitting well)

Table 5. Comparison of observed and calculated groundwater table in some wells (June 2015).

Well	position	elevation of borehole /m	Measured water level/m	Calculated water level/m	Fitting error/m
1#	Xinping	101.30	96.20	96.92	+0.72
2#	Dongqiu	107.72	105.87	104.88	-0.99
3#	Dongqiu	106.01	103.11	102.62	-0.49
4#	Dongqiu	104.72	99.92	100.53	+0.61
5#	Dongqiu	106.17	104.00	103.46	-0.54
6#	Dongqiu	106.22	103.22	103.61	+0.39

Table 6. Comparison of observed and calculated groundwater table in some wells (July 18, 2015).

Well	position	elevation of borehole /m	Measured water level/m	Calculated water level/m	Calculation error/m
1#	Xinping	101.30	95.30	95.18	-0.12
2#	Dongqiu	107.72	105.77	105.31	-0.46
3#	Dongqiu	106.01	102.71	102.78	+0.07
4#	Dongqiu	104.72	99.22	99.74	+0.52
5#	Dongqiu	106.17	101.97	102.01	+0.04
6#	Dongqiu	106.22	101.72	102.31	+0.59

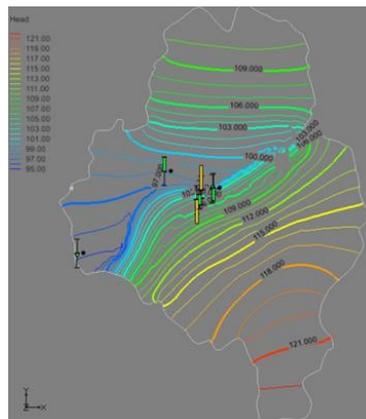


Figure 6. Model validation fitting effect.

4. Model prediction

4.1. The groundwater field prediction

A numerical model built by GMS was used to predict the decline of groundwater level on both sides after riverbed excavation. The precipitation used in this model is average annual rainfall. Simulation

results were shown in Figure 7 and the water level changes before and after excavation in observation wells were shown in table 7.

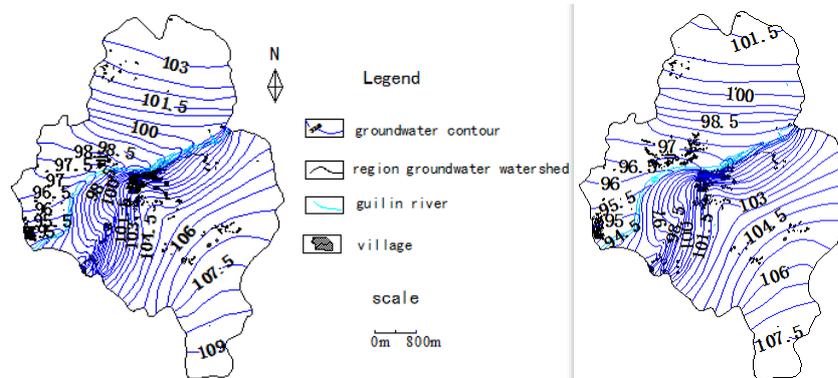


Figure 7. Groundwater flow field before(left) and after(right) riverbed excavation.

Table 7. Comparison of groundwater level in the observation wells before and after riverbed excavation.

Well	Groundwater level in wet season			Groundwater level in dry season		
	before excavation /m	after excavation /m	amplitude /m	before excavation /m	after excavation /m	amplitude /m
1#	96.20	95.86	-0.34	95.08	94.78	-0.30
2#	105.87	104.98	-0.89	102.99	100.96	-0.03
3#	103.11	101.83	-1.28	100.21	98.84	-1.37
4#	99.92	98.04	-1.88	98.59	96.71	-1.88
5#	104.00	102.04	-1.96	99.73	97.77	-1.96
6#	103.22	101.46	-1.76	99.88	98.32	-1.56

4.2. Prediction of the capillary water burial depth changes

According to the previous research experience and lithology in the study area, the curve intersecting method of plastic limit and water content is selected to determine the capillary water burial depth^[1-4]. According to prediction results, the contour map of the capillary water burial depth on both sides terraces was shown in figure 8. Results indicated that the capillary water burial depth on the right bank is about 0 to 5m and the height will decline 1.0 to 1.6m after excavation. The capillary water burial depth on the left bank is in the range of 0 to 5m and the height will decline 0 to 2.01m after excavation.

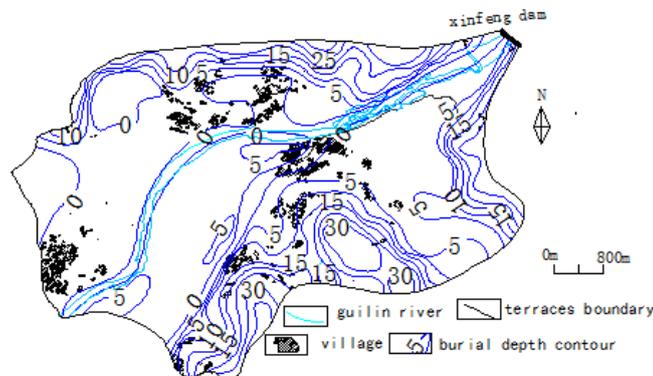


Figure 8. The capillary water burial depth contour map after bed excavation (in dry season).

5. Conclusion and suggestion

- (1) Results of model predication showed that, the groundwater level in Xinping village will decline 0.30 to 0.34m after riverbed excavation, the wells level in Dongqiu village will decline 0.003 to 1.96m. These indicated that the closer to the river bank and the closer to the dam, the lower the water level will be. The decrease of groundwater level along the river will affect groundwater usage in the people's life.
- (2) The capillary water burial depth will increase about 1.0 to 1.6m on the right bank and 0 to 2.01m on the left bank respectively after riverbed excavation. The increase of the capillary water burial depth will affect crops growth. However, because of the local drainage systems is well developed, this effect can be negligible.

References

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