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 effort 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 km². 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.

![Geology map of Cikapundung watershed.](image.png)

**Figure 1.** Geology map of Cikapundung watershed.
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 km², 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).

| Name | X    | Y    | Head (m asl) | T(°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 | 9207999 | 699.37    | 24.5  | 13.9    |
| GW17 | 789767 | 9230490 | 698.2     | 25.4  | 17      |
| SW1  | 788179 | 9238176 | 777       | 23.5  |         |
| SW2  | 788135 | 9238101 | 755       | 27.8  | 4.23    |
| SW3  | 787923 | 9237941 | 760       | 27.8  | 5.69    |
| SW4  | 787868 | 9237830 | 655       | 24.7  | 6.32    |
| SW5  | 787902 | 9237567 | 660       | 24.7  | 6.09    |
| SW6  | 787997 | 9237294 | 769       | 25    | 5.88    |
| SW7  | 788005 | 9236998 | 763       | 24.7  | 6       |
| SW8  | 787884 | 9236723 | 758       | 24.9  | 6.31    |
| SW9  | 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     |
| SP 1  | 788057| 9238320| 763          | 24.7  | 7.5      |
| SP 2  | 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 \(K_{xx}, \ K_{yy}, \ \text{and} \ K_{zz}\) are the values of hydraulic conductivity along the \(x, \ y, \ \text{and} \ z\) (major axes of hydraulic conductivity [L/T], \(H\) is hydraulic head [L], \(Q_s\) is volumetric flux of ground water sources and sinks per unit volume [1/T], \(S_s\) 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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