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Original Research Paper

Comparing Master Recession Curve Shapes Between Linear and Exponential Reservoir Models

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Abstract

The behaviour of river flows during periods of recession can be better identified than in other periods. The Master Recession Curve (MRC) approach is a technical approach that is quite effective and efficient in modelling baseflow. This study aims to compare the shape of the MRC between linear and exponential reservoir models. The research method uses two linear reservoir models, the Depuit-Boussinesq equation and an exponential model based on exponential hydraulic conductivity. The results showed that the combination of recession parameters (initial recession discharge, constant and coefficients) for MRC manually linear and exponential reservoir models, and hybridization of genetic algorithm processes, showed that MRC visualization for linear reservoir models was more optimal compared to exponential reservoir models. These results are closely related to the slope of the MRC, where the linear reservoir model is gentler, and the exponential reservoir model is relatively steeper. The slope of the MRC for both reservoir models relates to the storage capabilities of the baseflow and the hydraulic conductivity properties of the study area. The gentle slope of the MRC has the properties of relatively slow storage and is relatively long stored. In contrast, the steep slope of the MRC determines the somewhat wasteful nature of storage.

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1 INTRODUCTION

Watershed responses during periods of recession have a more regular flow and can be identified easily than flows during or immediately after a rain event. River flow during the dry season (dry weather) is generally dominated by groundwater flow (Wittenberg and Sivapalan, 1999; Wittenberg, 2003). Groundwater flow is closely related to storage and subsurface hydraulic properties rather than concentration time and surface flow. The variation of factors affecting surface flow is the type of rain events or variations in land cover. The quality and reliability of baseline flow data are more influenced by catchment behavior or watershed characteristics (Jing *et al.*, 2016; Zhang *et al.*, 2019). Baseflow recession events are more predictable, but the representation of baseflows in hydrological simulations is relatively weak. Various considerations that need to be considered in assessing the performance of low-flow hydrological models include the conceptualization of the good hydrological process, the suitable calibration method, high data reliability such as proper curve assessment, measurement of the baseflow and changes in the right cross-section of the river in the selection of the appropriate baseflow hydrological model (Tashie *et al.*, 2020).

Model structure and parameterization are inherently uncertain when choosing a hydrological model representing a natural hydrological system (Aboelnour *et al.*, 2020). The hydrographic recession separation technique using interactive solutions from linear and exponential MRC models is an interactive solution in low-flow hydrology (Brodie and Hostetler, 2005). Many research results offer a numerical algorithmic approach that is useful in realizing efficient and sustainable management of water resources. Wittenberg and Sivapalan (1999) and Wittenberg (2003) have investigated the nonlinear storage process of baseflow recession and groundwater infiltration.

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Numerical recession modeling was developed from 100 river flow measurement stations using nonlinear relationships between outflow storage. A recession modeling system with one nonlinear reservoir is more logical than a parallel linear model for a given catchment area. The nonlinear reservoir algorithm automatically separates the bottom flow from the daily river discharge in a time series. It calculates the storage and seepage of groundwater in the watershed using the nonlinear reservoir method.

Wu *et al.* (2017) investigated nonlinear models of hydrological drought indices and meteorological droughts in large-scale reservoirs. The results showed a significant nonlinear relationship between hydrological drought and meteorological drought. The threshold of hydrological drought began to respond to meteorological drought obtained according to a nonlinear function model. Hannah and Gurnell (2001) proposed a concept of a runoff linear reservoir model to investigate snowy winter changes in glacial hydrology in France. The results showed that reservoirs quickly respond to the melting of ice flowing into semi-distributed systems under glaciers, and reservoirs are slow to respond to distributed systems under upper glaciers. The nature of storage in hydrological systems is relatively significant in determining the outflow of glaciers compared to glacier problems on a broader research scale.

Heppner and Nimmo (2005) developed a computer program to predict groundwater infiltration using MRC in extracting the relationship between flow release rate and water level height by comparing measured well hydrographs and model hydrographs from MRC models at any given period. Posavec *et al.* (2010) perform MRC splitting using Microsoft Excel spreadsheets and Visual Basic for Applications (VBA) code. The coding program builds the MRC using adapted and updated strip methods (Posavec *et al.*, 2006; Posavec *et al.*, 2017). The results of automatic separation on two and three MRCs use the optimal separation model scenario of the duration of the flow rate, and the highest R^2 mean coefficient value is presented graphically and numerically.

Latuamury and Marasabessy (2020) and Latuamury *et al.* (2021) uses the daily discharge of surface flow and baseflow with the availability of a daily flow dataset for ten years. Select recession segments that optimally represent recession events and relatively low data measurement and calculation errors. The same study was conducted (Stoelzle *et al.*, 2013) using a numerical algorithm MRC that describes MRC in four numerical algorithms that show a nonlinear discharge relationship, where the value of the coefficient and recession constants are proportional to present information about the characteristics of groundwater aquifers and specific infiltration conditions. Carlotto and Chaffe (2019) developed an MRC using MRCP tool modified from MATLAB software covering 44 years of debit data and using a series of automated methods in flow recession rate analysis (-dQ/s) as a flow function (Q) and (vi) to develop linear and nonlinear MRC models.

The Keduang watershed is a reservoir that includes infiltration, spooling, and output components using the latest baseflow hydrological modeling innovations. One of the innovations uses curve recession master modeling (MRC) in the latest innovative water resource planning and management developments. The Keduang watershed is the most significant contributor to sedimentation in the Gajah Mungkur Reservoir, functioning as flood control in the rainy season with an inundation area of more than 93000 ha, a water supplier in the dry season and as a hydroelectric power plant (Latuamury and Talaohu, 2020). The development of MRC innovations has been developed for many areas of land and water resource management. However, MRC results for reservoirs using river flow data in a time series for this study area are still rare. Therefore, this study compared the shape of the MRC between linear and exponential reservoir models in the Keduang watershed of Central Java Province.

2 MATERIAL AND METHOD

2.1 Research Location

The selection of the Keduang watershed as the research location considers the Keduang watershed a strategic watershed supplying water resources for the Gajah Mungkur dam in Wonogiri Regency, Central Java (Figure 1). The Keduang watershed has the availability of a river flow measurement station under the supervision of the Surakarta Watershed Research and Technology Center at the Ministry of Environment and Forestry of time-series discharge data to facilitate the calibration of baseflow recession models.

The morphometric characteristics of the Keduang watershed show that the study area includes a large watershed area with an elevation of 338m, a river turf of 0.02m, a prominent river length of 36.85km, a drainage density of 2.99km/km^2, a branching and circulation ratio of 0.53 and 0.99, respectively with a dendritic watershed form as presented in Table 1.

The geological formations of the Keduang watershed are generally dominated by massive volcanic material upstream. The dominant material is in the form of volcanic rocks originating from Jobolarangan, Lawu, and Sidoramping. Materials derived from eruptions such as lava, tuffs, andesite and other volcanic rocks are dominant. Other materials in the form of alluvial, Nampol Formation, and Breezy Formation make up the downstream part which is part of the Baturagung Mountain Trail. The character of the upstream watershed, which is dominated by massive volcanic material, causes the resistance of rocks to water to be relatively high. The dendritic flow pattern also reinforces that the resistance of rocks tends to be the same because it comes from volcanic material. The

bedrock of a homogeneous nature characterizes the dendritic flow pattern. High resistance contributes significantly to surface flow (Latuamury, 2020).

2.2 Research Procedure

2.2.1 Recession Segments Selection

The reservoir model calibration uses two recession models from the RC.4.0 Hydro Office 12.0 software for both linear and exponential reservoir models (Gregor and Malík, 2014). The Depuit-Boussinesq equation generally uses flow deposits during relatively short recessionary periods and the exponential reservoir equation to obtain soil hydraulic conductivity conditions of an exponential nature with groundwater depth. Both recession equations are presented in Table 2.

The model calibration uses ten years of daily discharge data, i.e., daily discharge records from January 1, 2000 to December 31, 2010. The first stage in calibrating a recession model is the automatic selection of baseflow recession segments that represent recessionary events throughout the study, as presented in Figure 2.

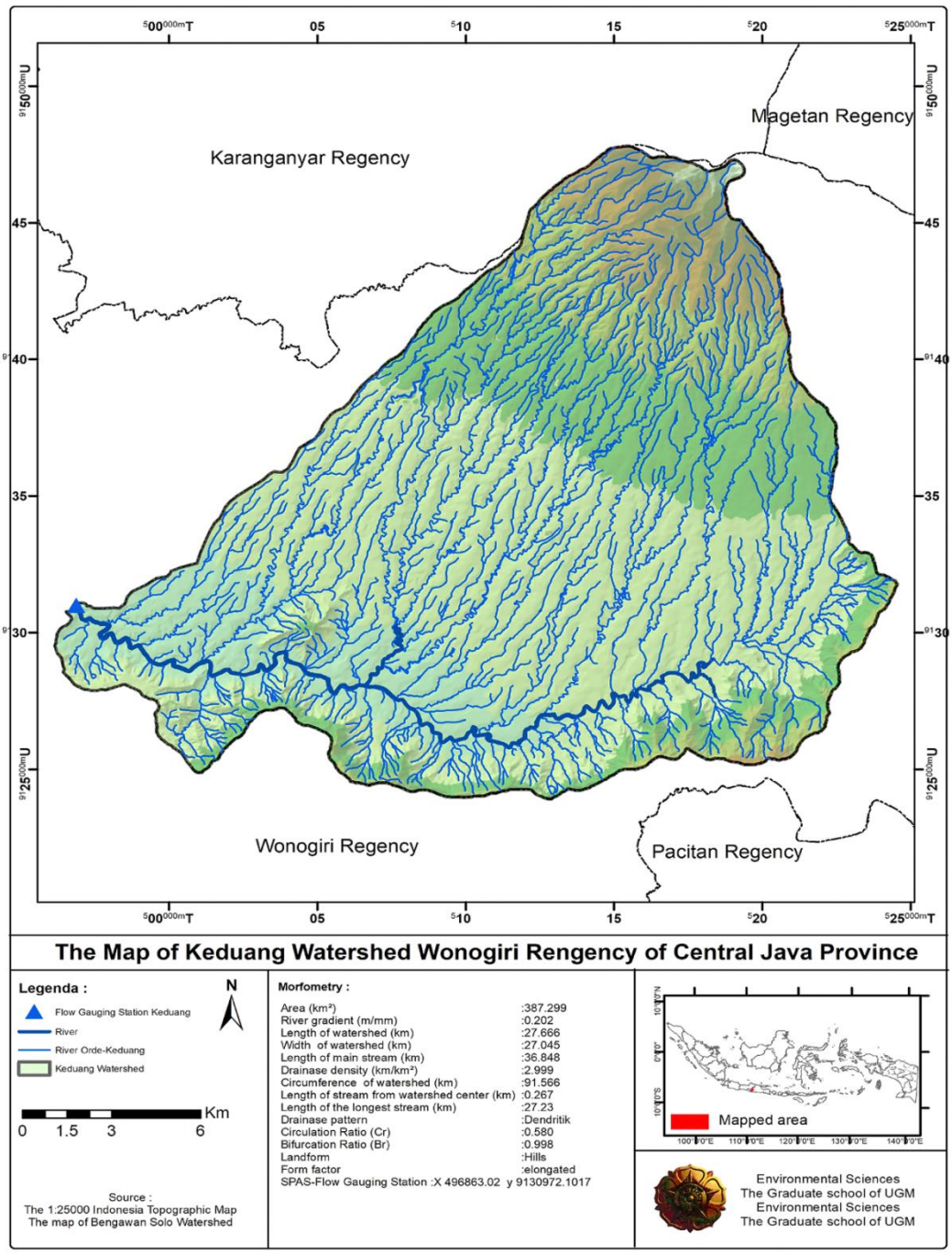

Figure 1. Keduang watershed, Wonogiri Regency, Jawa Tengah Province

Table 1**.** Morphometric characteristics of the watershed

Name of watershed	Area (km²)	Elevation (m)	River gradient (m)	The length of main river (km)	Drainage density (km/km²)	Circulation ratio (Rc)	Bifurc-ation ratio (Rb)	Watershed form factor	Watershed patterns
Keduang	387.30	338	0.02	36.85	2.99	0.53	0.99	Elips	Radial

Source: Topographic map of Indonesia in Central Java Province (Latuamury and Talaohu, 2020)

Table 2. Calibration of linear and exponential reservoir models

Conceptual model	Recession function equation	Deposit type
Linear reservoir (Boussinesq, 1877; Maillet, 1905)	$Q = Q_0 e^{e-kt}$	Depuit-Boussinesq equation, Generally, the equation utilizes for deposits with relatively short recession periods.
Exponential reservoir	$Q = Q_0 / (1 + \phi Q_0 . t)$	The model for soil hydraulic conductivity is assumed to decrease exponentially with groundwater depth.

Q = discharge, t = time of recession onset, Q_0 = time for t = 0; k,$^{\phi}$, = model calibration parameters. Source: (Gregor, and Malík, 2012; Gregor and Malík, 2014).

Table 3. Recapitulation of mean values and RMSE for individual recession segment parameters

Parameter model	Duration (days)	Q0	k/ ϕ	Qobs	Qcal	RMSE
Linear Reservoir Model	15	15.3821	0.0822	10.1155	10.1934	0.3953
Exponential Reservoir Model	15	15.4233	0.0269	10.7574	10.9657	0.5044

Source: Data analysis using RC.4.0 Hydro Office 12.0

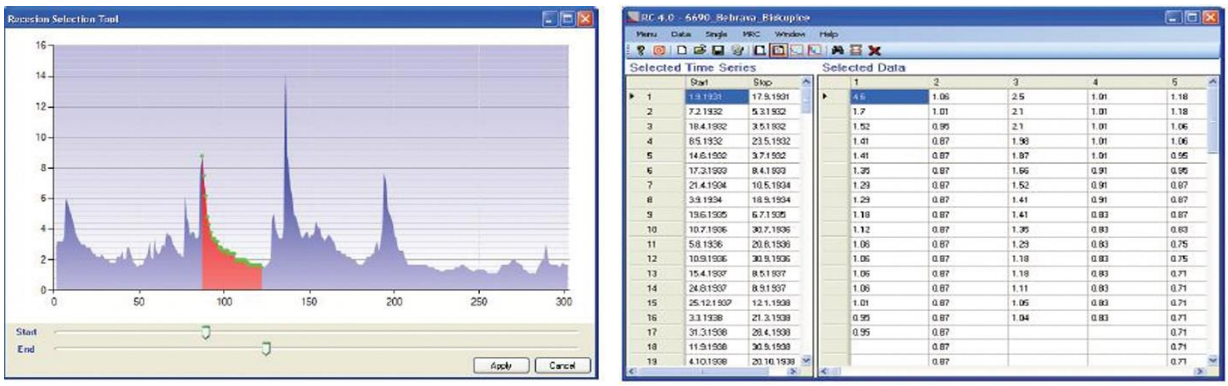

Figure 2. Automatic selection of recession segments (Gregor and Malík, 2012)

Selecting an automatic recession segment can make manual and automatic edits until it obtains the optimal recession segment. The process of editing recession segments can use several functions as follows:

- Remove the row function for line subtraction.

- Remove the curve function to remove the entire recession curve.
- Constant interpolation function for linear interpolation of time series values when the recession curve contains several periods with a constant discharge.
- Repair curve function eliminates some sequential constant values in the recession segment.

The optimal selection and processing stages involve assessing individual MRCs by calibrating the watershed model for the fully interpreted recession segment. Figures 3 represents the functions of automatic adjustment and their modification.

The latest methodology applies genetic algorithms to interpret MRC for surface flows and springs. This is an effective and efficient approach to preventing technical bottlenecks. The MRC construction of individual recession segments describes the process using the corresponding equation. Moreover, the series of recession segments is expected to occur naturally. The method of hybridization of genetic algorithms is the latest computational tool that allows the assembly of natural discharges best suited for recession events and describes the baseflow characteristics of a particular watershed (Latuamury *et al.*, 2020).

2.2.2 Calibration of Baseflow Recession Models

Severe recession segments from flood hydrographs and separation of flow components were analyzed individually and collectively to investigate flow components affecting river baseflows (Fatchurohman *et al.*, 2018; Nurkholis *et al.*, 2020; Pratama *et al*., 2020). Analysis of individual and master recession curves is done manually and based on algorithmic genetic processes using the models available in the RC module 4.0 (build 12) of hydro office 2012 software. Daily discharge simulation for ten years to calibrate linear and exponential reservoir models, Utilization of relatively long daily discharge records of at least ten years from River Flow Observation station data is accessible. The selection of a recession model must meet the specified requirements, including theoretical considerations and empirical assessments, as well as good visual compatibility.

3 RESULTS AND DISCUSSION

3.1 Master Recession Curve using a Reservoir Linear Model

Recession segments were selected in the linear reservoir model calibration of 57 individual recession segments. These were selected recession segments with relatively small RMSE model errors representing each year during the study period. The recapitulation results of recession parameters and recession discharges include duration, recession coefficients and constants, observational recession discharges and model recession discharges and model errors (RMSE). The duration of recession events during the period from 2000 to 2010 ranged from 11-21 days. The recession parameters combination for the initial recession discharge (Q0) ranges from 1.71-4.95 m^3/sec with an average of 3.14 m^3/sec, the recession coefficient (k) ranges from 0.06-0.15 with an average of 0.10; and the recession constant ranged from 0.861-0.941 with an average value of 0.907. The observational recession discharge calculation goes from 0.75-2.73 m^3/sec with an average of 1.79 m^3/second, and the model recession discharge calculation ranges from 0.82-2.74 m^3/ecs with an average of 1.82 m^3/s and the model error (RMSE) ranges from 0.0116-1.1133 with an average of 0.1775 as presented in Table 4.

The linear reservoir model calibration results for the study area can be compared with the results of baseflow recession research in some regions. The study results (Moore, 1997) analyzed simulated a baseflow recession for linear, exponential reservoirs, namely two parallel linear and two serial linear. The results showed that the double-reservoir model was substantially effective compared to a single setting. However, based

Table 4. Recapitulation of mean values and RMSE for individual recession segment parameters

Years	Duration (days)	Q0	k	Recession Constant	Qobs	Qcal	RMSE
2000	13	4.2100	0.0890	0.9148	2.4398	2.5157	0.1441
2001	14	4.4500	0.0860	0.9176	2.5859	2.7962	0.3235
2002	13	3.9500	0.0610	0.9408	2.7263	2.7386	0.1197
2003	13	1.7100	0.1100	0.8958	0.9201	0.9209	0.0116
2004	21	3.8500	0.0610	0.9408	2.4472	2.4700	0.0546
2005	11	2.3800	0.1000	0.9048	1.3943	1.4563	0.1043
2006	19	3.3300	0.0800	0.9231	2.0205	2.0850	0.1128
2007	19	3.9100	0.0800	0.9231	2.3159	2.2950	0.1006
2008	20	2.6600	0.1100	0.8958	1.3028	1.3197	0.0348
2009	18	1.8000	0.1500	0.8607	0.8356	0.8527	0.0653
2010	18	1.7500	0.1400	0.8694	0.7548	0.8218	0.0913

Source: Data analysis using RC.4.0 Hydro Office 12.0

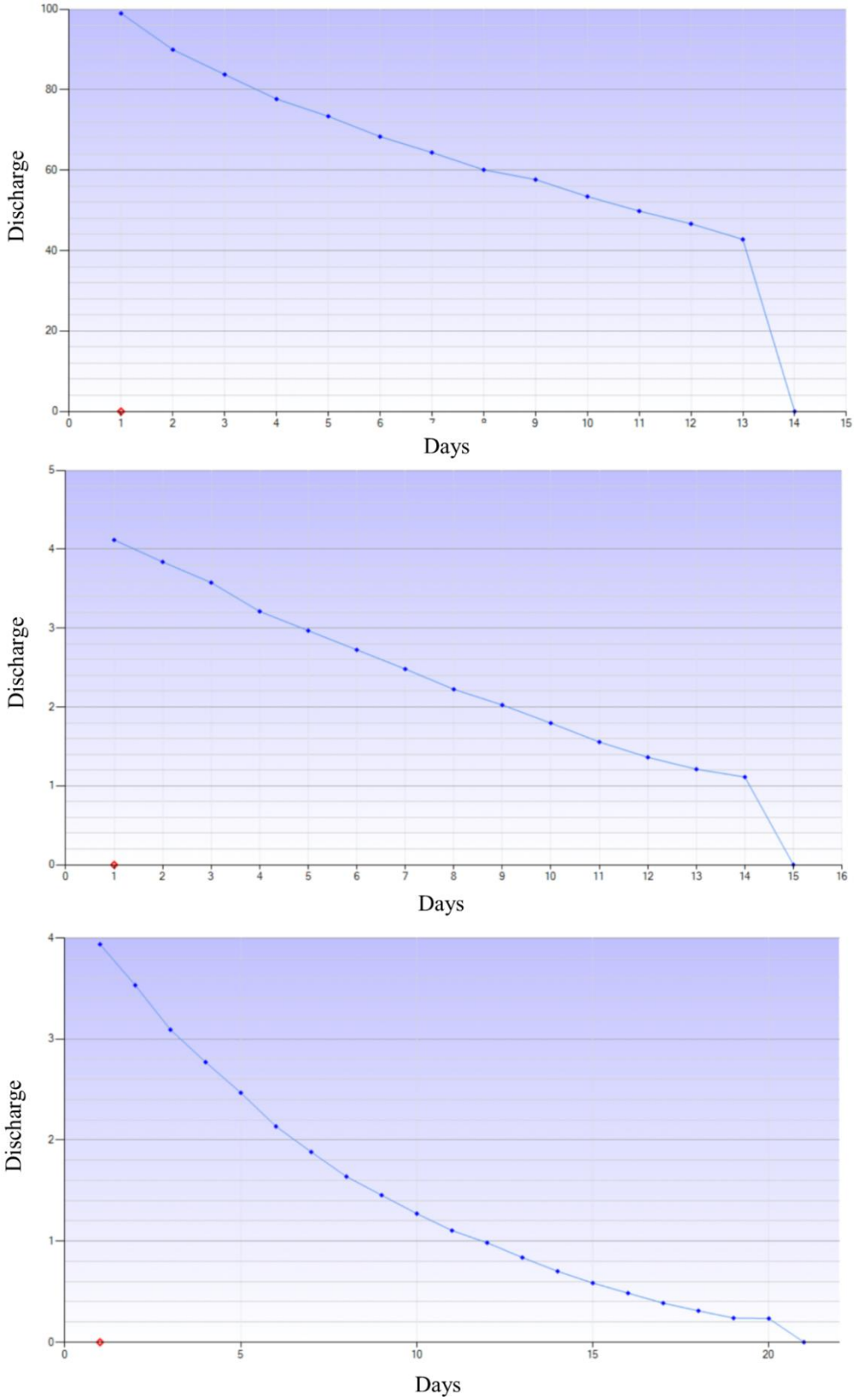

Figure 3. Automatic adjustment of recession curves with constant values (a) recession curve without modification (original), (b) curve after eliminating constant values with the Repair Curve function, (c) curve with interpolated discharge for a continuous period (Gregor and Malík, 2012).

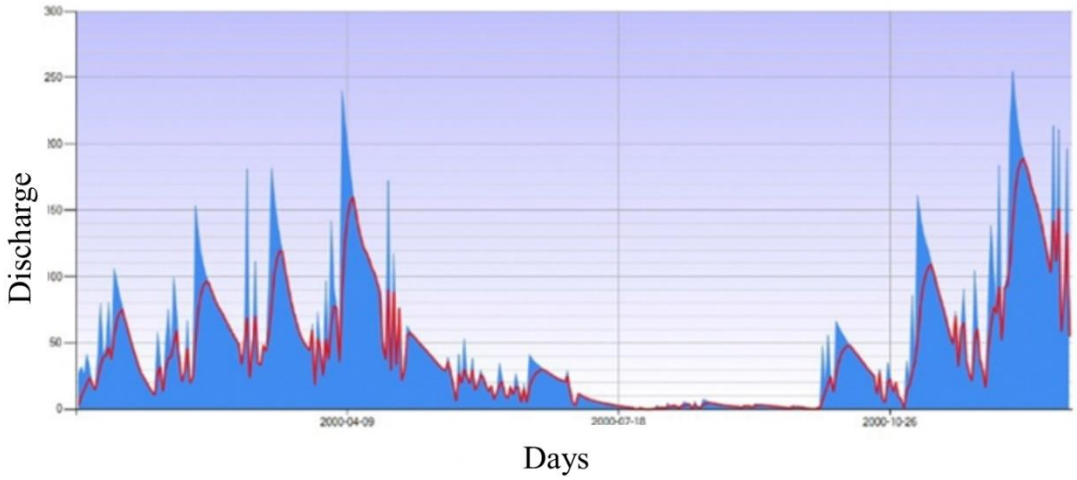

Figure 4. The Hydrograph of the Keduang Watershed of Central Java Province

on the recession segment pattern for the linear and exponential reservoir model, the suitability for the recession model is relatively consistent depending on the number of parameters and the flexibility of the resulting recession function. Calibration of the double reservoir model performs very well than linear reservoirs using the quadratic difference loss function.

3.1.1 Visualize MRC Manually using a Linear Reservoir Model

Visualization of recession and recession discharge parameter calculations for the research period was then further analyzed using a linear reservoir model to obtain a master recession curve manually and a process-based genetic algorithm. A visualization of the master recession curve for the research watershed is presented in Figure 5.

The series of recession segments shows a series of recession events in the research area ranging from the duration of the recession event to the shape of the slope of the recession curve, which then reflects the characteristics of the recession in the study area. Analyzing the characteristics of a baseflow recession is indispensable for prolonged recession duration, resulting in an optimal recession curve. The recession curve is short, containing only limited information regarding the recession process and the end of time that often occurs. To solve this problem, the master recession curve method is used to measure the recession characteristics of the research watershed. The recession's parameters and coefficients represent the baseflow recession analysis's linearity and non-linear aspects. Variations in individual recession curves in watershed research suggest that the Q0 initial parameters of a single recession event represented by peak discharges appear to influence the shape of the recession curve. Recessionary events with a more significant peak discharge result in a recession curve that tends to shift to the right, compared to a smaller peak discharge, as seen in the visualization of the master recession curve. This is because the recession phase is the stage where the contribution of subsurface flows is dominant. Hence, the recession parameters significantly affect the shape of the baseflow recession curve. The variation in the shape of the recession curve is determined mainly by selecting the type of recession model, the determination of the parameters' value, and the recession's coefficient (Latuamury, 2020).

3.1.2 Hybridization of Genetic Algorithms for Visualization of MRC Linear Reservoir Models

Hybridization of MRC through the process of genetic algorithms (generation) requires several stages to be determined, namely the determination of specific components, including the stability of the number of generations (NG) and individuals (NI), the maximum length of the master recession curve (ML MRC), and the optimal dispersion of mutations. This arrangement includes the optimal use of four evolution cycle parameter values NG 50, NI 10, cross probability 0.90, the maximum length of the recession master curve 50, and mutation 10 for the study area.

MRC visualization of genetic algorithms begins with the evolutionary process of dispersion, the best solution to produce an optimal MRC, as shown in Figure 6 and 7.

The process of hybridization of genetic algorithms through the best solutions shows the distribution of recession segments. The optimal performance of the algorithm for the Duang watershed shows a relatively similar and stable trend. However, data distribution tends to shift and accumulate towards the right. This dispersed performance is optimal for the characteristics of the recession segment, which are known to be relatively similar. Therefore, the calibration of linear and exponential reservoir models determines the coefficients and parameters of the master recession curve.

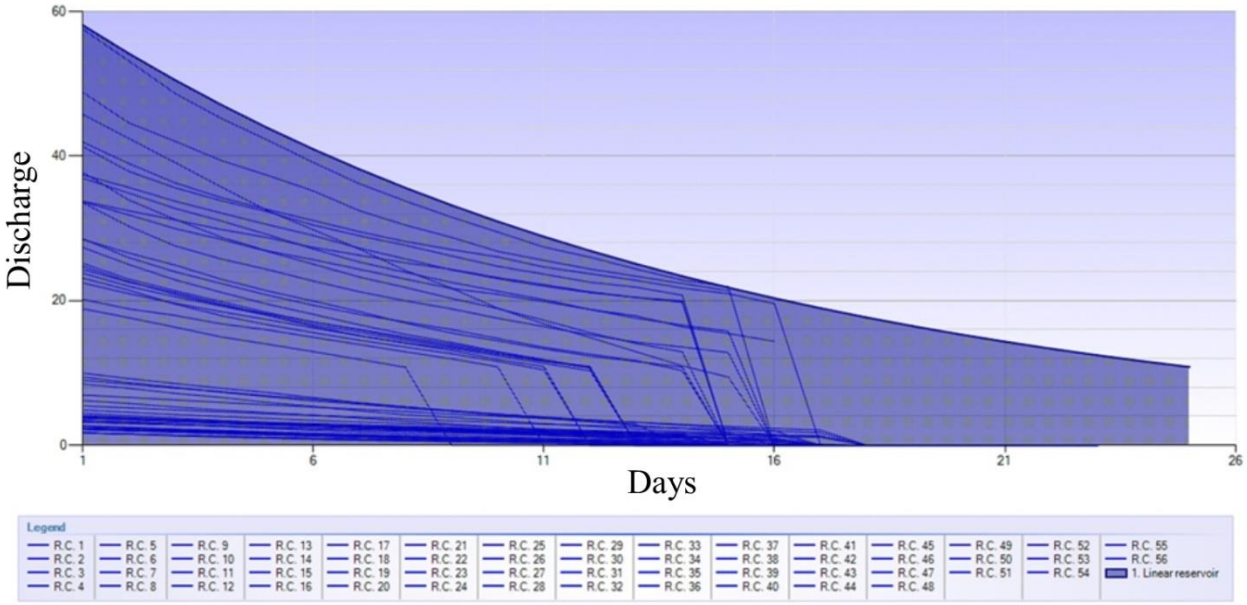

Figure 5. Visualization of MRC manually for linear models

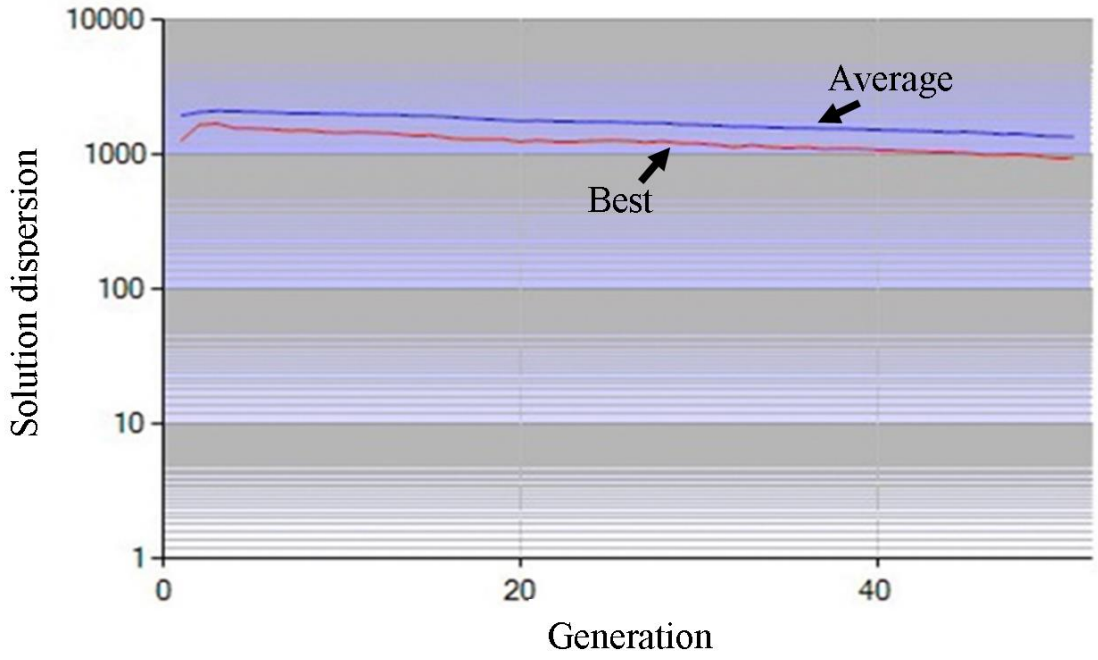

Figure 6. Visualization of logarithmic evolutionary processes for linear

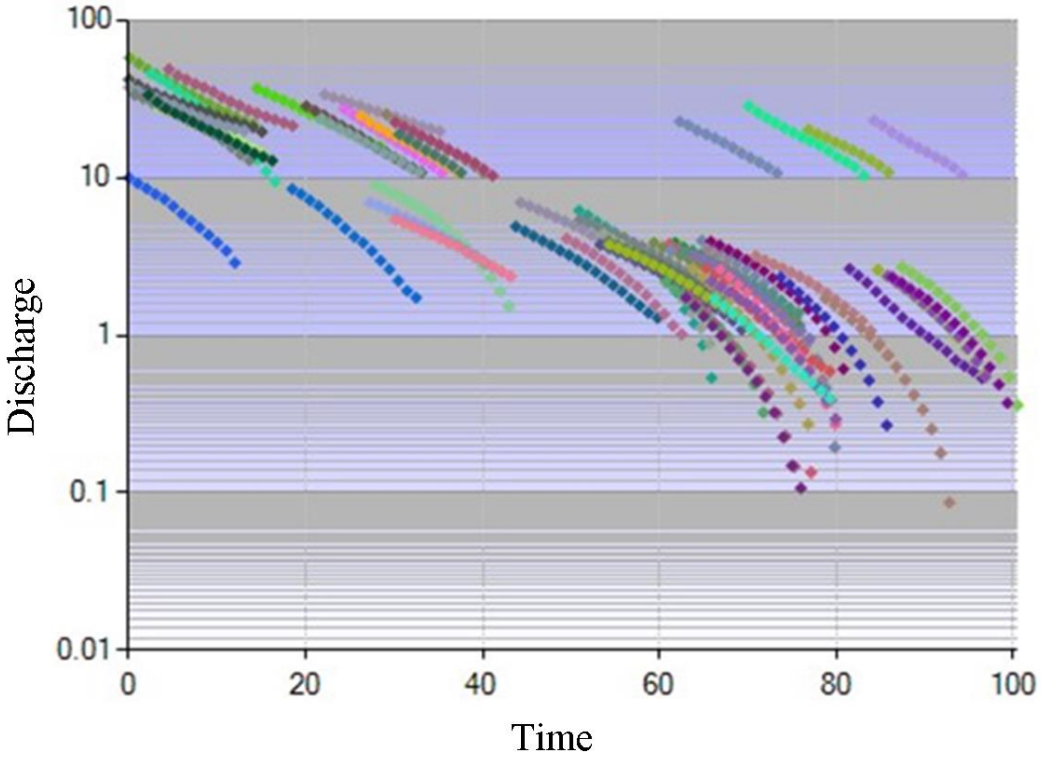

Figure 7. Visualization of the best logarithmic solution process for linear

The results of MRC calibration through hybridization of genetic algorithms for linear reservoir models describe the shape and slope of the MRC determined based on a combination of recession parameters for the calibration of linear reservoir models. The variety of linear reservoir model parameters for MRC resulting from the hybridization of genetic algorithms obtained an average recession discharge Q0 of 59.18 m^3/s, a recession coefficient (k) of 0.010 and a recession constant of 0.990. The results of the linear reservoir model calibration for the genetic algorithm hybridization process show that the MRC indicates that the slope of the MRC for the linear reservoir model is gentler compared to the exponential reservoir model, as presented in Figure 8.

3.2 Master Recession Curve Using Exponential Reservoir Model

Calibration of the exponential reservoir model used 57 individual recession segments and then selected 11 individual recession segments representing the study period with the smallest RMSE model error value estimate. The results of the recapitulation of recession parameters and recession discharges obtain variations in the duration of the recession (in days), the coefficients and constants of the recession, the observational recession discharge, and the model recession discharge as the minor model error (RMSE). The duration of recession events during the period from 2000 to 2010 ranged from 11-21 days, with an average duration of 16.5 days. The combination of recession parameters for the initial recession discharge (Q0) ranges from 1.71-4.44 m^3/second with an average of 2.96 m^3/sec, the recession coefficient ranges from 0.00-0.12 with an average of 0.05; and the recession constant ranges from 0.064-0.212 with an average value of 0.130. The calculation of observational recession discharge ranges from 0.76-2.29 m^3/sec with an average of 1.54 m^3/sec, and the calculation of model recession discharge ranges from 0.82-2.52 m^3/sec with an average of 1.69 m^3/second and model error (RMSE) ranging from 0.1215-0.4558 with an average of 0.2730 as presented in Table 5.

3.3 Manually MRC Visualization Exponential Reservoir Models

The results of manual calculations of a combination of recession parameters for exponential models obtained an average initial recession value Q0 of 59.990, a value of φ calibration parameter of 0.002, and a recession constant of 0.120. MRC visualizations for both reservoir models are presented in Figure 9.

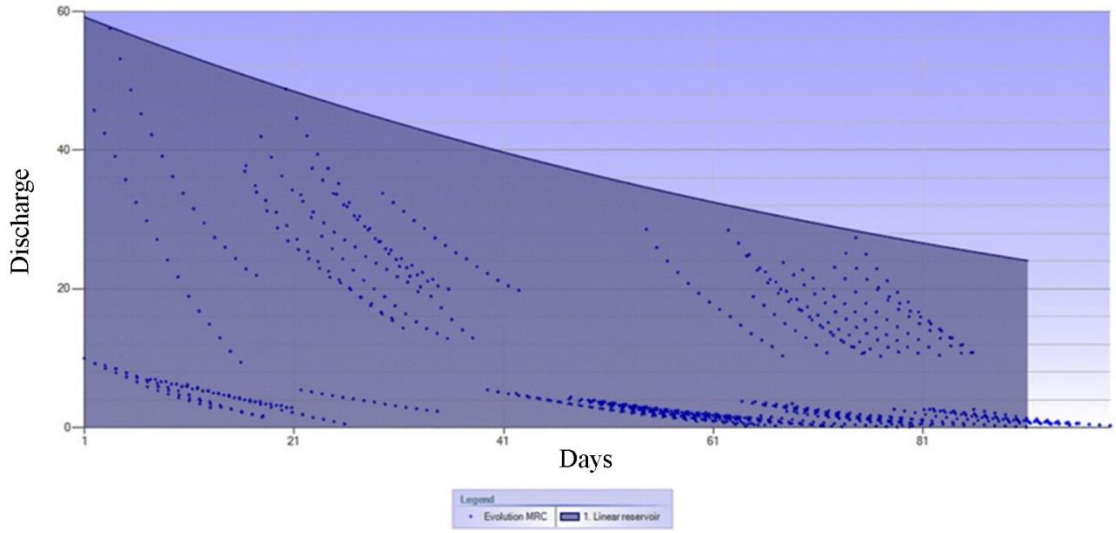

Figure 8. Visualization of MRC processes genetic algorithms for linear reservoir models

Table 5. Recapitulation of mean values and RMSE for individual recession segment parameters

Years	Duration (days)	Q0	ϕ	Recession Constant	Qobs	Qcal	RMSE
2000	14	4.4400	0.0018	0.0746	2.1355	2.1500	0.3299
2001	19	3.9500	0.0300	0.1185	2.1375	2.2975	0.4129
2002	14	3.8500	0.0019	0.0643	2.2882	2.5200	0.2149
2003	13	1.7500	0.0800	0.1400	0.9251	1.0119	0.1215
2004	21	3.8500	0.0270	0.1040	2.1971	2.3444	0.3471
2005	11	2.3700	0.0450	0.1067	1.4068	1.5842	0.2569
2006	13	2.3500	0.0510	0.1199	1.2957	1.4345	0.2498
2007	19	3.8900	0.0350	0.1362	1.8422	2.1506	0.4558
2008	20	2.6600	0.0750	0.1995	1.1314	1.2596	0.2540
2009	18	1.7700	0.1200	0.2124	0.7571	0.8421	0.1684
2010	19	1.7100	0.0900	0.1539	0.8543	0.9550	0.1916

Source: Data analysis using RC.4.0 Hydro Office 12.0

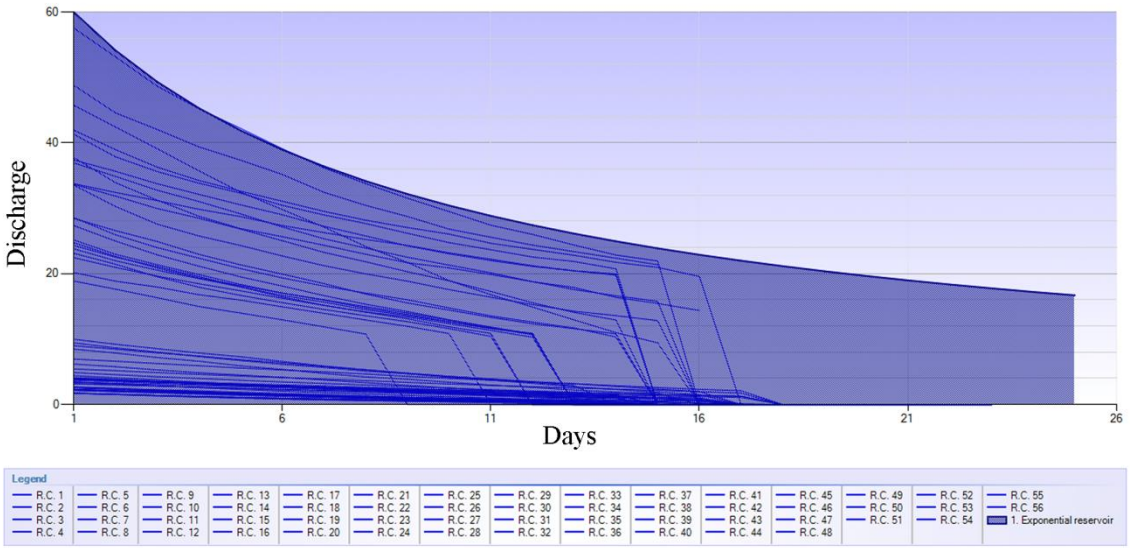

Figure 9. Visualization of MRC manually for exponential reservoir models

Manual MRC visualizations for both reservoir models based on recession parameters show variations in MRC slope for both reservoir models. The slope of the MRC for the linear reservoir model is gentler than the exponential reservoir model. The slope of the MRC is very closely assembled with the combination of recession parameters from the calibration results of both models, that the recession parameters for the linear reservoir model are higher than the exponential reservoir model.

3.4 Hibridisasi Algoritma Genetika Untuk Visualisasi MRC Exponential Reservoir Models

The MRC assembly stages through hybridization of the genetic algorithm process follow the same stages as the generated assembly for linear reservoir models, i.e., the number of generations (NG) and individuals (NI), the maximum length of the recession master curve (ML MRC), and the optimal mutation dispersion. The four parameters of the optimization of the evolutionary cycle parameters are NG 50, NI 10, cross probability 0.90, the maximum length of the recession master curve 50, and mutation 10. The calibration results of the MRC exponential reservoir model from the hybridization of the genetic algorithm process through the evolutionary process of dispersion, the best solution, obtaining the optimal MRC, as presented in Figures 10 and 11.

The best solution of hybridization MRC results through a genetic algorithm process shows the distribution of recession segments and optimal algorithm performance for research areas with relatively stable trends. Distributed performance is optimal for somewhat similar recession segments. Further, calibration of the exponential reservoir model establishes the parameterization of the MRC, as presented in Figure 12.

The combination of recession parameters for the calibration of the exponential reservoir model obtained an average initial discharge of recession (Q0) of 51.19 m^3/s, a recession coefficient (φ) of 0.00024, and a recession constant of 0.0120. The results of calibration calculations for exponential reservoir models using hybridization of genetic algorithms show that linear reservoir models have a higher recession initial discharge compared to exponential reservoir models. Recession parameters for both reservoir models show that the MRC slope for the linear reservoir model is more gentle compared to the exponential reservoir model as presented in Figure 12.

The results of the master recession curve visualization using the genetic algorithm process of the two reservoir models showed that the linear reservoir model had a gentler slope than the exponential reservoir model. This result gives a difference between the two models due to the recession parameters combination, the recession constant, and the coefficient of each model. Recession parameters for linear reservoir models are higher than for exponential reservoir models. The combination of recession parameters for both reservoir models results in a master recession curve of the genetic algorithm process that is more significant for both models. The recession constant and coefficients combination shows a visualization of a relatively flattened master recession curve for linear reservoir models and relatively steeper exponential reservoir models than linear reservoir models. The slope of the master recession curve for both reservoir models will determine the flow storage capability and also the nature of hydraulic conductivity for both reservoir models. The gentle slope of the master recession curve has a relatively slow storage nature, while the steep slope of the master recession curve determines the somewhat wasteful nature of storage. The storage properties of groundwater are also closely related to hydraulic conductivity and the characteristics of the catchment area in the surface flow. The calibration results of the linear and exponential reservoir models and the parameterization of the initial recession discharge, recession coefficients, and constants, and the observational recession discharge and recession model are closely related to the characteristics of the study area matched with the results of research in the catchment area in several countries among others (Boughton, 2015) developed a master computer program to build the latest MRC from the daily discharge records of 100 river measurement stations in Australia. Substantial variations of the recession segment show significant variations in the baseflow recession of the simple exponential decay model. The differences in theoretical exponential decay models and baseflow recessions are assumed due to various transmission losses. The average value of the recession segment in the recessionary period derives from the MRC of a more straightforward set of recession segments compared to the previous method. The transmission loss estimation method relies on the bottom flow recession segment within the MRC, so this method is not suitable for ephemeral rivers in semi-arid areas but is more suitable for assessing transmission losses in humid zones.

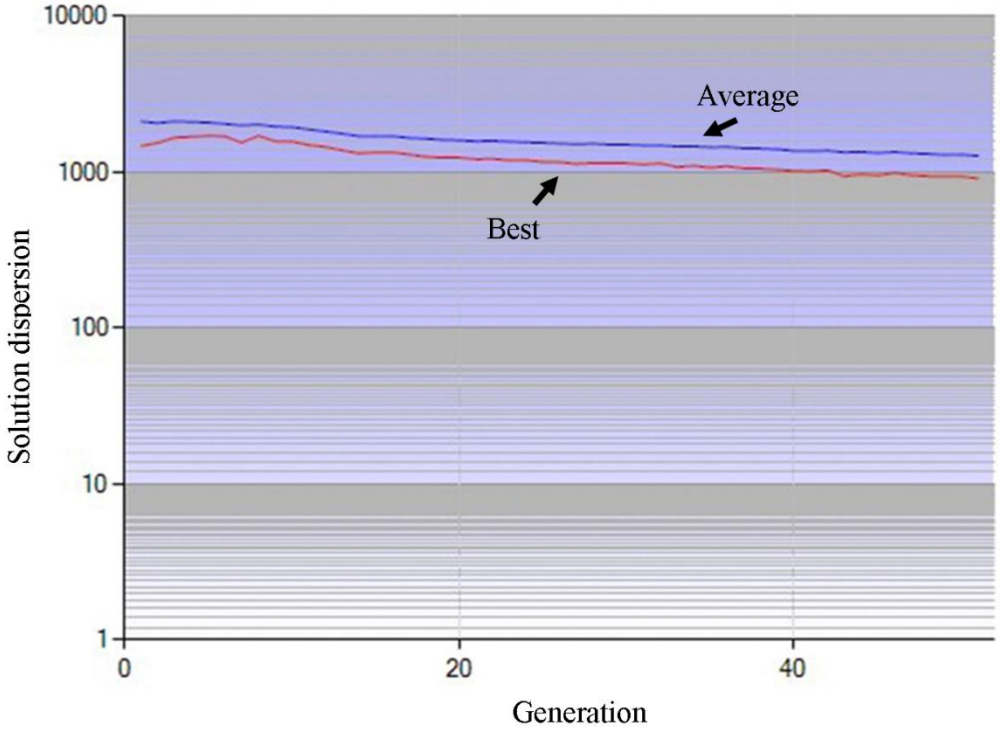

Figure 10. Visualization of logarithmic evolutionary processes for exponential models

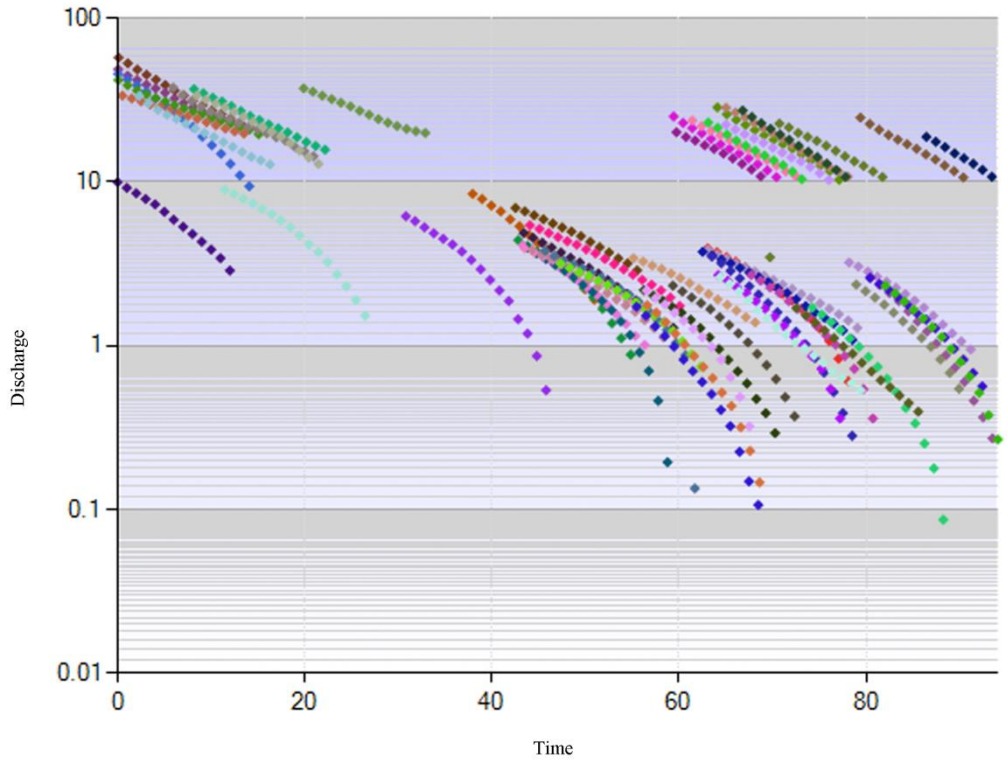

Figure 11. Visualization of the best logarithmic solution process for exponential reservoir models

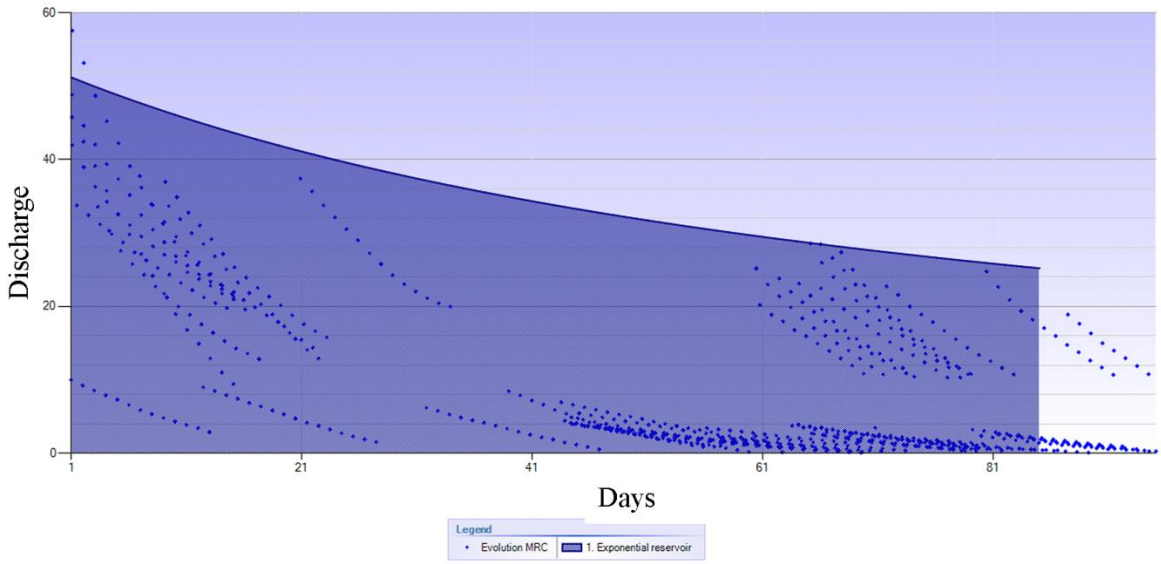

Figure 12. Visualization of MRC processes genetic algorithms for exponential reservoir models

The baseflow in many rivers often come from streams from shallow groundwater aquifers. This assumes that many algorithms show that aquifer outflows are disproportionately linear to flow storage (Wittenberg, 1999). The alternative hypothesis is that nonlinear reservoir functions are relatively more realistic than linear reservoir functions (Moore, 1997; Lin *et al*., 2007). A relatively rapid response, especially from groundwater flow and precipitation, results from the hydraulic head of the groundwater reservoir, which accelerates exfiltration and outflow to the baseflow (Hannah and Gurnell, 2001; Aksoy and Wittenberg, 2011; Chen *et al*., 2012). When pore pressure and volume are hydraulically related, a single nonlinear reservoir model makes sense for a particular catchment area or an independent parallel linear reservoir (Bonacci, 1993; Peters *et al*., 2005). The nonlinear reservoir algorithm uses an analytical derivation model in the automatic separation of the bottom flow from a series of daily discharge times from the river and the practical calculation of groundwater storage and watershed replenishment in the inversion of nonlinear reservoirs.

A comprehensive and objective approach to analyzing base flow recessions with recession innovations uses quantitative regression and efficient and accurate numerical estimation, including groundwater intake curves. Thomas (2012) introduced one of the innovations of quantitative regression models (Stoelzle *et al*., 2013), drawing the distribution of baseflow recession data within the lower limit of the hydrographic recession curve. The use of quantitative regression presents a rigorous and reproducible method of estimating recession parameters and a traditional subjective approach, resulting in the best model. The second innovation estimates the derivation time of the dQ/dt recession curve by comparing six estimators from more efficient algorithms for estimating baseflow recession parameters. The third innovation considers seasonal variations in baseline flows across various recession parameters that are statistically significant across all seasons. Wang and Cai (2010) introduced the fourth innovation by considering groundwater intake parameters into baseflow recession analysis. Thomas *et al*. (2015) The nonlinear response of recessionary behavior increases as groundwater intake increases, thus considering the availability of groundwater collection data on a similar regional scale (Mizumura, 2005; Aksoy and Wittenberg, 2011; Collischonn and Fan, 2013).

4 CONCLUSION

The recession parameters, the initial discharge of the recession, the recession constant, and the coefficient for both the reservoir model produces an individual recession curve and a varied master recession curve. The calibration results of both linear and exponential reservoir models, both manually and hybridized through a process of genetic algorithms for both reservoir models, showed a visualization of the master recession curve for a relatively gentle linear reservoir model compared to the exponential reservoir model. Manual visualization of the MRC and hybridization of algorithmic genetic processes for both reservoir models show that the slope of the MRC manually indicates a relatively more gentle linear reservoir model compared to the exponential reservoir model. While the visualization of the master recession curve using the genetic algorithm process of both reservoir models shows that the linear reservoir model has a more gentle slope than the exponential reservoir model. The slope of the master recession curve for both reservoir models reflects the flow storage ability and the nature of

hydraulic conductivity for both models. The gentle slope of the master recession curve has a relatively slow storage nature, while the steep slope of the master recession curve determines the somewhat wasteful nature of storage.

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ABBREVIATIONS

MRC: Master Recession Curve; **NG**: Number of Generations; N**I**: Individuals; **Rb**: Bifurcation Ratio; **Rc**: Circulation Ratio; **VBA**: Visual Basic for Applications.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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