International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9, Issue-7, May 2020

Annual Baseflow Estimation by Combining Hydrological Models and Graphic Hydrograph Methods

Ilham Poernomo, Suripin, Robert J Kodoatie

***Abstract** Streamflow consists of runoff, interflow and baseflow which is reflected / illustrated in the river flow hydrograph. Predicting the interflow and baseflow in a catchment is important for the water resource management, specifically to find out the relationship between groundwater with surface water and ground water potential. Although, baseflow analysis according to some researchers produces uncertainty, due to difficulties in measuring baseflow. In the hydrological cycle, the relationship between precipitation, evapotranspiration, runoff, recharge, interflow, percolation, groundwater storage changes, baseflow and streamflow is described in hydrological model. In this study, a simulation of the hydrological model above, evapotranspiration and runoff was analysed by the tank method, the recharge was analysed by using equations from previous researches, using precipitation data in 2011-2015. In addition, the analysis of interflow and baseflow was performed by using graphic hydrograph comparative method from the years 2011-2015 discharge data on catchment in Katulampa, Bogor, Indonesia. The results showed that streamflow is the same as baseflow at the end of the dry season in August or September or October. The annual flow of the model is smaller than the baseflow with the UKIH , HYSEP and PART hydrograph separation methods. The interflow value is 7 % and the baseflow is 53% from the precipitation in a year.*

***Keywords:** evaluation; performance; reliability; resiliency; vulnerability; water distribution..*

I. INTRODUCTION

T Baseflow is a representation of the presence of ground water. In the rainy season, its flow is fast and high (flood). In the dry season, it still flows from groundwater that is baseflow (Kodoatie & Syarief, 2010). The baseflow is the characteristic of low flow period and provides information about the available water resource at watershed during drought (Dukic & Mihailović, 2012). Miller et al. (2016) showed that the surface water in the Colorado River Valley relies on baseflow, a management approach that takes into account groundwater and surface water as a shared resource is required to manage water resources in watershed at the present time and in the future. The baseflow analysis usually depends on the observed streamflow in the measured watershed, but accurate prediction of streamflow through modelling can also be useful in estimating baseflow (Lee et al., 2018). The description confirms that performing the analysis of the baseflow in streams in a unit of watershed is important.

To find out the amount of baseflow, the hydrograph separation approach is used, that is by separating the baseflow from streamflow (Ackroyd et al., 1967). There are several hydrograph separation methods that have developed, including the simple graphic separation method by Linsley et al. (1949), the United Kingdom Institute of Hydrology's (UKIH) separation method by the Institute of Hydrology (1980) , the unit hydrograph method by Su (1995), the rating curve method by Sellinger (1996), the filtering method by Sloto & Crouse (1996), recession curve method developed by Rutledge (1998), recursive filtering method by Eckhardt et al. (2005), and the flow separation method by using a hydro chemical tracker by Gonzales et al. (2009) .

Barlow et al. (2015) from the United State Geology Survey (USGS) developed a Groundwater Toolbox computer program version 1.0 to separate baseflow from streamflow from several UKIH (BFI Standard) methods, HYSEP developed by Sloto and Crouse (1995) and PART developed by Rutledge (1998). The implementation of the Groundwater Toolbox has been widely used, such as by Nelms et al. (2015) who estimated the water balance component based on the hydrograph separation methods by PART, HYSEP and BFI (UKIH) in the Appalachian Plateaus aquifer, US. Raffensperger et al. (2017) who compared the hydrograph separation method using Recursive Digital Filter (RDF) with the graphic method PART, HYSEP and BFI (UKIH) in the Chesapeake Bay watershed in the US.

Jain (2002) and Ebtehaj (2017) describe the hydrograph of river flow as there are runoff, interflow and baseflow components. Jain (2011) illustrates the hydrograph, after reaching the peak (runoff), the flow will show falling limb where there is an interflow recession. After the flow crosses the straight line of the baseflow line, then a baseflow recession can occur. Some of the opinions mentioned above led to the idea that, interflow and baseflow can be analysed by using the hydrograph graphical method.

There are some studies which state that estimating baseflow by separating from streamflow is a subjective process (Sloto & Crouse, 1996).

Revised Manuscript Received on May 30, 2020.
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Baseflow estimation produces uncertainty even Singh & Singh (2001) states that such a separation is quite arbitrary and subjective. However, it remains useful for hydrographic analysis. The same thing was conveyed by Bosh et al. (2017), Pelletier & Andréassian (2019) who argue that it is even difficult to validate this method because it cannot measure baseflow in the field (Partington, et al., 2012). Lim et al. (2005) argue the first time that overestimates occur in baseflow estimation. The above description opens the widest opportunity to analyse baseflow by using various methods.

To analysis baseflow, this present study proposes a model of the hydrological cycle introduced by Chow et al. (1988) and Kodoati (2011). The strength of this model is that it displays the relationship between groundwater and surface water, including: precipitation, evapotranspiration, runoff, recharge, interflow, percolation, baseflow and streamflow. The analysis of evapotranspiration and runoff was performed by Mock tank method (Mock, 1973), the analysis of recharge was performed by using the equation of Wang et al. (2008), Zomlot et al. (2015), the percolation analysis was performed by using equations developed by Li & Simonovic (2001) using rain data. In addition, for interflow and baseflow in the analysis using graphical comparison approach to river flow hydrograph of river discharge data. These two approaches are combined in the above model so that the percolation, change in groundwater storage and streamflow can be figured out.

II. STUDY AREA

The area of study are located in the catchment at the Ciliwung river upstream area or often called Katulampa catchment in Bogor, which is located of the upstream of the Ciliwung river. Located at the downstream of the Ciliwung river is the city of Jakarta and whose estuary is the Bay of Jakarta. Katulampa catchment is located at the tropical area which has two climates: the dry and the rainy season.

In the catchment Katulampa, there is water level station or river discharge station of Katulampa, with the data of daily river discharge used in the study, from 2011 to 2015. In the Katulampa catchment, there are two rain stations: Gadog and Cilember station with the daily rainfall data from 2011 to 2015.

III. BASEFLOW ANALYSIS WITH SEVERAL HYDROGAF SEPARATION METHODS

Hydrograph separation using graphical methods consists of UKIH (BFI Standard) from the United Kingdom Institute of Hydrology (1980), HYSEP (Fixed Interval, Sliding Interval, Local Minimum) methods by Sloto and Crouse (1995), PART method by Rutledge (1998). The separation analysis was performed by using the daily river discharge data in the Katulampa station from the years 2011-2015 using a computer program, Groundwater Toolbox developed by Barlow et al. (2015) from the United State Geology Survey (USGS).

The results of Baseflow analysis by using hydrograph separation method with several methods above in 2011 can be seen on Figure 1 and Figure 5 (in this study, the image of hydrograph separation results in 2011 is displayed).

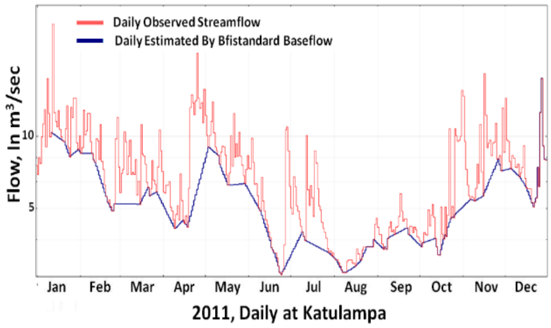

Fig. 1. Hydrograph separation with UKIH (BFI Standard) method

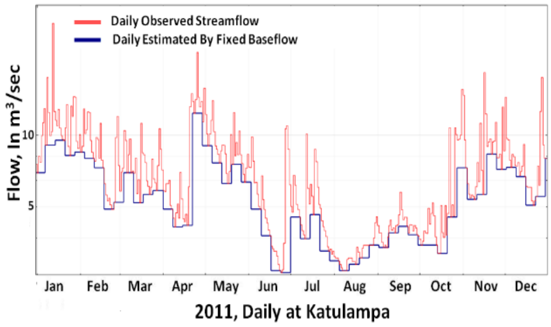

Fig. 2 . Hydrograph separation with HYSEP-Fixed method

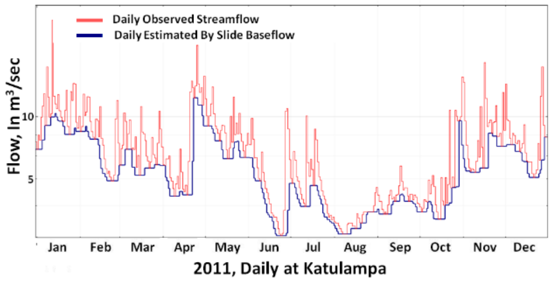

Fig. 3. Hydrograph separation with HYSEP-Sliding Interval method

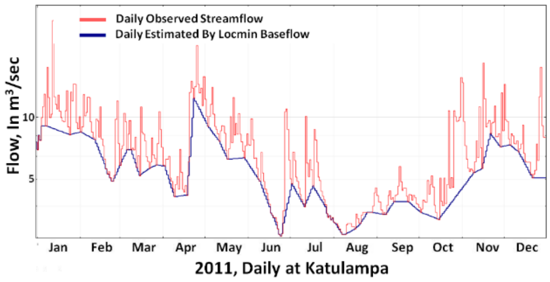

Fig. 4. Hydrograph separation with HYSEP - Local Minimum method

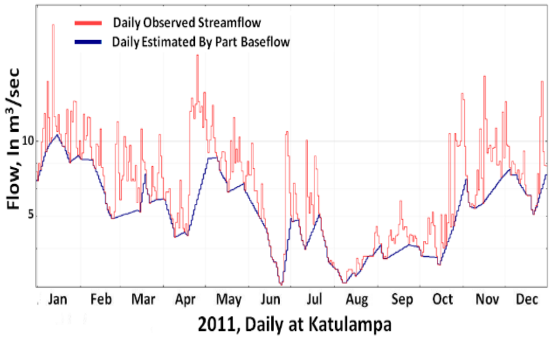

Fig. 5. Hydrograph separation with PART method

The results of Baseflow and streamflow (2011-2015) with the UKIH Method (BFI Standard) are presented on Table 1

Table -I. Baseflow and Streamflow with the UKIH (BFI Standard) method

Year	Baseflow				Streamflow			
	min	max	the mean	total	min	max	the mean	total
2011	5.04	13.29	7.11	2,517.06	5.04	17.41	8.13	2,968.72
2012	4.13	23.80	8.08	2,884.11	4.13	23.80	9.04	3,297.94
2013	4.91	13.36	7.61	2,667.88	4.91	30.15	9.28	3,385.90
2014	5.26	16.85	7.41	2,624.18	5.26	37.26	9.84	3,589.86
2015	3.13	11.62	6.84	2,416.10	3.13	18.65	8.02	2,928.04

The results of Baseflow and streamflow (2011-2015) with the Fixed-Interval HYSEP method are presented in Table 2.

Table - II. Baseflow and Streamflow with The HYSEP Fixed-Interval method

Year	Baseflow				Streamflow			
	min	max	the mean	total	min	max	the mean	total
2011	5.04	11.13	7.39	2,697.75	5.04	17.41	8.13	2,968.72
2012	4.13	13.98	8.24	3,009.20	4.13	23.80	9.04	3,297.94
2013	4.91	19.35	8.03	2,932.45	4.91	30.15	9.28	3,385.90
2014	5.26	18.75	8.17	2,983.00	5.26	37.26	9.84	3,589.86
2015	3.13	12.70	7.24	2,642.65	3.13	18.65	8.02	2,928.04

The results of Baseflow and Streamflow (2011-2015) using the HYSEP Sliding Interval method are presented in Table 3.

Table - III. Baseflow and Streamflow with HYSEP Sliding Intervals method

Year	Baseflow				Streamflow			
	min	max	the mean	total	min	max	the mean	total
2011	5.04	11.49	7.36	2,686.06	5.04	17.41	8.13	2,968.72
2012	4.13	13.98	8.24	3,009.20	4.13	23.80	9.04	3,297.94
2013	4.91	20.24	8.03	2,930.77	4.91	30.15	9.28	3,385.90
2014	5.26	26.23	8.26	3,016.12	5.26	37.26	9.84	3,589.86
2015	3.13	12.70	7.24	2,642.03	3.13	18.65	8.02	2,928.04

The results of Baseflow and streamflow (2011-2015) with the Local Minimum HYSEP method are presented in Table 4

Table – IV. Baseflow and Streamflow with The HYSEP Local Minimum method

Year	Baseflow				Streamflow			
	min	max	the mean	total	min	max	the mean	total
2011	5.04	11.13	7.37	2,689.08	5.04	17.41	8.13	2,968.72
2012	4.13	14.30	8.19	2,989.83	4.13	23.80	9.04	3,297.94
2013	4.91	13.36	7.89	2,879.41	4.91	30.15	9.28	3,385.90
2014	5.26	26.23	8.27	3,017.89	5.26	37.26	9.84	3,589.86
2015	3.13	12.48	7.14	2,607.22	3.13	18.65	8.02	2,928.04

The results of Baseflow and Streamflow (2011-2015) with the PART method are presented in Table 5 .

Table 5. Baseflow and Streamflow with The PART method

Year	Baseflow				Streamflow			
	min	max	the mean	total	min	max	the mean	total
2011	5.04	10.47	7.32	2,673.12	5.04	17.41	8.13	2,968.72
2012	4.13	11.92	8.09	2,954.32	4.13	23.80	9.04	3,297.94
2013	4.91	21.70	8.09	2,953.46	4.91	30.15	9.28	3,385.90
2014	5.26	18.85	8.26	3,015.35	5.26	37.26	9.84	3,589.86
2015	3.13	12.62	7.12	2,597.05	3.13	18.65	8.02	2,928.04

The results of the hydrograph separation using the UKIH (BFI Standard), HYSEP (Fixed-Interval, Sliding Interval, Local Minimum) and PART methods confirm that at the end of the dry season or the beginning of the rainy season, the month of August, September, October, the streamflow is the same as the baseflow.

IV. BASEFLOW ANALYSIS USING THE HYDOLOG Y CYCLE MODEL

Hydrological Cycle Model

The hydrological cycle model outlined in the background was also developed into the WetSpa model by Shafii & Smedt (2009), Brandyk et al (2011). This model completely describes the relationship between the rain, surface water with groundwater.

The hydrological cycle model proposed in this study was analysed on an annual basis with the following process : the surface soil precipitation (P), evapotranspiration (ET) and runoff (RO), then some of the water fill soil water (Rc), entered vadose zone and some water moves laterally into interflow (If) Harter & Hopmans (2004), Ymeti (2007), Welderufael & Woyessa (2010). Flow that moves laterally (interflow) will flow to the river (Brouziyne et al, 2017). The water then drops again vertically as Percolation (Pk) enters the phreatic zone or saturated zone and fills in groundwater storage (ΔGWS) and flows to the river as a baseflow (Bf), see Figure 1.

In general, the phenomenon of the presence of ground water is divided into two types: water in the vadose zone and water in the phreatic zone. In vadose zone, there is soil water. In the phreatic zone or saturated zone, there is a groundwater (Kodoati, 2011)

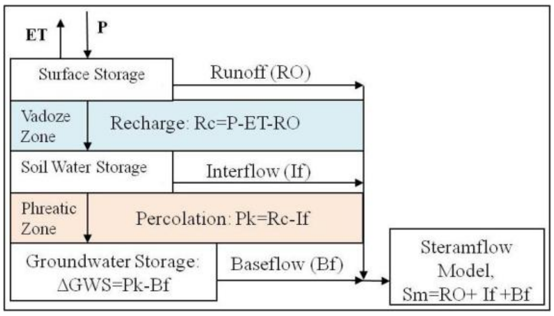

Fig 5. Hydrologic cycle model

Precipitation

Precipitation at the Katulampa catchment used daily rainfall data for the period 2011 - 2015 from the two stations of Gadog and Cilember. Rainfall data from these two stations were then analysed using the Thiessen Polygon Method into annual rain data (P) used in the model.

Evapotranspiration

Monthly evapotranspiration was analysed by the method of Mock (1973) which is often used in Indonesia with the following equation:

$$\Delta E = ETp \times (d/30) \times m \qquad (01)$$

$$d = 3/2 \times (18-n) \qquad (02)$$

$$\Delta E = ETp \times (m/20) \times (18-n) \qquad (03)$$

$$ETm = ETp - \Delta E \qquad (04)$$

where d is the number of dry or no rainy days in a month, n is the number of rainy days in a month, ΔE is the difference between potential evapotranspiration and limited evapotranspiration (mm/month); ETp is potential evapotranspiration (mm / month); ETm is monthly evapotranspiration (mm/month), m is the percentage of land covered in vegetation, estimated from the maps of land use (taken from Table 6)

Table - VI. Exposed Surface

Area	Exposed surface, m (%)	
	End of the rainy season	Dry season
Forest	0	0
Secondary Forest	0	Add 10% per month during the dry season.
Eroded area	10-40	same as above
Field / Agriculture Area	30-50	same as above

Source: Mock (1973)

ETm can be obtained from the equation (01) through (04) using the daily rainfall data from Gadog and Cilember station (2011-2015). The ratios seen in table 7 are obtained from the number of ETm in a year and the amount of rain for 1 year.

Table – VII. The Ratio of evapotranspiration and precipitation

Year	Ratio
2011	0.16
2012	0.12
2013	0.10
2014	0.12
2015	0.19

Runoff

Monthly runoff was analysed by the Mock method (1973) using this following equation:

$ER=Pm–ETm$ (05)

$SM=SMC–ISM$ (06)

WS=ER-· SM (07)

$I=ki \times WS$ (08)

$ROm=WS–I$ (09)

Where, Pm is the monthly precipitation (mm/month), ETm is monthly evapotranspiration (mm/month), ER: Excess Rainfall, rain which directly reaches ground level (mm/month), SM: Soil Moisture (mm), SMC: Soil Moisture Capacity (mm), ISM: Initial Soil Moisture (mm / month), WS: water surplus , the excess water from rain water after use to meet the Soil Moisture (mm/month), I: Infiltration, residual water that seeps into the soil (mm/month), Ki : The infiltration coefficient and ROm are monthly runoff (mm/month).

ROm is obtained from equations (05) to (09) using daily rainfall data from Gadog and Cilember stations (2011-2015). The ratios seen in Table 8 are obtained from the amount of ROm for 1 year and the amount of precipitation for 1 year.

Table -VIII. Ratio of runoff and precipitation

Year	Ratio
2011	0.19
2012	0.24
2013	0.25
2014	0.26
2015	0.22

Recharge

Wang et al (2008), Fischer (2013), Zomlot et al (2015) developed the simple water balance equation as follows:

$P - ET = RO + Rc$ (10)

$Rc = P - ET - RO$ (11)

Where P is precipitation (mm/year), ET is Evapotranspiration (mm / year), RO is Runoff (mm/year), and Rc is Recharge groundwater (mm/year), all rainwater entering the ground including Infiltration.

Interflow and Baseflow

Linsley et al . (1949), Viessman and Lewis (1997), Davie (2008), Bosch et al. (2017) argued that interflow is part of hydrograph but interflow tends to be ignored and interflow is often combined with direct runoff (Gupta, 2016).

The study that calculated the amount of interflow was conducted by Huang et al (2013), this study carried out simulations of surface flow, interflow, and baseflow with two HBV and TOPMODEL models.

In this study, analysis of interflow and baseflow was based on several considerations as follows:

1. Jain (2002) and Ebtehaj (2017), graphically show the components of the hydrograph: runoff, interflow and baseflow, shown in Figure 6.

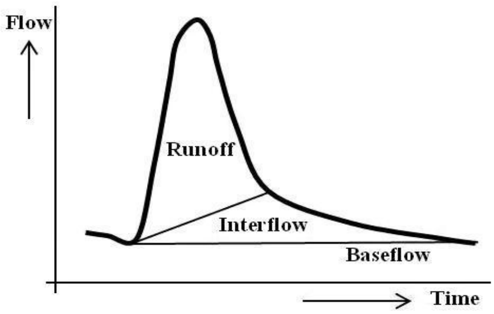

Fig. 6. Components of Hydrograph, Jain (2002) and Ebtehaj (2017)

2. Jain (2011) showed that after the peak of the hydrograph, recession of quickflow, recession of interflow and recession of baseflow occurred on a hydrograph (see Figure 7) ;

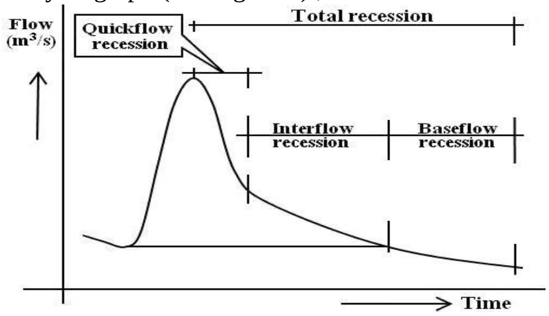

Fig.7. Recession in hydrograph , Jain (2011)

3. In the dry season, interflow = 0, Vasconcelos et al. (2012) , Rahayuningtyas et al. (2014) ;
4. Streamflow = baseflow which occurs at the end of the dry season (Smakhtin, 2001) , (Brodie & Hostetler , 2005) , (Julander & Clayton, 2018) ;
5. results of the separation of the UKIH (BFI Standard), HYSEP (Fixed-Interval, Sliding Interval, Local Minimum) and PART method using the Groundwater Toolbox (Barlow et al., 2015) argue that at the end of the dry season or the beginning of the rainy season, in August, September, October a streamflow equals the baseflow;
6. Observation of the hydrograph on the years of 2011-2015 (Figure 8 - Figure 12), there is a pattern of hydrograph fluctuations as follows: the peak of hydrograph always occurs in January or February (the early years) and the month of November or December (end of year). The lowest flow or low flow occurs in August or September or October. In either August or September or October there is a streamflow similar to baseflow.

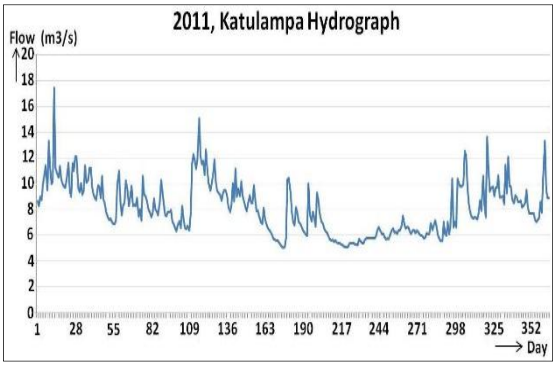

Fig. 8. Hydrograph 2011 at Katulampa.

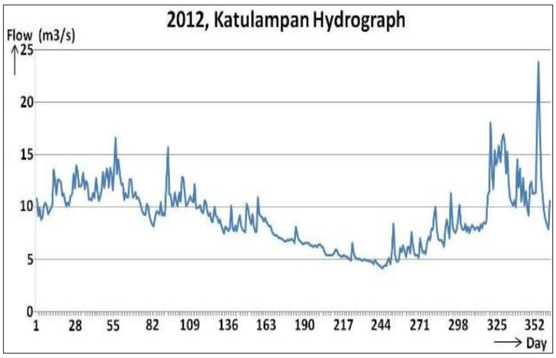

Fig. 9. 2012 Hydrograph at Katulampa.

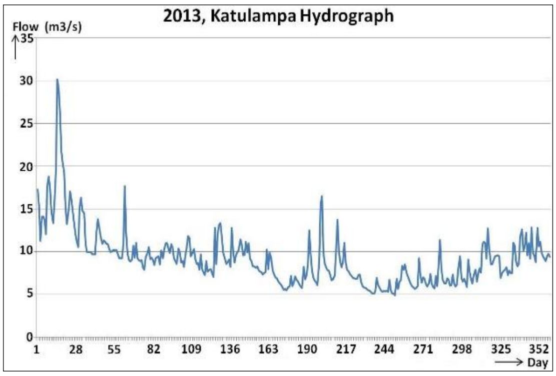

Fig. 10. Hydrograph 2013 at Katulampa.

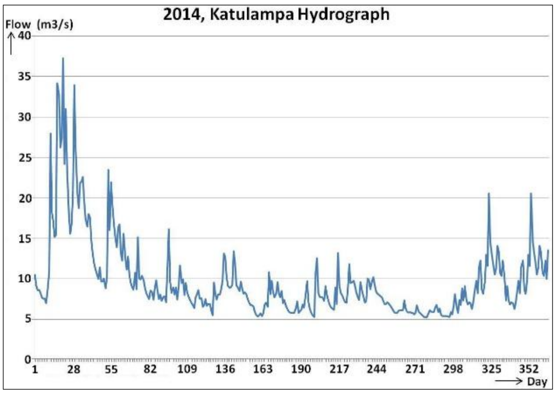

Fig.11. Hydrograph 2014 at Katulampa.

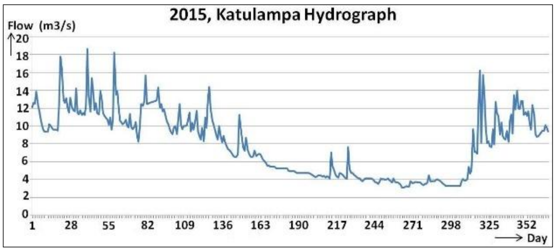

Fig. 12. Hydrograph 2015 at Katulampa.

With the six considerations above, interflow and baseflow for a year can be analysed by using the comparison of graphical hydrographs as follows:

1. Within a year, one of the highest peaks of the hydrographs is chosen which is at the beginning of the year, January or February. Based on the highest hydrograph, the starting point (point A), rising limb, peak flow, falling limb, inflection point (point B) can be determined to show the starting point of the interflow, the end point of the recession (point C) which is the starting point of the baseflow. AC line is a straight-line method that is a line that separates runoff and interflow with baseflow. The value of interflow is the inflection point value (point B) minus the recession end point (point C), (Figure 13). The same is done for the highest peak hydrograph in November or December. (Figure 14).

The selection process of the highest hydrograph in January and December and the occurrence of the lowest streamflow = baseflow can be seen in Table 9.

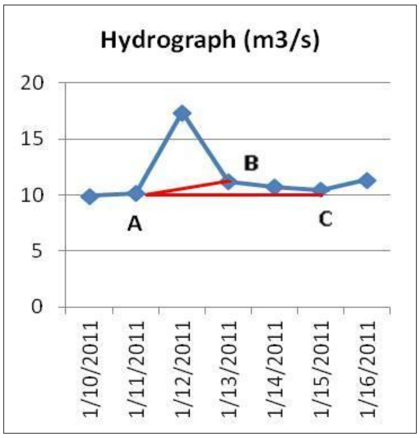

Fig. 13. Highest hydrograph was selected in January 2011

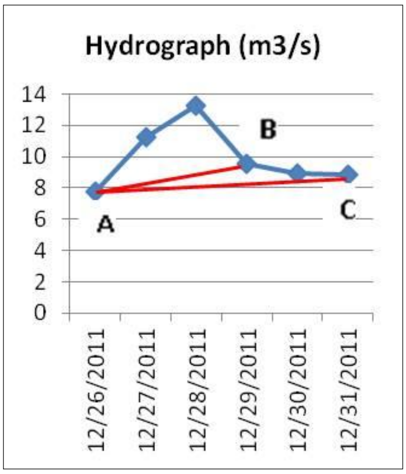

Fig. 14. The highest hydrograph was selected in December 2011

2. Interflow in August or September or October = 0. While Interflow on January and December was obtained from the number 1) above. The interflow on February, March, April, May, June, July, November was obtained from the comparison of interflow value = 0 with a value of interflow from January and December (see Figure 15).

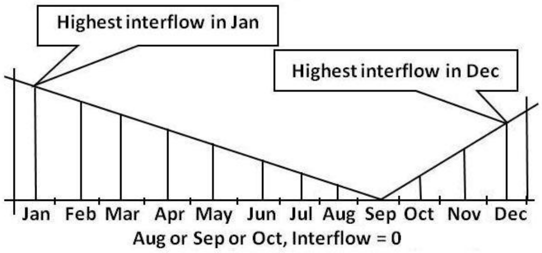

Fig. 15. Comparison of monthly interflow values

The results of monthly interflow analysis in 2011-2015 are presented in Table 4.5.

3. Baseflow that occurs on August or September or October is streamflow. In addition, the January and December baseflows were obtained from process number 1) above. To calculate the baseflow in February, March, April, May, June and July, the comparison in value between the baseflow value in January and the lowest baseflow value in August or September or October is used. Likewise for baseflow on November with the value of the ratio between the value of baseflow in December to the lowest value in August or September baseflow (see Figure 16.).

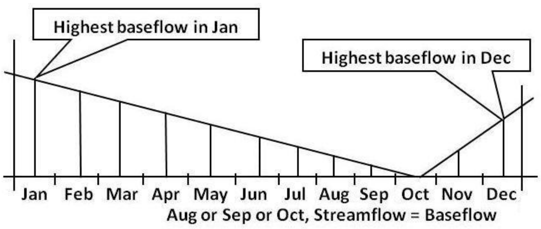

Fig. 16. Comparison of monthly baseflow values

The results of baseflow analysis on every month in 2011-2015 are presented in Table 4.6

Percolation, Groundwater Storage and Streamflow

Li & Simonov (2001), describe the dynamics of moisture in subsurface storage with the equation:

$$dS4/dt = RP1 – RE2 – RF2 – RP2 \quad (12)$$

where dS4/dt is the water in subsurface soil storage, RP1 the percolation, RE2 the evapotranspiration, RF2 the interflow and RP2 the percolation to groundwater storage. . If dS4 / dt and RE2 are ignored, percolation (R P1) as groundwater recharge (Rc) and percolation to groundwater storage (R P2) as percolation (Pk) then the equation is written as follows:

$$Pk = Rc - If \quad (13)$$

Where, Pk is Percolation (mm/year), Rc is Recharge of ground water (mm / year), and If is Interflow (mm / year).

Li & Simonov (2001), also argue that groundwater storage is a reduction in Percolation to groundwater storage (RP2) with baseflow (RBF), this equation becomes:

$$\Delta GWS = Pk-Bf \quad (14)$$

Where Δ GWS is the change of Groundwater storage (mm / year), Pk is Percolation (mm / year), and Bf is Baseflow (mm / year). Percolation (Pk) = 0, in the dry season (Vasconcelos et al. , 2012), (Rahayuningtyas et al., 2014) .

Streamflow consists of three components: runoff, interflow and baseflow (Jain and Singh, 2005) , (Bosch et al., 2017) with this following equation:

$$Sm = RO + If + Bf \quad (15)$$

Where, Sm is Streamflow (mm/year), RO is runoff (mm/year), If is Interflow (mm/year) and Bf is baseflow (mm / year) .

Model Simulation

Simulation of the model is presented on the table 12 by entering data annual precipitation (P) in 2011- 2015, and annual evapotranspiration (ET) resulting in the multiplication between the annual precipitation (P) with a ratio of evapotranspiration and precipitation (Table 7) and annual runoff (RO) resulting in the multiplication of annual precipitation (P) with a ratio of runoff and precipitation (Table 8).

Annual recharge (Rc) is obtained from the equation (11). Annual interflow (If) is obtained from Table 10 and annual baseflow (Bf) is obtained from Table 11. Annual percolation (Pk) is obtained from equation (13) and the change of groundwater storage (Δ GWS) is obtained from equation (14). The streamflow model is obtained from equation (15).

Retrieval Number: G5129059720/2020©BEIESP
DOI: 10.35940/ijitee.G5129.059720
Journal Website: www.ijitee.org

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Blue Eyes Intelligence Engineering
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Table - IX. Highest hydrograph at the beginning and the end of the year and lowest baseflow

Year	Highest hydrograph at the beginning of the year							Lowest streamflow		Highest hydrograph at the end of the year						
	Early	Peak	Inflection point	End	Inter flow	Base fow	Month	Streamflow = Lowest baseflow	Month	Early	Peak	Inflection point	End	Inter flow	Base fow	Month
2011	10.18	17.41	11.23	10.47	0.76	10.47	Jan	5.09	Augustus	7.79	13.29	9.53	8.88	0.65	8.88	Dec
2012	11.62	16.56	13.16	12.12	1.04	12.12	Feb	4.13	September	11.36	23.8	12.74	11.06	1.68	11.06	Dec
2013	13.36	30.15	13.22	11.18	2.04	11.18	Jan	4.91	September	8.8	12.79	9.9	8.93	0.97	8.93	Dec
2014	15.57	33.95	11.98	10.52	1.46	10.52	Jan	5.26	October	9.68	20.55	11.99	10.57	1.42	10.57	Dec
2015	11.24	18.65	10.96	9.59	1.37	9.59	Feb	3.13	September	9.13	13.97	10.3	9.58	0.72	9.58	Dec

Table - X. Distribution of interflow every month (2011-2015) Katulampa Catchment Area =149,510,000 m^2

Year	Month												Mean/Year	
	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Aug	Sep	Oct	Nov	Des	m^3/s	mm/y
2011	0.76	0.65	0.54	0.43	0.33	0.22	0.11	-	0.16	0.32	0.49	0.65	0.39	82.00
2012	1.04	0.91	0.78	0.65	0.52	0.39	0.26	0.13	-	0.56	1.12	1.68	0.67	141.32
2013	2.04	1.79	1.53	1.28	1.02	0.77	0.51	0.26	-	0.32	0.65	0.97	0.93	195.46
2014	1.46	1.30	1.14	0.97	0.81	0.65	0.49	0.32	0.16	-	0.71	1.42	0.79	165.76
2015	1.37	1.20	1.03	0.86	0.69	0.51	0.34	0.17	-	0.24	0.48	0.72	0.63	133.68

Table - XI. Distribution of baseflow every month (2011-2015) Katulampa Catchment Area =149,510,000 m^2

Year	Month												Mean/Year	
	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Aug	Sep	Oct	Nov	Des	m3/s	mm/y
2011	10.47	9.70	8.93	8.16	7.40	6.63	5.86	5.09	6.04	6.99	7.93	8.88	7.67	1,618.44
2012	12.12	11.12	10.12	9.12	8.13	7.13	6.13	5.13	4.13	6.44	8.75	11.06	8.28	1,746.76
2013	11.18	10.40	9.61	8.83	8.05	7.26	6.48	5.69	4.91	6.25	7.59	8.93	7.93	1,672.93
2014	10.52	9.94	9.35	8.77	8.18	7.60	7.01	6.43	5.84	5.26	7.62	10.57	8.09	1,706.64
2015	9.59	8.78	7.98	7.17	6.36	5.55	4.75	3.94	3.13	5.28	7.43	9.58	6.63	1,397.93

Table -XII . Model Simulation Katulampa Catchment Area =149,510,000 m2

Year	P (mm/y)	ET (mm/y)	Runoff RO (mm/y)	Recharge Rc=P-ET-RO (mm/y)	Interflow If (mm/y)	Baseflow Bf (mm/y)	Percolation Pk=Rc-If (mm/y)	ΔGWS (mm/y)	Streamflow Model Sm=R+If+Bf	
									(mm/y)	(m^3/s)
2011	1,919.58	300.2	361.1	1,258.31	82.00	1,173.12	1,176.31	3.20	1,616.19	7.66
2012	2,968.90	354.8	714.1	1,899.98	141.32	1,464.73	1,758.66	293.93	2,320.19	11.00
2013	3,019.88	314.7	740.1	1,965.07	195.46	1,430.63	1,769.61	338.99	2,366.17	11.22
2014	3,048.75	375.2	789.8	1,883.76	165.76	1,358.21	1,718.01	359.80	2,313.73	10.97
2015	2,096.43	401.6	454.2	1,240.61	133.68	1,280.16	1,106.94	(173.23)	1,868.05	8.86

Model Performance Evaluation

In this study, there are streamflow based on the results of the model simulation results and streamflow based on observation which is Katulampa catchment hydrograph data from the year of 2011-2015. The Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) has been used as a standard statistical model to measure performance as shown in Table 13.

Table - XIII. Value of error streamflow model and streamflow observation

No.	**Streamflow Model** Sm(m^3/s)	**Streamflow Observation** So(m^3/s)	**Error** Sm-So	**Abs Error** [Sm-So]	**Square of Error** $(Sm-So)^2$	**Abs Value of Error** (Sm-So)/Sm
1	7.66	8.13	(0.47)	0.47	0.22	0.06
2	11.00	9.04	1.96	1.96	3.86	0.18
3	11.22	9.28	1.94	1.94	3.77	0.17
4	10.97	9.84	1.13	1.13	1.29	0.10
5	8.86	8.02	0.83	0.83	0.70	0.09
		Sum	5.40	6.35	9.83	0.61

$$RSME = \sqrt{\{1/n \sum (Sm - So)2\}} = 1.40$$

$$MAPE = \frac{\sum[Sm - So]/Sm}{n} \times 100 = 12.21\% < 20\%$$

The results of streamflow model is almost similar to streamflow based on observation.

V. RESULT AND DISCUSSION

The hydrograph separation methods with UKIH (Standard BFI), HYSEP (Fixed Interval, Sliding Interval, Local Minimum), and PART methods explain that the lowest streamflow is equal to the lowest baseflow at the end of the dry season or the beginning of the rainy season: August, September, October.

The results of baseflow simulation model with the baseflow as the result of analysis using the hydrograph separation method are described in Figure 12.

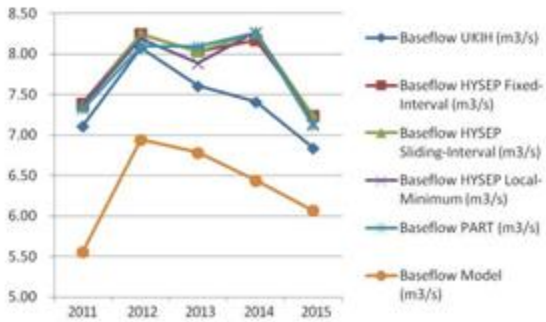

Fig.13. Baseflow model with baseflow with the UKIH, HYSEP and PART hydrograph separation methods

As can be seen in Figure 13, that baseflow estimation uses the UKIH (Standard BFI) method, HYSEP (Fixed Interval, Sliding Interval, Local Minimum) has the same fluctuation pattern. While the baseflow using the PART method and the model has different fluctuations. The baseflow value of the simulation model is smaller than all baseflows using the above method.

The percentage of annual average baseflow using UKIH (Standard BFI), HYSEP (Fixed Interval, Sliding Interval, Local Minimum) , and PART method for annual precipitation is 64%. While the percentage of interflow, baseflow average as the results of the model to the annual precipitation are 7% and 53%. This shows the potential for groundwater in the Katulampa catchment.

Precipitation greatly influences the existence of groundwater, in 2011 and 2015, the annual precipitation is smaller than those in 2012, 2013 and 2014. The results of model simulation show that ΔGWS value is negative which indicates there are no deposits of groundwater, this is evidenced by the decrease of the lowest streamflow on the lowest baseflow condition of 3.13 m3/s in 2015.

VI. CONCLUSION

The results of baseflow model estimation are generally smaller than baseflow using hydrograph separation methods: UKIH (BFI Standard), HYSEP (Fixed Interval Interval Sliding, Local Minimum) and PART because of the overestimation as stated by Lim et al. (2005). To reinforce this study, further study which estimates the baseflow associated with the type of soil and the geological condition in the Katulampa catchment.S

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