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Conceptual model of groundwater and river water interactions in Cikapundung riverbank, Bandung, West Java

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Abstract. Cikapundung river holds a very strategic role as one of the water supply source for Bandung, but the water quality is decreasing over the years. This degradation has also influenced the groundwater in its riverbank. This paper discusses our effor to build a conceptual model to reconstruct previous analytical model which was built in 1997. The base map was built using a total of 32 scenes of WorldView-2 image, combined with Aster image. The dimension of the model was one layer model with elevation (Z) 400 to 2200 m, 361 rows and 454 columns, covering the area of 21.6 x 27.2 km^2. Two types of property hydrogeology were defined based on the existing geological maps: Volcanic breccias and, Sand and clay intercalations. The parameterization of the stream was divided into two segments: Curug Dago to Viaduct, Viaduct to Dayeuhkolot. Initial head were observed at: 17 dug wells, 24 river points, and two spring points in 2013. All parameters accommodated by software SWS visual MODFLOW flex 2012 that used three-dimension mathematic equation in steady state to build a conceptual model. Model has been calibrated and showed an appropriateness with dug wells and springs with correlation coefficient of 0.92 and water balance in 0.01 steady state condition (2040 m3).The conceptual model successfully replicates the previous analytical model, showing three segments of water interactions: no flow at segment Maribaya to Curug Dago, combination of effluent and influent flow at segment Curug Dago to Viaduct, and influent flow Viaduct to Dayeuhkolot. However, the model shows some local variations that was not spotted in the previous model.

1. Introduction

Water from Cikapundung River is a potential source for water supply in several areas in Bandung. The usage, however, has not been increasing due to the low quality. Lubis (1997) has identified three hydraulic relationship between river water and unconfined groundwater along the river bank, as follows from north to south: isolated stream at Maribaya area (upstream), effluent stream (or gaining stream) at Maribaya to Viaduct (Central area of Bandung) segment, and influent stream (or losing stream) from Viaduct to Dayeuhkolot. Since then, the vast growth of Bandung and the land-use change on upstream area leads to the change of groundwater usage and possibly its hydraulic

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connection with river water. This paper discusses our effort to transform analytical research model on hydrodynamic interaction of groundwater-river water in 1997 into a numerical model. the model discussed in the paper is a numerical version of non-numerical previous result. We try to re-model the 1997 model based on new data and finite difference solution in ModFlow.

The regional geological and hydrogeological background of this paper is based on several previous studies by Sudjatmiko (1972), Silitonga (1973), Sutrisno (1983), Koesoemadinata and Hartono (1981), Priowirjanto and Marsudi (1995), Geyh (1990), Matahelumasi and Wahyudin (2009). A compiled geological map is shown in Fig. 1. This watershed is part of greater Citarum watershed. It consists of:

- Northern volcanic highland at 650-1000 masl, with slope of 3 to 15%. It is composed mostly of breccias and lava.
- Southern Alluvium lowland at 600-650 meter above mean sea level (masl), with slope of 0 to 3%. It is a fertile agricultural area composed of volcanic fan with grain size of clay, sand and pebble.

Faults and joints are found in the area, especially with the existing of Lembang fault in the northern volcanic highland. This east-west oriented fault confines the groundwater flow between the north and south block, based on his water quality measurements.

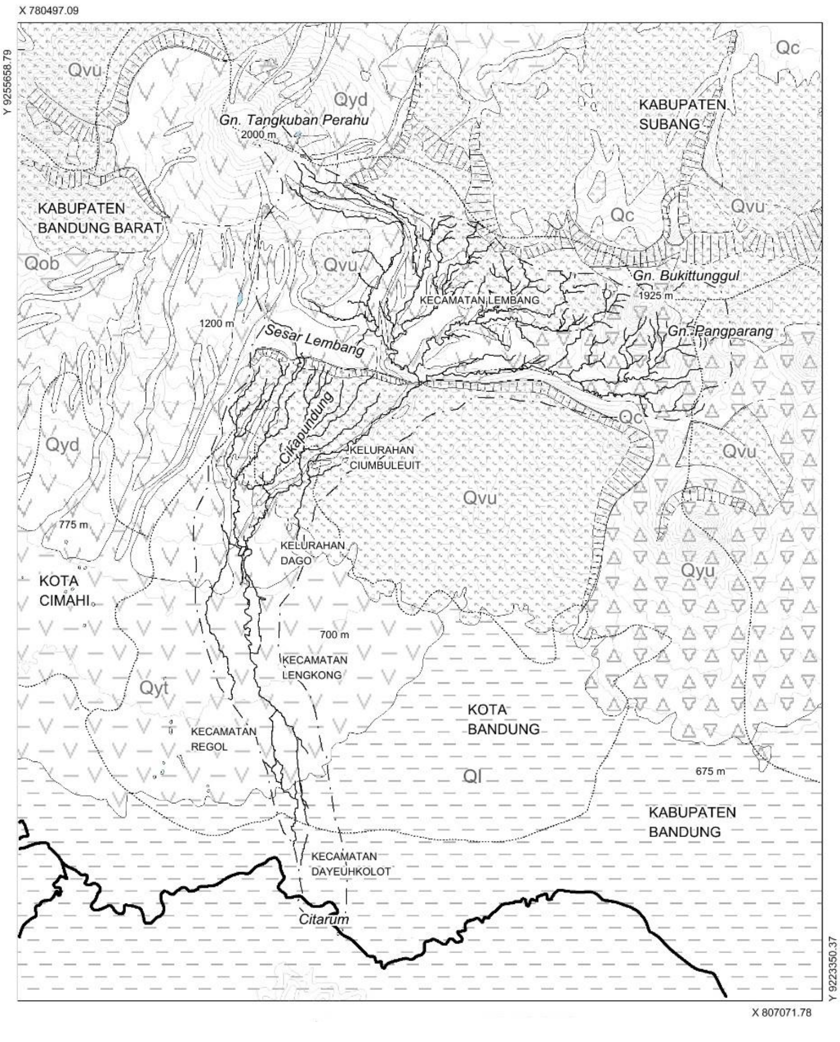

Figure 1. Geology map of Cikapundung watersheed.

2. Methods and Data

The base map was built using a total of 32 scenes of WorldView-2 image, combined with Aster image. The dimension of the model was one layer model with elevation (Z) 400 to 2200 above the sea level, total cell 361 rows and 454 columns, Cell activated was only 144 km^2, as wide as Cikapundung watershed, and the river was set in constant head condition.

Two types of rocks were defined based on the existing geological maps: Volcanic breccias with Conductivity=10^{-6} m/second; Storage=0.02; Specific yield=0.02; Total porosity =0.5; Effective porosity=0.1; Sand and clay intercalations with Conductivity =10^{-8} m/second; Storage =$3.3.10^{-6}$; Specific yield =0.08; Total porosity =0.11; Effective porosity =0.1. The parameterization of the stream was divided into two segments (width x depth x hydraulic conductivity): Curug Dago to Viaduct 4.5 m x 1.08 m x 10^{-5} m/sec, Viaduct to Dayeuhkolot 4.4 m x 1.5 m x 5.4e10-5 m/sec. Initial head were observed at: 17 dug wells, 24 river points, and two spring points in 2013.

Major problem in setting up the conceptual model was how we determine the boundary conditions, especially in the lateral directions. In this version, we try to adapt the following settings: zero flow as lower and lateral boundary and recharge as upper boundary. The final conceptual model is shown in Fig. 2. The method and preliminary part of the modeling was already published in Darul et al. (2014).

Table 1. Field survey of groundwater level initial head
(GW = Groundwater, SW = surface water, SP = Spring)

Name	X	Y	Head (m asl)	T(^{o}C)	DO (ppm)
GW1	787982	9238529	786	26.6	1.2
GW2	788010	9238541	864.92	26.5	5.2
GW3	787003	9238021	770.8	26.9	2.7
GW4	787976	9236921	741.16	25.5	4
GW5	788233	9238797	788.1	23.7	16.21
GW6	788682	9237790	723.61	24.1	7.3
GW7	787672	9237769	721.32	24.2	26.2
GW8	788284	9239120	739.2	23.4	12.2
GW9	788465	9239499	766.65	24.3	17.3
GW10	788985	9239867	857.63	23.8	9.3
GW11	788818	9233207	727.47	24.9	3.4
GW12	788839	9233307	728.54	25.4	14.7
GW13	788680	9233300	720.79	25	12.5
GW14	789027	9233463	718	24.9	14.4
GW15	789665	9230790	699.78	25.3	15.1
GW16	789742	9230799	699.37	24.5	13.9
GW17	789767	9230490	698.2	25.4	17
SW1	788179	9238176	777	23.5	
SW 2	788135	9238101	755	27.8	4.23
SW 3	787923	9237941	760	27.8	5.69
SW 4	787868	9237830	655	24.7	6.32
SW 5	787902	9237567	660	24.7	6.09
SW 6	787997	9237294	769	25	5.88
SW 7	788005	9236998	763	24.7	6
SW 8	787884	9236723	758	24.9	6.31
SW 9	788054	9236484	758	24.1	5.84

Name	X	Y	Head (m asl)	T(°C)	DO (ppm)
SW 10	788026	9236290	763	24.9	5.19
SW 11	788144	9238216	771	23.6	14
SW 12	788014	9238491	781	24.3	24.2
SW 13	788183	9238678	779	28.3	28.3
SW 14	788210	9238842	781	20	20
SW 15	788226	9239041	833	21.4	21.4
SW 16	788000	9235798	734	27.1	21.5
SW 17	788011	9235274	730	24	27.8
SW 18	788184	9235119	729	24.2	24.8
SW 19	788226	9239041	833	23.7	21.8
SW 20	788610	9239508	816	22	11.4
SW 21	788714	9239949	833	22.1	18.1
SW 22	788717	9240010	814	22.7	13.4
SW 23	788727	9233263	729	24.5	14.1
SW 24	789754	9230780	702	24.9	21.9
SP1	788057	9238320	763	24.7	7.5
SP2	787970	9238349	784	24.2	10.1

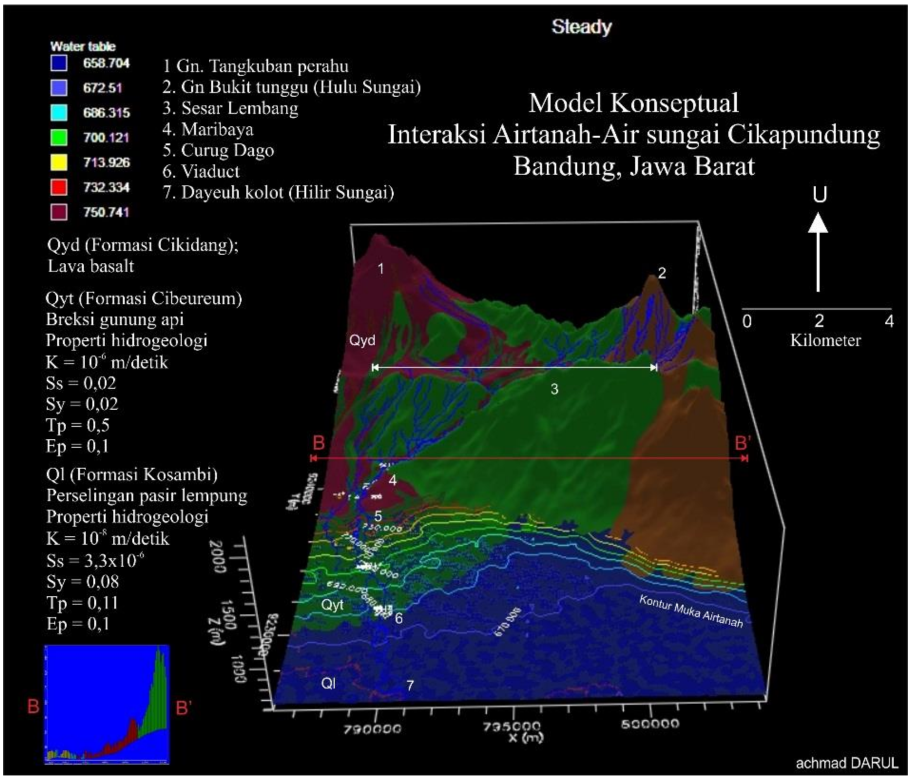

Figure 2. Three dimensions of Cikapundung watershed.

In the field survey, we measured the wells in a distance of 50 m on left and right direction from the river stream used handheld instruments a Solinst water level detector (WLD) for water level depth. This distance is chosen as the max lateral boundary condition. All parameters were loaded in Visual MODFLOW Flex 2012 that used three-dimension finite-difference approximation. The governing 3D equation used in this model was based on MODFLOW (McDonald and Harbaugh, 1988 and Harbaugh, etal., 2000), which combines Darcy's Law and the principle of conservation of mass in steady state condition, as follows.

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+q_s=S_s\frac{\partial h}{\partial t}$$

where K_{xx}, K_{yy}, and K_{zz} are the values of hydraulic conductivity along the x, y, z (major axes of hydraulic conductivity [L/T], H is hydraulic head [L], Qs is volumetric flux of ground water sources and sinks per unit volume [1/T], Ss is specific storage [1/L], and t denotes time [T]

3. Results

Model has been calibrated based on 17 dug wells and two springs with correlation coefficient of 0.92 and water balance in 0.01 steady state condition (2040 m^3) (see Fig. 3 and Fig. 4). We believe the calibration was fairly successful considering the simplification on the geology we had to overcome in the model.

There is no significant difference in water interaction boundaries if compared to 1997 model. The numerical model has also shown three zones (Fig. 5). However, we can see several anomalous spots in the effluent zone (Dago to Viaduct), which were not found in the old map. In such zones, local groundwater drawdown occurs due to possible near by groundwater pumping, presumably deep wells owned by local small-size hotels. This phenomena indicates the nature of multi-aquifer system in the basin, in which, the shallow and deep groundwater are interconnected. Shallow groundwater level will eventually drop along with extensive deep groundwater discharge in the vicinity. With the close relation of shallow groundwater and river water, seepage of river water into the aquifer is possibly inevitable.

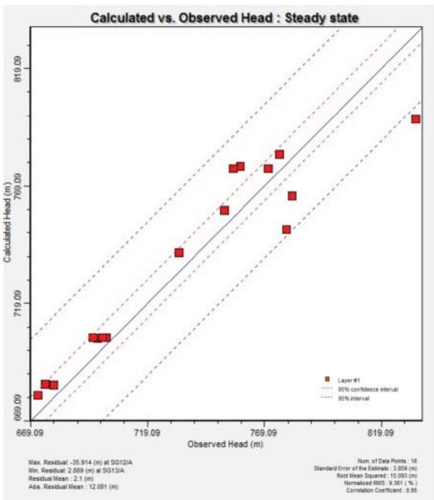

Figure 3. Calibration of head.

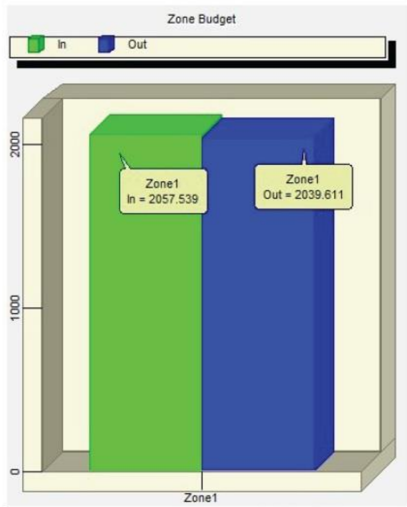

Figure 4. Calibration of water balance.

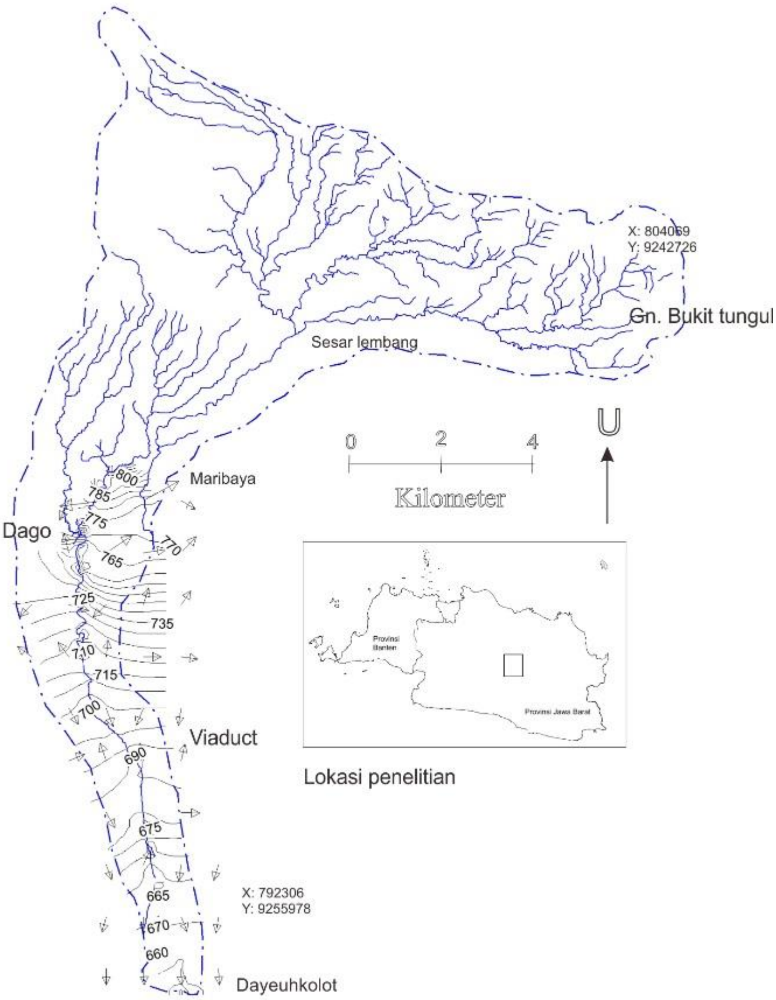

Figure 5. Results of the finite difference modelling of Cikapundung watershed.

4. Conclusions

This paper has successfully shown the relative constant state of groundwater and river interaction in the 16 years period in the Cikapundung riverbank. Therefore, the method is highly recommended to be used as a tool for water management. We will introduce this result to the authority responsible for water and environmental management. Nevertheless, small local changes are identified as one of the positive results. Both changes are due to deep wells owned by local hotel and accommodation businesses.

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