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Estimating Base Flow Index to Predict Soil Permeability

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Abstract:Predicting Base Flow Index (BFI) in catchments area is important especially for the management of water resources, specifically for developing integration between surface water and groundwater. BFI can be used to determine the characteristic and movement of groundwater flow, even the World Meteorological Organization (WMO) in 2008 used BFI as an indicator to determine soil permeability and groundwater availability in catchments. Some existing researches only estimate two option values, namely high BFI with permeable conditions and low BFI with impermeable conditions. The purpose of this study is to find the relationship between several soil permeability values and soil types from various BFI values that are more detailed in a catchment. Base Flow Index (BFI) is the ratio of base flow and total streamflow. Base flow is estimated by the hydrograph separation method including BFI Standard (The United Kingdom Institute of Hydrology), HYSEP and PART using The USGS (United State Geological Survey) computer program-Groundwater Toolbox version 1.0 with data on daily streamflow for five years (2011-2015). The PART method is chosen because it has a linear correlation with base flow with streamflow and base flow with annual average rainfall with the highest R2. The soil permeability range of analysis result is greater than the soil permeability in study area. It indicates that the base flow estimation using the hydrograph separation method can be conducted because there is an overestimate in determining the base flow.

Keywords: *hydrograph separation, base flow, BFI, soil permeability.*

I. Introduction

Base flow is a characteristic of the low flow period that provides information about water resource available in the watershed during drought, especially on the characteristic of aquifers and groundwater storage in watershed (Dukik&Mihailovic, 2012). Surface water in Colorado River Valley relies on base flow, and management approach that considers groundwater and surface water as shared resource will be needed effectively in managing current and future water resource in the watershed (Miller et al. 2016). Understanding the characteristic of base flow is very important to river ecosystem and water management. Base flow estimation usually depends on the flow observed in measured watershed, but accurate prediction of stremflowthrough modeling can also be useful in estimating base flow (Lee et al. 2018) Therefore a scientific understanding about the contribution of base flow to river and watershed processes is very important when dealing with water policy and management issues (Choi et al. 2018) The description emphasizes that it is important to conduct an analysis of the base flow of the river in one catchment.

Base flow Index (BFI) is the ratio of base flow and total streamflow, that is developed by the United Kingdom Hydrology Institute (UKIH) in 1980 as a low flow study for the purpose of providing a catchment hydrogeological index for a predictable base flow (Institute of Hydrology , 1980). Stating that BFI can describe the characteristic condition of watershed, this shows that there is an influence from the soil and geology on the streamflow (Abebe & Foerch, 2006). 44 catchment from the Thames Basin that correlates with region that has geological class based on lithostratigraphic and hydrogeological classification scheme (Bloomfield et al., 2009). Base flow volume and BFI can indicate the increasing of underlying aquifer refill due to increasing rainfall (Esralew & Lewis 2010). BFI and k (recession flow constant) are related to several climatic and physiographic characteristic, especially that has annual evaporation potential, snow depth, and surface water body abundance (Beck et al., 2013). Average flow per catchment unit (QmAR) and BFI show additional trend with ephemeral (temporary), intermittent and perennial rivers (Berhanu et al., 2015). The above description shows that predicting the BFI in catchment is important in the management of water resource especially to ensure integration between groundwater and surface water.

The World Meteorological Organization (WMO) in 2008 used BFI as an indicator to determine soil type (permeability) and groundwater availability in catchment. BFI between 0.15-0.2 for impermeable catchment with low water availability, while BFI = 0.95 for catchment with high capacity groundwater storage, stable flow (WMO, 2008). BFI that is obtained from long-term time series from average daily flow using a simple base flow separation procedure, ranged from 0.99 for flow hydrograph that is dominated by typical base flow permeable lime catchment to 0.10 for catchment that is very striking with hydrogeology and highly impermeable soil type (Gustard et al., 1992). In 1996 in England a study of 2 (two) different rivers in different geological condition was conducted, the first is Lambourn area which is a limestone area, BFI = 0.96 and Ray area that is dominated by glacier clay and mud rock, BFI = 0.20 (Tallaksen & lanen, 2004). In Ireland, the measured BFI value ranges from 0.26 to 0.91, the BFI value in that place mainly depends on the geology, river bank, and characteristic of the catchment area (Irish Public Works Office, 2009). In Slovenia in the Alpine-Dinaric karstic hydrogeological region, with BFI > 0.5, an alluvial plain area with intergranular porosity with BFI> 0.8, conversely in the Eastern Alps which is a metamorphic and igneous rock region with BFI value <0.2 (Andjelov et al., 2016). The description above explains that BFI can be used to determine soil permeability in a catchments.

Base Flow Index (BFI) is the ratio between base flow and total streamflow. Base flow can be estimated by hydrograph separation method, including BFI Standard (Wahl & Wahl, 1995), HYSEP (Sloto & Crouse, 1995), PART (Rutledge, 1998). From the three methods, the one that has the best correlation between base flow and streamflow is chosen (Lee & Risley, 2002) and between base flow and rainfall (Quyang et al., 2018).

The above study states that the BFI value is low (0.1-0.26) with impermeable soil conditions and

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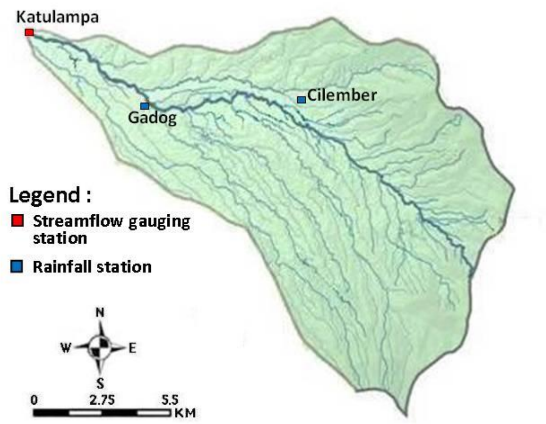
high BFI values (0.8-0.99) with permeable soil conditions, without assessing soil permeability and soil type in detail. This is considered to be very limited because it only estimates two option values namely high BFI with permeable conditions and low BFI with impermeable conditions. This study aims to find the relationship between several soil permeability values and soil types from various BFI values in more detail.

II. STUDY AREA AND DATA

Katulampa catchment is located upstream of Cilwung River, Bogor Regency, West Java Province, in the south of Jakarta City, Indonesia and it covers an area of approximately 149.51 km2 (Fig.1). Ciliwung River stretches from upstream in the big mountain and Salak mountain to downstream in the estuary of Jakarta bay. The climate in this catchment consists of dry season and rainy season.

Figure 1. Study Area Location



In Katulampa catchment, there is only one streamflow gauging station, namely Katulampa station with daily discharge data from 2011-2015 and two rain stations, Gadog and Cilember with daily rainfall data from 2011-2015. The Thiessen polygon method (Thiessen, 1911), (Chowdhury et al.,2016), (Olawoyin & Acheampong, 2017) is used to estimate the average annual rainfall from the two stations (table 1).

Table 1. The average of annual rainfall at Gadog and Cilember stations

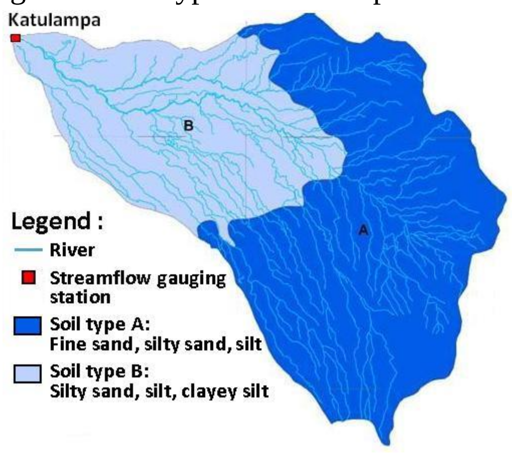
Year	Rainfall (mm/year)
2011	1,919.58
2012	2,968.90
2013	3,019.88
2014	3,048.75
2015	2,096.43

Soil types in Katulampa Catchment consist of two types as shown in table 2 and figure 2 (BBSDLP Bogor, 2011; Sari, 2017).

Table 2. Types of Soil in Katulampa Catchment

Area	Soil Type
A	Fine sand, silty sand, silt
B	Silty sand, silt, clayey silt

Figure 2. Soil type in Katulampa catchment



III. METHODS

Base flow and BFI estimation with Hydrograph Separation Method

Base flow Index (BFI; Standard) is based on a series of procedure developed by the United Kingdom Institute of Hydrology (UKIH) where streamflow records are partitioned into long N-day interval. The BFI standard sets N up to 5 days. The minimum streamflow every N-day

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interval is then identified and compared with the minimum approach to determine the "turning point". If 90 percent of the given minimum ("turning point test factor") is less than the two adjacent minimums, then the minimum is a turning point. Base flow hydrograph is solved by connecting turning point (Wahl & Wahl, 1995).

There are three methods of using HYSEP software to separate base flow component and runoff hydrograph: fixed interval, sliding interval, and local minimum method (Pettyjohn & Henning, 1979). Three methods use different algorithms to draw a connecting line (base flow hydrograph) between the low point of the flow hydrograph.

PART program is used to equate base flow to flow on days defined as not affected by surface runoff or storm flow, and linear interpolation between these days to determine the base flow for the remaining hydrograph. Days that are not affected by surface runoff are identified by the program as preceded by the day of the ongoing recession of Nsr (Rutledge, 2007), (Rutledge, 1998).

$$Nsr = A^{0,2} \quad (1)$$

Where Nsr is counting day and A is a drainage area.

1.0 version of US Geological Survey Groundwater Toolbox includes 3 (three) hydrograph separation methods for calculating base flow, Base flow Index (BFI; Standard), HYSEP (Fixed Interval, Sliding Interval, and Local Minimum), and PART method (Barlow et al., 2015). Groundwater Toolbox version 1.0 is used to estimate the annual base flow for the water budget component based on the separation of hydrograph in Appalachian Plateaus aquifer (Nelms et al., 2015), estimating the average proportion of base flow contribution to annual streamflow at each measurement determined by the station in 19 Wyoming drainages selected (Taboga & Stafford, 2016), to provide baseline flow estimates for concurrent and future investigation regarding the quantity and quality of base flow associated with land use, land cover, and management practice in Chesapeake Bay watershed (Raffensperger et al., 2017).

Type and Soil Permeability

Soil type ranged from porous, sand, silt to impermeable clay, they all have soil permeability coefficient (Terzaghi et al., 1996), even the hydraulic conductivity score of various deposit in saturated flow condition can be known for its permeability (Lewis et al., 2006). Soil permeability can also be said to be Soil Hydraulic Conductivity (Das, 2016). Soil permeability and soil type above can be summarized in table 3.

Table 3. Type and Soil Permeability

Soil permeability (cm/sec)	Type of soil
>1	Medium to coarse gravel
0.1-1	Coarse to fine sand
0.01-0.1	Fine sand, silty sand
0.001-0.01	Fine sand, silty sand, silt
1.10^{-5}-0.001	Silty sand, silt, clayey silt
1.10^{-5}-1.10^{-7}	Silty clay, clay
< 1.10^{-7}	Clay

Soil types in the upstream area of the Katulampa station (downstream of the Katulampa catchments) are Silty sand, silt, clayey silt with soil permeability values ranging from 1.10-5 - 0.001 (cm / sec).

BFI and Soil Permeability

Several studies linking BFI with soil permeability have been discussed in the introduction and they only mention two soil conditions, impermeable and permeable. In Germany, there are studies linking hydrogeological class, soil permeability and base flow indices (Bogena et al., 2003). All the above studies can be summarized in table 4.

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Table 4. Summary of Soil Permeability Classification and BFI, taken from Several Studies

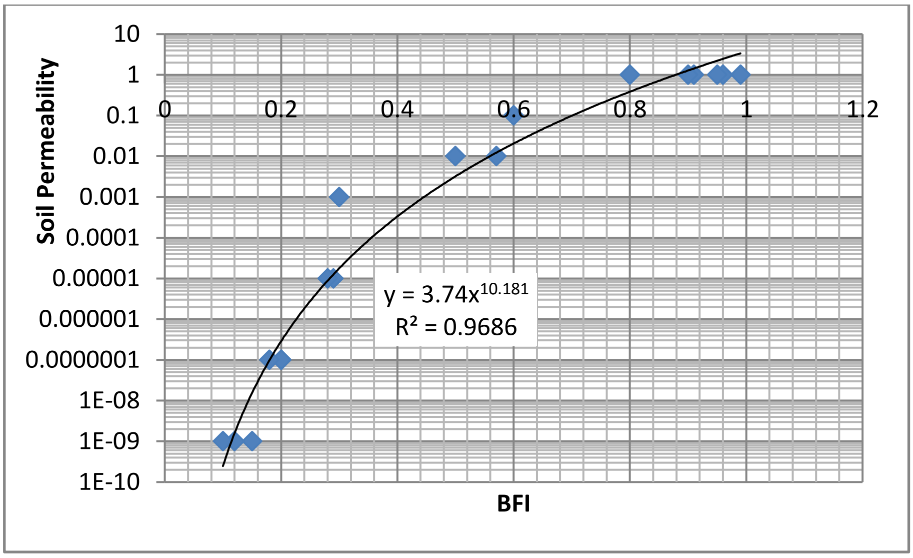
Soil Permeability		BFI					
Classification	(cm/sec)	Gustard et al., 1992	Tallaksen&Lanen, 2004	WMO, 2008	Irish Public Works Office, 2009,	Andjelov et al., 2016	Bogena et al., 2003
Very high	1	0.99	0.96	0.95	0.91	0.8	0.9
High	0.1						0.6
Medium	0.01					0.5	0.57
Moderate	0.001						0.3
Low	1.10^{-5}				0.28		0.29
Very low	1.10^{-7}		0.2			0.2	0.18
Extremely low	1.10^{-9}	0.1		0.15			0.12

The relationship between soil permeability and BFI above can be generated with the following regression equation:

$$y = 3.74\,x^{10.181} \quad (2)$$

With $R^2 = 0.9686$ as seen in Figure 3.

Figure 3. Correlation between soil permeability and BFI



IV. RESULT AND DISCUSSION

Base flow estimation with several hydrograph separation methods

Base flow estimation in 2011 using the hydrograph separation method using BFI Standard (UKIH), Fixed-Interval HYSEP, HYSEP Sliding Interval, Local Minimum HYSEP, and PART are shown in Figure 4 to 8.

Figure 4. Hydrograph separation with BFI Standard (UKIH) method.

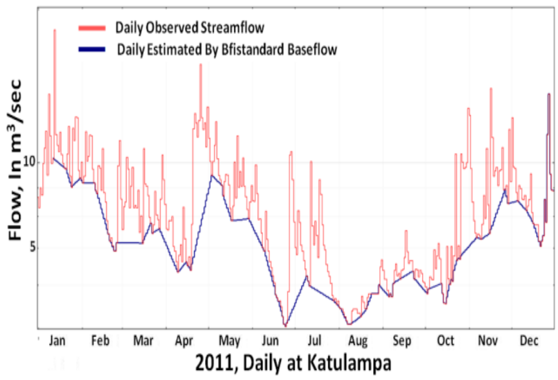


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Figure 5. Hydrograph separation with HYSEP-Fixed method.

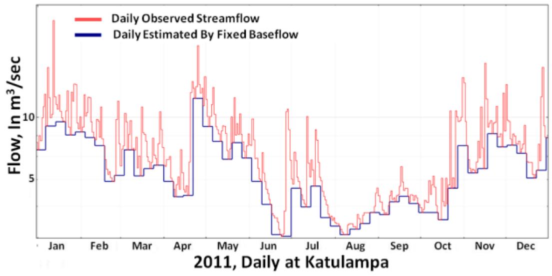


Figure 6. Hydrograph separation with HYSEP-Sliding Interval method.

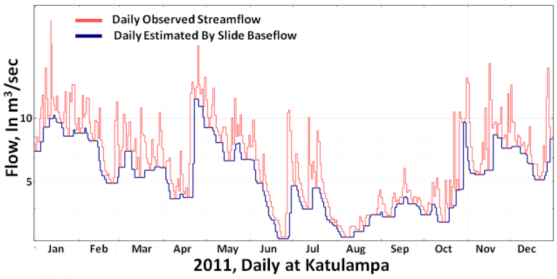


Figure 7. Hydrograph separation with HYSEP-Local Minimum method.

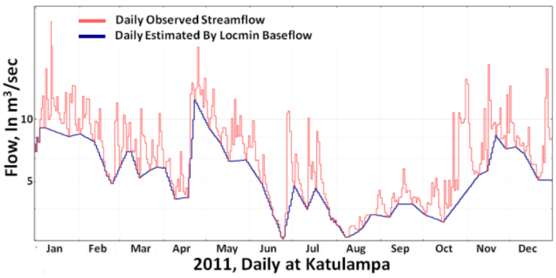
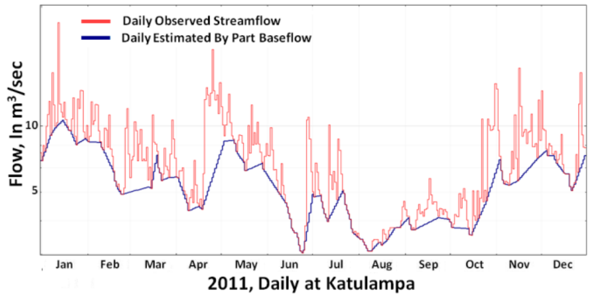


Figure 8. Hydrograph separation with PART method.



Base flow result (maximum, minimum, average and total) and streamflow (maximum, minimum, average and total) from various hydrograph separation method above can be seen in table 5. The result of BFI estimation from several hydrograph separation methods above can be seen in table 6.

In dry season, the lowest streamflow is the lowest base flow (Smakhtin, 2001), (Brodie & Hostetler, 2005), (Julander & Clayton, 2018).

From the result of BFI analysis using several hydrograph separation methods, it can be concluded that all separation methods explain that at the end of dry season or the in the beginning of rainy season, in August, September and October, the lowest streamflow is the minimum base flow.

Table 5. Base flow and stream flow using several hydrographic separation methods (m3 / sec)

Year	Base flow UKIH			HYSEP Sliding Interval			HYSEP Fixed-Interval			HYSEP Local Minimum			PART			Streamflow			
	max	mean	total	max	mean	total	max	mean	total	max	mean	total	max	mean	total	min	max	mean	total
2011	13.29	7.11	2,517.1	11.49	7.36	2,686.1	11.13	7.39	2,697.7	11.13	7.37	2,689.1	10.47	7.32	2,673.1	5.04	17.41	8.13	2,968.7
2012	23.80	8.08	2,884.1	13.98	8.24	3,009.2	13.98	8.24	3,009.2	14.30	8.19	2,989.8	11.92	8.09	2,954.3	4.13	23.80	9.04	3,297.9
2013	13.36	7.61	2,667.9	20.24	8.03	2,930.8	19.35	8.03	2,932.4	13.36	7.89	2,879.4	21.70	8.09	2,953.5	4.91	30.15	9.28	3,385.9
2014	16.85	7.41	2,624.2	26.23	8.26	3,016.1	18.75	8.17	2,983.0	26.23	8.27	3,017.9	18.85	8.26	3,015.3	5.26	37.26	9.84	3,589.9
2015	11.62	6.84	2,416.1	12.70	7.24	2,642.0	12.70	7.24	2,642.6	12.48	7.14	2,607.2	12.62	7.12	2,597.0	3.13	18.65	8.02	2,928.0
Note: minimum base flow of all method is the same as minimum stream flow.																			

Table 6. BFI using hydrograph separation method

Year	Base flow Index				
	Base flow UKIH	HYSEP Fixed-Interval	HYSEP Sliding Interval	HYSEP Local Minimum	PART
2011	0.85	0.91	0.90	0.91	0.90
2012	0.87	0.91	0.91	0.91	0.90
2013	0.79	0.87	0.87	0.85	0.87
2014	0.73	0.83	0.84	0.84	0.84
2015	0.83	0.90	0.90	0.89	0.89

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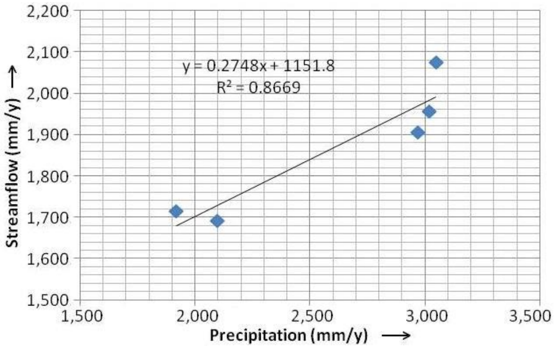
The correlation of Stream flow and Rainfall

Stream flow that occurred during 2011-2015 has a significant influence on rain, this is evidenced from the linear correlation between the two with R2 = 0.87 (Figure 9).

Figure 9. Correlation between Stream flow and Rainfall



The Best Base flow

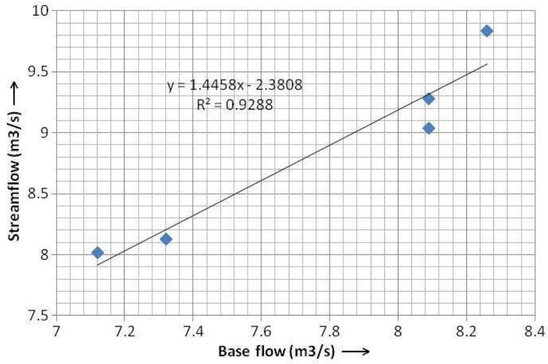
Looking at the five methods above, it will be very difficult to determine the best base flow result because of the difficulty of measuring base flow in the field (Partington et al, 2012), (Zhang et al, 2012). Base flow separation is a subjective method because there is no appropriate method that is able to identify each base flow (Bosh et al., 2017).

The correlation of base flow with the average stream flow annually in Calapooia River (station 14172000), Oregon U.S. shows a strong correlation, with R2 = 0.94 (Lee and Risley, 2002). The five methods are compared in this study, the method with the highest R2 is considered the best. The best base flow result is the PART method with R2 = 0.9288. See table 7 and Figure 10.

Table 7. Base flow and stream flow taken from the result of PART separation method

Year	Base flow (m3/sec)	Streamflow (m3/sec)
2011	7.32	8.13
2012	8.09	9.04
2013	8.09	9.28
2014	8.26	9.84
2015	7.12	8.02

Figure 10. The correlation between base flow and streamflow with PART method

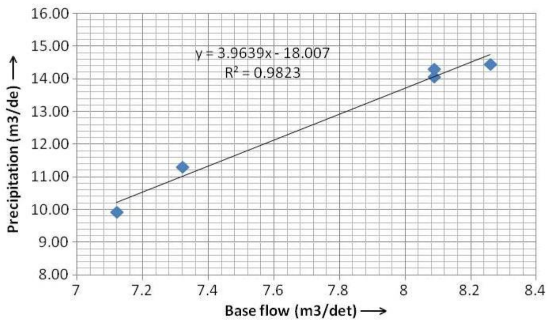


In Pengchongjian small watershed, Jiangxi China which has four seasons, the linear correlation of base flow and average rainfall with R2 = 0.67 (Quyang et al., 2018). There are five methods compared, PART method with R2 = 0.98 is the highest method of the others. See Table 8 and Figure 11.

Table 8. Baseline flow and annual average rainfall with PART method

Year	Base flow (m3/sec)	Precipitation (m3/sec)
2011	7.32	11.30
2012	8.09	14.08
2013	8.09	14.32
2014	8.26	14.45
2015	7.12	7.12

Figure 11. The correlation between base flow and annual average rainfall with the PART method



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The analysis result of base flow correlation with streamflow and base flow with annual average rainfall is the PART method.

BFI with Soil Permeability in Study Area

The BFI value from the PART method is entered in equation (2) so that the soil permeability value is obtained. Soil types are obtained from Table 3. The results can be seen in Table 9.

Table 9 The result of BFI PART, soil permeability and soil type

Year	BFI PART	Soil Permeability (cm/sec)		Soil Type
		Equation(2)	Range	
2011	0.9004	1.2856	>1	Medium to coarse gravel
2012	0.8958	1.2199	>1	Medium to coarse gravel
2013	0.8723	0.9305	0.1-1	Coarse to fine sand
2014	0.8400	0.6335	0.1-1	Coarse to fine sand
2015	0.8870	1.1028	>1	Medium to coarse gravel

The results from the above table show that the soil permeability in the Katulampa catchment ranges from 0.1-1 to > 1 cm / sec with the type of soil being coarse to fine sand and medium to coarse gravel.

V. CONCLUSION

Base flow and BFI in the Katulampa catchment from year to year always changes, this shows the dynamics of changes in groundwater. The existence of ground water is strongly influenced by rainfall.

All hydrograph separation results using the Standard BFI (UKIH) method, HYSEP Fixed Interval, HYSEP Sliding Interval, Local Minimum HYSEP, and PART indicate that at the end of the dry season or the beginning of the rainy season (August or September or October) the lowest river flow occurs is the lowest base flow.

The relationship between base flow-streamflow and base flow-annual average rainfall from the five hydrograph separation methods was chosen by the PART method with the highest R2 values of 0.93 and 0.98, respectively.

Soil permeability in Katulampa catchment ranged from 0.00001 to 0.01 cm/sec with BFI values ranging from 0.2820-0.4457, while the permeability of the soils from the analysis results ranged from 0.1-1 to > 1 cm/sec with BFI ranging from 0.84-0.90. This shows that the BFI estimation using the PART separation method has a tendency for soil permeability and a high BFI value. The possibility of overestimation in estimating base flow (Lim et al, 2005) and (Vasconcelos et al, 2013). For this reason, further studies need to be done, especially in other catchments or watersheds.

For further research development can be done spatially. To predict the value of BFI, soil type and soil permeability with a spatially distributed water balance model (Zomlot et al., 2015), for ungauging locations with BFI regression as a function of capture characteristics (Singh et al., 2018), so that in one catchments there are several BFI values that can describe the type of soil and soil permeability. Opinions of some researchers who state that it is very difficult to estimate base flow is agreed by the author. However, efforts to obtain an accurate base flow need to be continued with various methods.

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