Hydrodynamic relationships between groundwater and river water: Cikapundung River Stream, West Java, Indonesia

DENY JUANDA PURADIMAJA[1] AND RACHMAT FAJAR LUBIS[2]

[1] *Dept.of Geology,Institut Teknologi Bandung-Indonesia. (e-mail: denyjp@bdg.centrin.net.id, denyjp@gc.itb.ac.id)*
[2] *Dept.Geology,Institut Teknologi Dan Sains Bandung-Indonesia.(e-mail: fajarlubis@graduate.chiba-u.jp)*

Abstract: The Cikapundung River flows from north to south, pass through Bandung (West Java). It flows through 3 productive aquifers of the Cibeureum Formation, the Cikapundung Formation, and the Kosambi Formation. Flow net analysis at riverbanks shows 3 types of hydrodynamic interaction between river water and groundwater: Type I [zone Maribaya to Curug Dago] characterized by isolated flow; Type II [zone Curug Dago to Viaduct area] characterized by convergent groundwater flow to the river with a hydraulic gradient of 27% (on the east bank) and 8% (on the west bank); Type III [zone Viaduct to Dayeuh Kolot] characterized by divergent flow of river water to a shallow aquifer, with a hydraulic gradient of 2.5% on the east bank and 4% on the west bank. Based on the zonation,in the zone Curug Dago to Viaduct area, river water is supported by groundwater outflow, therefore river water quality depends on groundwater quality. On the contrary, in the zone Viaduct to Dayeuh Kolot, groundwater is supported by river water inflow, therefore groundwater quality depends on river water quality. This study shows that hydrodynamic relationship between river water and groundwater must be well known in order to set up the suitable water management.

Résumé: Ce travail a ete realise dans le cadre d'une recherche hydrogeologie detail au sujet des relation entre les ecoulements des eaux superficiels et de l'aquifere du bassin de la riviere du Cikapundung, Bandung Ouest Java, Indonesie qui constitues des terrains volcaniques. Les precipitations annuelles 2000 mm et sont entre 150 – 350 mm/mois au pluie session (Octobre-Mai) et moins de 60 mm/mois (Juin-Septembre) au seche session.

On peut y distinguer trois types ou categorie du relation hydrodynamiques. *La premiere categorie*, situee entre Maribaya et Curug Dago, sont caracteristiques d'un ecoulement limite/localise ou sont independent entre les eaux superficiels et eaux souterraines dans la nappe libre. *La second categorie,* zone entre Curug Dago et Viaduct, sont caracteristiques d'un ecoulement de l'eau souterraine (avec 27 % gradient hydraulique a la partie de l'east et 8% gradient hydraulique a la partie de l'ouest) est orientee vers la riviere du Cikapundung. La Cikapundung est donc une riviere drainante. *La troisieme categorie,* situee entre Viaduct et Dayeuh Kolot, caracteristiques d'un ecoulement du Cikapundung alimente vers dans la nappe libre (avec 2,5% gradient hydraulique a l'east et 4 % a l'ouest parties de l'aquifere).

Keywords: aquifers, case studies, hydrogeological control, mapping, surface water, water management

INTRODUCTION

Study of the hydrodynamic conditions of groundwater and surface water interaction is very important because surface water bodies are integral parts of groundwater flow systems (Groundwater interacts with surface water in nearly all landscapes, ranging from small streams, to major river valleys). Although it, generally, is assumed that topographically high areas are groundwater recharge areas and topographically low areas are groundwater discharge areas, this is just true primarily for regional flow systems. The superposition of local flow systems associated with surface-water bodies results in complex interactions between groundwater and surface water. Hydrologic processes associated with the surface-water bodies themselves, such as seasonally high surface-water levels, evaporation and transpiration of groundwater from around the perimeter of surface-water bodies, are a major cause of the complex and seasonally dynamic groundwater flow fields associated with surface water

In a humid region many rivers are fed by overland flow, interflow and base flow at high altitudes. As they wind their way to a lower elevation, the local precipitation amounts decrease; consequently, there is less infiltration and a lower water table. There may also be a dramatic change in the depth to groundwater when a stream draining of lower or higher permeability materials.

A stream that is normally an effluent stream during base flow recessions may temporarily become an influent stream during floods. If the flood-crest depth in the channel is greater than the local water table elevation, the hydraulic gradient in the aquifer next to stream is reserved. The hydrologic interaction in stream-aquifer system can be described by use a flow net model along the river. This paper illustrates the important interconnections in the hydrodynamic relationship between river and groundwater.

This research examines the hydrodynamic relationship between river water and groundwater. The result will be used as a model of micro-hydrogeological scale research to control as well as to monitor water quantity and quality in unconfined aquifer along riverbanks, which generally pass through big cities in Indonesia. Some of them are: Ciliwung River in Jakarta (Capital of Indonesia), Cisadane River in Tangerang (Banten), Cikapundung River in Bandung (West Java), Kali Mas in Surabaya (East Java), Musi River in Palembang (South Sumatera), Mahakam River in Kota Samarinda (East Kalimantan), etc.

The study area is Cikapundung River, which lies across Bandung. Bandung is the Capital of West Java Province, located 180 km south-east of Jakarta. Along its flow, Cikapundung River passes on various litology (Silitonga, 1972; Koesoemadinata R.P & Hartono D, 1981), which has distinct characteristic to hydrodynamics of both, river water and groundwater.

GENERAL HYDROGEOLOGY

In terms of Geology, Bandung is part of Bandung Basin. The basin is dominantly covered by Volcanic Products and Lake Deposits. Total rainfall is 2000 mm/year. Dry seasons occur from June to September with rainfall less than 50 mm/month. The other 8 months are wet seasons with rainfall varied of 150 – 350 mm/month.

Many rivers are flowing in the area, which end at main river, Citarum River, and also pass through different deposits with different hydraulic properties. Cikapundung River flows from north to south, passes through 3 deposits (Figure 1): Cibeureum Fm, Cikapundung Fm, and Kosambi Fm. All the deposits are exposed at river bottom and river bank (left and right). Because of vast population and industrial growth, the quality of river water can be divided in to 2 types: good quality at up stream and poor quality at down stream. Many counter measures have been launched to control water quality and to prevent groundwater contamination. One of them is Program Kali Bersih (PROKASIH)/River Water Clean Up Program, but the success of this has yet to be evaluated.

Previously, researchers have studied the geology of Bandung Basin including Van Bemmelen, (1949), Silitonga (1971), Koesoemadinata & Hartono (1981), Alzwar (1992); IWACO-PU (1990), Dam & Suparan (1994). According to spring and water table mapping by IWACO-WASECO (1990), in Bandung Basin, there are no indications of large discharge spring especially in the north part that feed Cikapundung River. The soil characteristics, generally show high permeability (Sukrisno 1990). Bender & Boesch (1981) stated that Citarum River is effluent (fed by groundwater), while minor streams are effluent and influent (Figure 2). In contrast to Bender & Boesch (1981), Deny Juanda (1995, 1997) and Deny Juanda & Lubis (2001) cast doubt on the assertion that all the segments of the Citarum River and its minor streams are effluent. In depth research must be conducted to prove this hypothesis.

THEORY ON GROUNDWATER AND RIVER RELATIONSHIPS

In a humid region many rivers are fed by overland flow, interflow, and baseflow at high altitudes. As they wind their way to a lower elevation, the local precipitation amounts decrease; consequently, there is less infiltration and a lower water table. There may also be a dramatic change in the depth to groundwater adjacent to a stream draining lower or higher permeability materials. Four type of interaction between groundwater and rivers are identified (Lee 1980): effluent (gaining) stream, the typical stream receives groundwater discharge; influent (losing) stream, if the bottom of the stream channel is higher than the local water table and groundwater receives river discharge. Isolated stream, the typical where there is no interaction between stream and groundwater. Perched stream, the typical of stream channel flows on unsaturated zone such as soil or unconsolidated materials (Figure 3)

A stream that is normally an effluent stream during baseflow recessions may temporarily become a influent stream during floods. If the flood-crest depth in the channel is greater than the local water table elevation, the hydraulic gradient in the aquifer next to stream is reversed. The hydrologic interaction in stream-aquifer system can be described by use a flow net model along the river.

Flow line, in this case, is an imaginary line that traces the path that a particle of groundwater would follow as it flows through an aquifer (Fetter 1988). Flow lines are helpful for visualizing the movement of groundwater (Figure 4). In this study flow lines are used to determine and identify the relation between stream and aquifer based on water table and stream level measurement. The method of flow-net construction presented here is based on the following assumptions:

- The aquifer is homogenous and isotropic.
- The aquifer is fully saturated
- There is no change in the potential field with time (steady state)
- The soil and water are incompressible
- Flow is laminar, and Darcy’s law is valid
- All boundary condition are known

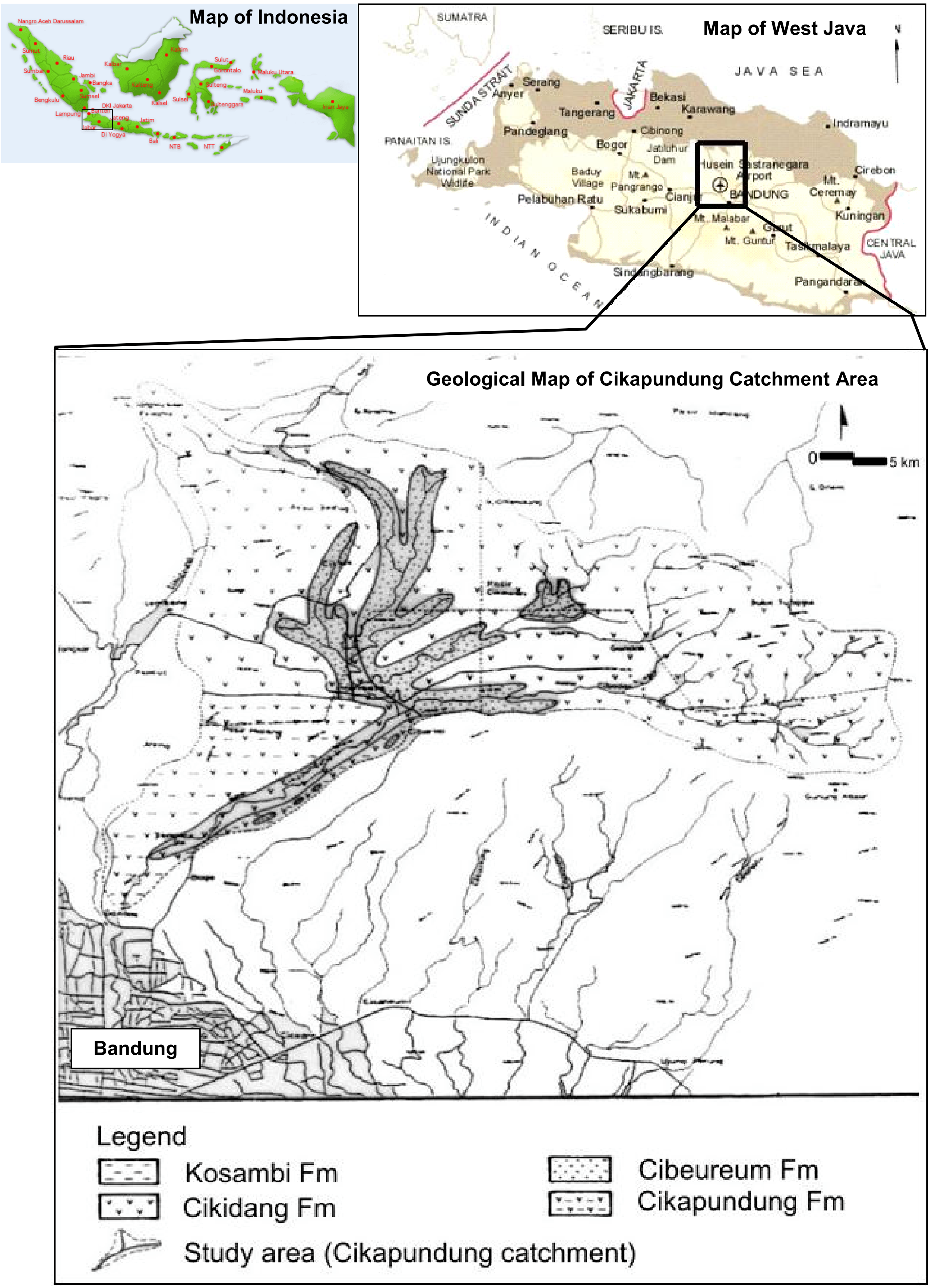

Figure 1. Geology of Cikapundung catchment. Lithogical description: (1) Kosambi Fm (Lake Deposit): unconsolidated sand and clay moderately productive unconfined aquifer. (2) Cibereum Fm: volcanic breccia (coarse grain) and volcanic sand with lava intercalation. (3) Cikapundung Fm: volcanic breccia (fine grain). (4) Cikidang Fm: basaltic lava, impermeable layer.

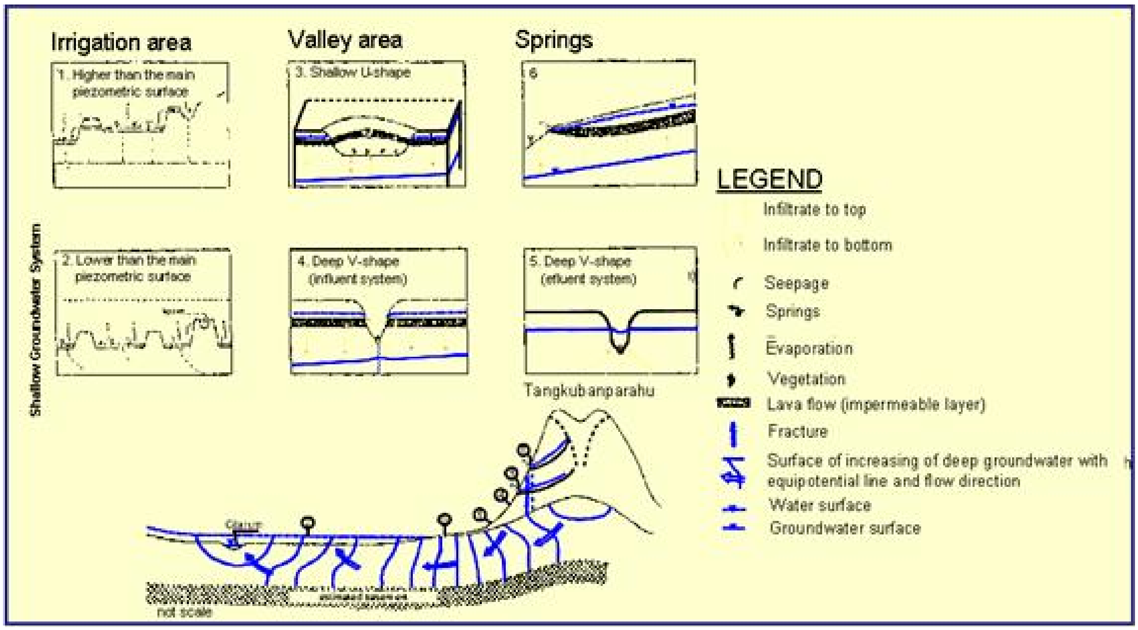

Figure 2. Hydraulic model in Cikapundung river, Bandung Indonesia (Bender ,1980)

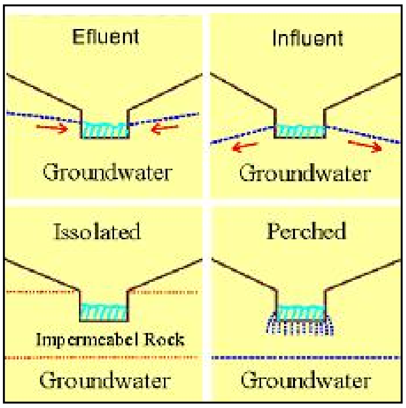

Figure 3. Relation between groundwater and surface water (Lee 1980)

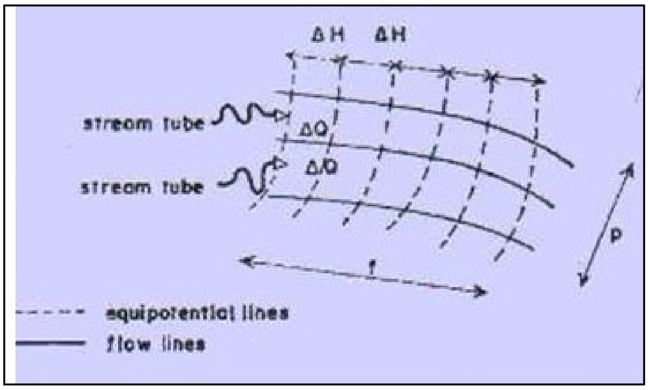

Figure 4. Flow line model (Forcheimer, 1914 op.cit Fetter 1988)

METHOD

This research used 3 approaches: spring observation and water table measurements on dug wells, resistivity mapping, soil permeability measurement, and flow line analysis. Spring observation aims to map spring distribution along Cikapundung River banks, from up stream to down stream. Application of resistivity mapping is to map sub surface geological condition. Soil permeability measurement is used to quantify the soil capability to infiltrate water (rain water and surface water). Subsequently, flow line analysis is utilized to draw water hydrodynamics, between river water and groundwater. Flow line is drawn from data series of water table measurements on dug wells and spring distributions. Flow chart of the method is shown in Figure 5.

DATA

The observation and measurement of data points along Cikapundung River consist of: 9 resistivity measurements, 7 infiltration measurements, 8 DGTL well observations, and many dug wells. Data point distribution is drawn in Figure 6. Resistivity points, well points, river water elevation and general river-groundwater relationship are listed in Table 1, while infiltration measurements are listed in Table 2.

Water table measurements shows elevation difference between river water and groundwater (Table 1). At well points W1,W2,W3,W5,W7 river water is lower than groundwater, which indicates that groundwater flows to the river. At well points W4,W6,W8.1,W8.2 river water is higher than groundwater and indicates that river water infiltrates to the aquifer.

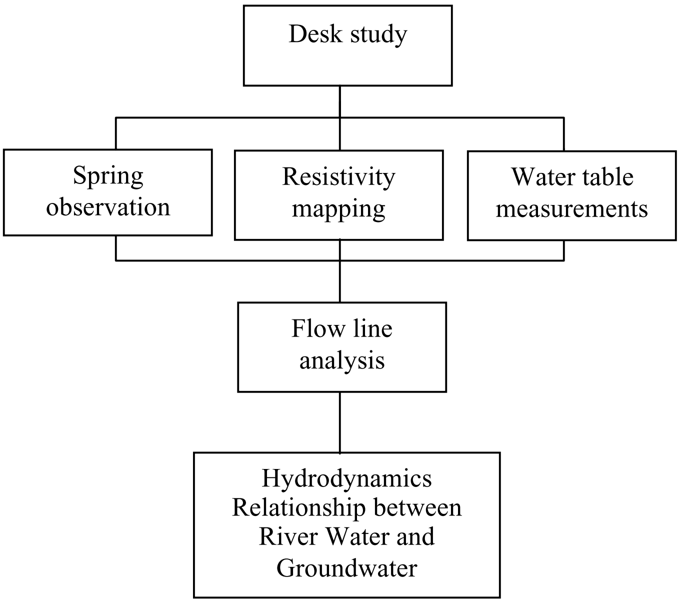

Figure 5. Flow chart of the study

Table 1. Resistivity points, water table measurements, river water elevation, and hydrodynamic relationship

Resistivity Points	Location	Well Points	Elevation (masl)	Water table elevation (masl)	River water elevation (masl)	River water-Groundwater Relationship
GL1	Gandok - Lebak Siliwangi	W1	742	740.2	735	Effluent stream
GL2		W2	739.5	738.3		
GL3		W3	739.5	737.27		
GL4	Bukit Jarian – Ciumbeuleit	W4	828	826.45	826.5	Effluent stream
GL5		W5	831.8	828.35		
GL6	Pasir Salam - Buah Batu	W6	678	676.15	677,2	Influent stream
GL7		W7	679	678.48		
GL8	Bojong Soang	W8.1	650	642.3	647,5	Influent stream
GL9		W8.2	650	642.7		

Infiltration rate was measured at 7 locations, along Cikapundung River stream. The test was taken on soil from weathers breccia, tuff, and lava. From the data, clay loam soil type has infiltration rate in the range 0.22 – 0.49 cm/minute, silty clay 0.42 cm/minute, and clay 0.06 – 10.16 cm/minute (Table 2). According to Fetter (1988), this infiltration value classifies these materials as low infiltration material.

Result from resistivity and water table measurements shows interesting facts (Figure 7). From field data, it can be found that there are layers of sandstone, breccia, tuff scoria, and clay at the Cikapundung riverbank and riverberd. These formations presumably controls the hydrodynamics of river water and groundwater. Different hydrodynamics is reflected by various position river water and water table. At segment Cikapundung Type 1, there is no productive aquifer with lava flows at riverbank and river bed. At segment Cikapundung Type 2, water table is higher than river water table. At segment Cikapundung Type 3, water table is lowe than river water.

Table 2. Infiltration measurements

Points	Locations	Lithology	Soil type (USDA)	Final infiltration rate (cm/minute)
P1. P2.	Cikurutug Bongkor	Cikapundung Fm (Breccia)	*Silty Clay* *Clay*	0.42 0.16
P3. P4.	Cisitu Lama Suapati	Cibeureum Fm (Tuff scoria)	*Clay Loam* *Clay Loam*	0.49 0.22
P5. P6.	Cigadung Curug Dago	Cikidang Fm (Lava & Sandy Tuff)	*Clay* *Clay Loam*	0.06 0.22
P7.	STT Telkom Bojong Soang	Kosambi Fm (Lake deposit)	*Clay*	0.08

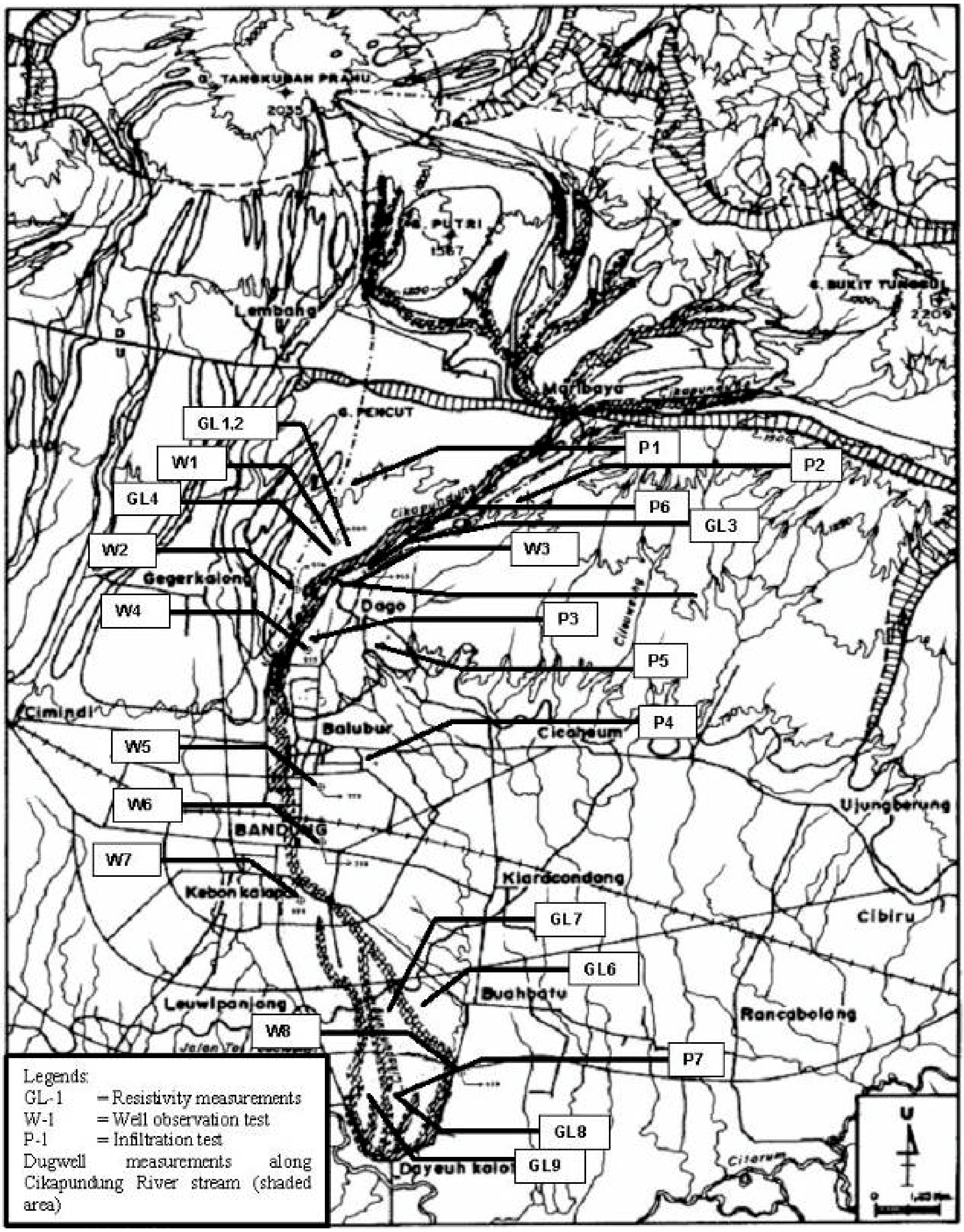

Figure 6. Observations points along Cikapundung River catchment area.

ANALYSIS AND INTERPRETATION

Based on the result of a flow line analysis, it shows that there is considerable amount of natural groundwater flow. The present study reveals an intricate groundwater flow pattern that is controlled by lithological and structural factors that create zones of surface water and groundwater interaction. Hence the relationship of geometrical aquifer along the Cikapundung River can be identified into 3 types (Table 3 and Figure 7), which across pore space and fracture media. The 3 types are: Cikapundung Type 1, Cikapundung Type 2, and Cikapundung Type 3. The 3 types are described from upstream (east) to down stream (west) as follows:

Cikapundung Type 1 is characterised by no relationship between river water and groundwater (isolated type). This type stretches from Maribaya to Curug Dago. Lava flows rests at riverbank and riverbed, resulting no hydrodynamic relationship between river water and groundwater.

Cikapundung Type 2 is characterised by river water fed by the groundwater (effluent type). Groundwater discharges permanently to Cikapundung through aquifer exposures at left and right wall. This segment spreads from Curug Dago to Banceuy Viaduct area. At this segment, groundwater flow converges toward the river with gradient 27% (right wall) and 8% (left wall).

Cikapundung Type 3 is characterised by river water recharge to groundwater (influent type). The water is flowing divergently to aquifer vertically and laterally, with gradient of 2.5% (at right riverbanks) and 4% (at left riverbanks). This segment lies from Banceuy Viaduct to Citarum river. The river infiltration is temporarily in dry season, when groundwater is lower than riverbed. Conversely, in wet season, the relationship is changing to effluent mechanism.

Based on above description, the change of volcanic lithology is clearly the main hydrogeological control in this area. It controls groundwater flow to river and river water infiltration to aquifer. At Viaduct area, it can be discover lithological change from Volcanic Breccias to Lake Deposit, at approximately 700 masl. The location is assumed to be the boundary of Cikapundung Type 2 and Type 3.

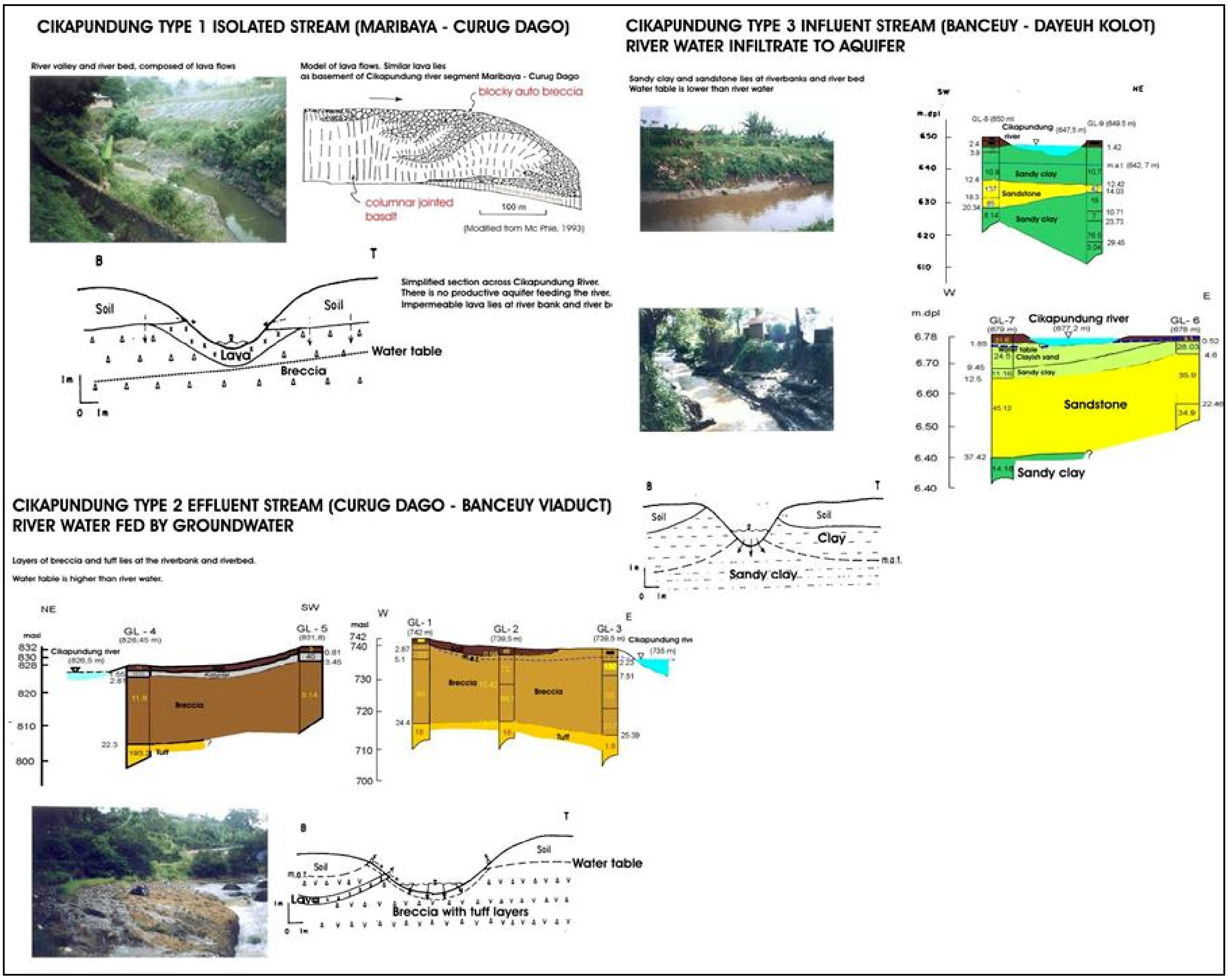

Figure 7. Summary of field data, from resistivity and water table measurements.

Table 3. Characteristic of Hydrodynamic Relation in Cikapundung River (flowing north to south)

Parameter Analyzed	Influent Stream (Downstream)		Effluent Stream (Middle Stream)	
Hydraulic Gradient	4 % Eastward	2.5 % Westward	8 % Eastward	2.7 % Westward
Groundwater Flow Line Pattern	Divergent		Convergent	
Morphological Unit	Lake Deposit		Volcanic Deposit (Volcanic breccias)	
Aquifer (Input – Output)	Recharge to Aquifer		Discharge from aquifer	
Vulnerability to Groundwater Pollution	High		-	

CONCLUSION

This research shows that surface water and groundwater must be managed in integral manner, because surface water bodies are integral parts of groundwater flow systems. Groundwater interacts with surface water in nearly all landscapes, ranging from small streams, to major river valleys. The interaction between river water and groundwater can be 4 types: influent type, effluent type, isolated type, and perched type. They can be permanent or seasonal interaction, controlled by the hydrodynamics condition.

In case of Cikapundung River, the relationship can be divided in to 3 types. **Cikapundung Type 1** is isolated type, characterised by no relationship between river water and groundwater. This type stretches from Maribaya to Curug Dago. Lava flow rests at riverbank and riverbed, resulting no hydrodynamic relationship between river water and groundwater.

Cikapundung Type 2 is effluent type, characterised by river water fed by the groundwater. Groundwater discharges permanently to Cikapundung through aquifer exposures at left and right wall. This segment spreads from Curug Dago to Banceuy Viaduct area. At this segment, groundwater flow converges to the river with gradient 27% (right wall) and 8% (left wall).

Cikapundung Type 3 is influent type, characterised by river water recharge to groundwater (influent type). The water is flowing divergently to aquifer vertically and laterally, with gradient of 2,5% (at right wall) and 4% (at left wall). This segment lies from Banceuy Viaduct to Citarum river. The river infiltration is temporarily in dry season, when groundwater is lower than riverbed. Conversely, in wet season, the relationship is changing to effluent mechanism.

Based on above description, lithology is clearly the main hydrogeological controls in this area. It controls groundwater flow to river and river water infiltration to aquifer. Substancially in terms of water quality, Cikapundung Type 3 segment from Banceuy Viaduct to Citarum River is the most vulnerable to groundwater contamination. Waste water management, domestic and industrial waste, must be the priority program at this segment.

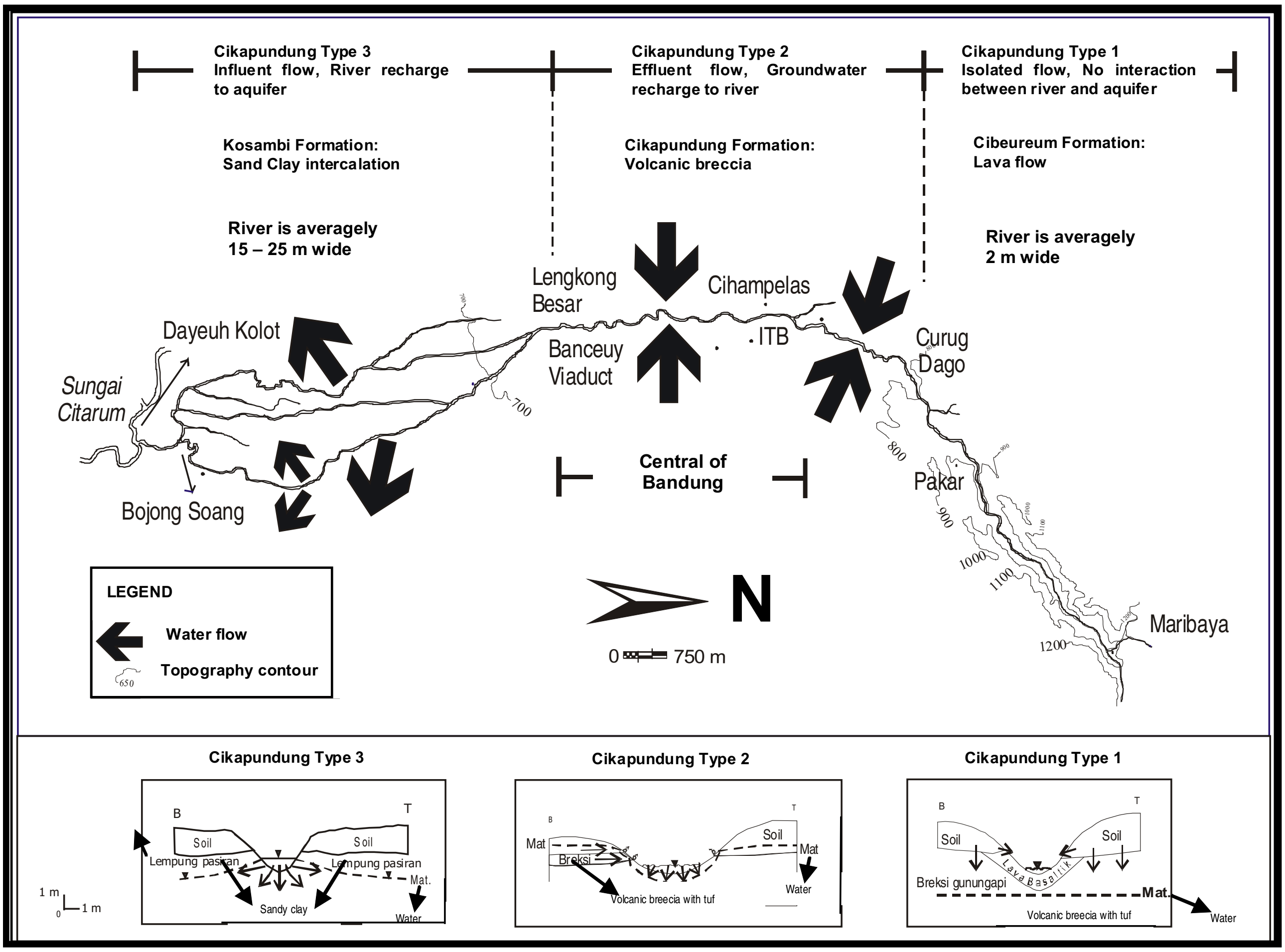

Figure 8. Result of study described three segments with different hydrodynamic relationships.

Corresponding author: Dr.Deny Juanda Puradimaja, Associate Professor, Dept.Geology,Institut Teknologi Bandung, Jl Ganesa No 10, Bandung, West Java Province, 40132, Indonesia. Tel: +62 222508133. Email: denyjp@bdg.centrin.net.id or denyjp@gc.itb.ac.id

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