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RESEARCH ARTICLE

Characterizing River Baseflow Recession Using Linear Reservoir Model in Alang Watershed, Central Java, Indonesia.

Bokiraiya Latuamury*, Lydia Riekie Parera and Husain Marasabessy
Faculty of Agriculture, Pattimura University, Ambon, Indonesia.

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Correspondent email:
oky.environmentalscience@gmail.com

Abstract Alang is a sub-watershed emptying into the Gajah Mungkur Reservoir in Wonogiri, Central Java Indonesia, with an area of 51.01 km^2 and lithology composed of Baturetno Formation and Wonosari Formation. Baseflow is a major component of river flow during the dry season. Hence, the characterization of its recession becomes necessary, and it can be performed with innovation in baseflow hydrological modeling, that is, the recession curve. This study was designed to describe the distinctive features of baseflow recession using a linear reservoir model, which is depicted in individual and master recession curves. The baseflow recession in AlangSubwatershed was represented by a combination of varying initial recession discharge (Q0), α, and recession constants (Krb). The individual recession curves were typified by Q0=0.19-9.11, α= 0.089-0.243, and Krb=0.7843-0.9148. As for the master recession curve, it had Q0=9.99, α=0.085, and Krb=0.928. These results signify a sloping recession curve, meaning that the water storage and aquifer characteristics that store and transmit water in Alang Subwatershed are in good condition.

1.Introduction

River flow is the result of a complex natural process and occurs on a scale of a watershed. Conceptually, river basins can be used as reservoirs that are composed of the catchment, storage, and output (Szilagyi et al., 2007). Hydrological phenomena are very complex and may never be understood holistically. For these reasons, studies necessarily depend on innovations in hydrological modeling, including baseflow recession curve analysis.

Recession curves exist in flood hydrographs after watersheds no longer receive rainfall, and they persist until no more flood events occur. During the recession period, the flow comes from four main sources, namely surface detention, channel storage, interflow, and groundwater. In the analysis of recession curves, surface detention and channel storage merge into surface runoff that is continually present even though the rain has stopped (Harto, 1993). Therefore, hydrograph recession curves, as depicted in Figure 1, represent the theoretical relationship between aquifer structure and groundwater flow toward the river channel (Thomas et al., 2015). Flood hydrograph from a previous rainstorm eventually recedes, and the river discharge returns to baseflow level. Then, in the event of no rain, subsurface storage or aquifer releases its baseflow component. The slope of the recession curve moves away from the peak of the flood and flattens because the river flow is now dominated by baseflow (Biswal and Marani, 2010).

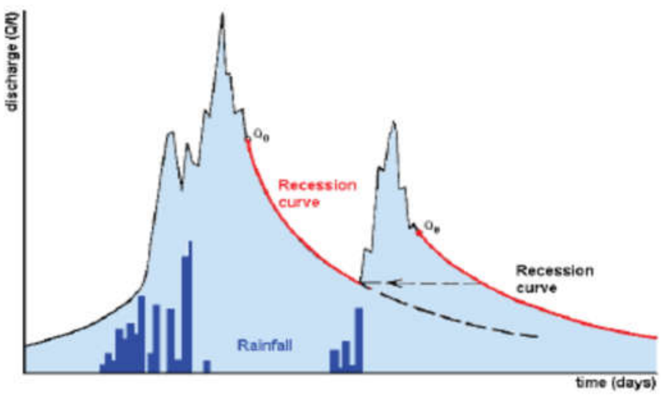

Figure 1. Recession curve (Gregor and Malik, 2012).

Recession segments can be selected from a flood hydrograph and analyzed individually or accumulatively to understand how and which flow components affect the characteristics of baseflow. Conventionally, recession curve analysis can employ graphical approaches, but hydrological research most likely uses mathematical models. Each recession segment is considered an exponential decline.

Krb is a recession constant or depletion factor, which is commonly used as an indicator of baseflow continuity. Yue and Hashino (2000) create several ranges of constants for the daily recession, namely 0.2-0.8 for channel flow, 0.7-0.94 for intermediate flow, and 0.93-0.995 for baseflow. The higher the recession constant, the greater the proportion of baseflow in the subsurface river.

Brutsaert (2008) explains that each watershed has an individual recession curve and a master recession curve as a reflection of the overall watershed storage capability, which is a combination of river and groundwater systems in responding to rain events. According to Carillo et al. (2007), the process of water storage on a watershed scale is characterized by a master recession curve with the following characteristics. (a) A sloping master recession curve is the result of high baseflow storage in river and groundwater systems, which indicate the characteristics of watersheds that have been developing over several years based on the size of the long-term rainfall input system. (b) A steep master recession curve illustrates storage capacity that has been saturated for several days. Small storage capacity, which is attributable to relatively small rainfall inputs, is localized in certain parts of the watershed. Compared to river and groundwater storage potentials, it has a small volume, especially when the depression storage in the river basin is large and the fact that only 50% of watershed storage contributes to surface runoff.

The manual of the Recession Curve RC 4.0 module (build 12) from the HydroOffice 2012 software explains the functions and limitations of using the baseflow recession model manually and automatically. This module offers broader benefits, specifically for processing and analyzing complex recession curves, and flexibility to analyze either individual or master recession curve. The master recession curve can be created manually, by an innovative tool that combines hybrid genetic algorithms, and by a method that adopts an artificial immune system. The program also allows the analysis of the superposition of four sub-regime watersheds and 13 recession models that are most frequently used in hydrogeological research. Furthermore, it provides a significant advantage in the stages of baseflow recession processing because it incorporates the same graphical user interface structure (Gregor and Malik, 2010; 2012).

Baseline recession curves play a significant role in the low number of hydrological studies because they are generally expressed as natural storage of river flows and contain valuable information about the storage and aquifer properties. Their analysis is useful in many fields of water resource planning and management, including: (1) in the forecasting of low water level in irrigation management, water supply, hydroelectric power, and waste dilution, (2) in mathematical modeling for calibration or as an input for rainfall-runoff modeling, (3) in hydrograph analysis for graphical separation of different flow components, and (4) in frequency analysis for statistical estimation in several studies, starting from regional low water flow to watershed storage capacity index (Tallaksen, 1995).

Based on the brief description above, this study focuses on "*Characterizing river baseflow recession using a linear reservoir model in Alang Watershed, Central Java, Indonesia.*" Therefore, it was designed to characterize the river baseflow recession based on the shapes of individual and master recession curves as its representation.

2.The Methods

This research was carried out in AlangSubwatershed in Wonogiri Regency, Central Java Province, Indonesia using a time series of daily discharge data starting from January 1, 2000, until December 31, 2010, as obtained from the Research Institute for Watershed Management and Technology (BPTPDAS). Alang was considered in this research due to available daily discharge data (gauged at the river flow observation station) suitable for baseflow recession curve analysis to characterize the recession of the river baseflow.

Ten years of data of daily discharge rate were analyzed with the recession curve package (RC 4.0) of HydroOffice 12.0 to identify the segments of baseflow recession (Gregor and Malik, 2012). Recession segments were selected automatically using the Automatic RC selection function for all decreasing discharges. The first step was selecting and processing individual recession segments, then continued to analyzing individual and master recession curves both manually and by a genetic algorithm. Selected recession curves were subjected to further editing and analysis whose results were later imported into individual recession curve analysis to calibrate the recession model. Considering the relatively short recession period of AlangSubwatershed, this research chose a linear reservoir model to generate the recession model, and the used formula is as follows (Equation 1) (Boussinesq, 1877; Maillet, 1905):

$$Q = Q_0 e^{-kt} \tag{1}$$

where: *Qt* is water discharge at time *t*, *Q0* is initial discharge (*t*=0, linear storage), *k* is a coefficient of recession, and *e* is epsilon number (2.71828).

Master recession curve analysis focuses on explaining the course of recession when the flow of a hydrological system (i.e., watershed) or structure has decreased by recording the lowest water discharge. During the recession, baseflow does not depend on meteorological and climatic parameters in the region but hydraulic nature and hydrogeological structure.

3.Results and Discussion

This study used 90 selected individual recession segments with varying durations between 15 and 22 days (median= 18 days). According to Brutsaert (2008), the recession period is categorized as a long one when it exceeds the time that hydrographs of shallow groundwater aquifer need to reach initial discharge, that is, 45 ± 15 days. Prolonged recession curves allow optimal investigation of individual recession events. A wide time lag from the peak of the hydrograph helps to distinguish the contributions from sources other than groundwater reservoirs, and long recession segments also enrich information about groundwater drainage processes (Shaw and Riha, 2012).

Individual recession curves

After calibrating the initial recession (Q0) using a linear reservoir model, the research found that Alang Subwatershed had Q0 ranging from 0.19 to 36.92 m^3/s (median=2.91 m^3/s) and Q0 of each year in 2000-2010 between 0.19 and 9.11 m^3/s (median=2.82 m^3/s), as well as α varying from 0.081 to 0.243 (median=0.129) and annual α in 10 years between 0.89 and 0.243 (median=0.113). Then, α for the entire recession segments was used to calculate the recession constants (Krb). The Krb was 0.7843-0.922 (median=0.8790), while the annual Krb varied between 0.7843 and 0.9148 (median=0.8932). These constants meet the criteria for an optimum recession condition suggested in Nathan and McMahon (1990), i.e., within the range of 0.80-0.90 (good water storage condition) (Table 1). The higher the recession constant, the more dominant the baseflow of the river.

The shape of individual recession curve of Alang Subwatershed

Based on individual recession curves analysis, Alang Subwatershed had a combination of initial recession (Q0)= 0.19-9.11, α= 0.089-0.243, and Krb= 0.7843-0.9148. Variations in these curves show 90 recession segments with the following grouping: Krb= ± 0.90 in 19 segments (or 21.11%), Krb= ± 0.80 in 70 segments (77.78%), and Krb=0.70 in only one segment (1.11%), as presented in Figure 2. Referring to Nathan and McMahon (1990), these figures are in the range of 0.80-0.90, which represents an optimum recession process.

The shape of individual recession curves illustrates the condition of watershed storage. Analyzing the derivative in time of discharge recession (dQ/dt) as a function of discharge (Q) enables the identification of comparative relationships between different events in the same watershed. Biswal and Marani (2010) suggest that individual recession curves have the coefficient k that can vary significantly for all recession events. Variations in k imply that the shape of the recession curve shifts from one recession event to another linearly or logarithmically.

Estimated residual values in the linear reservoir model of individual recession curves

Individual recession curves were estimated by choosing individual recession curve with the smallest root mean square error (RMSE) value. With relatively small RMSE, the selected recession curve is expected to eliminate bias in characterizing the individual recession of Alang Subwatershed and, thereby, increase its representativeness. In this study, the RMSE of individual recession curves was 0.007886-0.913478 (median= 0.137035), while that of the annual recession segments ranged from 0.0089 to 0.2314. Figure 2 visualizes the individual recession segments of Alang Subwatershed with small RMSE, that is, <0.1.

Manually produced master recession curves

The manual generation of master recession curves employed a linear reservoir model with Q0= 9.99, α= 0.085, and Krb= 0.919. Based on the combination of these three parameters, the baseflow recession constant was deemed optimum as it approached the range of recession constant proposed by Nathan and McMahon, i.e., 0.80 - 0.90, as presented in Figure 3.

The analysis of individual recession curves as a whole found that Alang Subwatershed had an excellent baseflow recession, i.e., its characteristics are influenced by aquifer properties and subsurface water storage that tends to be optimum. This estimate corresponds to Tallaksen (1995), which claims that a high recession coefficient is associated with a

Table 1. The calculated parameters and coefficients of the recession of Alang Subwatershed in 2000-2010

Years	Date of recession curve	Duration (day)	Q_0	α	Krb	Q-Obs	Q-Cal	RMSE
2000	Jun 6-15	19	9.11	0.09	0.913	4.78	4.40	0.23137
2001	Sep 9-28	19	1.73	0.11	0.893	0.60	0.59	0.00893
2002	Jun 12-30	18	6.95	0.19	0.830	2.06	2.09	0.05407
2003	Oct 10-28	18	2.88	0.11	0.895	1.28	1.26	0.04042
2004	May 1-17	16	3.78	0.20	0.823	1.23	1.17	0.08006
2005	May 6-23	17	2.82	0.24	0.784	0.76	0.75	0.06260
2006	May 12-27	15	1.98	0.18	0.837	0.61	0.57	0.07413
2007	Nov 10-28	18	2.92	0.09	0.915	1.38	1.31	0.04961
2008	May 4-26	22	1.14	0.11	0.897	0.44	0.38	0.04241
2009	Jun 5-23	18	1.59	0.15	0.860	0.48	0.48	0.01761
2010	May 10-28	18	0.19	0.11	0.897	0.10	0.08	0.01383

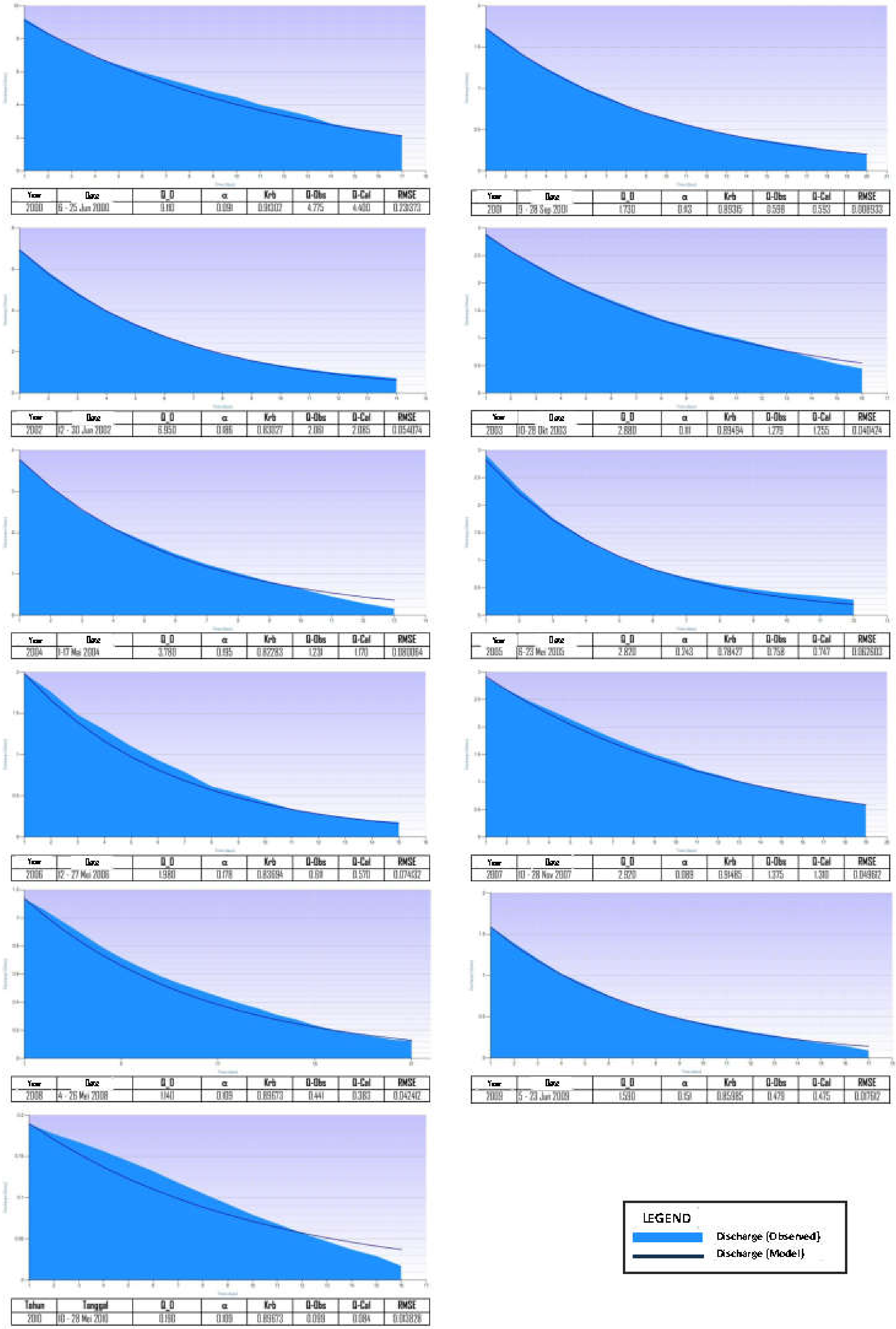

Figure 2. Variations in individual recession curves of Alang Subwatershed from the year 2000 to 2010

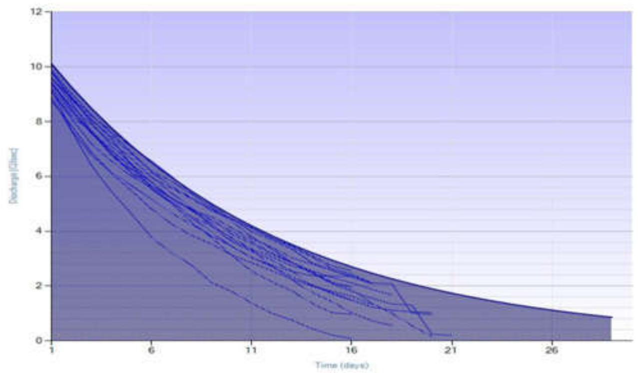

Figure 3. The shape of manually developed master recession curves of Alang Subwatershed

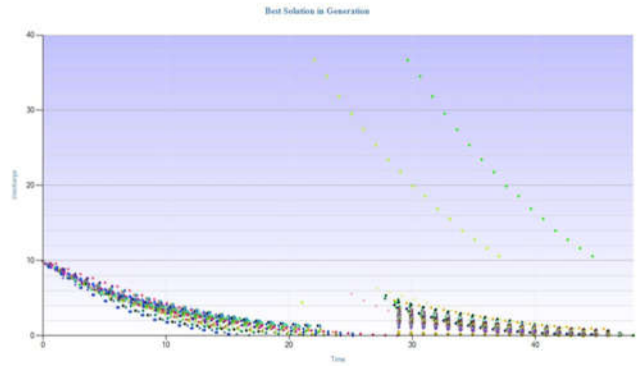

Figure 4. Visualization of the best solution in generating the genetic algorithm

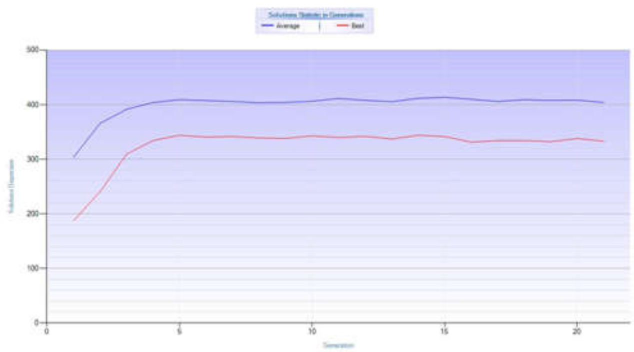

Figure 5. The development of dispersion of solution in the evolutionary cycle of Alang Subwatershed

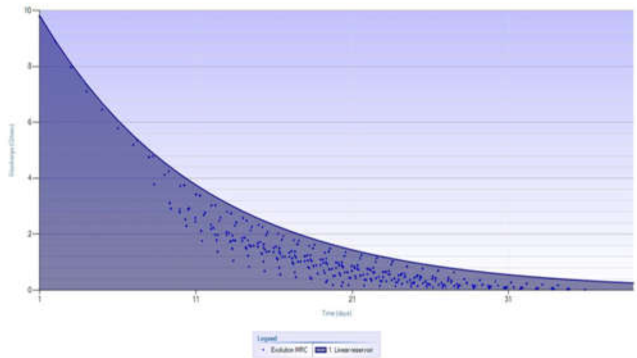

Figure 6. The master recession curve of Alang Subwatershed, as generated by a genetic algorithm

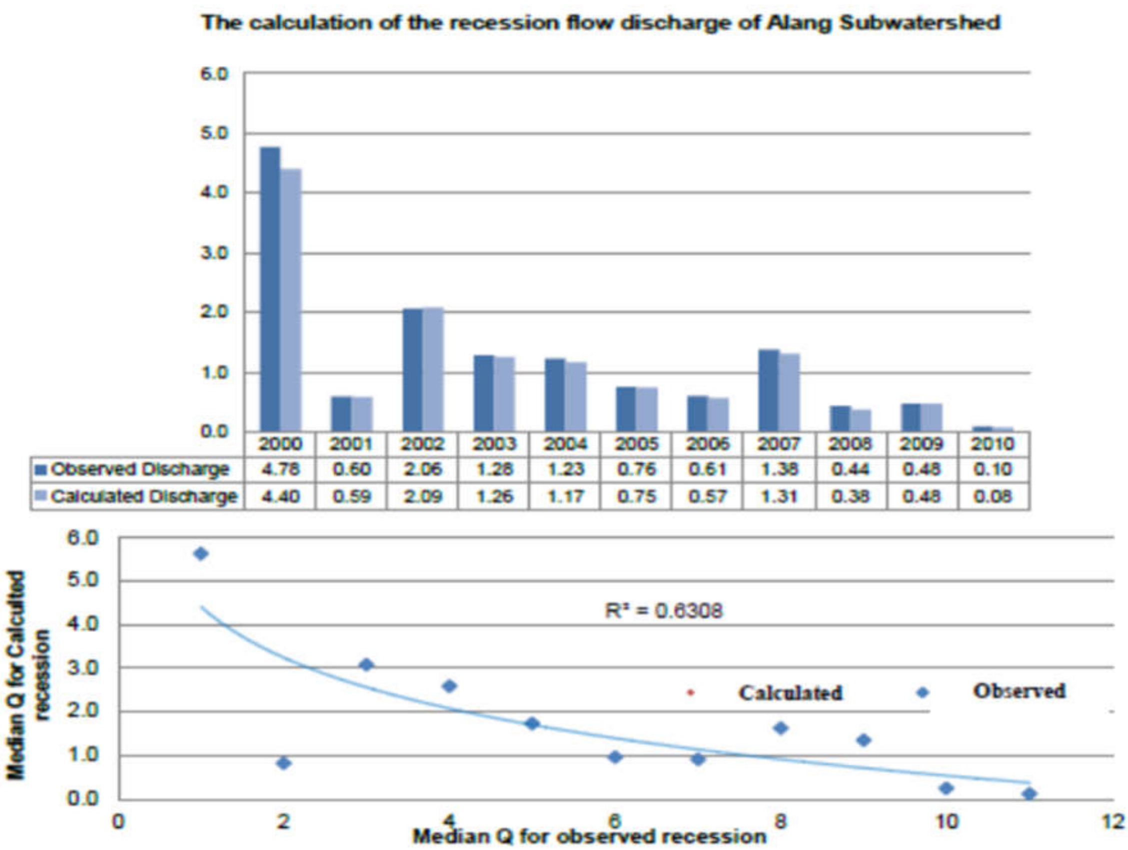

Figure 7. The calculation of observed and calculated median of the recession flow discharge of Alang Subwater-

sloping curve and, conversely, a low one has a steeper curve. Steep recession curves represent the massive and rapid release of water from the baseflow component, whereas gently sloping ones demonstrate large baseflow storage that discharges water in a prolonged duration (Shaw and Riha, 2012).

Genetic algorithm of master recession curve

Generating master recession curves with genetic algorithm involves several stages, including the regulation of the number of evolution cycles in the following parameters: number of generation (NG), number of individuals (NI), the maximum length of master recession curve (ML MRC), and maximal dispersion of mutation. This study used 20 necessary cycles. The best solution display of the genetic algorithm is presented in Figure 4, with evolution cycles composed of NG=20, NI=10, the cross of probability=0.90, ML MRC= 25, and 10 mutations.

The disperse values of Alang Subwatershed are visualized in Figure 5. The optimal algorithm performance shows a relatively uniform and stable trend and recession data distribution that tends to shift and accumulate to the right. Since this disperse performance is considered to be quite optimal for the characteristics of a relatively uniform recession segment, the analysis continued to calibrating the model by identifying the recession parameters and coefficient of the master recession curve. The results of the evolution were then calibrated with a linear reservoir model for recession curve analysis using a genetic algorithm.

In the analysis of the master recession curve, 90 selected individual recession curves were processed. Variations in manually generated individual and master recession curves were completed with the recession curves obtained by applying a genetic algorithm in the recession curve package of the HydroOffice 12.

The optimization of parameters and coefficients of recession using a linear reservoir model involved a genetic algorithm in producing the shape of the master recession curve of Alang Subwatershed. It yielded Q0=9.82, α=0.096, and Krb=0.921. The results showed that the master recession curve was gently sloping with a recession constant of ± 0.900, representing substantial baseflow storage, as presented in Figure 6.

The visualization of the master recession curve by genetic algorithm shows that the distribution of data points shifts to the right and tends to accumulate. The curve is gently sloping toward the results of manually developed individual and master recession curves, i.e., a more gently sloping curve between baseflow recession events in Alang Subwatershed.

Observed and calculated recession discharge

In 2000-2010, the median ranges of the observed and computed recession discharges were, respectively, 0.084-4.40 m^3/s and 0.089-0.231 m^3/s. The plotting of these median data on a scatter diagram produced a coefficient of determination (R^2) of 0.6308, as presented in Figure 7.

The relationship between baseflow recession and geological aspect

The results of the recession curve analysis and observed and calculated recession can be associated with geological features. The characteristics of baseflow recession are strongly controlled by regional lithology, particularly through its response to water. Regions with fine-textured, dense, and highly porous rocks are hydrologically characterized by high surface runoff, small infiltration, dry rivers in the dry season, and low groundwater accessibility. Rock type also modifies river flow, flow pattern and density, and groundwater quality.

Hydrogeologically, Alang Subwatershed lies on two geological formations. Wonosari Formation is composed of limestone, black clay, mud, silt, and sand, and was formed in the Pleistocene Period. Baturetno Formation primarily contains young fluvial sediments like black clay, mud, silt, and sand. These two rock formations typically have aquifers that store and transmit a significant amount of groundwater, as presented in Appendix 1.

Conclusion

The baseflow recession of Alang Subwatershed is characterized by varying individual and master recession curves. For the individual recession curves, the recession parameters are Q0=0.19-9.11, α=0.089-0.243, and Krb=0.7843-0.9148. Meanwhile, the master recession curve is composed of Q0=9.99, α=0.085, and Krb=0.919. These figures indicate gently sloping recession curves. Due to the dominance of permeable geological structure in the aquifer, recession curves with this shape also represent excellent water storage conditions.

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