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T. Harianto
M Asad A

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PREFACE

It is widely believed that the effect of climate change have increased the awarness of people on the severe impact of water and air pollution, the rise of temperature, and the limitation of energy deposites. Besides that, global warming and climate change have played significant role in the change of infrastructure technology. Consequently, the development of infrastructure technology will be evaluated in order to create ecology-environmental friendly and optimized energy.

Sharing knowledge of infrastructure and civil engineering technology which well agree with environmental preservation are valuable to be implemented in the *1st International Conference on Civil Engineering and Infrastructure : "Future Challenges in Civil Engineering Infrastructure Technology"*. The conference is organized by Badan Musyawarah Perguruan Tinggi Teknik Sipil Indonesia (BPMTTSI).

This conference is a media for civil engineers, infrastructure practitioners, academicians, environmentalists and research, to discuss, explore and share recent development and research of infrastructure and civil engineering technology. In future, this conferece will contribute in improving human resources.

Sincerely,

Dr. Tri Harianto
Chairman

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STUDY ON HYDROLOGICAL CHARACTERISTICS OF THE UPPER CATCHMENT OF SELOREJO RESERVOIR

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ABSTRACT: Selorejo Reservoir as one of the key reservoirs in Brantas system has been intensively managed by Public Corporation of Jasa Tirta I as regard to its roles in supplying raw water for irrigation, generating electricity through a series of hydropower plants, and enhancing the fisheries and recreation activities. Being located in the upper of Konto River, Selorejo Reservoir also receives water from Pinjal River and Kwayangan River with total area of upper catchment of 236 km^2. This study is aimed to understand the hydrological characteristics of the upper catchment of Selorejo Reservoir by making use of NRECA and HBV96 models. Based on the monthly basis analysis starting from year of 1999 to 2008, the NRECA model shows that the upper catchment of Selorejo Reservoir has experienced slight changes in soil moisture and groundwater storage since year of 2002. Similar responses also given by HBV96 model for the considered years. The values of Nash Sutcliffe (NS) values obtained for NRECA and HBV96 models are 0.728 and 0.780 respectively. While according to the objective function of Relative Volume Error (RVE), the HBV96 model gives more accurate result compared than NRECA model. Being implemented in duration curve, both models deliver slightly lower stream flow for various probabilities.

Keywords: hydrological characteristics, NRECA, HBV96, Selorejo Reservoir

1. Introduction

In line with the rapid urbanization, many areas are now struggling in dealing with much more complicated issues including water demand. In most cases, such issue has led to serious conflicts among water users in many river basins. Selorejo Reservoir with a capacity about 40 MCM is one of the key reservoirs in Brantas system that has been intensively managed by Public Corporation of Jasa Tirta I as regard to its roles in supplying irrigation water for about 5,700 ha, generating electricity through a series of hydropower plants (Selorejo, Mendalan, and Siman hydropower plants), and enhancing the fisheries and recreation activities [1].

Being located in the upper of Konto River, as illustrated in Figure 1, Selorejo Reservoir receives water from not only Konto River but also Pinjal River and Kwayangan River. The total catchment area for this upper part is about 236 km^2 that comprises Konto River 148 km^2, Pinjal River 44.3 km^2, Kwayangan River 12.5 km^2, and Selorejo Reservoir 31.3 km^2 [2]. With average annual rainfall of 2,700 mm and annual evaporation about 1,470 mm, the amount of water that can be stored within Selorejo Reservoir is mainly depending on the river water flowing from those upper basins. Based on this reason, any changes occur in the basins will consequently impact on the river flows. This study is done in order to understand the basin response (hydrological characteristics) to rainfall using two conceptual models, NRECA and HBV96. Due to limited data availability, however, the study is conducted on monthly basis by taking into account rainfall data collected from 5 rainfall stations and stream flow measured at the inlet of Selorejo Reservoir starting from year of 1999 to 2008.

2. Water Balance Models

2.1. *NRECA Model*

The NRECA Model was developed by Norman H. Crawford as regard to the estimation of potential flow for the construction of mini hydropower. As this model was developed on basis of water balance in the watershed, the total runoff obtained is estimated by considering the relationship between precipitation, actual evapotranspiration and storage. This water balance equation applies to the watershed over any time interval. As presented in Figure 2, precipitation, actual evapotranspiration and runoff are the volumes of water entering and leaving the watershed in the time interval, while the storage is considered as the change in soil moisture and groundwater storage in the time interval. In order to define the watershed or basin characteristics, NRECA model uses three variables: NOMINAL, PSUB, and GWF.

NOMINAL represents the soil moisture storage level that permits half of any positive monthly water balance to leave the watershed as excess moisture. When the soil moisture is less than NOMINAL, the majority of monthly water balance will be retained in the soil moisture. While when soil moisture is greater than NOMINAL, it becomes direct runoff or an addition to groundwater storage. PSUB, on the other hand, represents the fraction of runoff that moves out of the watershed on subsurface flow paths rather than as direct or surface runoff. The soil permeability in this case will strongly influence the amount both of surface or direct runoff and sustained discharge. PSUB would increase to 0.8 I watersheds known to have highly permeable soils and would decrease to 0.3 in watersheds with low permeability or thin soils. Finally, GWF is defined as an index to the time of flow along subsurface flow paths that enter the stream. It is the fraction of total groundwater volume that will enter the stream in the current month. Conversely to PSUB, GWF value would increase to 0.9 in the watersheds that have little sustained flow and would decrease to 0.3 in watersheds known to have reliable sustained flows.

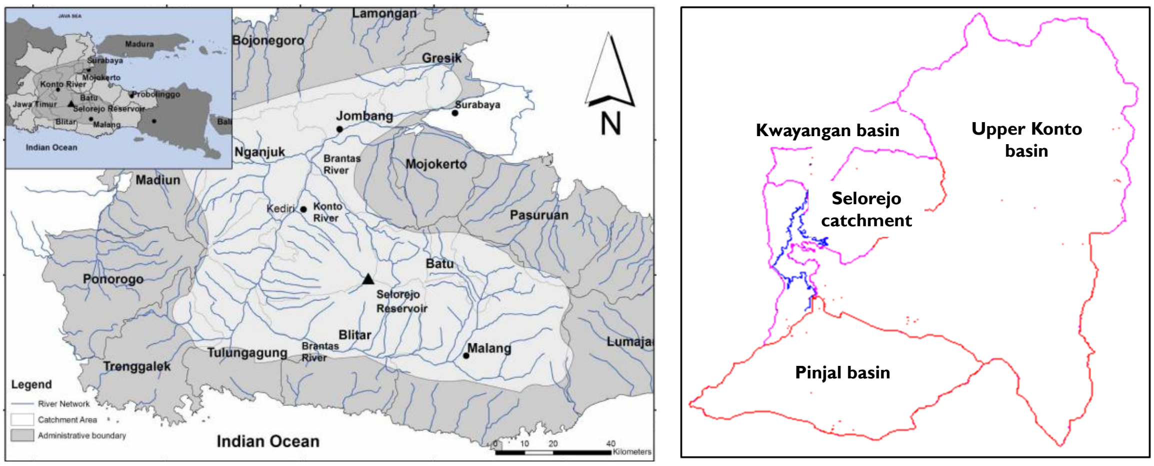


Figure 1. Location of Selorejo reservoir

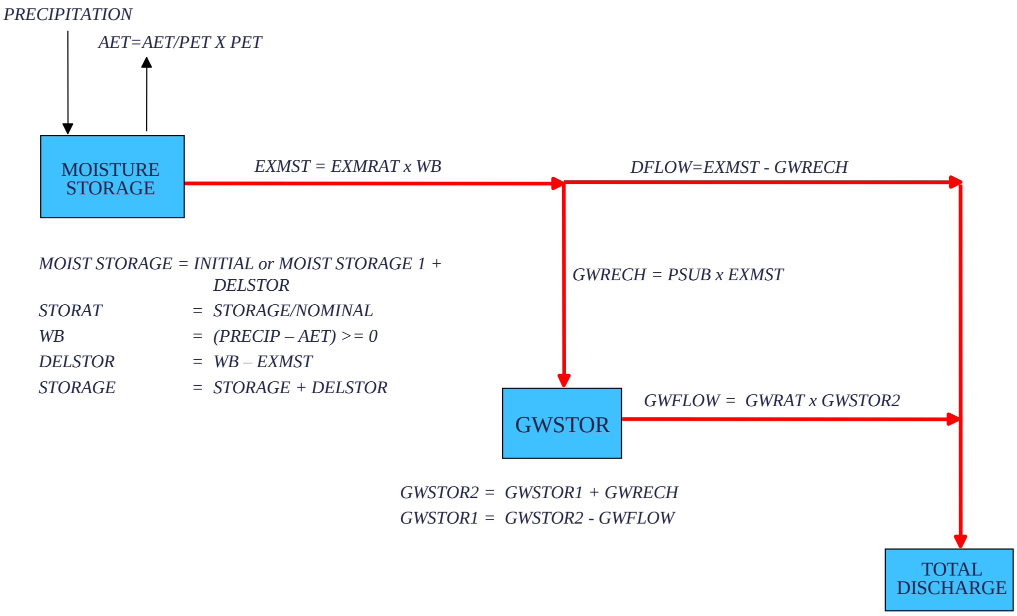
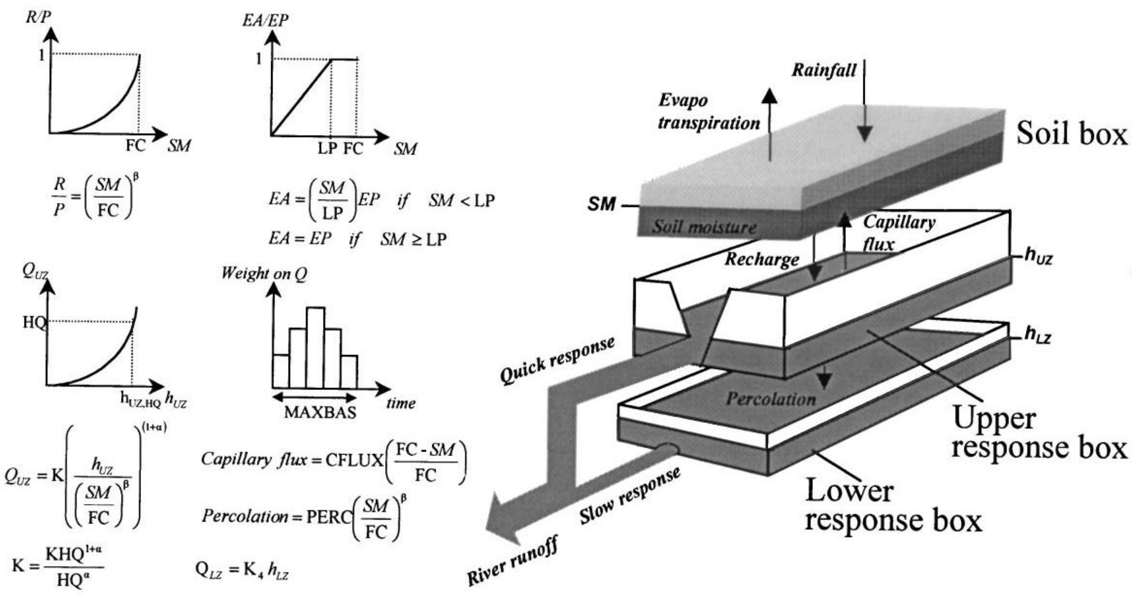


Figure 2. Scheme of NRECA model

2.2. *HBV96 Model*

Since it was developed at the Swedish Meteorological and Hydrological Institute in early 1970s, the model has been subject to modifications over time due to its wider scope of applications in more than 30 countries. A major revision of the HBV structure model was basically done in 1993 as regard to re-evaluate the existing model and to develop a new model version so called HBV96 for hydrological problems related to hydropower production and design [3].

Different to NRECA model, HBV96 model was developed in daily basis with more soil layers. As presented in Figure 3, Liden and Harlin further explained how the runoff is generated in the HBV96 model [4]. Here in the model, the evapotranspiration (EA) is estimated as a function of the soil moisture conditions and the potential evapotranspiration (EP). When the soil moisture exceeded a storage threshold (LP), water would evaporate at the potential rate. While at lower soil moisture values, a linear relation between the ratio EA/EP and soil moisture is used. Later on, the soil moisture storage (SM) and storage in the upper and lower response boxes, respectively (h_{UZ} and h_{LZ}), would form the general storage (S). While recharge to groundwater is estimated through a non-linear relation between the ratio R/P and soil moisture. The flood regime of the catchment is described by the outflow from the upper nonlinear reservoir (Q_{UZ}), while the baseflow (Q_{LZ}) is governed from the lower response box which is filled by percolation from the upper response box. Finally, the total runoff (Q) is given by the sum of the outflow from the lower two response boxes.



Components	Physical Meaning	Decisive Parameter
EA	Actual Evapotranspiration	LP
R	Recharge from soil box to upper response box / infiltration	FC, β
CF	Upflow from upper response box to soil box / capilarity	CFLUX, FC
Quz	Overland flow	kf, α
PERC	Amount of percolation that stores the groundwater aquifer	PERC, FC, β
Qlz	Base flow and groundwater flow	k4

Figure 3. Scheme of HBV96 model

3. Data Availability and Methods

As previously mentioned, this study makes use of monthly rainfall data collected from 5 rainfall stations from 1999 to 2008. Those available stations are Pujon, Ngantang, Selorejo, Kedungrejo, and Sekar. Using the method of Thiessen polygon, the average regional rainfall for the whole basin is estimated based on the weighting factor and ratio to Selorejo station obtained for all stations as given in following Table 1. Again, due to limited data, the potential evapotranspiration (PET) values employed in this study is derived based on the last 3 years data. The average monthly PET values are given in following Figure 5.

Table 1. Weighting factors and ratio to Selorejo station

Station	Ngantang	Pujon	Kedungrejo	Sekar
Kwajangan	0,58	0,42	-	-
Konto	0,02	0,47	0,44	0,08
Pinjal	-	-	0,02	0,98
Selorejo	0,60	0,09	0,21	0,10

Station	Annual rainfall (mm)	Ratio to Selorejo station
Ngantang	2386,67	1,05
Pujon	1861,00	0,82
Kedungrejo	1968,00	0,86
Sekar	2948,33	1,29
Selorejo	2281,00	1,00

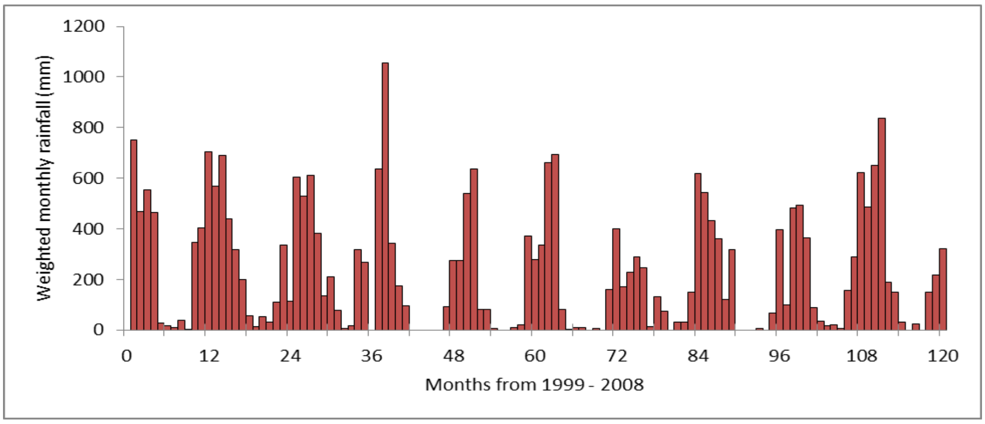


Figure 4. Average regional rainfall over the basins

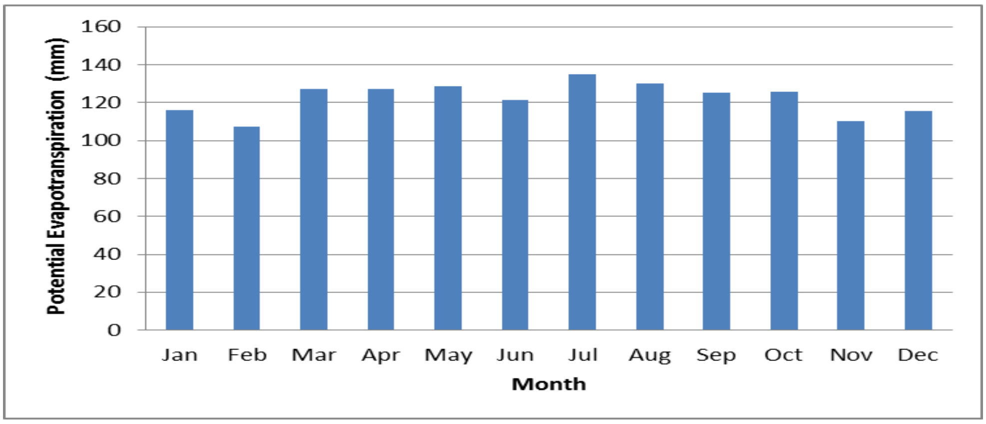


Figure 5. Average PET over the basins

While for the model calibration, the water stage information obtained at the inlet of Selorejo Reservoir is converted into flow as presented in the following Figure 6. The calibration is done yearly to identify if any changes on the hydrological characteristics occurred within the constraint periods. Due to the data available is monthly data, the HBV96 model will also be employed for monthly based analysis. The final result is then verified using duration curve for some important flow probabilities.

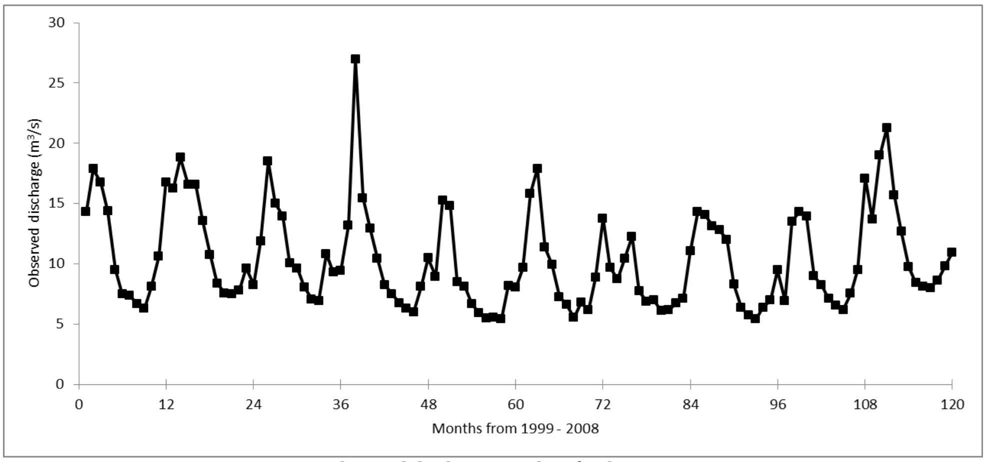


Figure 6. Observed discharge at inlet of Selorejo Reservoir

4. Results and Discussion

4.1. *NRECA Model Calibration*

Based on the initial result obtained for the whole 10 years calibration, the NRECA model shows that the computed flow does not fit to the observed ones. As can be noticed from the Figure 7 below, significant gap occurs after year of 2001. After seperating the calibration into 4 periods, however, the result shows good fitting. As presented in the Figure 8, the calibration result has excellent objective function values for both Nash Sutclife (NS) and Relative Volume Error (RVE) even though the computed ones failed to reach some peak values. The NS obtained is 0.728 while the RVE is 0.001. According to this calibration result, the NRECA model parameters obtained change slightly. As presented in Table 2, the value of PSUBs for all basins change from 0.80 to 0.78, while the GWFs remain constant at 0.10. These values show that the upper catchments are in still very good condition.

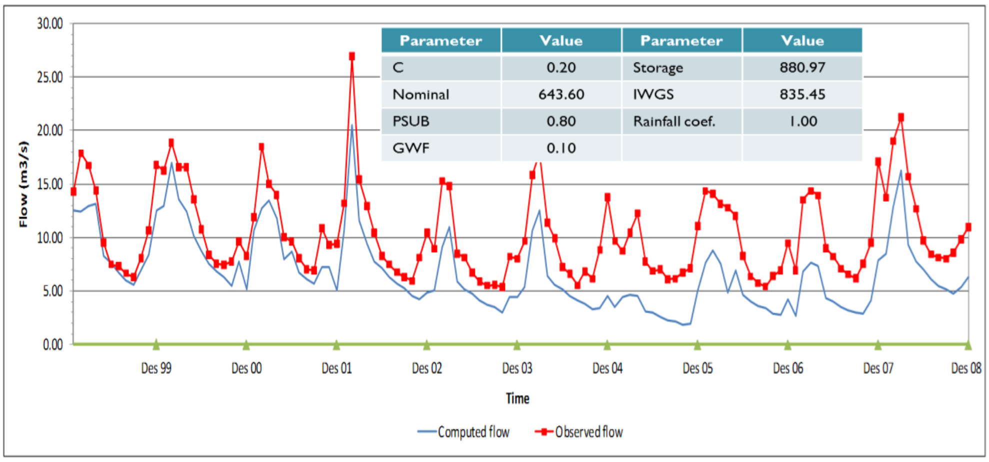


Figure 7. Initial calibration result of NRECA model for the whole year of 1999 – 2008

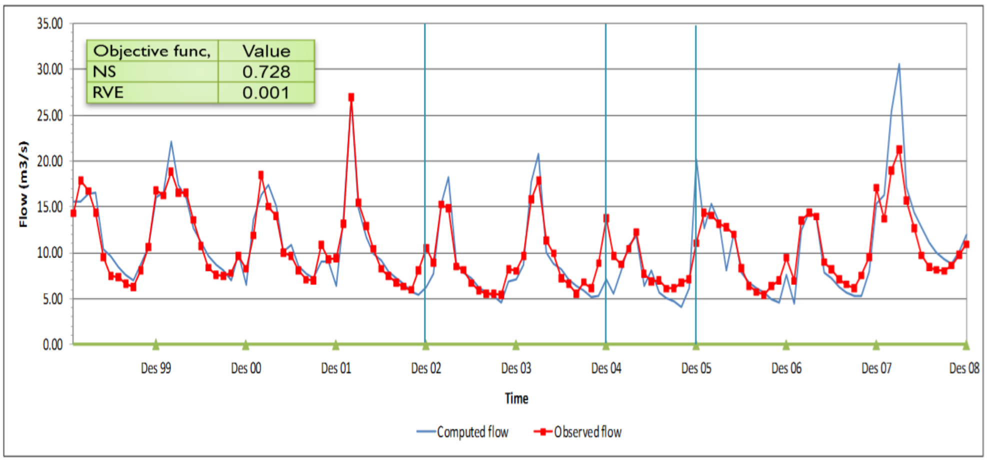


Figure 8. Improved calibration of NRECA model

Table 2. Calibrated parameters of NRECA model

Basin	Year	PSUB	GWF	Moisture Storage	Initial Groundwater Storage
Konto	1999 - 2002	0,80	0,10	903,86	578,84
	2003 - 2004	0,78	0,10	699,60	482,26
	2005	0,78	0,10	489,56	480,54
	2006-2008	0,78	0,10	814,63	427,29
Pinjal	1999 - 2002	0,80	0,10	969,74	819,75
	2003 - 2004	0,78	0,10	746,04	667,64
	2005	0,78	0,10	489,73	500,93
	2006-2008	0,78	0,10	720,37	459,16
Kwayangan	1999 - 2002	0,80	0,10	930,15	662,59
	2003 - 2004	0,78	0,10	717,26	547,45
	2005	0,78	0,10	489,62	487,82
	2006-2008	0,78	0,10	720,36	455,01
Selorejo	1999 - 2002	0,80	0,10	946,29	718,95
	2003 - 2004	0,78	0,10	728,26	591,10
	2005	0,78	0,10	489,66	492,62
	2006-2008	0,78	0,10	708,65	437,95

4.2. *HBV96 Model Calibration*

Compared to the above NRECA model calibration, the HBV96 model generally offers even more excellent result. Although delay or lag for about 1 month ahead is identified occurred at the beginning of calibration, but the computed flow shows similar pattern to the observed values. Similar research work done by Dance (2012) in fact also performed the same result when HBV96 model was applied for monthly basis analysis [5]. As presented in Figure 10 below, it can be noticed that by accomodating the lag, the computed flow shows much better fitting. The NS value obtained is 0.780, while the RVE value obtained is 0.021. If the NRECA model failed to approach some peak values, the HBV96 model is found to be able to meet both lower and most peak values. Considering the HBV96 model parameters obtained from the improved calibration, it confirms that the basins are in very good condition. Detail parameters obtained are shown in Table 3.

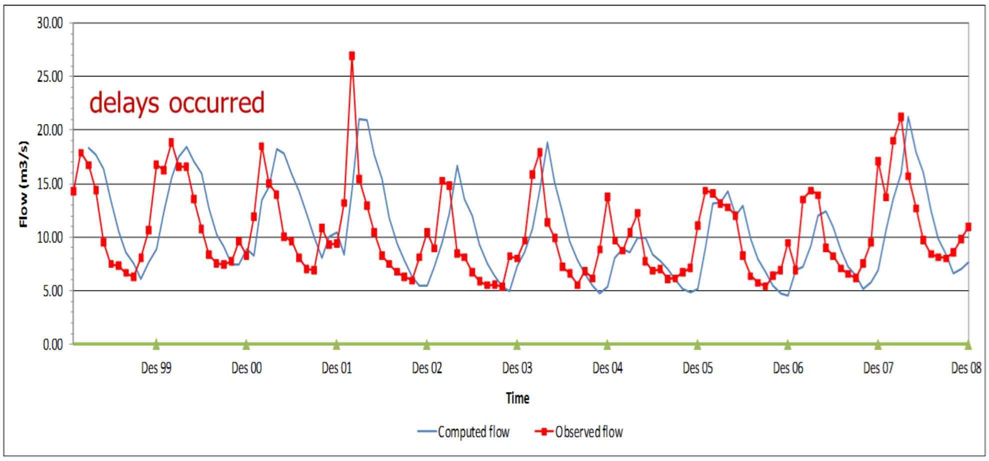


Figure 9. Initial calibration result of HBV96 model for the whole year of 1999 - 2008

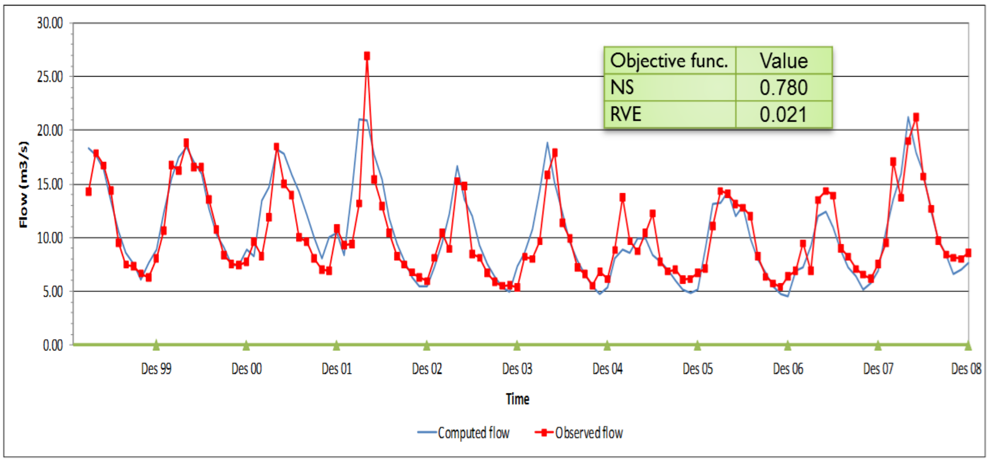


Figure 10. Improved calibration result of HBV96 model

Table 3. Calibrated parameters of HBV96 model

Parameter	Value	Parameter	Value	Parameter	Value
FC	9,000	Kf	0.25	SM	1,000
LP	2,500	K4	0.002	HUZ	1,000
PERC	1	Alfa	0.001	HLZ	15,000
CFLUX	0.10	Beta	1		

4.3. *Result Verification*

In order to verify the result obtained from the above calibration, especially values obtained by HBV96 model, this study use duration curve to evaluate the deviation. Based on the duration curve derived from the computed flow, it can be noticed that the computed flow show a relatively small of deviation to the observed flow. As presented in Figure 11 below, the errors obtained for 75%, 80%, and 90% probability of flow are 0.341%, 4.75%, and 13.75% respectively.

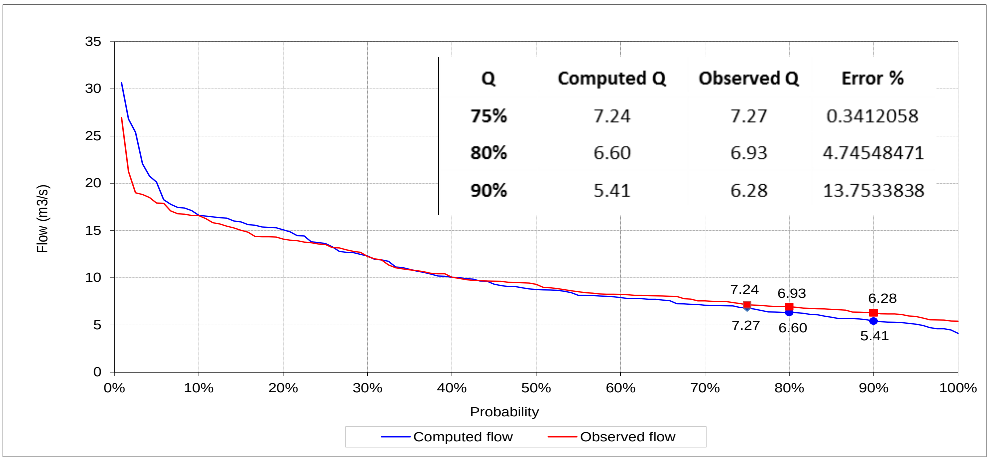


Figure 11. Duration curves derived based on computed and observed flows

5. Conclusions

The implementation of both NRECA and HBV96 models on the upper catchment of Selorejo Reservoir show excellent calibration and verification results. Further more, based on the model parameters obtained, it can be concluded that the upper catchment of Selorejo Reservoir is in very good condition. For more accurate results, it is recommended to analyse the characteristics on daily basis.

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