APPLICABILITY OF A TWO PARAMETER WATER BALANCE MODEL TO SIMULATE DAILY RAINFALL RUNOFF – CASE STUDY OF KALU AND GIN RIVER BASINS IN SRI LANKA

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Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Water Resources Engineering and Management

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DECLARATION

I hereby declare that, this is my own work and this thesis does not incorporate without acknowledgement of any material previously submitted for a Degree or Diploma in any other University or Institute of higher learning to the best of my knowledge and belief. It does not contain any material previously published or written by another person except where the acknowledgment is made in text.

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P.K.M.Dissanayake Date

The above candidate has carried out research for the Master's thesis under my supervision.

....

Professor N.T.S. Wijesekera Date

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ABSTRACT

Most of hydrological models are complex, data intensive and require optimization of many model parameters. Due to prohibitively high institutional pricing and access constraints associated with data, water research even at daily time scale is a challenge. In this aspect monthly data can be treated as better. Lack of a simple and reliable rainfall runoff model to simulate daily rainfall runoff with an indication for soil moisture is a concern when field applications are carried out. In this backdrop the present work investigated the applicability of a monthly model in the daily time scale. The two-parameter monthly water balance model (Xiong and Guo,1999) performed well in two Sri Lankan watersheds was selected. This model after an initial evaluation was calibrated with monthly data. Daily streamflow estimations were done for Ellagawa (1372 km2) and Thawalama (364 km2) watersheds for the respective durations 2006-2014 and 2000-2015. Estimations were compared using MRAE as the objective function, hydrographs, duration curves and water balance. Nash-Sutclifff was used to observe the goodness of fit in the high flow estimates. Initial evaluations with the previously calibrated dataset showed satisfactory results with the recent data used for the present work but were inferior to the previous outputs probably due to temporal setting or other data quality issues.

The two parameter model calibrated and verified for the recent data showed very good results for the Tawalama watershed and good results for the Ellagawa watershed with different degrees of overestimation. Daily flow estimations agreed reasonably well with the Thiessen averaged rainfall and observed streamflow patterns but demonstrated an overestimation with a noticeable pattern.

After observing monthly and daily outputs in both catchments, the model concept was modified to incorporate a third parameter called AF (Adjustment Factor) to arrest over estimation which may have caused due to the need to incorporate watershed effects arising from variations in slope, land cover, detention and soils.

This Three Parameter Monthly model showed excellent results with the matching of outflow hydrographs, duration curve and water balance for water resources management. In case of Tawalama watershed, the average MRAE values for the two parameter and Three Parameter Models were 0.2061 and 0.1657 respectively. In Ellagawa watershed average MRAE values for the same were 0.7668 and 0.3135 respectively. Respective c and Sc values for the Two Parameter Model were 0.89 and 1,288.63 for Tawalama watershed while the same were 1.29 and 829.84 for Ellagawa. Respective c, Sc and AF values for the Three Parameter Model were 1.02, 1,292 and 0.83 for Tawalama watershed while the same were 0.52, 975.2 and 0.46 for Ellagawa.

Conceptualization extended in the three parameter model demonstrates the potential of successful catchment process conceptualization within the monthly and daily temporal resolutions.

Present work concluded that in case of two case study watersheds, the three parameter monthly model concept is applicable for both monthly and daily time scales.

Therefore this model is recommended for water resources planning and identification of climate change impacts in similar watersheds.

Key Words

Water balance optimization, Water Resources Management, Sri Lanka, Hydrologic Model Objective Function, Flow Duration Curve, Absolute Error

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LIST OF ABBREVIATIONS

Abbreviation	Description
AF	Runoff Adjustment Factor
c	Parameter c
C	Runoff Coefficient
DSD	Divisional Secretary Divisions
E	Nash–Sutcliffe coefficient
E (t)	Actual Evapotranspiration
EP (t)	Pan Evaporation
MAR	Mean Annual Rainfall
MRAE	Mean Ratio of Absolute Error
MSE	Mean Square Error
NEM	North East Monsoon
P (t)	Rainfall
Q (t)	Runoff
RAEM	Ratio of Absolute Error to Mean
RE	Relative Error
RMSE	Root Mean Square Error
S (t)	Soil Moisture Content
SC	Field capacity of the catchment
SWM	South West Monsoon
2PM	Two Parameter Model
3PM	Three Parameter Model

1. INTRODUCTION

1.1 General

Water is an essential and a finite commodity, being an increasingly scarce resource in the world, its sustainable management has become a challenge across the world. At the outset, failure in water sources management adversely affects the society, and the economy of a country and the sustainability of the entire world. Sustainable water management is of fundamental importance for the society with many water related issues such as lack of sanitation, the depletion of water for cultivation and controlling of damages associated with hydrological extremes linked to floods and droughts. Furthermore, water supply systems in many cities of the world are stated as under stress due to the changing climate regime. Proper management of water resources in a basin, essentially requires the understanding of dynamics and availability for uses such as drinking water supply, Irrigation water, hydropower generation etc. Therefore, proper planning of water resources management is very important.

In Sri Lanka, water resource management has encountered a setback due to lack of daily resolution streamflow data for assessments and evaluations. To overcome the flow prediction difficulties, reliable streamflow estimations using mathematical models are important. In Sri Lanka, whilst limited mathematical models have been applied to simulate monthly rainfall runoff, applications those which can estimate daily streamflow, are very limited. However, at the daily time scale, runoff time series exhibit much more variability in terms of high flows, low flows or the transition flows between them. These extremes combined with the effect of antecedent soil moisture conditions and the feedback between runoff processes and soil moisture storage do not appear at annual or monthly time scales (Eder, 2002). In water balance, coarser resolution outputs such as monthly or annul can be generated easily from finer resolution. Hence, daily models are valuable than models that generated monthly or annual outputs.

The National Water Supply and Drainage Board (NWSDB), of Sri Lanka, is the major water supply institution. In water supply project planning, once the required water demand is identified a source should be identified to extract the required volume. The Planning Manual (P1) of NWSDB (http://www.waterboard.lk), does not recommend models for the determination of water yield from watersheds. Therefore, in order to estimate water availability, it is important for the NWSDB planning manual to explore and recommend a suitable model. Hence, one major gap in water research to check the applicability is the lack of an appropriately researched, a simple and a reliable daily runoff estimation model. This is causing a significant ambiguity during field applications of water yield evaluations. For this purpose it is necessary to carry out a research to check the applicability of a simple model, preferably with lesser inputs and if available then would be the most suitable for streamflow simulations.

There are many mathematical models incorporating water balance or in other words the application of system continuity. However, the existence of a large number of parameters and variables in these makes not only calibration and validation difficult but also questions the interpretation of the final output because of the many unverified conceptualizations built into the model. Under such circumstances, two parameter water balance model of (Xiong.L., Guo.S., 1999) appears as a very simple and an easy to use model which was proposed for monthly time scale inputs and outputs. Already the applicability of this model has been tested in four Sri Lankan watersheds (Sharifi.M.B., 2016, unpbl) and (Khandu.D., 2016, unpbl). Also, there are suggestions that it is worthwhile researching on the applicability of this model with daily input data to generate daily outputs. Therefore two watersheds from Ginganga and Kaluganga basins were chosen to carryout case study applications.

1.1 Objectives

1.1.1 Overall Objective

Overall objective of the model to identify a simple but reliable daily runoff estimation model for sustainable water resources management for water, food and health security.

1.1.2 Specific Objectives

1. Carryout a critical evaluation of the available simple and reliable mathematical model for streamflow estimations issues and constraints.
2. Evaluate applicability, relationship, options and sufficiently monthly and daily streamflow models for water resources planning and management.
3. Develop, calibrate and verify hydrologic mathematical models for two case study watersheds in order to determine the applicability of the same monthly streamflow model to generate daily output.
4. Make recommendations on the applicability of a simple but adequate monthly rainfall-streamflow model to generate daily streamflow ensuring sustainable water resources management.

1.2 Project Area

Two watersheds namely Ellagawa in Kalu River catchment and Tawalama in Gin River basin were selected for the study mainly because of the availability of data and also considering the minimal land use changes within the study period. Kalu Ganga is the largest river (Ganga) in Sri Lanka in terms of annual discharge while Ginganga is the fifth in rank. Length of the Kalu River is 129km and Catchment area is 2766 km^2. Annual discharge amounts to 4000 Million m^3. Rainfall pattern is bimodal and falls from May to September and November to February with an average annual volume of 4000 mm. River Kalu originates from central hills to meet the ocean at Kalutara. Kaluganga consists of three major sub basins. They are Ellagawa, Horana and Sinharaja. The Ellagawa Sub basin has an area of (1371.65 km^2). Ratnapura, a major town of the province is located within this catchment and is heavily affected by frequent floods.

Length of the Gin River is 113 km and catchment area consists of 932 Km^2. River originates from Gongala mountain in Deniyaya and flows to the Indian Ocean at Gintota. Annual discharge is 1268 Million m^3. Rainfall pattern is bimodal falling from May to September and November to February with an average annual total of 4000 mm. Kalu and Gin rivers can be considered as unregulated.

The study areas of Kaluganga and Ginganga basins are as shown in Figure 1-1 and Figure 1-2.

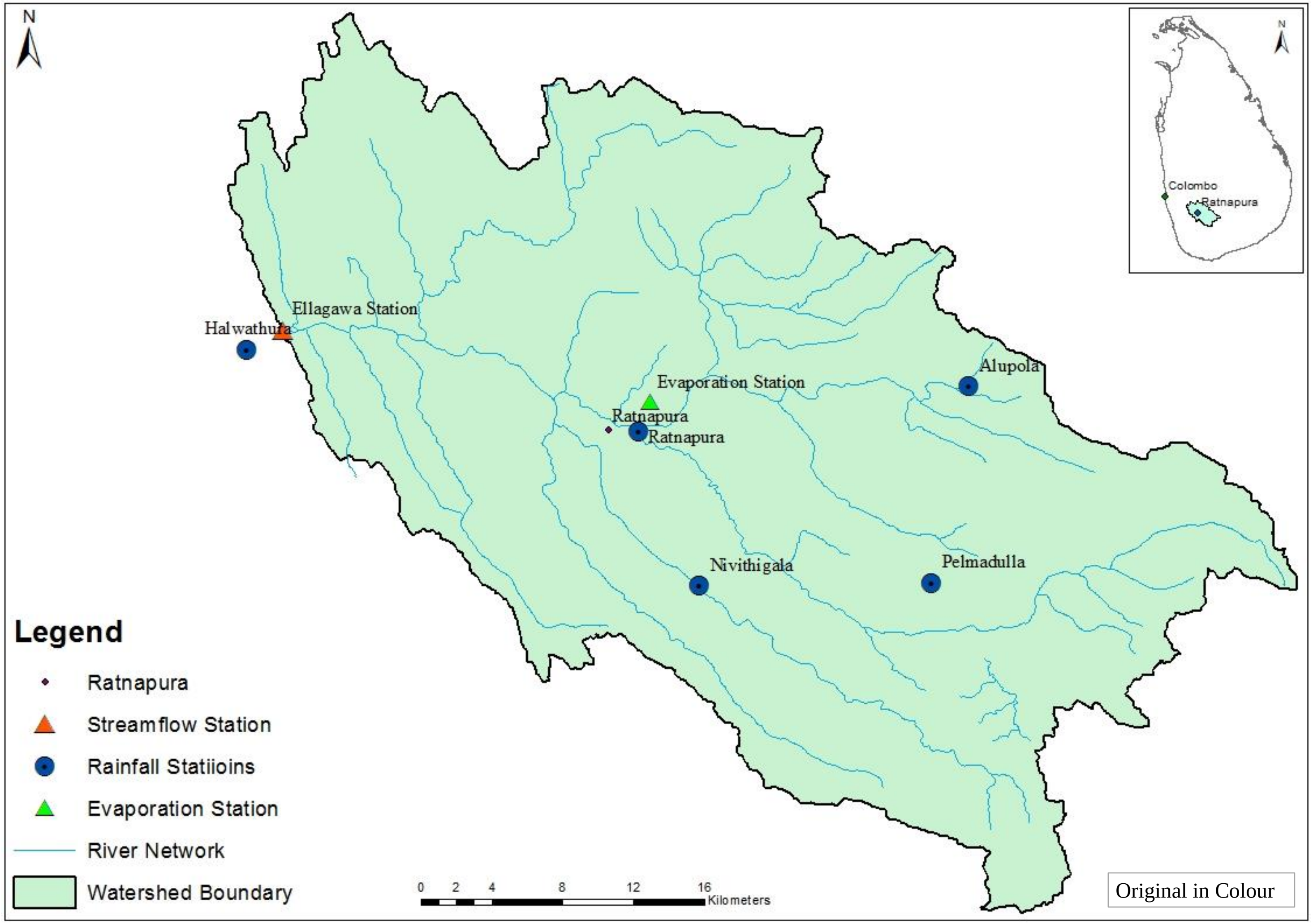

Figure 1-1: Project Area – Ellagawa Watershed

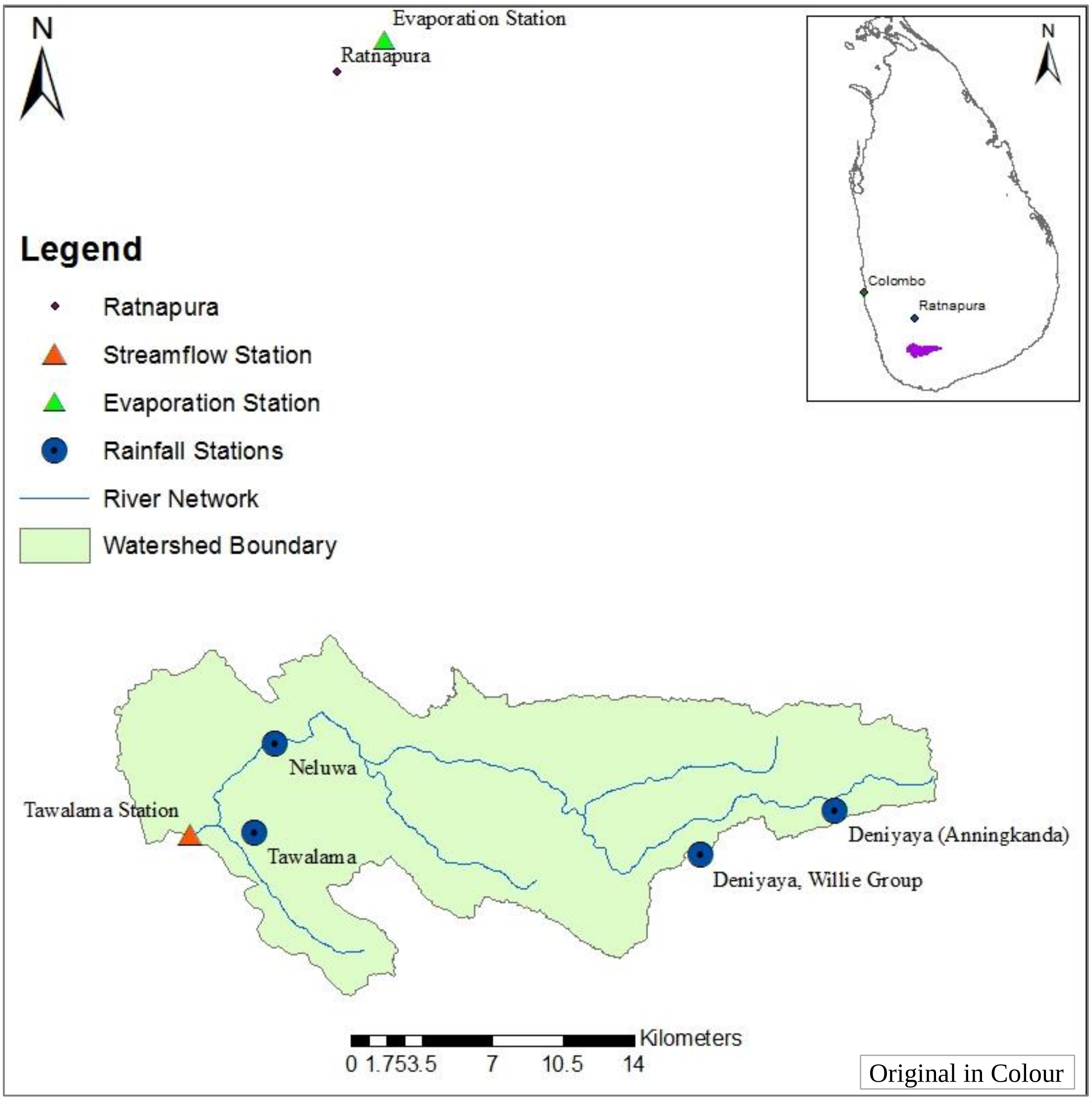

Figure 1-2: Project Area – Thawalama Watershed

2. LITERATURE REVIEW

2.1 General

A Model is a simplified representation of a real-world system (Weather, Sorooshian and Sharma, 2008) which can also be defined as an abstraction of reality in the simplest way as adequate for the purpose of the modelling (Wainwright and Mulligan (2004)). The best model, according to the above, is always that achieves the greatest realism with the least number of parameters and the least model complexity. Huggett (1980) describing a model as a system of inter-related components and relationships mentions that, A systems analysis involves in breaking down the associated complexities into simple and manageable subsystems connected by flows of causality, matter, energy or information.

This literature review looks at streamflow estimation models that are simple for field application in data scarce situations and also obtaining the estimation of soil wetness for watershed management. Hence, the recent works on model evaluations, modelling, data access, and evaluations, model calibration and verification were studied and reviewed.

2.2 Watershed Modeling

Singh and Frevet (2006) defined the concept of watershed models as tools to simulate natural processes corresponding to flow of water, sediment, chemicals, nutrients, and microbial organisms within watersheds, and also quantification of associated human activity impacts. Simulation of these processes is a fundamental component when addressing a range of water resources, environmental, and social problems.

Beven (2001) differentiated three kinds of rainfall-runoff models as perceptual, conceptual and procedural. The perceptual model is the summary of modeler's perceptions of how the catchment responds to rainfall under different conditions. The first stage in the formulation of a model is a mathematical description to make quantitative predictions. This mathematical description is called the conceptual model.

Using techniques such as numerical analysis, a procedural model is defined in the form of a code that will run on a computer (Dzubakova, 2010). Models are generally classified to describe and discuss their capabilities, strengths, and limitations. There is no universal method to classify rainfall runoff models. In literature, watershed models are classified in several ways. They are, 1) Event and Continuous Simulation Models, 2) Conceptual and Hydrodynamic Models, 3) Lumped and Distributed Parameter Models, and 4) Models with Fitted, Physically Determined, or Empirically Derived Parameters (H. Vernon Knapp, 1991). According to (Dzubakova, 2010) models can be classified in to three categories as, 1) Metric (also called data-based, empirical or black box), 2) Parametric (also called conceptual, explicit soil moisture accounting or grey box), and 3) Mechanistic (also called physically based or white box) model structures. Watershed models are also classified as Annual, Monthly, Weekly, Daily and Hourly according to the temporal resolution of the data.

2.2.1 Monthly water balance models

Monthly water balance models are valuable tools for water resources management, reservoir simulation, drought assessment or long term drought forecasting. There are many types of monthly water balance models used in the world. A Monthly water balance model was first developed by Thornthwaite in 1948 and later revised by Thornthwaite and Mather (1955, 1957;Xu.C.Y.& Sing.V.P.,1996). Since inception, these models have been adopted, modified, and applied in a wide spectrum of hydrological problems. Recently, monthly water balance models have been applied to explore the impact of climatic change (Schaake and Liu, 1989; Arnell, 1992; Xu and Halldin, 1996;Xu.C.Y.& Sing.V.P.,1996). Furthermore these have been utilized for long-range streamflow forecasting (Alley, 1985; Xu and Vandewiele, 1995;Xu.C.Y.& Sing.V.P.,1996).

There is an increasing demand for monthly water balance models for a variety of hydrological problems. Many monthly water balance models are available to predict the monthly water yield. Haan.C.T.,(1972) with a monthly rainfall runoff model satisfactorily predicted monthly streamflow in seven small watersheds using a selfcalibrating four parameter model. In (Kuczera.G, 1982) developed a monthly streamflow model using a daily time step with two storages and having 9 parameters.

After nearly 50 years of development, the monthly water balance models have become much more complicated, to unitize more information, to achieve more physical soundness, and to apply for many purposes but, a simple monthly water balance model can still be considered as efficient and useful in terms of runoff simulation (Woolhiser, 1996 & Ye.et al.,1997) found that a six parameter conceptual model did not yield inferior accuracy to a complex model using twenty-two parameters for monthly runoff in low-yielding catchments. Thus, a simple model should be plausible if it delivers satisfactory results, at least in practical operations. When number of parameters are high, parameter variability also will be high requiring assumptions that would create issues during model calibration.

2.2.2 Two parameters monthly water balance models

In 1993, a two parameter monthly water balance model developed for French watersheds comprised two reservoirs (Claude.M, 1994). In 1999 Lihua Xiong and Shenglian Guo developed a two parameter monthly water balance model to simulate the rainfall runoff of seventy subcatchments in the Dongjiang, Ganjiang and Hanjiang Basins in the south of China (Xiong, 1999). Application results show that Nash efficiencies were high for both calibration and verification periods reaching values between 84.78% and 90.98%. in this work it has been argued that result of two-parameter water balance model is quite equal to a five-parameter water balance model used by Guo, (1992) and Guo, (1995). The simplicity and high efficiency in performance of this two-parameter monthly water balance model enables easy water resources planning and climate impact studies. Safouan.M.et al., (2005) developed a two parameter Monthly water balance model using a stepwise approach. That was clearly empirical and a bulk data set has been used.

2.2.3 Daily Water Balance Models

At the daily time scale, runoff time series exhibit much more variability in terms of high flows, low flows or the transition between them. These extremes are incorporated to random nature of storm events; not appeared at the annual or monthly time scales, combined with the effect of antecedent soil moisture conditions and the feedback between runoff processes and soil moisture storage (Eder, 2002). Gerald Eder (2002) developed a daily model for water balance in Alpine catchments at different spatial and temporal scales. In this work since the monthly model was unable to simulate daily streamflow, especially high and low flows, the model structure had been changed as a eight parameter daily model. The author describes that the inclusion of more complexities to the model leads to more uncertainty in the simulations due to inclusion of additional parameters. This model also incorporates the use of parameters related to snowmelt.

Grimmond. et,al (1986) developed a simple daily model to calculate water balance components for an urbanized catchment. Model time scale can be varied from one day to one year. The inputs such as precipitation, evaporation, pipe borne water supply and soil moisture are necessary to specify the characteristics of the catchment under three steps. i.e. hydrologic properties of the surface and subsurface water use and initial storage conditions. Accordingly the model consists of information related to the nature of the physical land cover, hydrologic properties of surface and subsurface materials, data on water use, and status of various water storages. Daily consumption data of pipe borne water is required for the model to be applied. Further it was also suitable only for an urban catchments and application would be quite limited.

Edijatno et al. (1999) developed a daily model, was based on a sort of process lumping, i.e. with no ambition to model hydrological processes separately. Parsimony of this could also be questioned, on grounds of the presence of obvious fixed parameters. Further reflection is needed to fully appreciate the future of this way of modeling.

Bari.K.R. & Smettem.J. (2005) developed a conceptual daily model to represent changes in streamflow generation processes following land use changes and was successfully applied to two experimental catchments in the south-west of Western Australia. The model consists of five inter-connecting stores which were, (i) Dry, Wet and Subsurface Stores for vertical and lateral water flow, (ii) transient Stream zone Store, and (iii) Groundwater Store. The Dry, Wet and Stream zone Stores represent the dynamically varying stream zone saturated area and are responsible for surface runoff, interflow and percolation. The model was calibrated using observed groundwater level and daily streamflow data. Catchment average surface slope, soil depth and distribution, porosity, hydraulic conductivity are the most important parameters. The model successfully predicted the daily streamflow in terms of flow duration, peaks and recessions. The model successfully predicted the daily streamflow having 0.84 of $R2$. However this model structure is very complex with more parameters

A simple monthly conceptual model incorporating the land clearing effects on the streamflow generation has been developed for Ernies and Lemon catchments in Western Australia (Bari, 2006). In this work using a downward approach, a daily model had been developed by connecting a monthly model to a daily model. This model contains four moisture stores namely, (i) Upper store, (ii) Subsurface Store, (iii) Groundwater store and (iv) Stream zone store. However, since the model could not produce the daily peak flow as observed with a four stores model, the number of stores had been increased by dividing the upper stores in to two as dry and wet stores. The model structure which was complex, could deliver reasonable results but model structure needed much more data such as groundwater, rainfall, evaporation and streamflow data for verification. Furthermore each store required many assumptions and complicated were adopted and procedure requiring the assistance of hydrological specialist.

Dripps (2007) developed a soil water balance model to calculate the groundwater recharge. This was a Digital Elevation Model (DEM) to simulate the daily runoff and calculate groundwater recharge. Since this was incorporated to a spatial and temporal distribution, an expensive data collection programme was required.

There are no any standard for length of the data period to simulate a daily model. However, Habte.A.et.all,(2007)simulated a distributed water balance model to Abbay River basin using two years for calibration period and one year for verification period. Bari.M.A.,(20016) was used 5 years for calibration and 5 years for validation period and it was performed well. A reliability analysis of rainwater tanks daily water balance model was done using only overall three years period. Muthumala.P.,(2016,unpuble) used 8 years data period to simulate daily rainfall runoff in Kulu River basin.

2.3 Objective Functions

The mathematical measures of how well a model simulation fits the available observations are defined as objective functions (Beven, 2001; Krause.P.et.al, 2005). In general, many of objective functions contain a summation of the error term (difference between the simulated and the observed variable at each time step) normalized by a measure of the variability in the observations. To avoid the canceling of errors of opposite sign, the summation of the absolute or squared errors is often used for many objective functions. As a result, an emphasis is placed on larger errors while smaller errors tend to be neglected (Krause.P.et.al, 2005).

The main reasons for need of evaluation, based on model performance are: (1) to provide a quantitative estimate of the model's ability to reproduce historic and future watershed behavior, (2) to provide a means for evaluating improvements to the modeling approach through adjustment of model parameter values, model structural modifications, the inclusion of additional observational information and representation of important spatial and temporal characteristics of the watershed, (3) to compare current modeling efforts with previous study results (Krause, 2005). The automatic optimization technique is a classical approach to fitting a rainfall-runoff model to the observed data to obtain an optimum parameter set involves minimizing an objective function of observed and simulated flows. This is often a purely mathematical calculation, where the optimization algorithm has no knowledge of the model structure, or of what constitutes a sensible parameter set, though constraints are usually placed on the values parameters may take and a reasonable starting set selected;

furthermore, the objective function itself can be varied and detailed as required (Houghton.C., 1999).

There are different objective functions to make subjective and/or objective estimates of the “closeness” of the simulated behavior of the model to observations in a watershed model. Visual comparison of simulated and observed hydrographs provides a quick and often comprehensive means of assessing the accuracy of model output. However, visual comparison are subjective, especially when a number of similar, but not identical, model outputs are compared to observed data and the "best" fit is sought. To overcome this difficulty, as well as to highlight certain model particularities, one or more of the statistical goodness-of-fit procedures discussed in several research. Green & Stephenson (2009) listed 21 numbers of objective functions introduced by difference producers and 12 numbers of objective functions were recommended. Inter comparison of conceptual models (WMO, 1975) explains 4 objective functions and their relative merits.

The most commonly used objective function for hydrologic simulation models is the sum of squared deviations (Diskin. M.H. & Simon. E.,1977), defined by:

$$R2 = \sum(q_o - q_s)^2 \quad (1)$$

Stephenson (1979); Green & Stephenson (2009) adopted the sum of absolute values of residuals as a goodness-of-fit criterion in an optimization study.

Sum of Absolute Error,

$$SAE = \sum_{i=1}^{n} Abs(q_o - q_s) \quad (2)$$

Where, q_o is observed streamflow and the q_s is simulated streamflow.

The Nash objective function First proposed by.Nash (1969) and again by Nash & Sutcliffe (1970), the formulation of this 'objective function is (Servat.E & Dezetter.A.,1991).:

$$\boldsymbol{D} = \mathbf{1} - \frac{\sum(q_c - q_s)^2}{\sum(q_o - q_s)^2} \quad (3)$$

Where q_c is the mean observed streamflow, q_o is the observed streamflow and q_s is the modelled streamflow. As the model fit improves and D approaches unity. The efficiency criterion is a form of normalized least squares objective function. A perfect agreement between the observed and simulated flows yields an efficiency of 1.0, whilst a negative efficiency represents a lack of agreement. However, the value of the efficiency depends strongly upon the initial variance of the observed flow record, so it is not entirely valid to use it to compare model performances between basins. But this can be used to optimize an individual basin for this study.

This expression tends towards 1 when q_c tends towards q_s. It is easy as far as it is concerned, to draw an analogy with a regression analysis. The term $(q_o\text{-}q_s)^2$ corresponds to a form of the variance of the observed series. The term $(q_c\text{-}q_s)^2$ can be likened to a form of residual variance. The formulation of the Nash objective function thus expresses a kind of "efficiency" (or "yield") in a model similar in the R2 of a regression analysis (Servat.E & Dezetter.A.,1991).

Patry & Marino (1983) in assessing the performance of a nonlinear functional runoff model adopted the root-mean-square error as a criterion for comparison of hydrographs Green & Stephenson (2009).

$$RMSE = (\frac{1}{n}\sum_{i=1}^{n}(q_o - (q_s)^2))^{1/2} \quad (4)$$

Most of the modelers has used this objective function to check the efficiency of the model.

Patry & Marino (1983) assessed the performance of a nonlinear functional runoff model adopted the root-mean-square error as a criterion for comparison of hydrographs. It can be seen that the root-mean-square error is dimensional, having dimensions of flow rate.

$$\mathbf{RAEM = 1/n[(\sum|Qo - Qs|)/\ \bar{Q}o]}$$
(5)

Qo is the observed streamflow , Qs is the calculated streamflow, Qo is the aerage observed streamflow and n is the number of observations used for comparison. This objective function indicates the ratio between observed and calculated discharge with respect to the mean of observed discharges. It compares the error values with respect to the mean of the observed flows. This objective function depends on the characteristics of the observed flow series. When there are big and small peaks, the error values may not enable for easy comparison and mean of observed flow does not reflect the real mean value of the flow series (Muthumala.P.2016,unpubl.; World Meteorological Organization, 1975).

Wijesekara.N.T.S.,(2000), Wijesekara.N.T.S.,& Ghanapala.P.P.,(2003) and Wijesekera and Abeynayake (2003); Muthumala.P.,2016,(unpubl) defined that Mean Ratio of Absolute Error (MRAE) is the difference between calculated and observed flow with respect to that particular observation. This method recommended by WMO(1975); IAHS Publ. no.138,1982 and it is given by equation given below.

$$\mathbf{MRAE} = \frac{\mathbf{1}}{\mathbf{n}}\left[\sum \frac{|\mathbf{Qo}-\mathbf{Qs}|}{\mathbf{Qo}}\right] \qquad (6)$$

In this objective functions too, Qo is the observed streamflow and Qs is the calculated streamflow, and n is the number of observations used for comparison.

Makridakis.S.S.,(1993), Hyndman.R.J.et.al.,(2006) and Tofallis.C.,(2014) defined Mean Average Percentage Error (MAPE) as a percentage of MRAE.

The least squares objective function (e.g. Dawdy & O'Donnell, 1965) has been used to optimize the parameters in a conceptual model developed by Bari,M.A., et.al in 2006. The objective function is described as below.

$$\mathbf{OBJ}\ (\mathbf{LS}) = \frac{\sum_{\mathbf{i=1}}^{\mathbf{N}} (\mathbf{Qobsi} - \mathbf{Qsimi})}{\mathbf{N}} \qquad (7)$$

where Q_{obs}, is the observed flow on day i, Q_{sim}, is the simulated flow on day i, and N is the total number of days.

Xiong.L. & Gu.S.,(1999) were used two objective functions to evaluate the model efficency in Two Parameter MonthlyWater Balance. They were Nash–Sutcliffe efficiency criterion and Relative Error (RE).

$$\mathbf{RE} = \sum(\mathbf{Qi} - \mathbf{Qi'})/\sum \mathbf{Qi} * \mathbf{100}\% \quad (8)$$

Where, Q_i and Q_i' represent the observed maximum monthly runoff and the simulated runoff, respectively.

Thapa.G.,2016,(unpubl) developed an event based model to simulate streamflow for reliable flood mitigation and drainage infrastructure designs using snyder's synthetic unit hydrograph method. With this model he has demonstated that different objective functions would yield different parameters from the same model. Sudheer.K.P.,et.al.,2006 observed the impact of time-scale on the calibration objective function with the performance of watershed models. The results indicate that evaluation of models should be conducted considering their behavior in various aspects of simulation, such as predictive uncertainty, hydrograph characteristics, ability to preserve statistical properties of the historic flow series, etc.

In watershed models, objective functions vary for purposes such as floods, water resources, envioronmental flows and for combinations. Thapa.G.,2016,(unpubl) evaluated the his flood model using MRAE and RAEM and had concluded with the MRAE & RAEM. Muthumala.P.,2016,(unpuble) developed a HEC-HMS model to simulate daily streamflow and it was compared with MRAE which performed very good accuracy for high flows and intermediate flows. Furthermore, Thapa.G.,2016,(unpubl) and Muthumala.P.,2016,(unpuble) demonstrated the RAEM for long term hydrologic time seiries modeling are not performing weell. Also Wijesekera,2000; Perera & Wijesekera,2010; and Wanniarachchi,2013 shows that Peak and low flows are matching moderately while intermediate flows are matching perfectly with the MRAE.

According to the research by Xion & Guo, (1999), (David A. Post, 1999), (Nandalal.H.K. and Ratnayake.U.R.,2010) and Cohen.L.T., et.al, (2014) Nash sutcliffe is performing very well for high flow and medium flow conditions. Also it has observed an underestimation during low flow conditions (Krause et al., 2005).

Many of comparisions studies WMO,1975, Diskin.M.H., & Simon.E.,1977, Servat.E. & Dezetter.A.,1991, Houhton.H.A.,1999, Krause.P.et.al,2005 have investigated the interms of various objective functions. Furthermore, Khandu.D.,2017,(unpuble) evaluated Nash Sutcliffe, RAEM, MRAE, RMSE, BIAS and RE and then MRAE was selected as most suitable objective function.

A daily steramflow modeling study of Kalu river basin in Sri Lanka using HEC-HMS Muthumala.P..,2016,(unpubl) evaluated the suitability of Nash-Sutcliffe, MRAE and RAEM. In this work it was recognized that the Nash-Sutcliffe efficiency was a better objective function to easily match the high flows. The MRAE and RAEM demonstrate advantages over the Nash-Sutcliffe when the intermediate and low flows are matched. RAEM and MRAE Comparison had shown that MRAE clearly reflects the convergence on parameters when modellers perform peak and low flow region matching.

2.4 Parameter Optimization

Conceptual models generally have a large number of parameters which are not directly measurable. Thus they must be estimated through model calibration by fitting the simulated outputs of the model to the observed outputs of the watershed by adjusting the model parameters. The aim of calibration is to find those values for the model parameters which minimize (or maximize as appropriate) the specified calibration criterion (Duan.Q et al.,1994).

Two broad approaches are used in assigning values to the parameters of mathematical rainfall-runoff models for application to given watersheds. 1) Optimized from available knowledge of processes or from measurements of physical properties of the watershed, it being assumed that the model realistically represents measurable physical processes. 2) Which is the subject of the study described herein, parameter values are found by a systematic optimization technique (Johnston.P.R. & Pilgrim.D.H.,1976). Characteristic difficulties were encountered by optimization methods when searching for minimum/maximum of the objective function, are 1) Interdependence between model parameters 2) In difference of the objective function to the value of a parameter 3) Defining the gradient direction 4) Local optima 5) Scaling of parameters (Johnston.P.R. & Pilgrim.D.H.,1976).

Duan.Q.et al.,(1992) in their study concluded that optimization techniques employed for parameter estimation are not powerful enough to deal with the response surface conditions encountered in model calibration. The commonly used calibration techniques rely on direct-search optimization algorithms such as the Simplex method of Nelder and Mead (1965) and the pattern search method of Hooke and Jeeves (1961) (Duan.Q.et al.,1994).

Brazil (1988) investigated the use of the Adaptive Random Search (ARS) method (Pronzato et al., 1984) to calibrate a soil moisture accounting model of the NWSRFS (NWSRFS-SMA), and reported that the ARS method was capable to produce promising results when used as part of a multi-level calibration strategy. Wang (1991) reported that the genetic algorithm (Holland, 1975), with fine-tuning by a local search method, can provide an efficient and robust means for calibration of the Xinanjiang watershed model. Duan et al. (1992, 1993) presented a new global optimization method known as the SCE-UA method (abbreviation for Shuffled Complex Evolution method developed at The University of Arizona). This method is based on a synthesis of the best features from several existing methods, including the genetic algorithm, while introducing a new concept of complex shuffling (Duan.Q.et al.,1994).

In the two parameter monthly water balance model, the optimum values of the proposed two parameters were found by automatic optimization (Xiong, 1999). In which, optimization procedure was included two steps, first; the c & SC were optimized according to the criterion RE to achieve a good simulation of the total runoff volume and Second step; the parameter SC was optimized again according to the criterion R^2, keeping the value of c obtained in the first step fixed and to further achieve the good fit of shape of runoff hydrograph. This two-step optimization procedure had helped to reduce the effects of inter-relationship between the two parameters on model performance.

2.5 Warm up period

A warm-up period is to allow a model to run for a sufficient period prior to the simulation period to initialize important model variables or allow important processes to reach a dynamic equilibrium (Daggupati. P.et.al.,2015).

There are five main methods for dealing with initialisation bias (Robinson 2004) which, 1. Run-in model for a warm-up period until it reaches a realistic condition (steady state for nonterminating simulations) and Delete data collected from the warm-up period. 2. Set initial conditions in the model so that the simulation starts in a realistic condition. 3. Set partial initial conditions then warm-up the model and delete warm-up data. 4. Run model for a very long time making the bias effect negligible. 5. Estimate the steady state parameters from a short transient simulation run (Sheth-Voss et al. 2005);Hoad.K.et.al.,2008.

There were 42 warm-up methods according to the literature search done by (Hoad.K.et.al, 2008). Each method was categorised into one of 5 main types of procedure as described by Robinson (2004) which are graphical, Heuristic, Statistical, Initialisation bias tests and Hybrid.

Length of the warm-up period may vary for different watershed-scale processes (Daggupati. P.et.al.,2015).. However, model developers recommend using warm-up periods of two to three years for hydrological processes and five to ten years for sediment and nutrientrelated processes (Raghavan Srinivasan, Texas A&M University; Jeffrey Arnold, USDA-ARS; James Almendinger, St. Croix Watershed Research Station, Minnesota, personnel communication, 20 January 2014).

A new method for determining the warm-up period, based upon the principles of statistical process control (SPC) was described by Robinson.,(2002). In his research that at least three observations for have been suggested selecting a warm-up period. This work had developed an Engine Block Matching line Model and it was compared with time series inspection and Welch's method (Welch, 1983) results for warm-up period were 200 hours, 9 hours and 300 hours respectively. In this method moving averages with a window are calculated for the means of observations from replications. The window size is increased until the plot of moving average becomes 'reasonably smooth'. The warm-up period is selected at the point at which the plot becomes smooth. According to Law and Kelton (2000), warm-up period, w should be $10 \leq w \leq m/2$, where m is the number of observations made in a replication. There were many of literature regarding warm-up period and many of problems are there. Pawlikowski (1990) and Alexopoulos and Seila (2000) both note problems with autocorrelation and the estimation. Law (1983) also points out that this method may require many replications to obtain smoothing. Finally, since the method is based on the use of cumulative statistics, it may well be conservative, overestimating the warm-up period (Gafarian et al, 1978; Pawlikowski, 1990; Roth, 1994; Wilson and Pritsker, 1978b).

Graphical methods are useful when user involvement in the estimation of the warm-up period is seen as advantageous. The heuristic methods have the advantage of providing specific rules for determining the warm-up period, making automation of the procedure possible. It would seem sensible to apply initialization bias tests to any decisions concerning the warm-up period, to determine whether the estimate is reasonable.

In Xiong,(1999), two parameter monthly water balance model, calculation of warm-up period was important find the initial soil water content. It was calculated based on the warm-up period and the value of S(0) is decided while providing that a year is regarded as a reasonable cycle period of some hydrological variables, for instance, the soil water content S, then S(0) should not be very different from the soil water content of the month having same rank within a year, such as S(12), S(24) and so on. Hence, it is reasonable to choose S(0) as the mean value of the soil water content S over all months having the same rank within a year.

3. METHODOLOGY

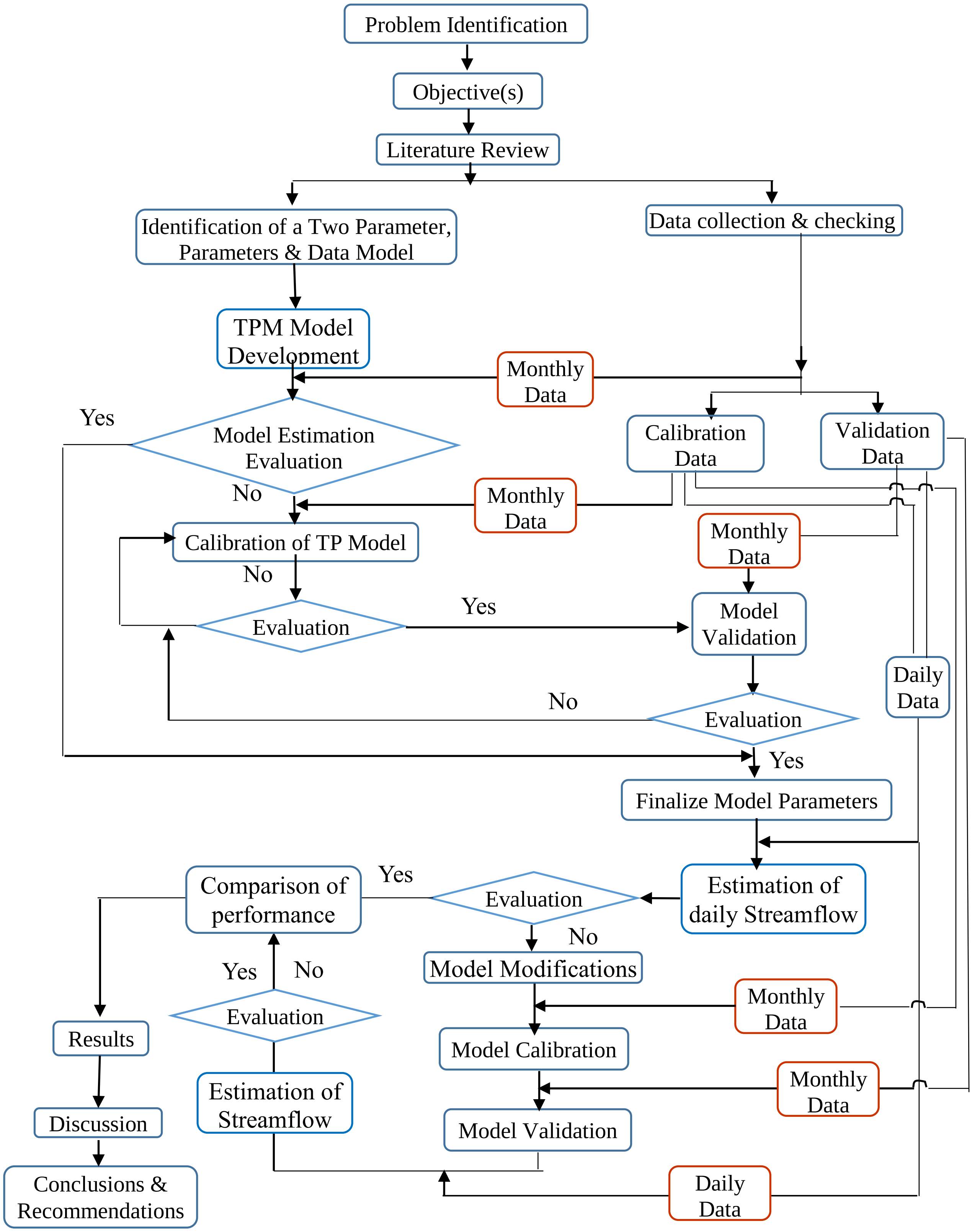

Figure 3-1: Methodology Flow chart

The methodology used in this research is shown in Figure 3-1. After identifying the objective and specific objectives, a literature survey was carried out to study the commonly used daily water balance models, their applications and other aspects such as, various objective functions. Two basins were selected. Rainfall, streamflow and evaporation data were collected for both basins. Data check was done under different steps. After determining two data sets for calibration and validation, a model was developed for the selected data set to identify a suitable objective function. After carrying out few trials for each low, intermediate, peak and overall flow conditions, best objective function was determined.

The initial soil water content which is an important factor for performance of the model, was calculated by running the model for a few years till initial soil water content become stabilized. Once initial soil water content was identified, objective function was developed for calibration. Eight years data from 2006 to 2014 were collected for Kaluganga and 2006 to 2010 data were selected as calibration period and balance set of data were selected as the validation period. Fifteen years data from 2000 to 2015 were collected for Ginganga and 2000 to 2008 data were taken for the calibration period and balance were used for validation period.

The Gin Ganga and Kalu Ganga watersheds had been previously modelled with the same model but with different spatial data of monthly resolution. Initially models were checked for performance with the previously calibrated parameters. Subsequently the monthly model was calibrated and verified. Verified monthly model was then used to evaluation the performance with daily data and make recommendations.

4. DATA AND DATA CHECKING

Daily data of rainfall, evaporation and streamflow from 2006 to 2014 for Ellagawa and from 2000 to 2015 for Thawalama sub basins were collected. Visual data checking was done for rainfall, streamflow and evaporation data to check for inconsistencies. Annual water balance was carried out for data from each gauging station. Double mass curve was used to check the consistency of data. Distribution of gauging stations were compared with WMO (1975) and it is in the Table 4-5.

4.1 Kaluganga Basin at Ellagawa

River gauging station of selected watershed is at Ellagawa. Four rain gauging stations namely, Ratnapura, Alupola, Pelmadulla and Nivithigala located within the study area and one station namely Halwathura located outside the downstream boundary were selected. Locations of river and rain gauging stations are shown in Figure 1-1. Data sources and resolutions are in Table 4-1. Land use details of the watershed area are in Table 4-2 and Figure 4-1.

Table 4-1: Details of Data for KaluGanga Basin at Ellagawa

<table>
<tr><th>Data Types</th><th>Spatial Reference</th><th>Resolution</th><th>Data Period</th><th>Source</th></tr>
<tr><td>Rainfall</td><td>Halwathura</td><td rowspan="5">Daily</td><td rowspan="5">2006 – 2014</td><td rowspan="5">Dept. of Meteorology</td></tr>
<tr><td></td><td>Rathnapura</td></tr>
<tr><td></td><td>Alupola</td></tr>
<tr><td></td><td>Pelmadulla</td></tr>
<tr><td></td><td>Nivithigala</td></tr>
<tr><td>Evaporation</td><td>Rathnapura</td><td>Daily</td><td>2006 – 2014</td><td>Dept. of Meteorology</td></tr>
<tr><td rowspan="2">Streamflow</td><td>Ellagawa</td><td>Daily</td><td>2006 - 2014</td><td>Dept. of Irrigation</td></tr>
<tr><td>Rathnapura</td><td>Daily</td><td>2006 - 2014</td><td>Dept. of Irrigation</td></tr>
<tr><td>Topo Map</td><td rowspan="2">Nuwaraeliya, Awissawella, Rakwana, Matugama, Balangoda, Ratnapura</td><td>1:50,000</td><td>Updated 2003</td><td>Dept. of Survey</td></tr>
<tr><td>Land Use</td><td>1:50,000</td><td>Updated 2006</td><td>Dept. of Survey</td></tr>
</table>

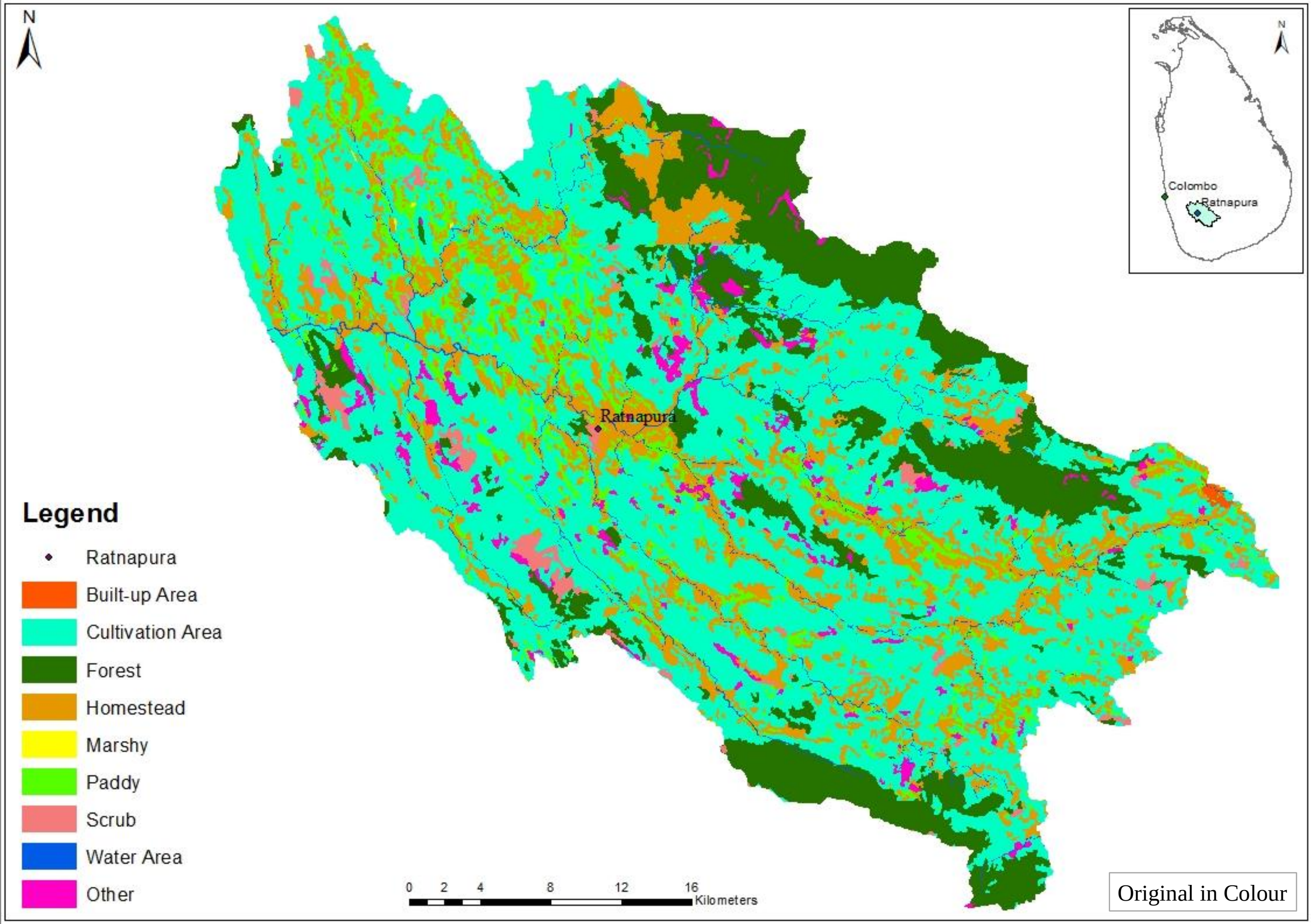

Figure 4-1: Landuse Map – Kalu Ganga Basin at Ellagawa

Table 4-2: Landuse data – KaluGanga Basin at Ellagawa

Landuse Type	Area (km2)	Percentage
Coconut	3	0%
Chena	276	20%
Forest	220	16%
Homestead	241	18%
Marshy	0	0%
Paddy	91	7%
Rubber	348	25%
Scrub	21	2%
Water	19	1%
Tea	119	9%
Other	34	2%
Total	1,372	100%

4.2 Ginganga Basin at Tawalama

River gauging station of study area is located at Tawalama. Out of four rain gauging stations namely, Tawalama, Neluwa and Aningkanda are located within the study area and Deniyaya is located outside the upstream boundary. Location of river and rain gauging stations are shown in Figure 1-2. Data sources and resolutions are given in Table 4-3. Landuse details of the study area are in Table 4 4 and Figure 4-2.

Table 4-3: Details of Data Gin Ganga basin at Tawalama

Data Types	Spatial Reference	Resolution	Data Period	Source
Rainfall	Tawalama	Daily	2000 – 2015	Dept. of Irrigation
	Neluwa			
	Deniyaya			
	Anningkanda			
Evaporation	Rathnapura	Daily	2000-2015	
Streamflow	Rathnapura	Daily	2000- 2015	Dept. of Irrigation
Topo Map	Ambalangoda, Morawaka, Rakwana, Matugama	1:50,000	Updated 2003	Dept. of Survey
Land Use		1:50,000	Updated 2006	Dept. of Survey

Table 4-4: Landuse data Gin Ganga Basin at Tawalama

Landuse Type	Area (km2)	Percentage
Cultivation	138	44%
Forest	86	27%
Homesteads	31	10%
Marshy	0	0%
Paddy	16	5%
Rock	2	1%
Scrub	35	11%
Water	4	1%
Other	4	1%
Total	317	100%

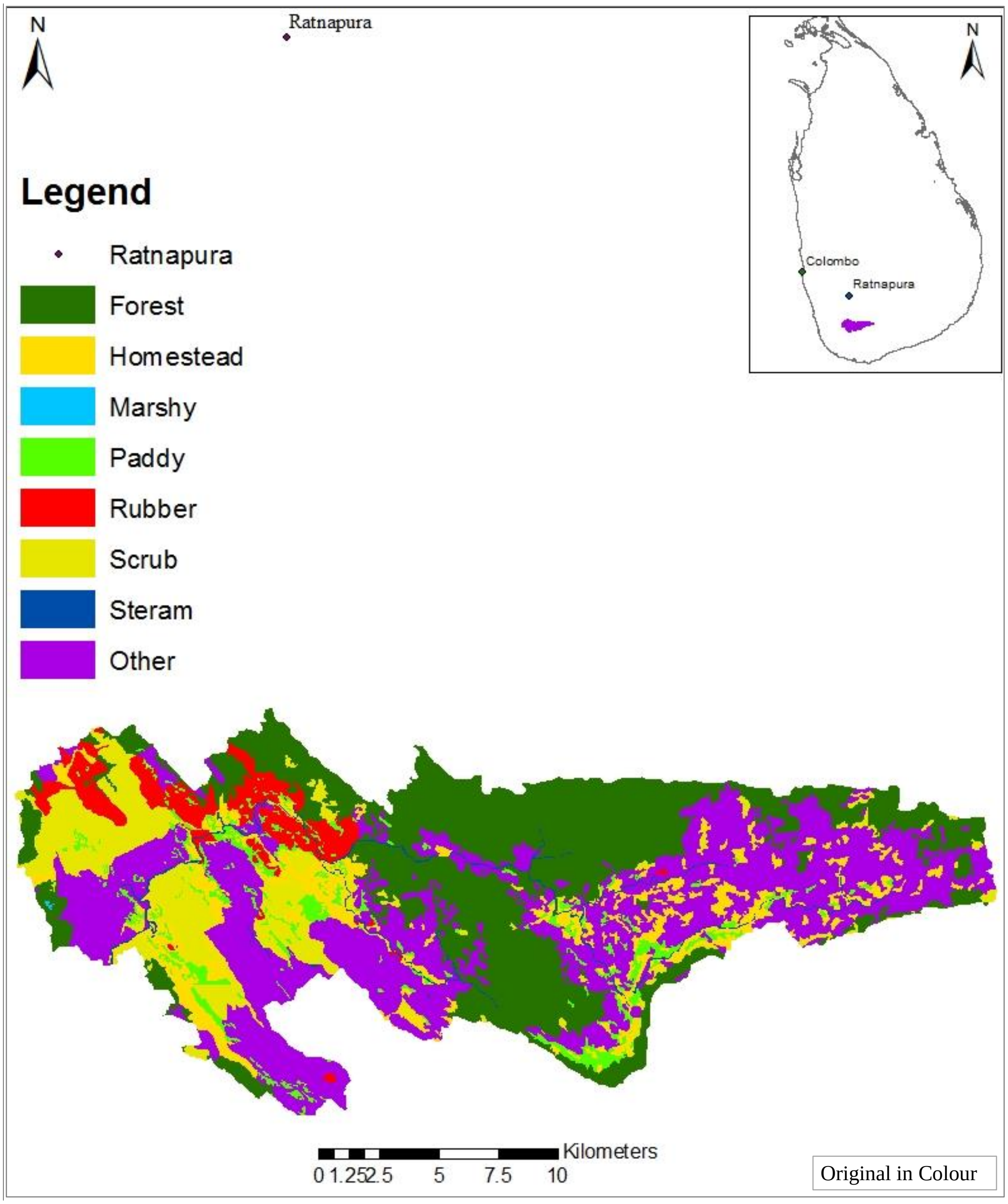

Figure 4-2: Landuse Map Gin Ganga Basin at Tawalama

Table 4-5: Comparison of Distribution of Gauging Stations of Tawalama and Ellagawa Watersheds

Gauging Station	**Number of Stations**		**Station Density (km^2/station)**		**WMO Standards (km^2/station)**
	Tawalama	Ellagawa	Tawalama	Ellagawa	
Rainfall	4	5	91	274.4	575
Streamflow	1	1	364	1372	1875
Evaporation	1	1	364	1372	

4.3 Thiessen Average Rainfall

4.3.1 Ellagawa Watershed

Theissen polygon method (Chow, 2010) was used to calculate the catchment average rainfall. Theissen polygons developed for the Ellagawa watershed is shown in Figure 4-3 and Theissen average weights for Ellagawa watershed is in Table 4-6.

Table 4-6: Thiessen Weights for Ellagawa Watershed

Rainfall Station	**Thissen Polygon Area (Km2)**	**Thiessen Weight**
Ratnapura	446	0.32
Alupola	212	0.15
Pelmadulla	322	0.23
Nivithigala	183	0.13
Halwathura	210	0.15

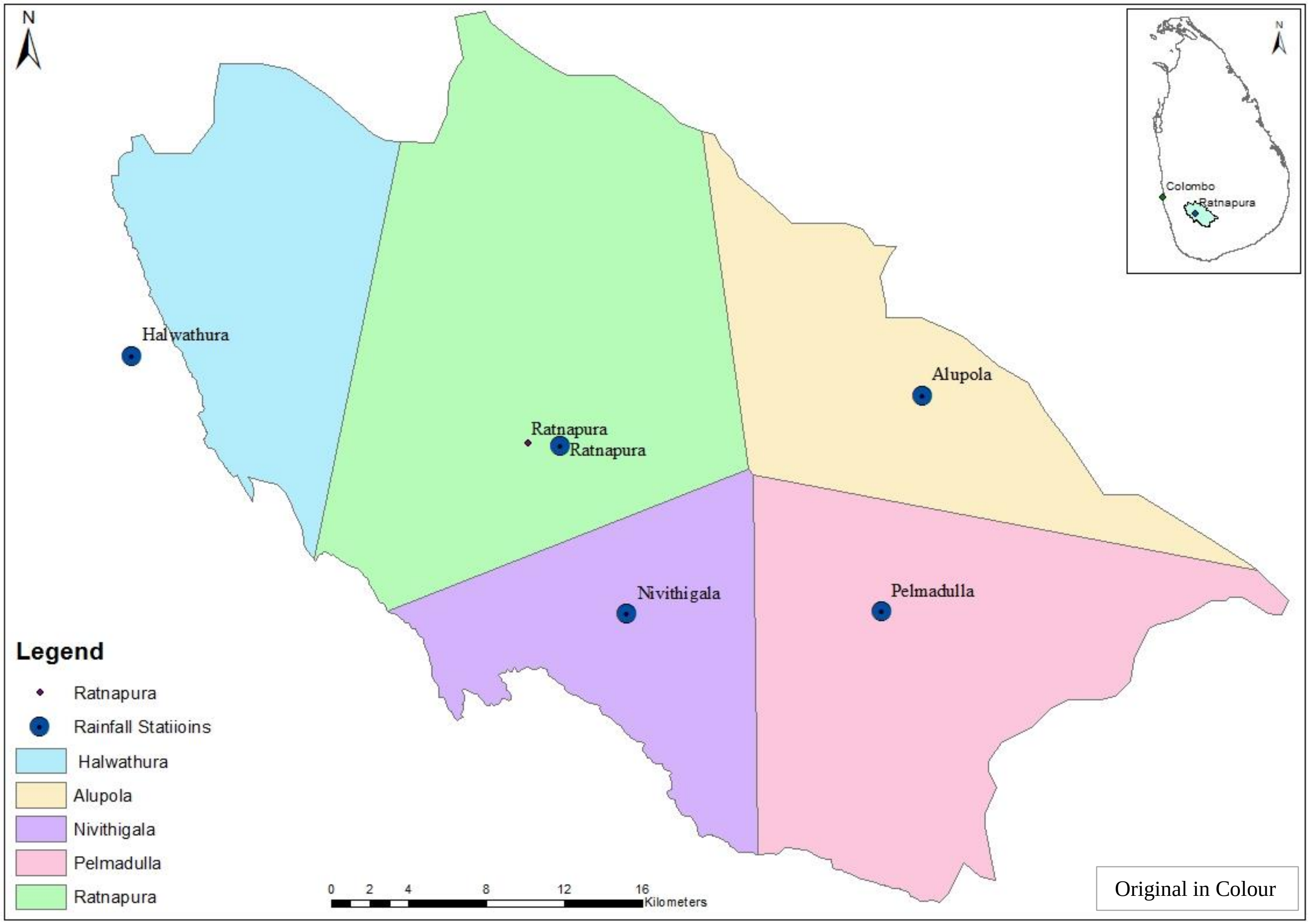

Figure 4-3: Thiessen Polygons – Ellagawa Watershed

4.3.2 Tawalama Watershed

Theissen polygons developed for the Tawalama watershed is shown in Figure 4-4 and Theissen average weights for Tawalama basin is in Table 4-7.

4.3.3 Annual Average Rainfall

Average monthly rainfall and average annual rainfall for Ellagawa and Tawalama watersheds are shown in Table 4-8 and Table 4-9 respectively.

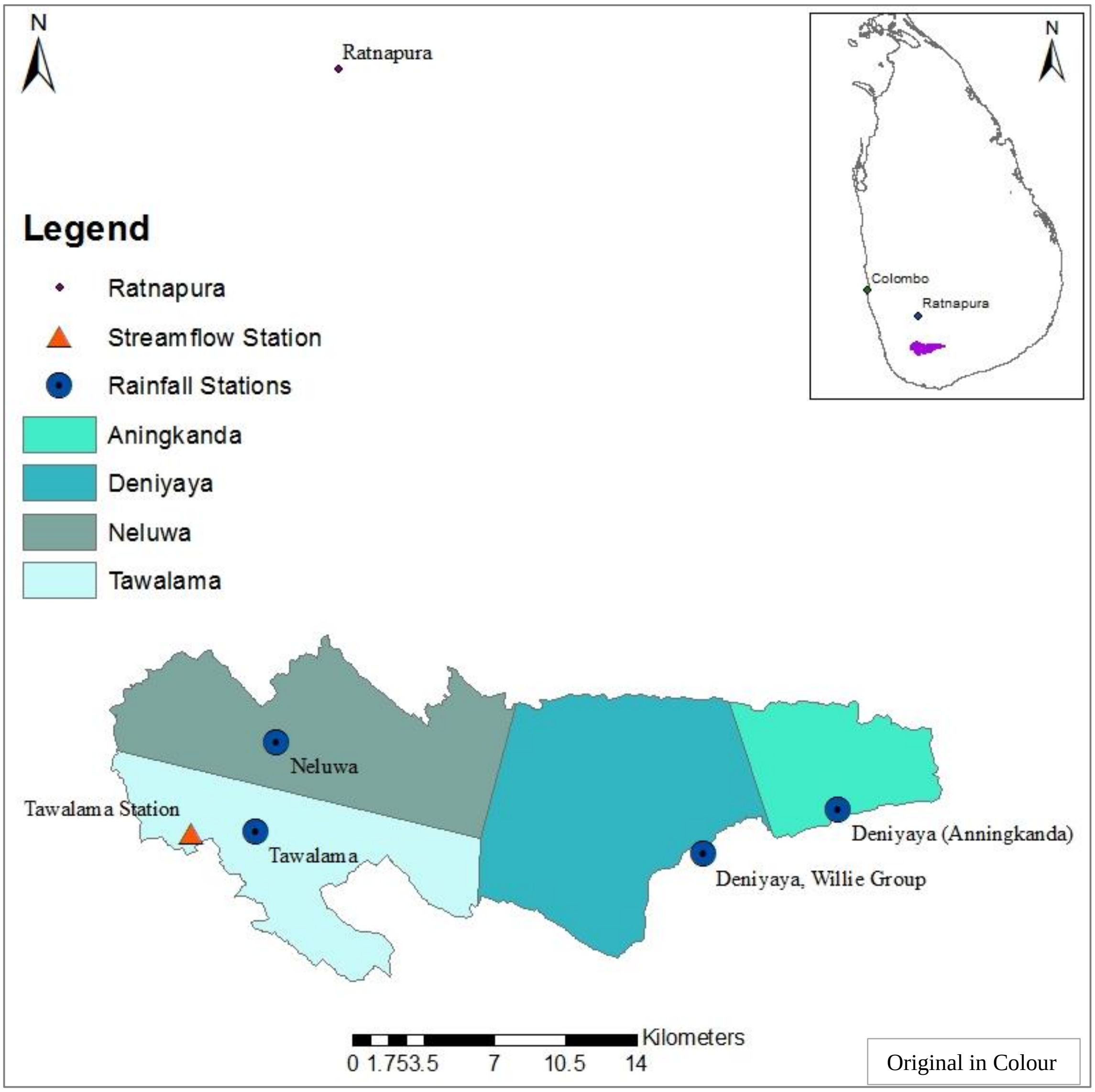

Figure 4-4: Thiessen Polygons – Tawalama Watershed

Table 4-7: Thiessen Weights for Tawalama Watershed

Rainfall Station	Thiesen Polygon Area (Km2)	Thiessen Weight
Aningkanda	49	0.13
Deniyaya	124	0.34
Tawalama	82	0.23
Neluwa	109	0.30

Table 4-8: Thiessen Average Rainfall - Ellagawa Watershed

Rainfall Station	Avg. Monthly RF (mm/Month)	Avg. Annual (mm/year)
Halwathura	317	3,807
Ratnapura	303	3,641
Alupola	358	4,295
Palmadulla	196	2,349
Nivithigala	151	1,816
Thissen Average	268	3,359

Table 4-9: Thiessen Average Rainfall - Tawalama Watershed

RF Station	Avg. Monthly RF (mm/Month)	Avg. Annual (mm/year)
Tawalama	359	4,311
Neluwa	312	3,749
Aningkanda	273	3,275
Deniiyaya	280	3,357
Thissen Average	309	3,713

4.4 Streamflow Data

4.4.1 Ellagawa Watershed

Average, minimum and maximum monthly streamflow is in Table 4 10 and variation is as in Figure B-1.

Table 4-10: Streamflow Data – Ellagawa Watershed

	Ellagawa	
	Monthly (mm/Month)	Annual (mm/Year)
Max	523	2,089
Mean	126	1,518
Min	21	754

4.4.2 Tawalama Watershed

Average, maximum and minimum streamflow is in Table 4-11 and variation is in Figure C-1.

Table 4-11: Streamflow Data – Tawalama Watershed

	Monthly (mm/Month)	Annual (mm/Year)
Max	839	3,976
Mean	228	2,733
Min	35	1,919

4.5 Evaporation Data

Ratnapura evaporation data was used for both Ellagawa and Tawalama basins. Daily evaporation data at Ratnapura station was collected and variation of maximum, mean and minimum evaporation is in Table 4-12 and variation shown in Figure B-1.

Table 4-12: Evaporation Data

	Tawalama		**Ellagawa**	
	Monthly (mm/Month)	Annual (mm/Year)	Monthly (mm/Month)	Annual (mm/Year)
Max	124	1,061	124	1,061
Mean	77	924	79	944
Min	44	769	49	869

4.6 Visual Data Checking

Visual checks were carried out to find whether there are inconsistences in the collected Daily data. Daily streamflow responses to daily rainfall were plotted for each rain gauging station data for each year.

4.7 Daily Data Comparison

4.7.1 Ellagawa Watershed

Streamflow responses at Ellagawa river gauging station for rainfall at each rain gauging station's data were visually checked and it is for year 2007/2008 is shown in Figure 4-5. While carefully observing this graphs, it could be observed that Ellagawa streamflow has not responded to the individual station rainfall at Ratnapura in December 2007 and March 2008 and these points are marked with purple colour circles. Though a very good stream flow response has occurred with the Alupola rainfall, there is no such response to Pelmadulla rainfall too in January 2008 and June 2008. Further, responsiveness with Nivithigala rainfall is also satisfactory except December 2007 and January 2008 whilst streamflow does not respond with Halwathura rainfall in January and May 2008. However, while observing the entire data series, data does not indicate major issues. Streamflow responses of Ellagawa in all other years are shown in Figure B-2 to Figure B -17.

Furthermore, response in streamflow with the Thiessen average rainfall were checked with Ellagawa streamflow. The streamflow response with Thiessen average rainfall for years 2006/2007, 2007/2005, 2008/2009 and 2009/2010 are shown in Figure 4-6. It was observed very low streamflow values while Thiessen average rainfall is having higher values during January 2007 and June 2007. Thiessen average rainfall data responded to the streamflow at Ellagawa very well in Year 2007/2008. Sufficient streamflow did not occur during March/2009 when compared with rainfall. During June/2010 and July/2010 it was observed same streamflow values for difference pulses of rainfall.

Thiessen average rainfall response with streamflow during year 2011 to 2014 is shown in Appendix A and where non responsive data is marked with a pink colour circles. Considering overall data checking for inconsistency and homogeneity it was taken that using Thiessen averaged rainfall would be reasonable for the present study.

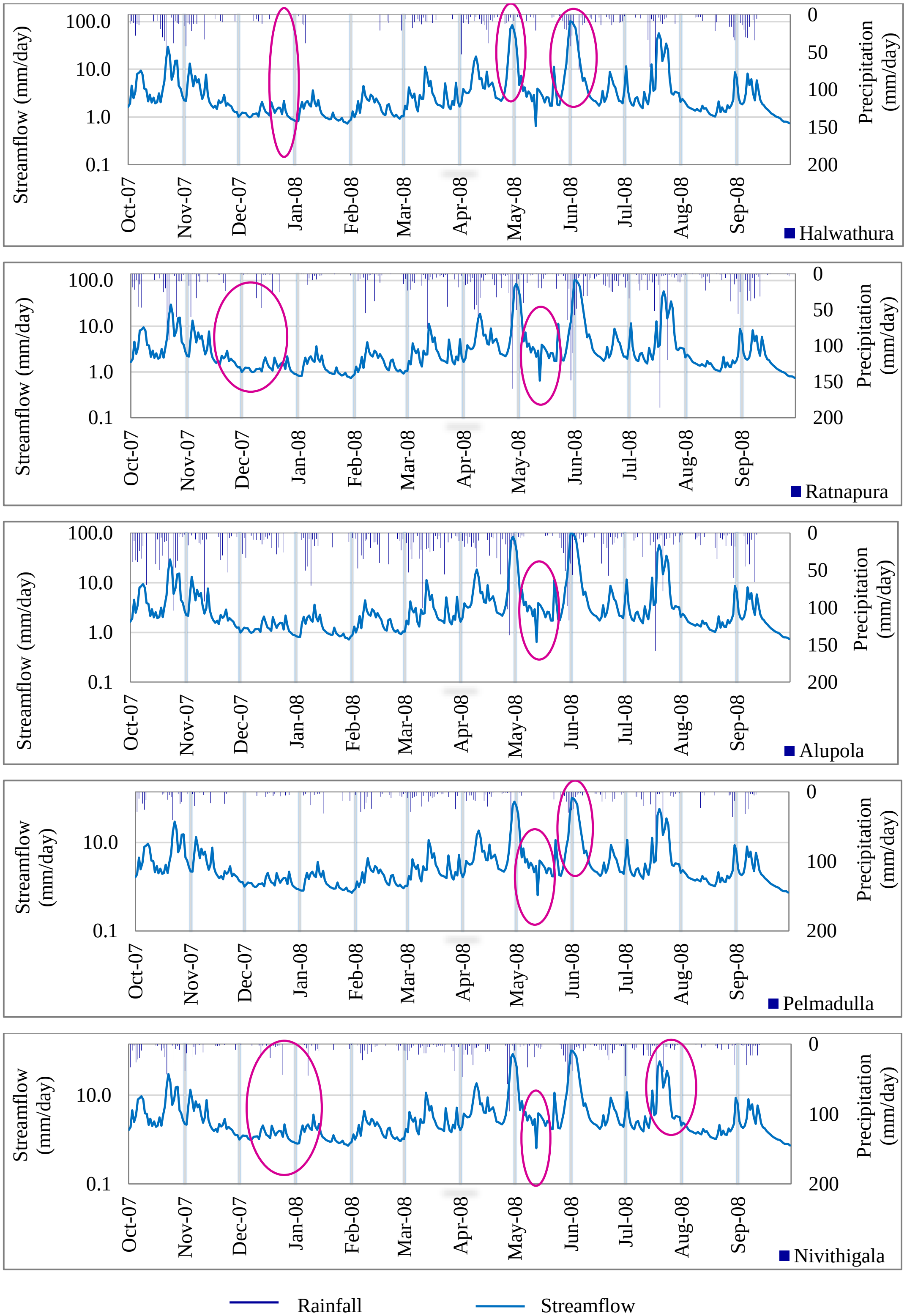

Figure 4-5: Ellagawa Streamflow response with each rainfall station data in 2007/2008

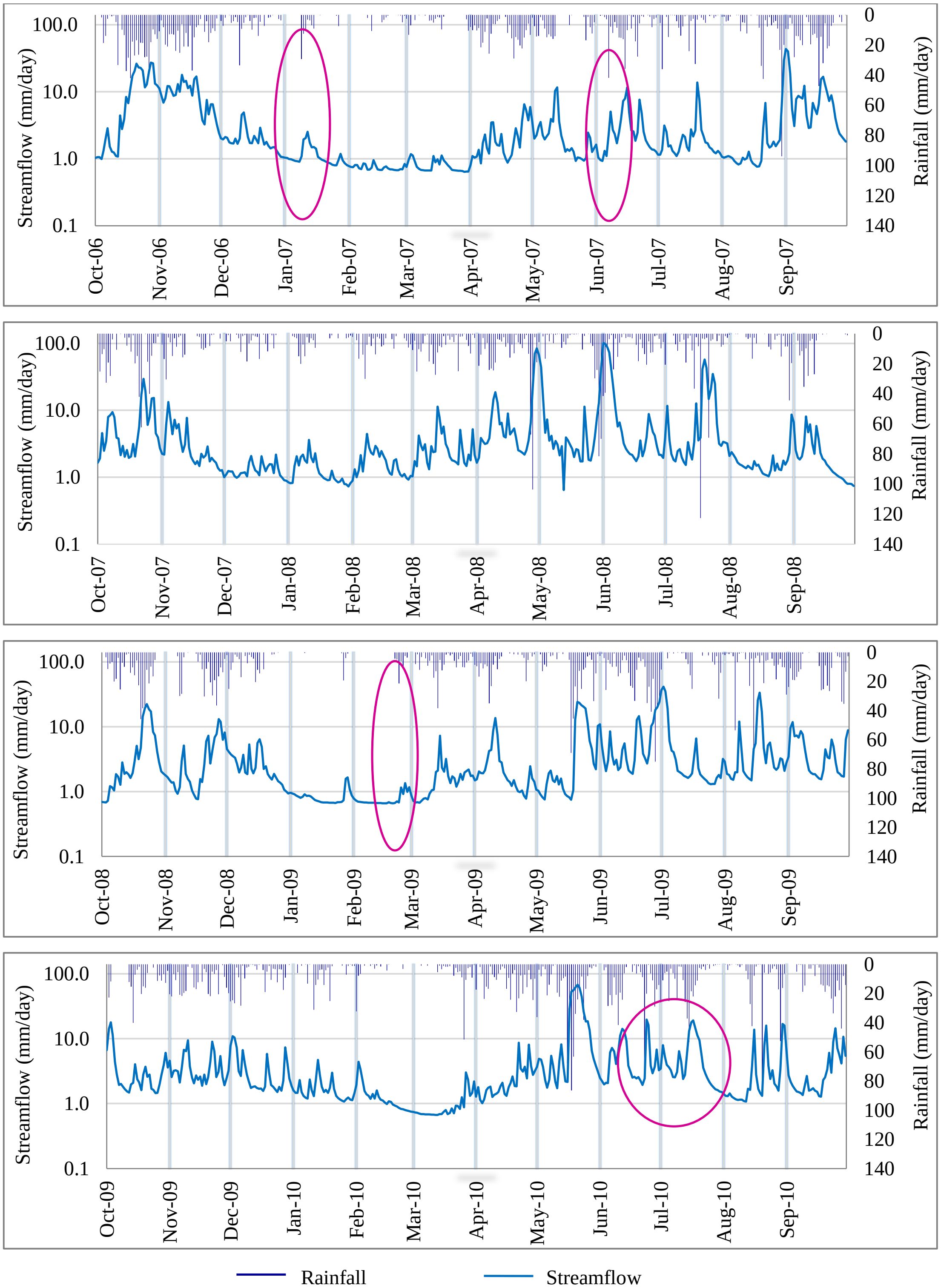

Figure 4-6 **:** Streamflow responses with Thiessen averaged rainfall – Ellagawa Watershed

4.7.2 Tawalama Watershed

Daily sreamflow responses to the daily rainfall was observed and for year 2012/2013 is shown in Figure 4-7. According to Figure 4-7 only few points were not good response with streamflow and these points are marked with pink colour circles. Though a very good streamflow response could generally be noted with Deniyaya rainfall, in January 2013, for a heavy rainfall, the streamflow response appears inadequately. Furthermore, responsiveness with Deniyaya rainfall is also satisfactory except April 2013 where streamflow does not respond with Deniyaya rainfall in April 2013. According to the Figure 1-2 Deniyaya station is located at outside the watershed boundary. From above observations, it could be noted that there are abnormalities in rainfall and streamflow in January, April, August and September months of 2012/2013 probably due to some spatial variations. But when it is compared with Ellagawa basin data Tawalama streamflow responses are better. Streamflow responses of Tawalama in all other years are shown in Figure C-2 to Figure C -18. According to the visual checking, Tawalama streamflow had responded well with the rainfall for all four stations in December 2014/2015.

The streamflow response with Thiessen average rainfall for years 2000/2001, 2001/2002, 2002/2003, 2003/2004 and 2004/2005 are shown in Figure 4-8. Thiessen average rainfall data responded to the streamflow at Tawalama very well in Years 2001/2002 and 2002/2003. Thiessen average rainfall response with streamflow during year 2005 to 2015 is shown in Figure C-17 to Figure C-18.

4.8 Monthly Data Comparison

4.8.1 Ellagawa Watershed

In order to investigate the mismatch of daily streamflow and daily rainfall, monthly comparison of streamflow and rainfall for the Ellagawa watershed were checked and are in Figure 4-9. Monthly comparisons did not show a significant mismatch. Monthly average, maximum and minimum rainfall variation were checked and are shown in Figure B-1.

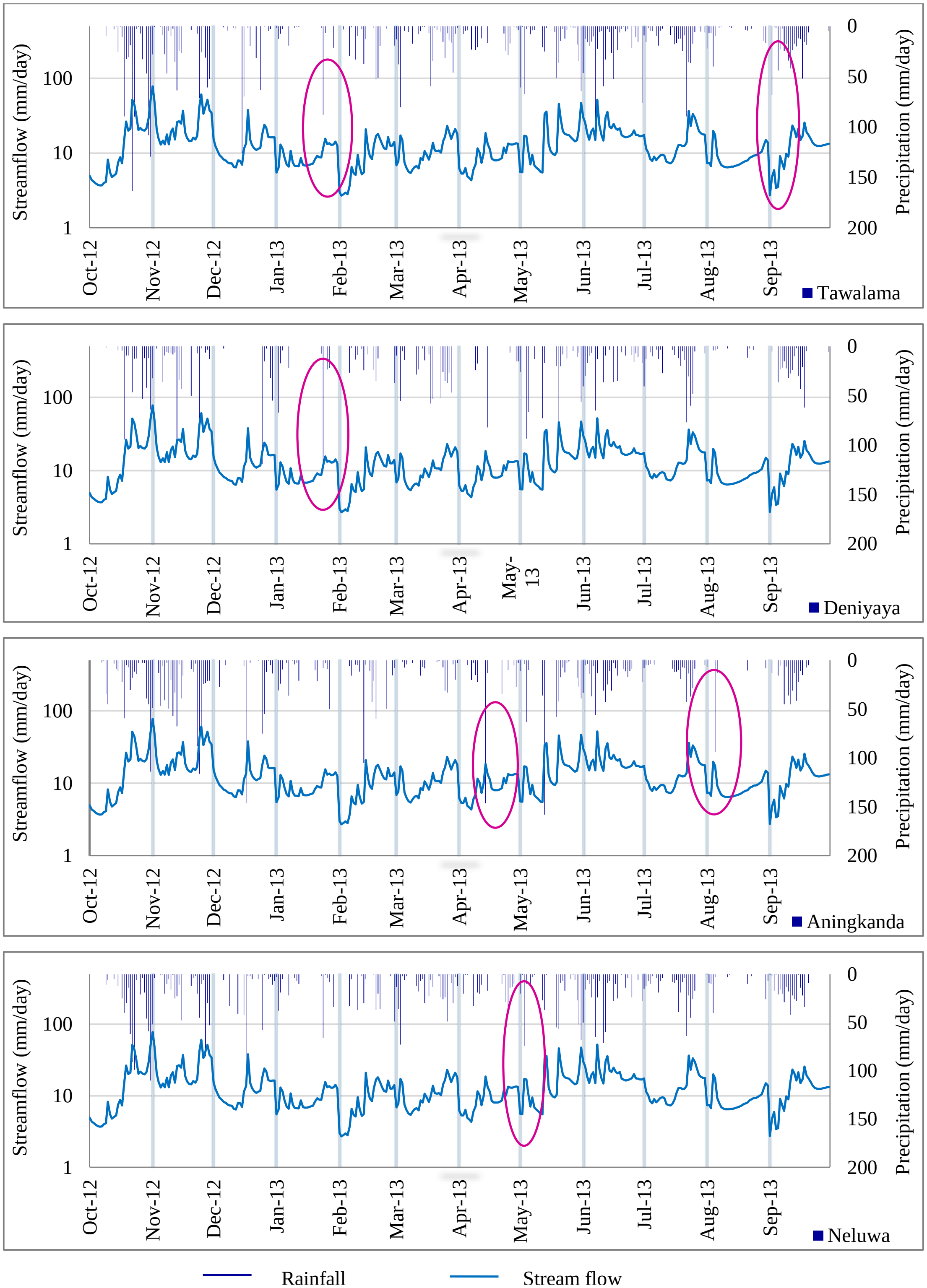

Figure 4-7: Streamflow response with each rainfall station data -Tawalama (2012/2013)

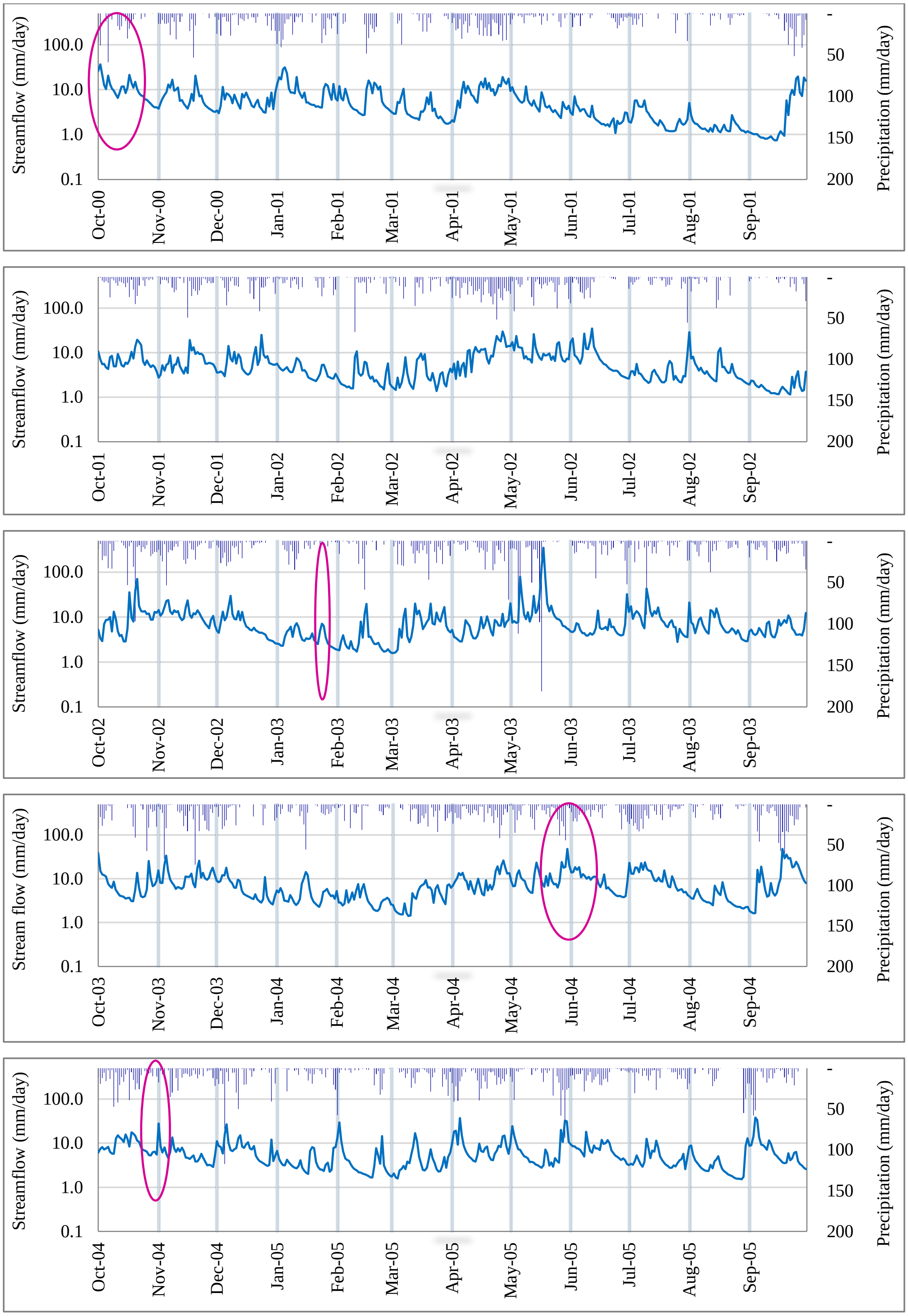

Figure 4-8: Streamflow responses with Thiessen average rainfall at Tawalama Year 2000~2005

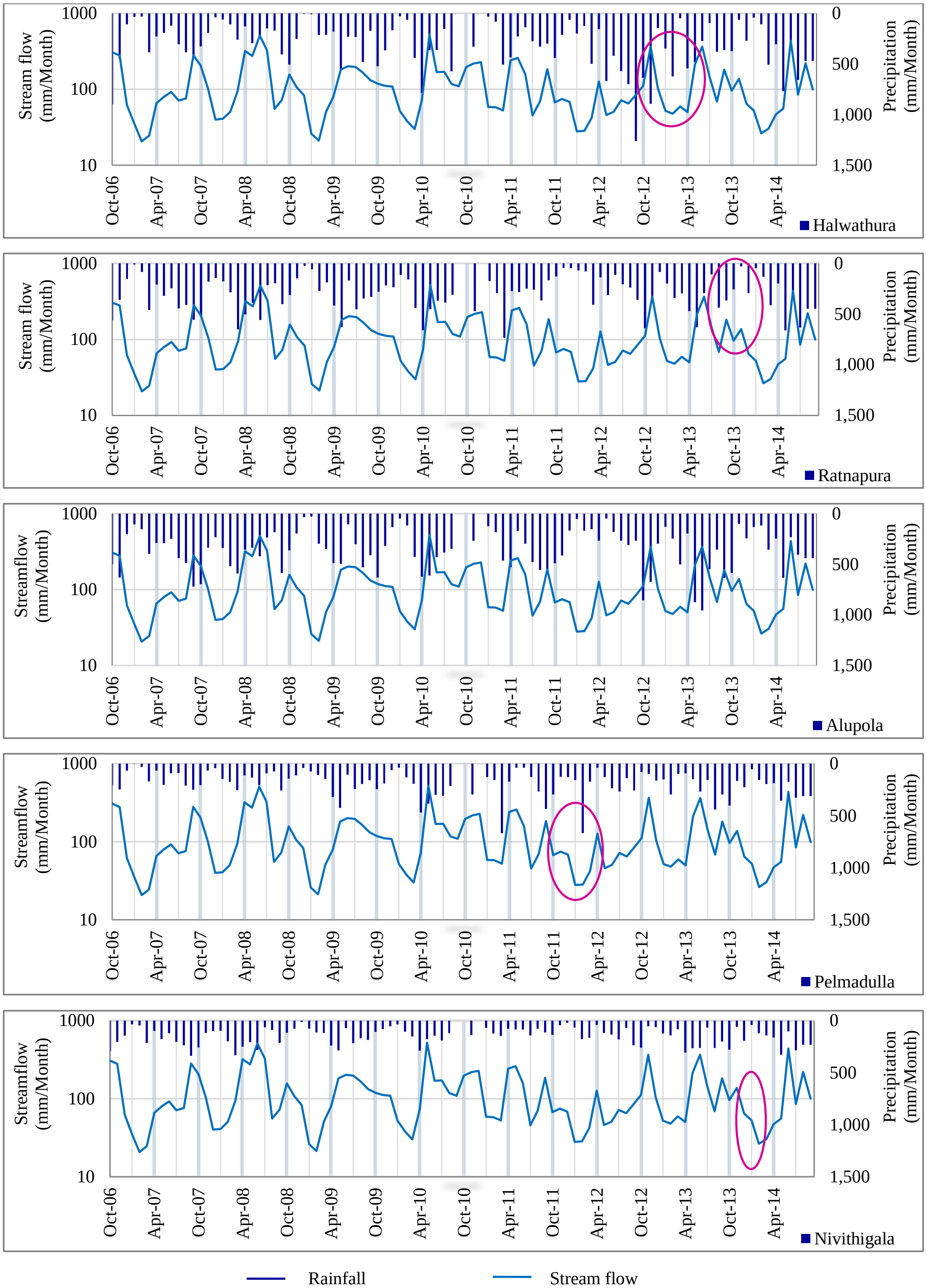

Figure 4-9: Ellagawa monthly streamflow response with each rainfall station monthly data

4.8.2 Tawalama Watershed

Due to those non-responsive points in daily streamflow responses, monthly rainfall responses were compared in each stations and are shown in Figure 4-10.

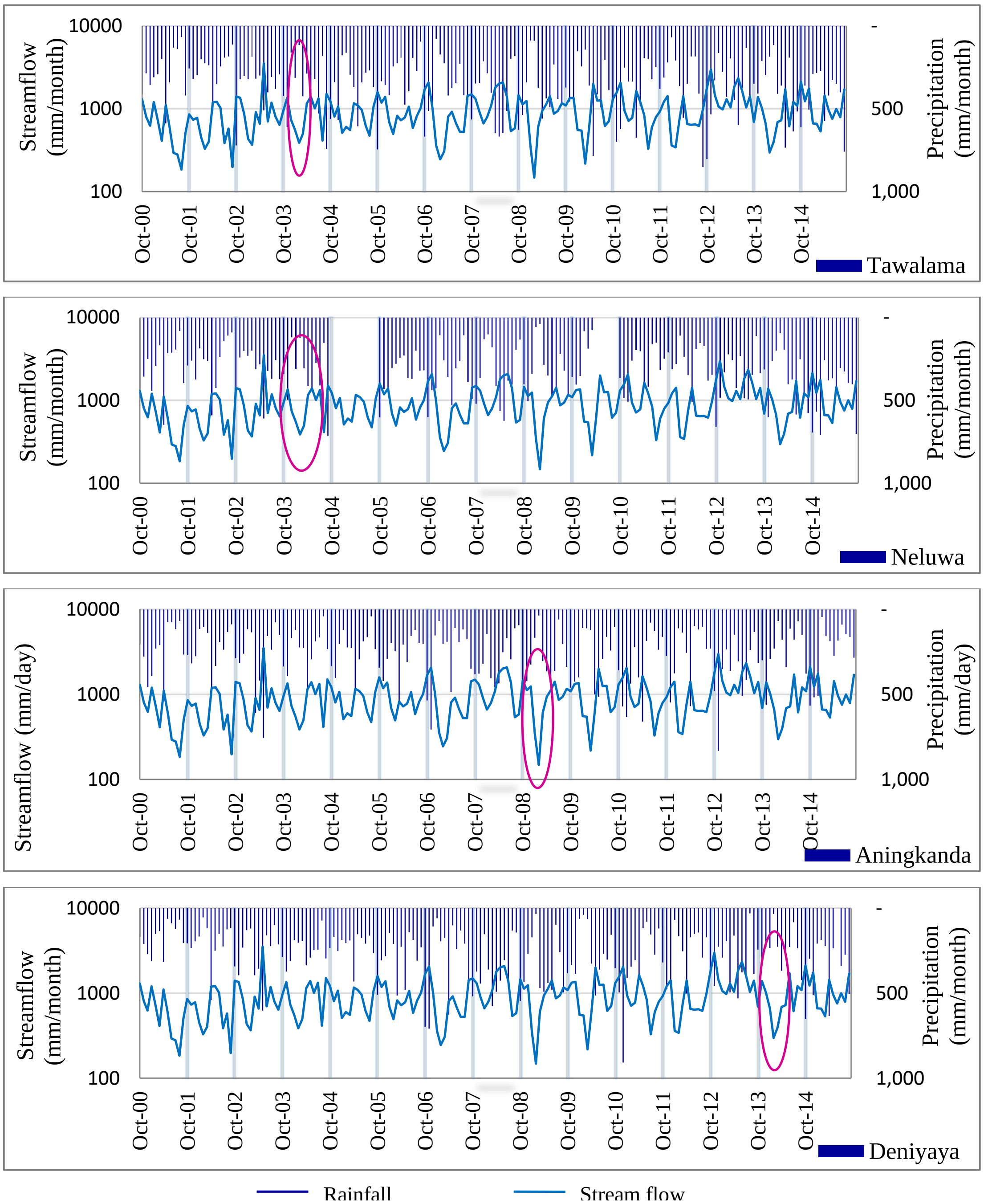

Figure 4-10: Tawalama monthly streamflow response with each rainfall station monthly data

4.9 Annual Data Comparison

4.9.1 Ellagawa Watershed

However further verification was done by comparing annual rainfall patterns and results for Alupola rainfall station is shown in Figure 4-11 and for other stations in Figure B -19.

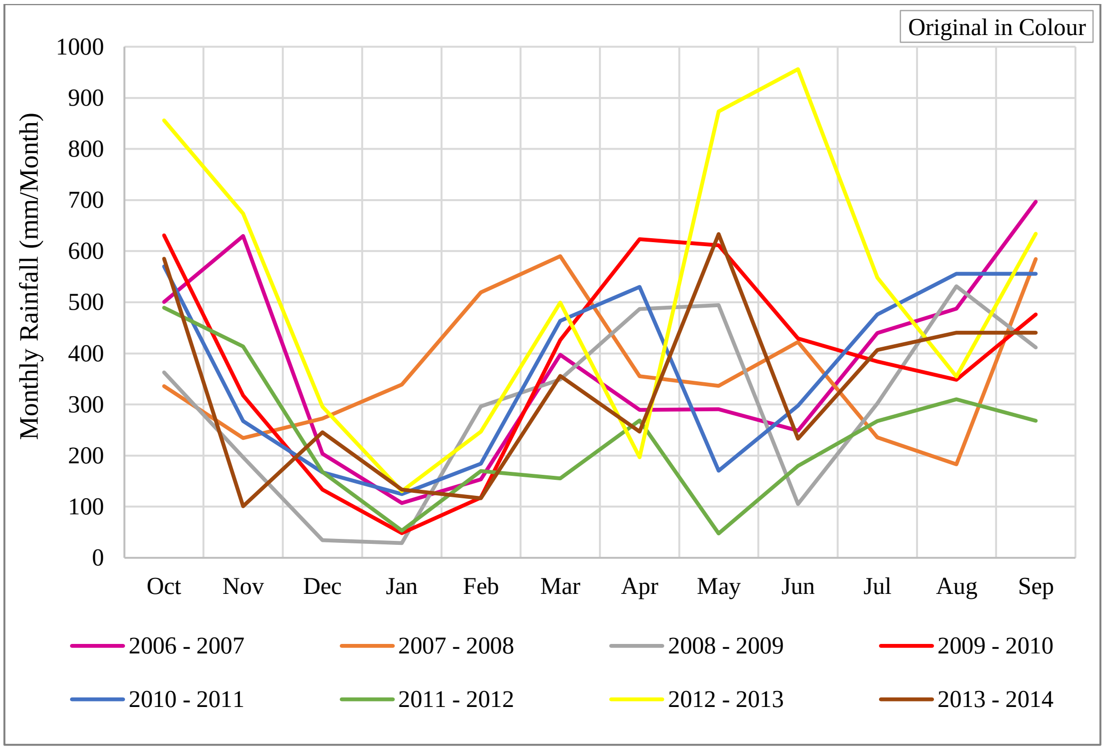

Figure 4-11: Annual Rainfall Pattern –Alupola

As above, in general similar rainfall pattern can be observed in the considered period except for years 2012/2013, 2013/2014 and 2007/2008. A significant deviation could be noted in the rainfall pattern during November to March and June to September of 2007/2008. During April to July in 2013, a different pattern was observed as heavy rains experienced during the period. Monthly rainfall pattern comparison for other stations are shown in Appendix A.

4.9.2 Tawalama Watershed

Tawalama monthly data did not show a significant mismatch. For further clarification, annual rainfall pattern was compared. Monthly rainfall patterns for Tawalama Station data is shown in Figure 4-12 and other annual patterns are in Figure C 36

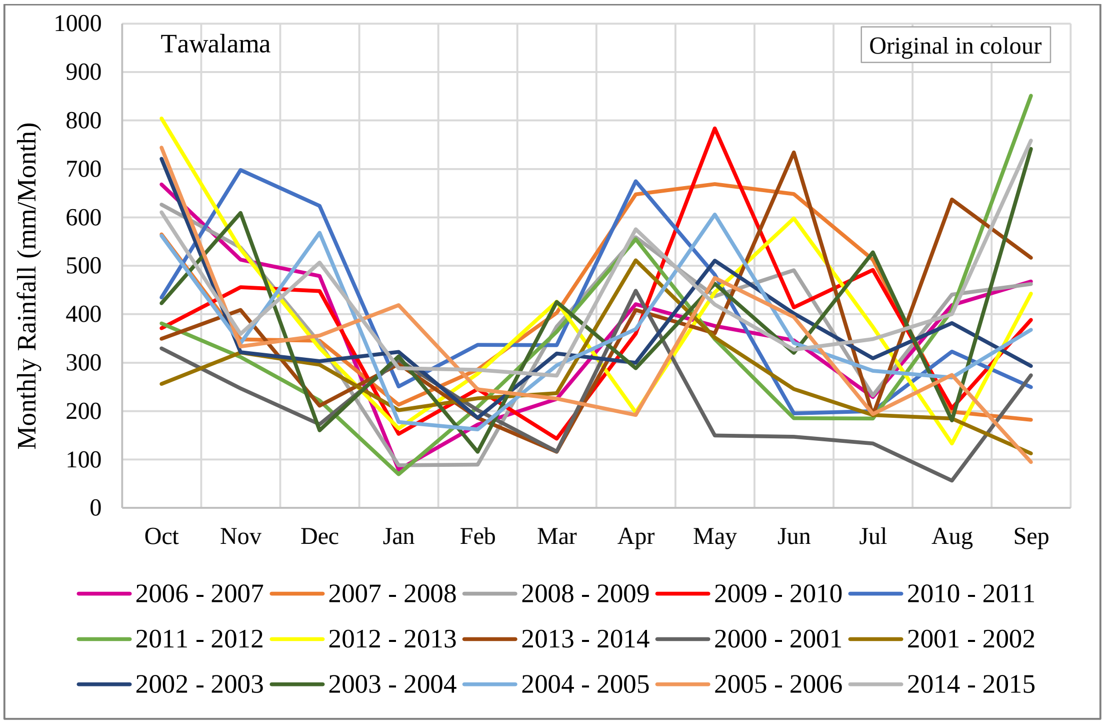

Figure 4-12: Annual Rainfall Pattern - Tawalama

As observed, streamflow showed almost equal pattern from October to April while only few points demonstrated a different behavior. The streamflow pattern had changed in month of November in year 2012/2013 and 2006/2007, showing a significant variation in the pattern from April to September. The pattern from April to September in year 2014/2015 showed a significant difference. Also except year 2007/2008, 2009/2010, 2013/2014 and 2014/2015 all other years showed a similar pattern from April to September.

4.10 Annual Water Balance

Annual water balance were done to observe the watershed behavior over the study period.

4.10.1 Ellagawa Watershed

Annual water balance was calculated with Thiessen averaged rainfall and streamflow data at Ellagawa gauging station. Annual water balance of Ellagawa sub basin with Ellagawa streamflow data is shown in Table 4-13 and Figure 4-13.

Table 4-13: Annual Water Balance – Ellagawa Watershed

Water Year	Thiessen Average Annual Rainfall (mm/year)	Annual Streamflow (mm/year)	Annual Pan Evaporation (mm/year)	Annual Water Balance (mm/year)	Runoff Coefficient
2006 / 2007	2,954	1,394	952	1,560	0.47
2007 /2008	2,853	2,089	924	764	0.73
2008 / 2009	3,033	1,403	1061	1,630	0.46
2009/ 20010	3,570	1,621	944	1,948	0.45
2010 / 2011	3,304	1,770	869	1,534	0.54
2011 / 2012	3,002	748	994	2,253	0.25
2012 / 2013	4,523	1,761	870	2,762	0.39
2013 / 2014	3,630	1,352	899	2,278	0.37

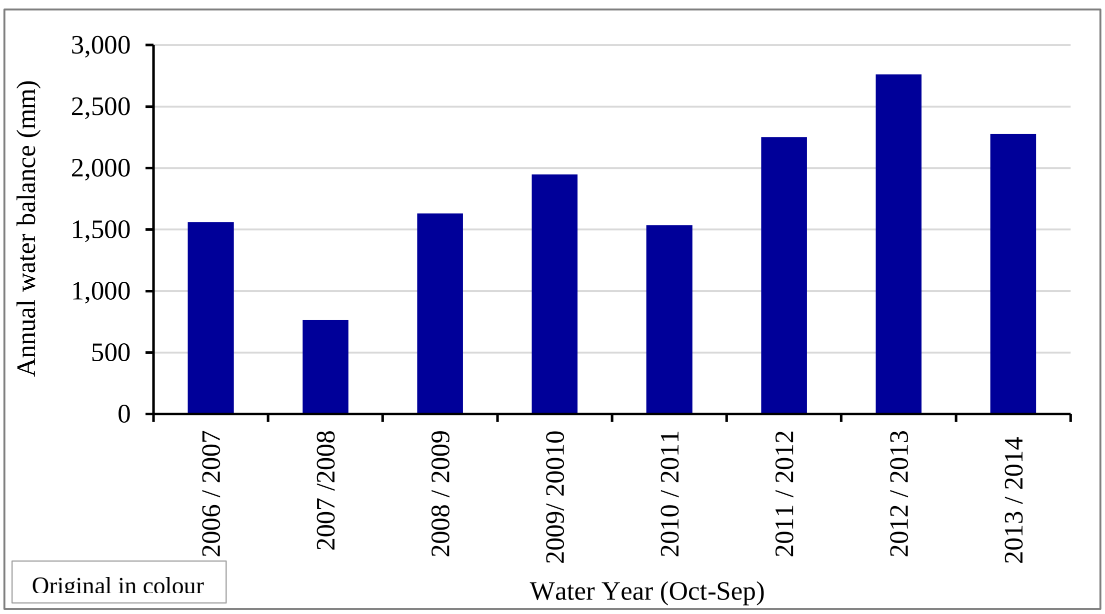

Figure 4-13: Annual water balance Kalu Ganga Basin at Ellagawa

During the review of annual water balance data, it was observed minimum rainfall (2853 mm) during selected period had been in 2007/2008 water year. In visual observations also 2007/2008 period was observed with some abnormalities. The maximum streamflow (2089 mm) was also received in the same water year according to the Ellagawa gauging station data. Moreover highest runoff coefficient was also pertaining to the same year. Maximum rainfall was observed in 2012/2013 water year with a runoff coefficient of 0.4. Lowest runoff coefficient of 0.2 was reported during 2011/2012 water year. Average runoff coefficient for the watershed over the data period was 0.46. The average runoff coefficient value for Kaluganga basin at Ellagawa is similar to the value of 0.49 reported by Perera and Wijesekera (2010). However, annual water balance is not showing systematic order. This annual water balance was compared with pan evaporation shown in the Figure 4-14.

According to Figure 4-14 annual pan evaporation and annual water balance is not having an acceptable linear relationship.

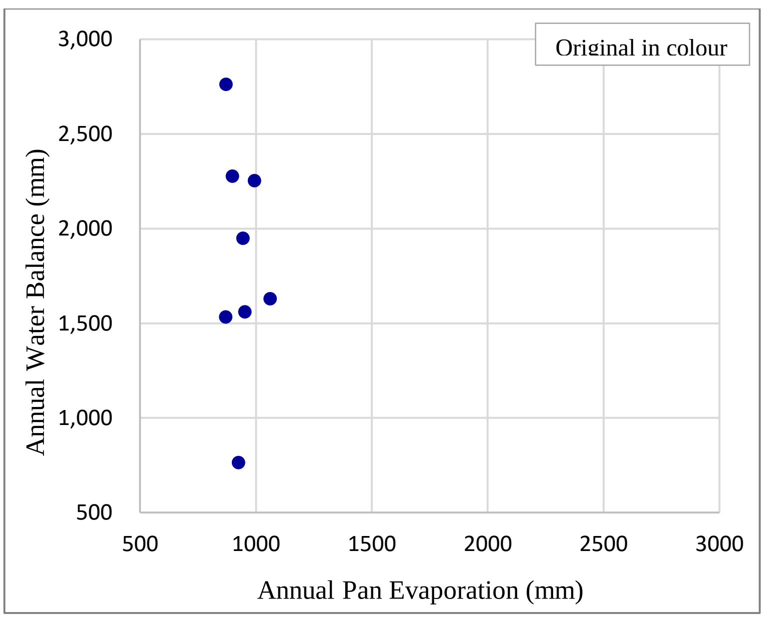

Figure 4-14: Pan Evaporation vs Annual water balance– Ellagawa Watershed

4.10.2 Tawalama Watershed

Annual water balance for the Tawalama basin was calculated with Thiessen averaged rainfall and steramflow. Annual water balance of Tawalama Basin with Tawalama streamflow data is shown in Table 4-14 and Figure 4-15.

Table 4-14: Annual Water Balance – Tawalama Basin

Water Year	Annual Rainfall (mm/year)	Annual Streamflow (mm/year)	Annual Pan Evaporation (mm/year)	Annual WB (mm)	Runoff Coefficient
2000 - 2001	3,006	1,669	769	1,337	0.80
2001 - 2002	2,842	1,682	953	1,161	0.78
2002 - 2003	3,794	2,656	921	1,138	0.93
2003 - 2004	3,719	2,325	913	1,394	0.83
2004 - 2005	3,565	2,094	924	1,471	0.92
2005 - 2006	3,763	2,304	921	1,459	0.81
2006 - 2007	3,924	2,185	994	1,739	0.73
2007 - 2008	4,339	3,032	924	1,307	0.92
2008 - 2009	4,167	2,353	1,061	1,814	0.75
2009 - 2010	3,807	2,386	944	1,421	1.01
2010 - 2011	4,149	2,638	869	1,510	0.84
2011 - 2012	3,437	2,061	994	1,376	0.80
2012 - 2013	4,684	3,890	870	793	1.19
2013 - 2014	3,666	2,171	899	1,496	0.78
2014 - 2015	4,639	2,814	898	1,825	0.80

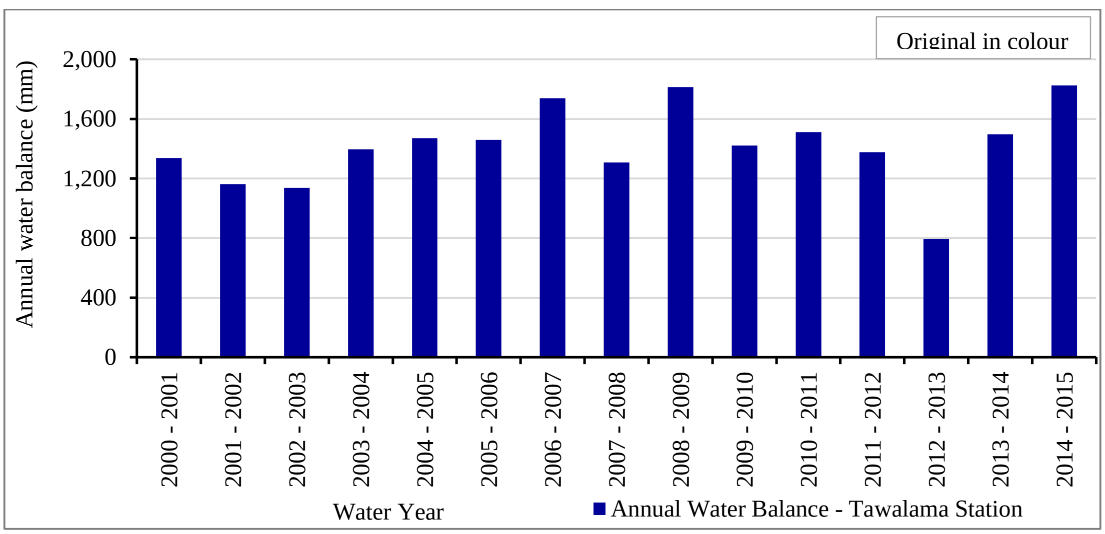

Figure 4-15: Annual water balance at Tawalama– Gin Ganga Basin

Minimum annual rainfall (2756 mm) during the selected period was in 2000/2001 water year. The minimum streamflow (2208 mm) too received in the same water year according to the Tawalama gauging station data. During years 2009/2010 and 2012/2013 annual streamflow is greater than the annual rainfall and highest runoff coefficients were also pertaining to the same years. Maximum rainfall was observed in year 2014/2015 while maximum streamflow occurred during year 2012/2013. However, lowest runoff coefficient i.e. 0.73 was reported during 2006/2007 water year. Accordingly average runoff coefficient for the sub watershed was 0.86. Annual water balance was compared with pan evaporation and it is as in Figure 4-16. According to Figure 4-16 pan evaporation and annual water balance do not show a consistent behaviour. But, some of years are deviating very highly.

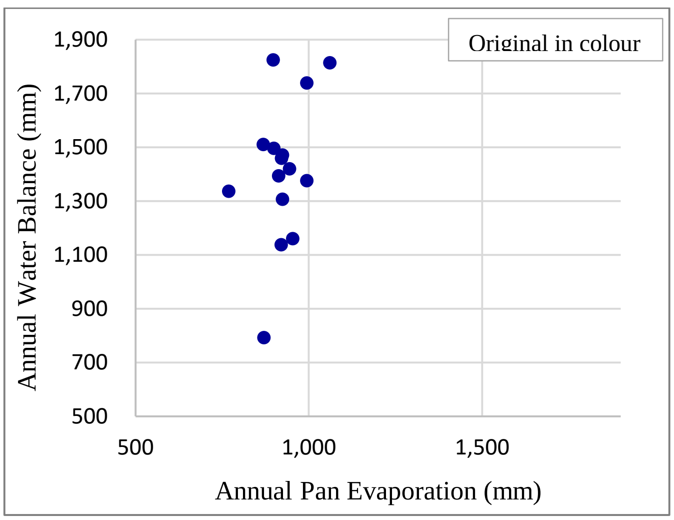

Figure 4-16: Annual Water Balance vs Pan Evaporation – Tawalama Watershed

4.11 Double Mass Curve

Double mass curve was used to check the consistency of the hydrologic data.

4.11.1 Ellagawa Watershed

Double mass curves are shown in Figure B -20. A significant inconsistency could be observed in rainfall data.

4.11.2 Tawalama Watershed

Double mass curves are shown in Figure C-37. A significant inconsistency could not be observed in rainfall data.

4.12 Identification of Missing Data

Three missing rainfall data were found in Ellagawa watershed corresponding to 31st January 2008 and 3rd December 2013 at Alupola and 3rd December 2013 at Nivithigala. It is only 1% from the overall data series. In the Tawalama watershed it was there were found only 2.8% of missing data. The proportion of missing data is directly related to the quality of statistical inferences and there is no established cutoff from the literature regarding an acceptable percentage of missing data in a dataset for valid statistical inferences (Dong.Y., & Peng. C.Y.J., 2013). However, Bennett,(2001); (Dong.Y., & Peng. C.Y.J., (2013) maintained that statistical analysis is likely to be biased when more than 10% of data are missing. Since, percentage of missing data for the two watersheds are below 10% they were assumed acceptable. During missing data periods, Theissen average rainfall was calculated by calculating weights with the relevant stations only.

4.13 Outlier check

Outliers was checked to identify whether there are adnormal maximum or minimum data are in the data sample. Six outliers were identified at Ellagawa watershed and two outliers at Tawalama watershed according to the regression method. However data series was not changed and outliers were not replaced.

5. ANALYSIS AND RESULTS

5.1 Introduction

The two parameter model proposed by Xiong (1999) is a simple rainfall runoff model capable of providing estimates of steramflow and soil moisture. This model has already been developed for Kalu Ganga at Ellagawa and Gin Ganga at Tawalama (Sharifi.M.B.,2016,unpubl and Khandu.D.,2016,unpubl). The Xiong & Guo, (1999) model has been used with monthly data to estimate monthly outputs. In this study the main objective is to evaluate the capability of the same model to estimate daily streamflow with daily inputs. Since daily data for the periods used in Sharifi.M.B.,(2016,unpubl) and Khandu.D.,(2016 unpubl) were not available this research used a recent alternate data set.

Therefore in the analysis, the first step was to evaluate the founder models (Sharifi.M.B.,2016,unpubl and Khandu.D.,2016,unpubl) with alternate datasets. The step 2 was to calibrate the 2PM with monthly inputs for alternate dataset used in the present work.

5.2 Model Development

A two parameter model was developed using concepts of (Xiong, 1999). This two parameter monthly model uses three fundamental equations.

$$E(t)/\ EP(t) = C \times \text{Tanh}\ [P(t)/\ EP(t)] \quad (9)$$

$$Q(t) = S(t-1) + \text{Tanh}\{(S(t-1)+P(t)-E(t)/Sc)\} \quad (10)$$

$$S(t) = S(t-1)+P(t)-E(t)-Q(t) \quad (11)$$

Where, E(t) – Evaporation Estimation of Model

EP(t) – Pan evaporation

P(t) – Rainfall

C – Monthly evaporation coefficient

$Q(t)$ – Runoff discharge

$S(t-1)$ – Soil water content at the end of (t-1) month

$S(t)$ - Soil water content at the end of (t) month

In order to identify realistic values as model outputs, following conditions were imposed on the computations.

Condition 1; $E(t)$ at any given time must be greater than or equal to zero.

Hence, $E(t) \geq 0$ (12)

Condition 2; Actual evapotranspiration at any time t is less than or equal to potential evaporation at that particular time.

Hence,

$E(t) \leq EP(t)$ (13)

Condition 3; Streamflow estimation by the model at any time t is greater than and equal to zero.

Hence,

$Q(t) \leq 0$ (14)

Condition 4;

Watershed moisture storage at any given time t is non negative.

$St \geq 0$ (15)

5.3 Evaluation of Objective Function

Based on the literature review, the three main objective functions selected were; Nash-Sutcliffe, MRAE and RAEM. Muthumala.P.,2016,(unpubl) evaluated the same and stated that MRAE would respond well as the objective function when compared with-Nash Sutcliffe and RAEM.

Therefore, model computations used MRAE as the main objective function while observing the behavior of Nash Sutcliffe for the suitability of high flow matching.

5.4 Identification of High, Medium and Low flows

To identify the high, medium and low flows, flow duration curves in Monthly and Daily scales were prepared for Tawalama and Ellagawa watersheds. Flow duration curves of daily and monthly scales for both watersheds are shown in (Figure D-1- Figure D-8). The values of percentage exceedance used in Ellagawa and Tawalama watersheds in monthly and daily scale are shown in Table 5-4.

Table 5-1**:** Medium and Low flow limits with Monthly and Daily Data

	Percentage of Exceedance			
	Ellagawa (2006 – 2014)		Tawalama (2000 – 2015)	
	Monthly	Daily	Monthly	Monthly
High	<30	<15	<30	<15
Medium	>30 & <80	>15 & <75	>30 & <70	>15 & <85
Low	<80	<75	<70	<85

In daily time series, most data are within the medium flow in both Ellagawa and Tawalama watershed.

Values of percentage exceedance in monthly scale used in Ellagawa and Tawalama watersheds by Kandu.D.,2016, (unpubl) and Sharifi. M. B.,2016, (unpubl) are shown in Table 5-2. The Low flow distribution values are different when compared with founder data series and alternate data of present study in both Ellagawa and Tawalama watersheds. This may be due to the length of each dataset.

Table 5-2**:** Medium and Low Flow Limits of Founder data periods with Monthly Data

	Percentage of Exceedance			
	Ellagawa		**Tawalama**	
	Founder (1972 – 2012)	Alternate (2000 – 2015)	Founder (1983 – 2012)	Alternate (2006 – 2014)
High	<30	<30	<30	<30
Medium	>30 & <63	>30 & <80	>30 & <65	>30 & <70
Low	<63	<80	<65	<70

5.5 Two Parameter Founder Model (Monthly Input) – Comparison with Alternate Data

Initially Xiong & Guo (1999) developed the two-parameter monthly water balance model, in which the two parameters are monthly evaporation coefficient ‘c’ and the field capacity of the catchment ‘SC’. It has been applied to Kaluganga and Ginganga basins in Sri Lanka and the results had demonstrated good performance. In these applications, the calibration and verification data and outputs are as shown in Table 5-3.

Table 5-3: Comparison of Parameters and Estimation Errors – Watersheds at Tawalama & Ellagawa

Watershed		**Tawalama (Kandu.D.,2016,unpubl)**		**Ellagawa (Sharifi.M.B.,2016,unpubl)**	
Founder Data Sets of Model		Calibration (1972 to 1992)	Validation (1992 to 2012)	Calibration (1983 to 1998)	Validation (1992 to 2012)
Parameter	c	0.89	0.89	1	1
	SC	1,292	1,292	800	800
Objective Function Values	MRAE	0.09	0.116	0.1446	0.226
	NASH	0.9445	0.876	0.9355	0.809

Comparison of data and data durations with the previous work (Founder Data) showed that though model and catchment area the same, the data selected for present work (Alternate Data) differed both spatially and temporally (Table 5-4 and Table 5-5). The Founder model parameters were used with the present data to compare differences with the performance of model with founder data. The model outputs are shown in Table 5 6.

Table 5-4: Temporal & Spatial Comparison with Founder and Alternate model data - Tawalama watershed

Description		**Temporal & Spatial Data (Founder Data)**	**Temporal & Spatial Data (Alternate Data)**	**Same /Different**
Number of RF Stations		5	5	Same
RF Station		Rathnapura	Ratnapura	Same
		Keragala	Alupola	Different
		Galathura Estate	Pelmadulla	Different
		Balangoda Post Office	Nivithigala	Different
		Wellandura Estate	Halwathura	Different
Evaporation Station		Rathnapura	Rathnapura	Same
Steramflow Station		Ellagawa	Ellagawa	Same
Data Period	Calibration	1983 to 1998	2006-2010	Different
	Validation	1998 to 2013	2010-2014	Different

Table 5-5: Temporal & Spatial Comparison with present and previous model data - Ellagawa watershed

Description		**Available Model (Founder Data)**	**Present Model (Alternate Data)**	**Same /Different**
Number of RF Stations		4	4	Same
RF Station		Lauderdale Group	Aningkanda	Different
		Tawalama	Tawalama	Same
		Millawa	Deniyaya	Different
		Panilkande Estate	Neluwa	Different
Evaporation Station		Rathnapura	Rathnapura	Same
Steramflow Station		Tawalama	Tawalama	Same
Data Period	Calibration	1972 to 1992	2000-2008	Different
	Validation	1992 to 2012	2008-2015	Different

Table 5-6: Results of already Calibrated Model with Alternate Data

Watershed		**Tawalama**	**Ellagawa**
Parameters	c	0.89	1
	Sc	1292	800
	MRAE	0.2393	0.8066

In this comparisons after the model warm up, similar soil moisture levels reported in the previous work could be observed (Table 5-7) with the model execution using alternate data.

Table 5-7: Comparison of soil moisture of Tawalama and Ellagawa watersheds with Founder and Alternate model data

Description	**Tawalama watershed**		**Ellagawa watershed**	
	Model (with Founder data input)	Model (with Alternate data input)	Model (with Founder data input)	Model (with Alternate data input)
Minimum	231	200	102	95
Mean	325	315	195	199
Maximum	360	359	223	233

Streamflow estimate comparisons during calibration for Tawalama and Ellagawa watersheds are in Figure 5-1 and Figure 5-2. The normal plots in Figure D-9 and Figure D-10 also show the degree of matching.

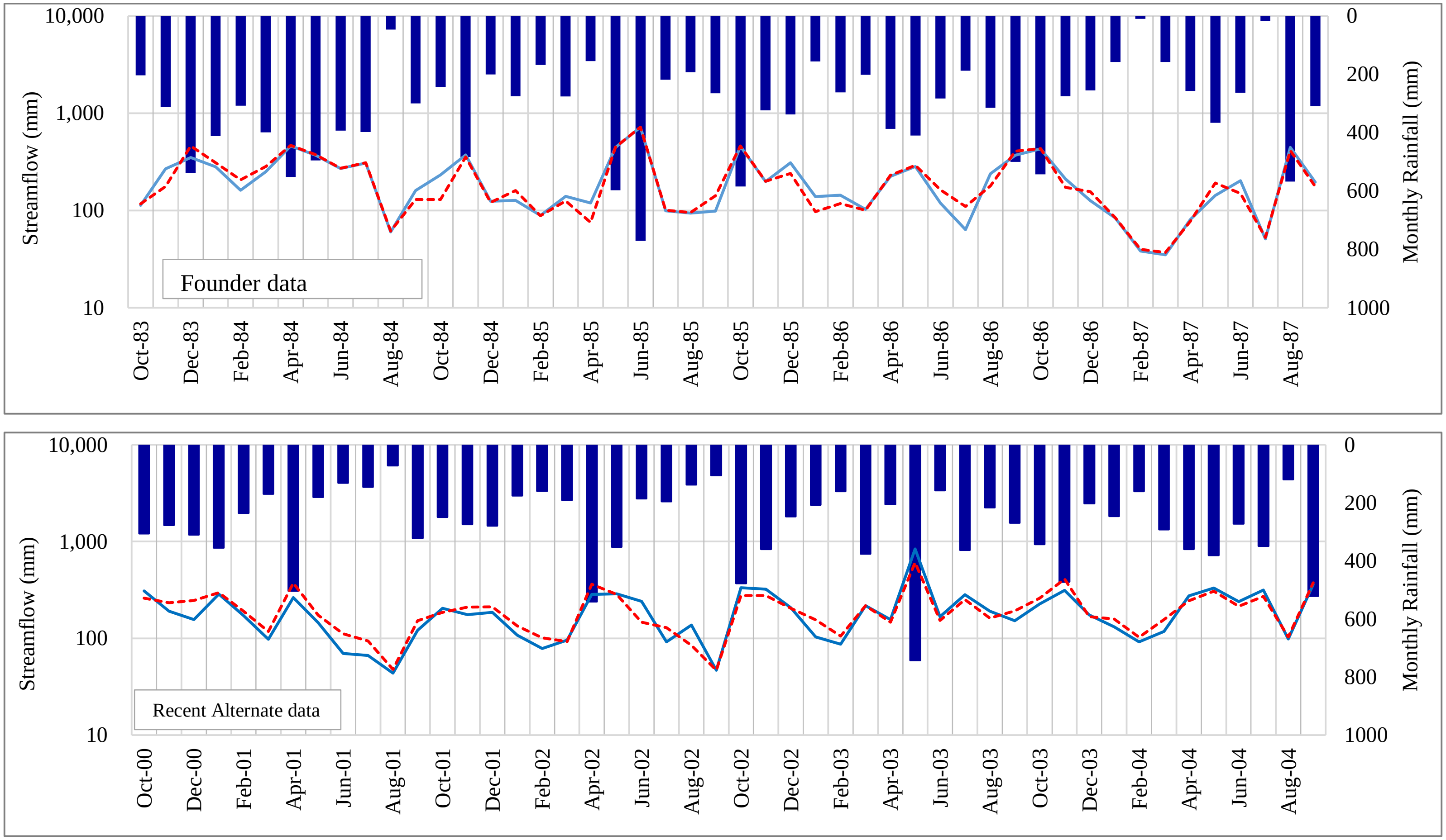

Figure 5-1: Streamflow Comparison with Kandu.D.,(2016,unpuble) Model– Tawalama watershed – Founder and Alternate Data

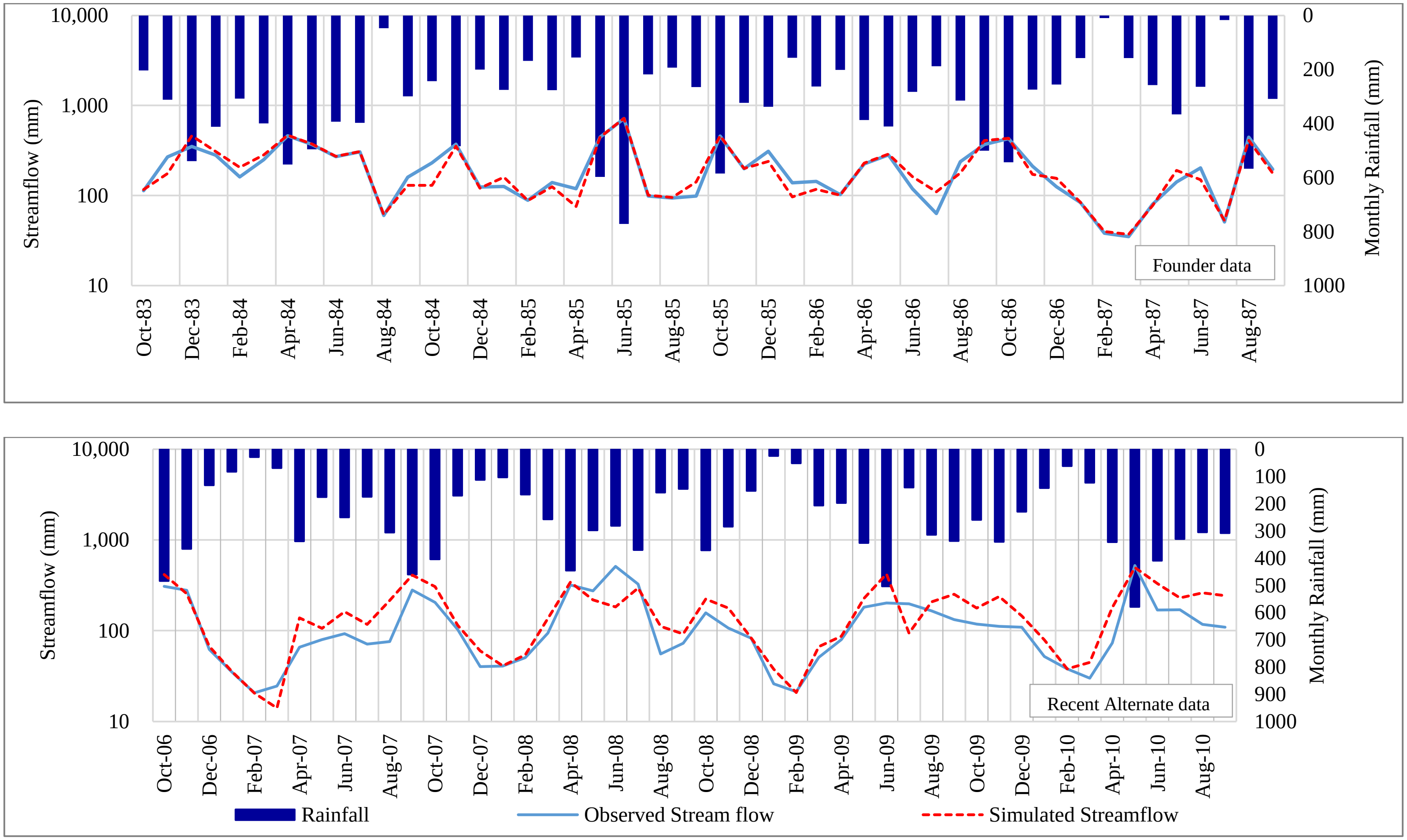

Figure 5-2: Streamflow Comparison with Sharifi.M.B.,(2016,unpuble) Model – Ellagawa watershed – Founder and Alternate Data

5.6 Calibration of Two Parameter Monthly Model (Monthly Alternate data)

5.6.1 General

Xiong & Guo,(1999) carried out parameter optimization in two steps. The first step optimizes both parameters simultaneously using one objective function. Then, while keeping the parameter c constant, the parameter Sc is optimized with a secondary objective function. Xiong & Guo,(1999) had initially optimized using RE (Relative Error) as objective function and then used Nash-Sutcliffe to optimize Sc. In the present work, the initial optimization used the MRAE while the step 2 was carried out with Nash-Sutcliffe as the objective function. MS Excel 'solver' as illustrated in https://support.office.com was used for the parameter optimization.

5.6.2 Determination of Global Minimum

The range of parameters cited in literature varies between 0.2 and 1.25 for C. Parameter Sc in literature varies between 300 – 2000. The governing equation determines the minimum level of C, Sc by the greater than zero criteria. The upper limits have not been specified. Therefore in order to capture the global minimum of objective function surface, many trials with varying C and Sc were attempted. The behavior of objective function, respective coarser resolution C and Sc values are shown in Figure 5-3 and Table D-3 for Tawalama watershed.

Results of Ellagawa Watershed are in Figure 5-4 and Table D-4.

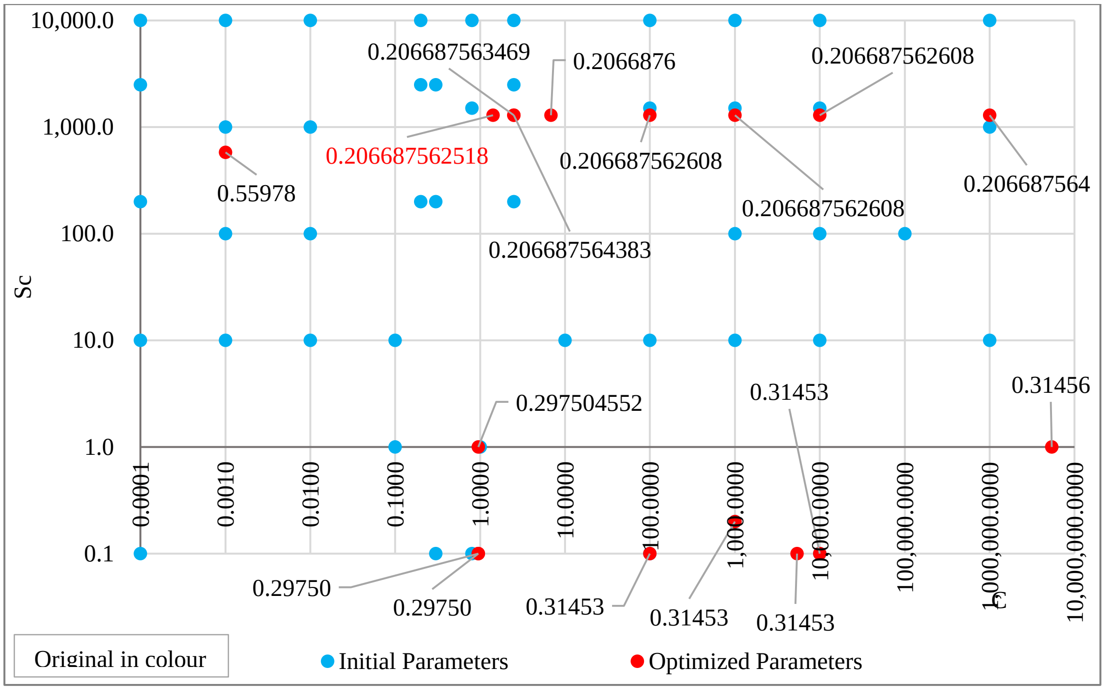

Figure 5-3: Search for Global Minimum of MRAE– Tawalama Watershed

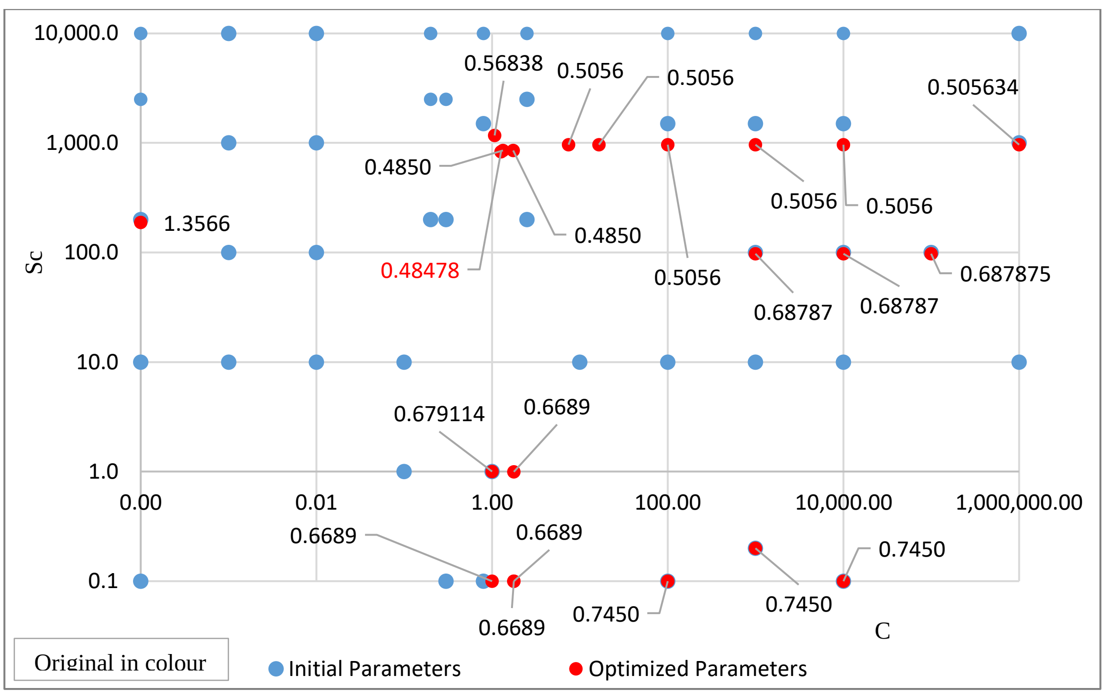

Figure 5-4: Search for Global minimum of MRAE – Ellagawa Watershed

The trial and error computations revealed the range for global minimum identification. Figure 5-5 and Figure 5-6 show the determination of global minimum for both watersheds. The parameter search with coarser resolution initial parameters and using solver, identified the most likely minimum of MRAE for both watersheds. Then the search continued with finer resolution initial parameters to search the minimum near the identified range. Variation of objective function surface near the global minimum for both watersheds are in Figure 5-5 and Figure 5-6.

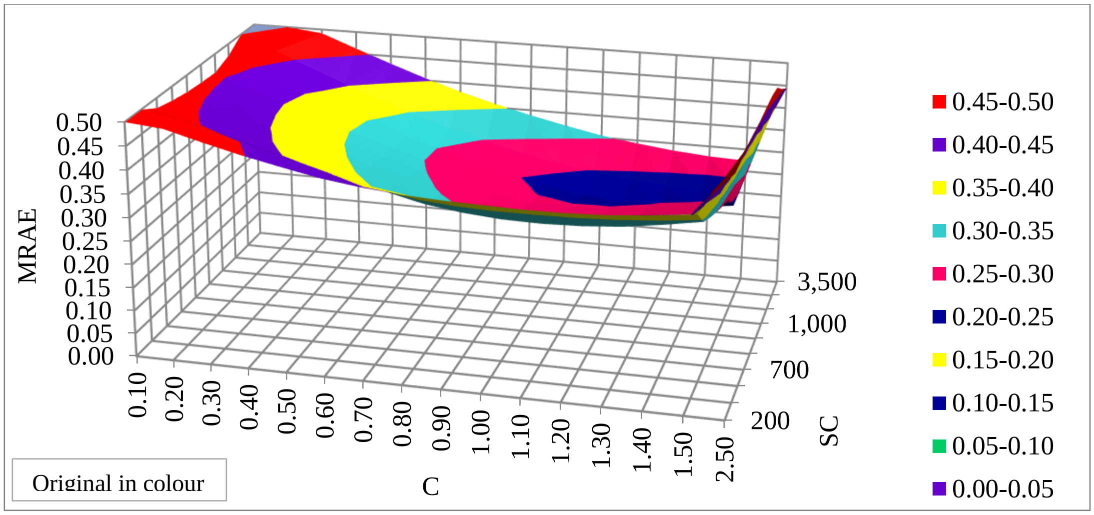

Figure 5-5: Variation of Objective Function with Parameter Values – Tawalama Watershed

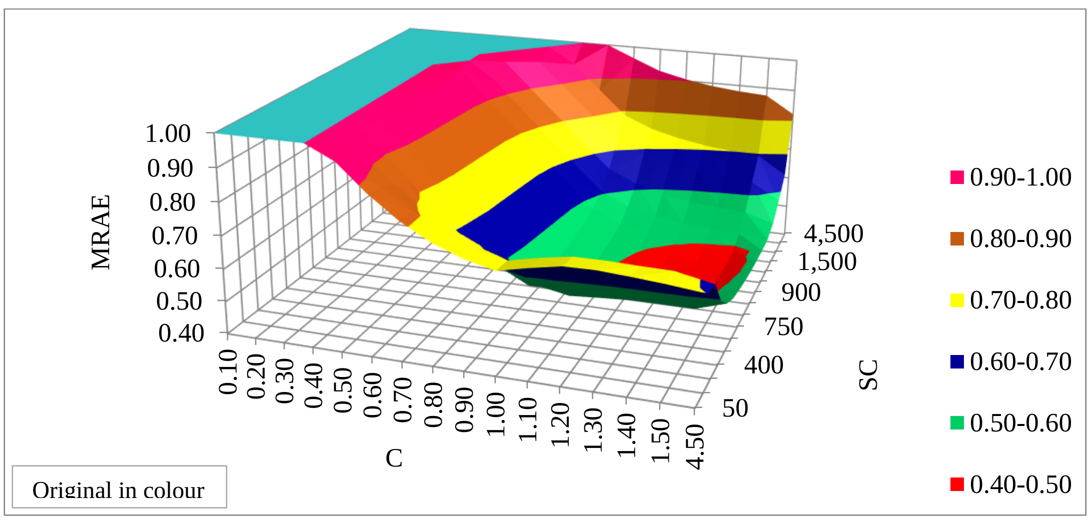

Figure 5-6: Variation of Objective Function with Parameter Values – Ellagawa Watershed

Corresponding values for Tawalama and Ellagawa watersheds are in Table 5-8 and Table 5-9. Calibration results of Tawalama watershed are in Figure 5-7, Figure 5-8 and Figure 5-9. Verification results are in Figure 5-10, Figure 5-11 and Figure 5-12. Calibration results of Ellagawa watershed are in Figure 5-13, Figure 5-14 and Figure 5-15. Verification results are in Figure 5-16, Figure 5-17 and Figure 5-18.

Table 5-8: Comparison of Model Performance – 2PM (Monthly Input) with Founder Parameters and Alternate dataset – Tawalama Watershed

Comparison of Model Performance	**With Founder data**	**With Present alternate data**	
		Calibration	**Validation**
MRAE - Overall	0.2393	0.2067	0.2055
MRAE - High	0.1832	0.1787	0.1921
MRAE - Medium	0.2495	0.2097	0.2101
MRAE - Low	0.5084	0.2399	0.9096
Nash-Sutcliffe	0.7376	0.7398	0.7279
Parameter - c	0.89	1.42	1.42
Parameter - Sc	1292	1,288.63	1,288.63
Average WB Error	257.96	119.70	128.95
Data Duration	2000 - 2015	2000 - 2008	2008 - 2015

Table 5-9: Comparison of Model Performance – 2PM (Monthly Input) with Founder Parameters and Alternate dataset – Ellagawa Watershed

Comparison of Model Performance	**With Founder data**	**With Present alternate data**	
		Calibration	**Validation**
MRAE - Overall	0.8066	0.4848	1.0489
MRAE - High	0.3646	0.3934	0.4654
MRAE - Medium	1.6874	0.6989	1.4272
MRAE - Low	2.9373	0.2089	1.0809
Nash-Sutcliffe	0.6204	0.4089	(0.3420)
Parameter - c	1	1.29	1.29
Parameter - Sc	800	827.84	827.84
Average WB Error	696.41	442.03	1,008.46
Data period	2006 - 2014	2006 - 2010	2010 - 2014

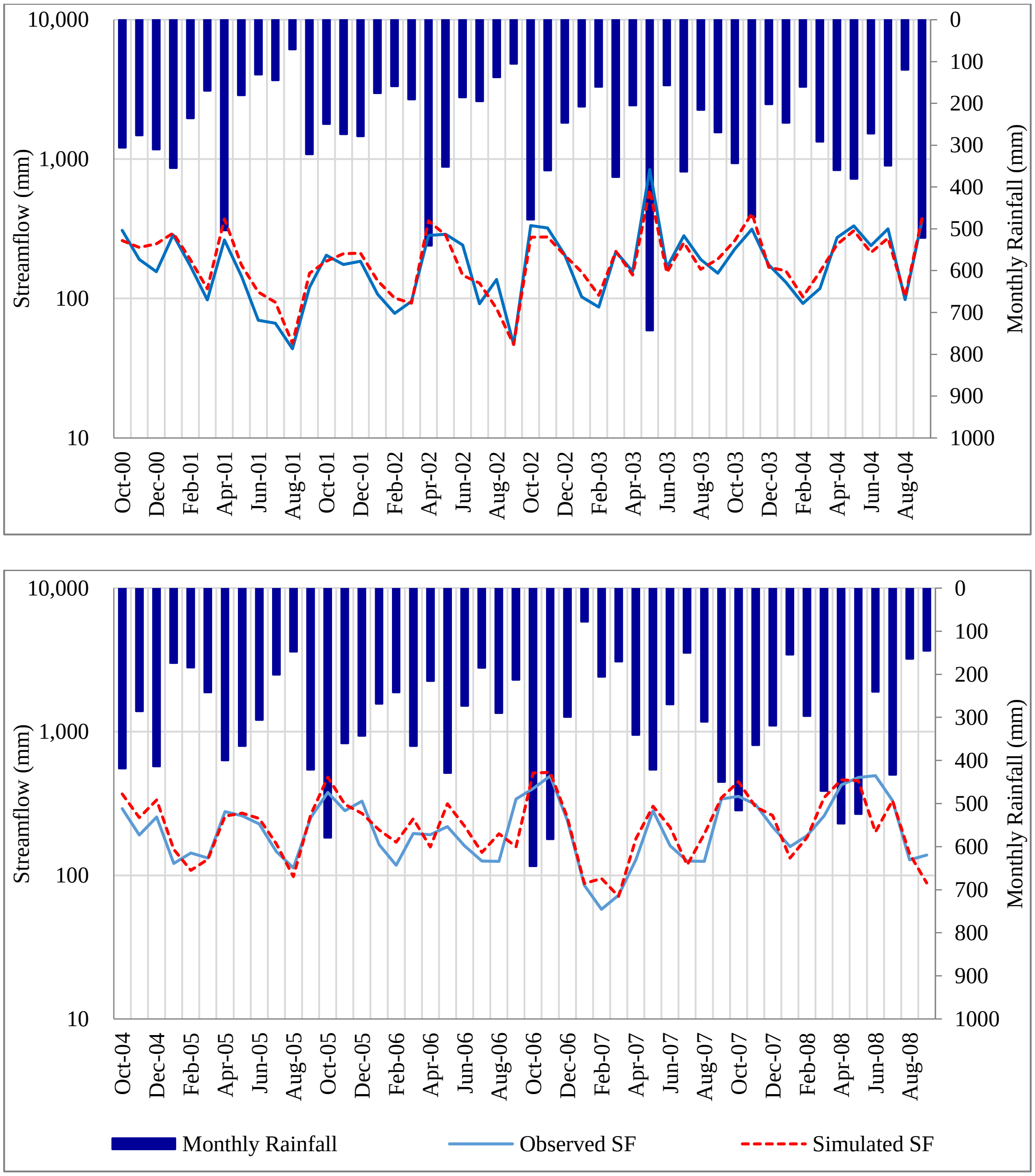

Figure 5-7: Hydrographs of 2PM (Monthly Input) for Tawalama Watershed – Calibration – Alternate Data

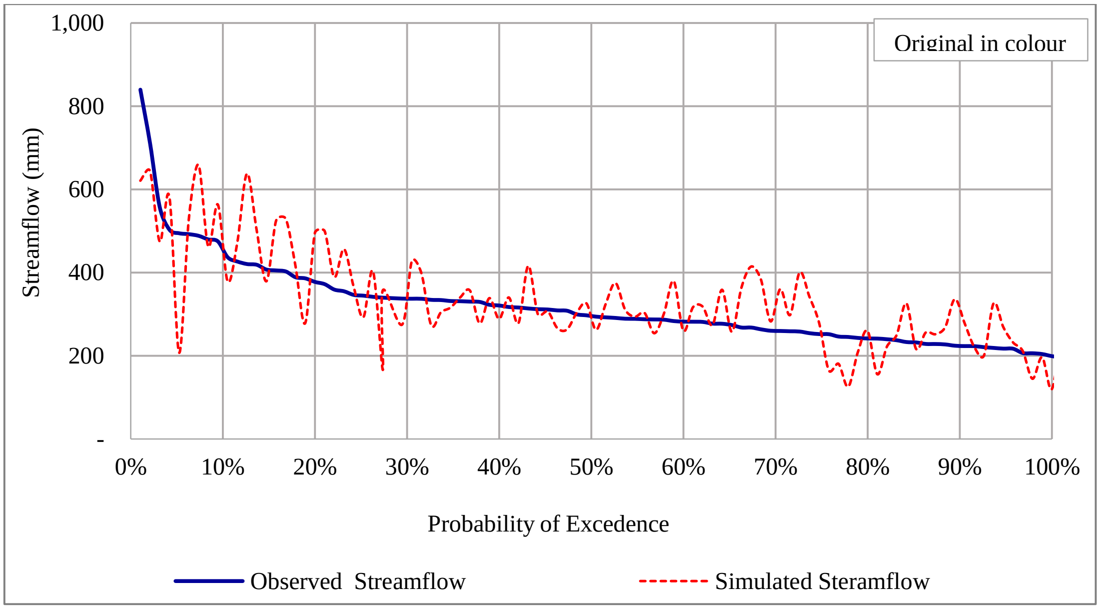

Figure 5-8: Flow duration curve of 2PM (Monthly Input) for Tawalama Watershed – Calibration – Alternate Data

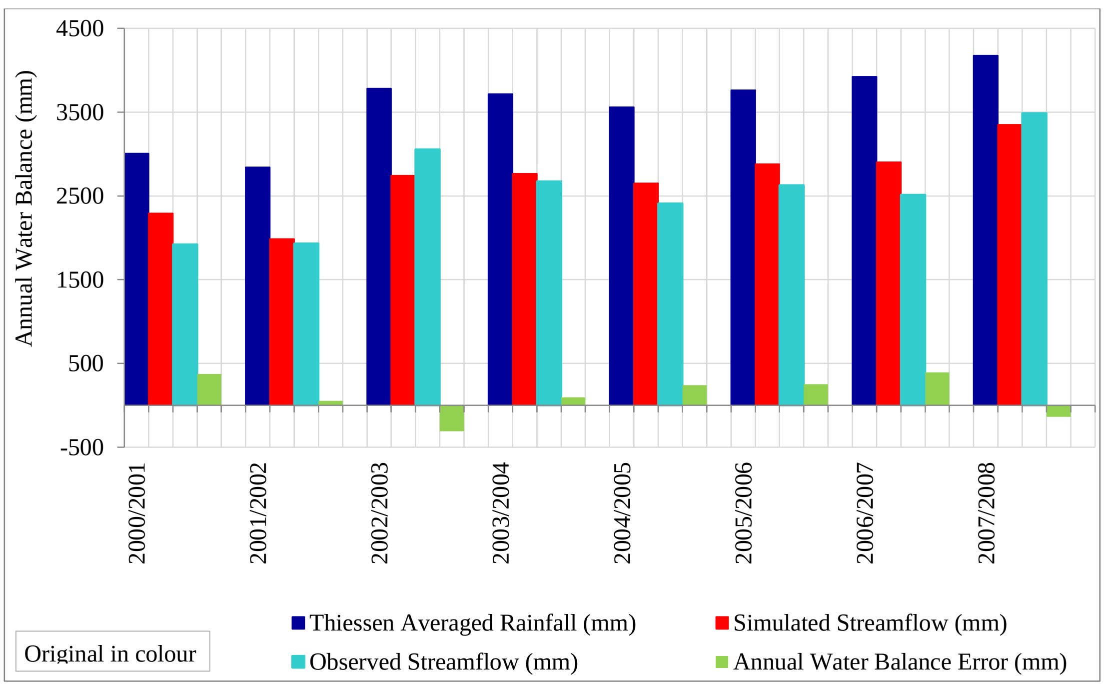

Figure 5-9: Annual Water Balance of 2PM (Monthly Input) for Tawalama Watershed – Calibration – Alternate Data

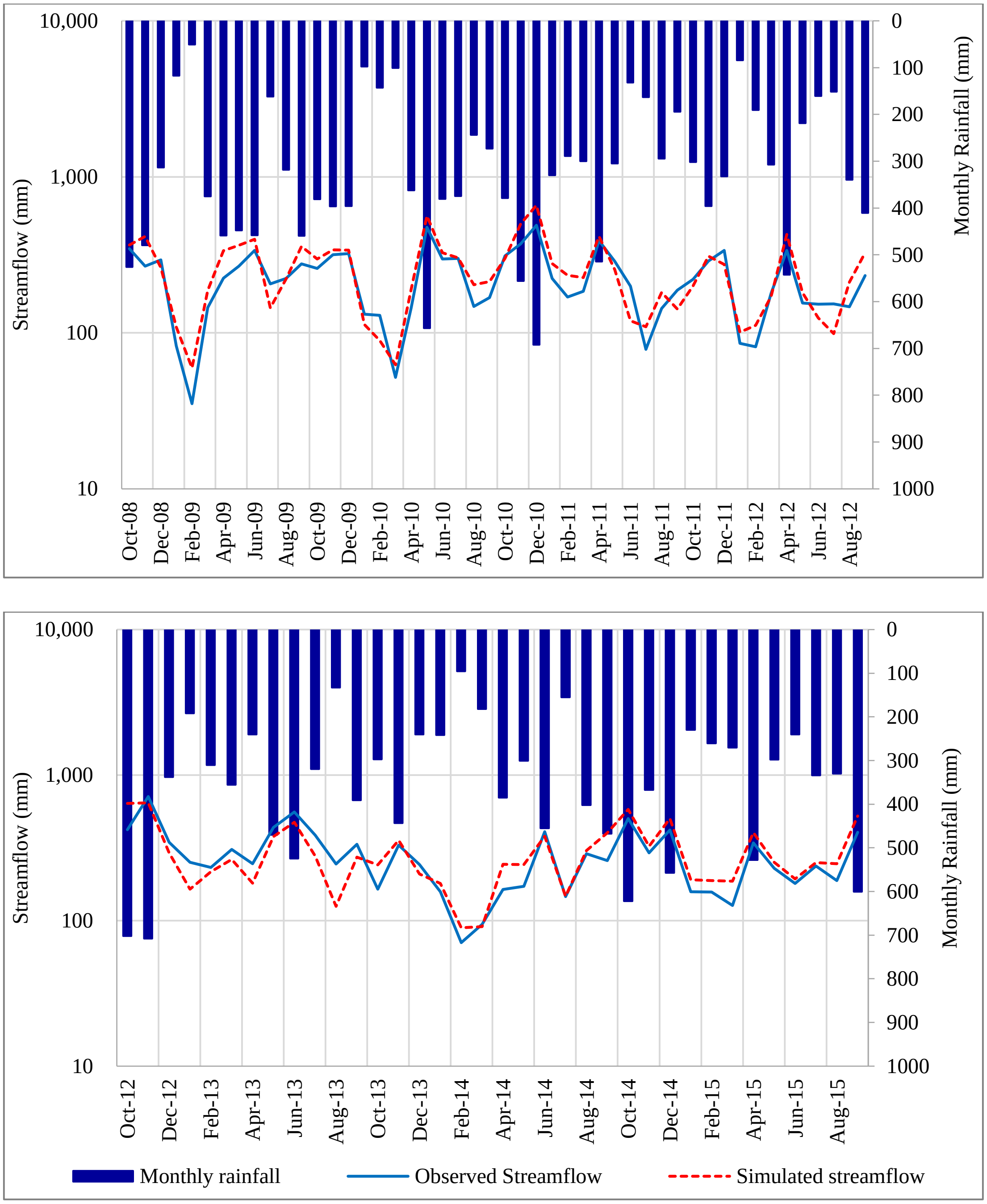

Figure 5-10: Hydrographs of 2PM (Monthly Input) for Tawalama Watershed - Verification

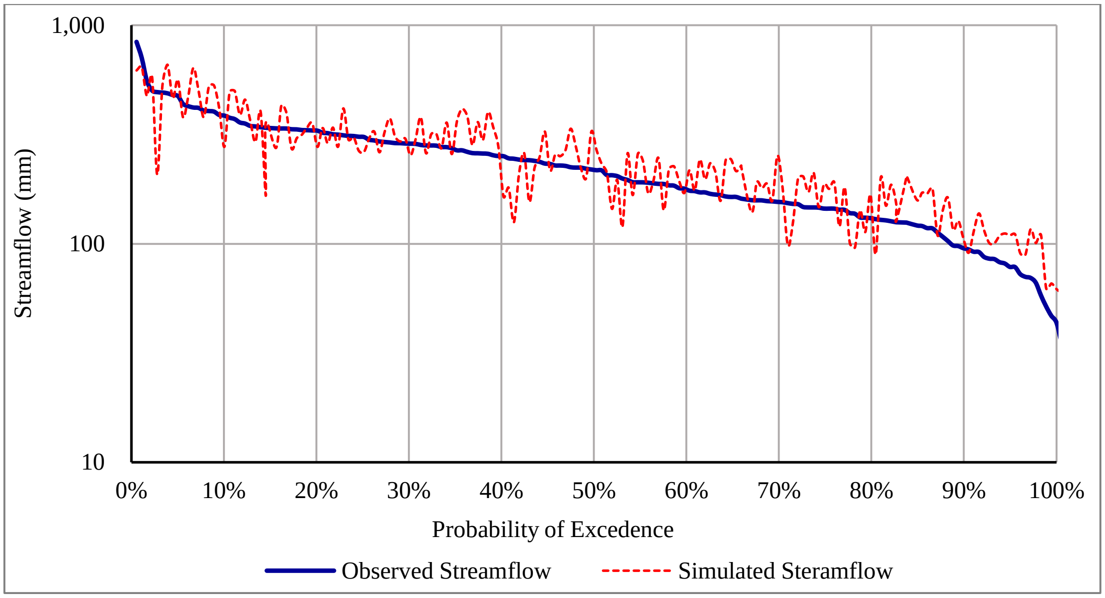

Figure 5-11: Flow duration curve of 2PM (Monthly Input) for Tawalama Watershed - Verification

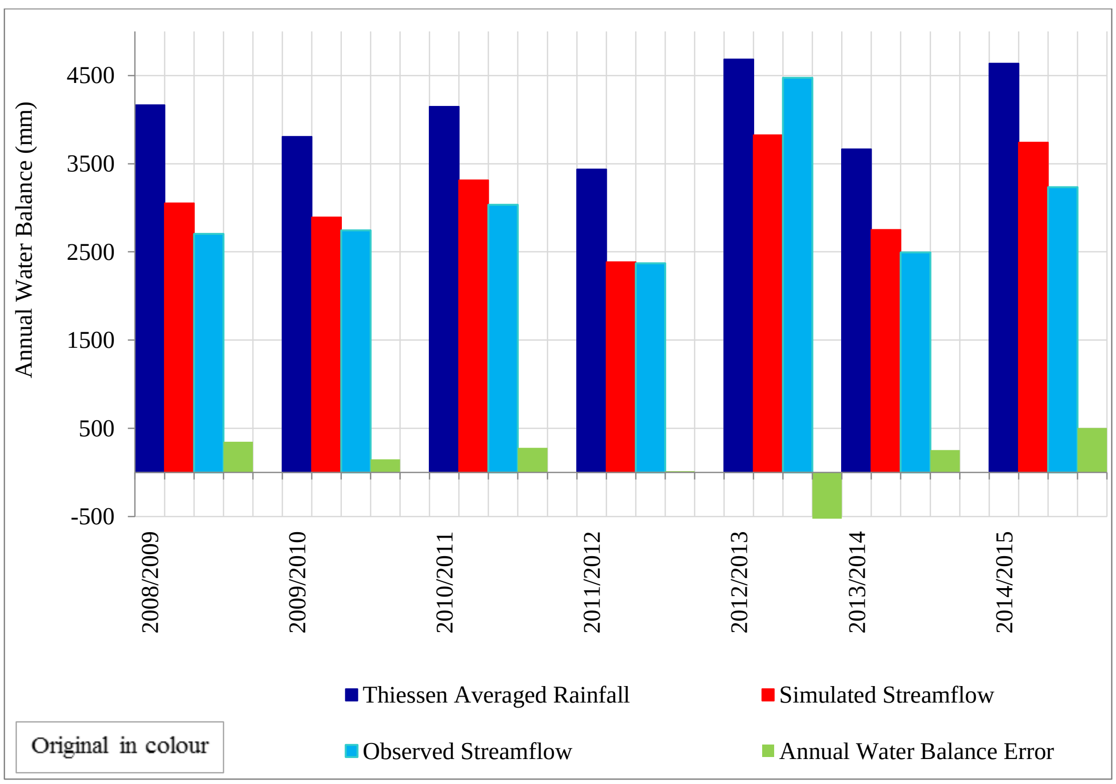

Figure 5-12: Annual Water Balance of 2PM (Monthly Input) for Tawalama Watershed - Verification

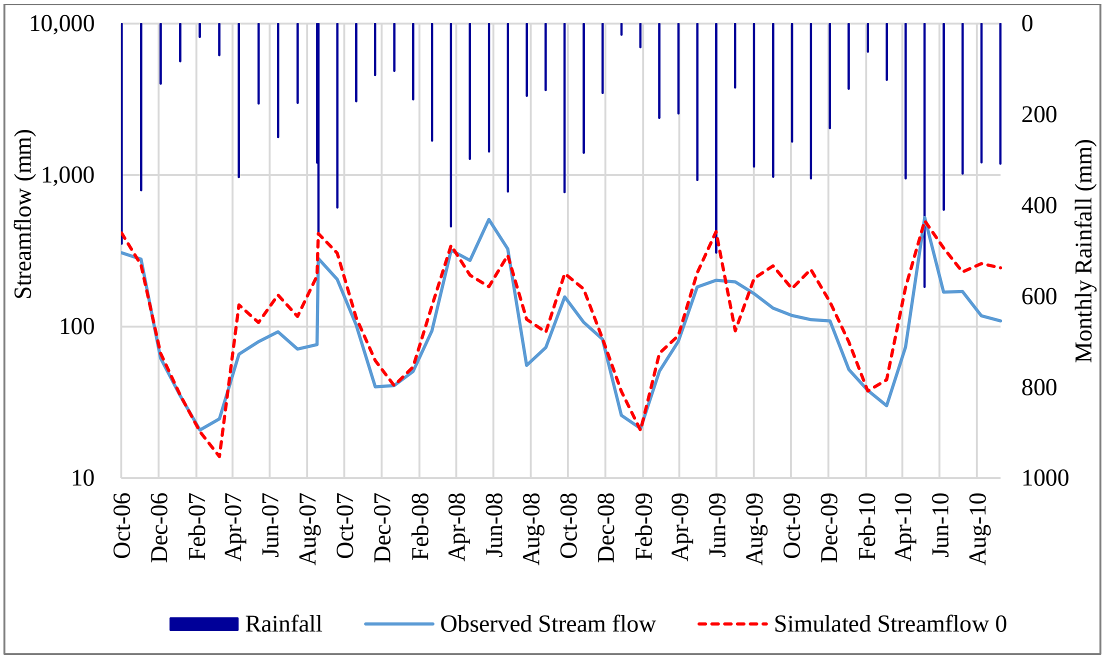

Figure 5-13: Hydrographs of 2PM (Monthly Input) for Ellagawa Watershed – Calibration

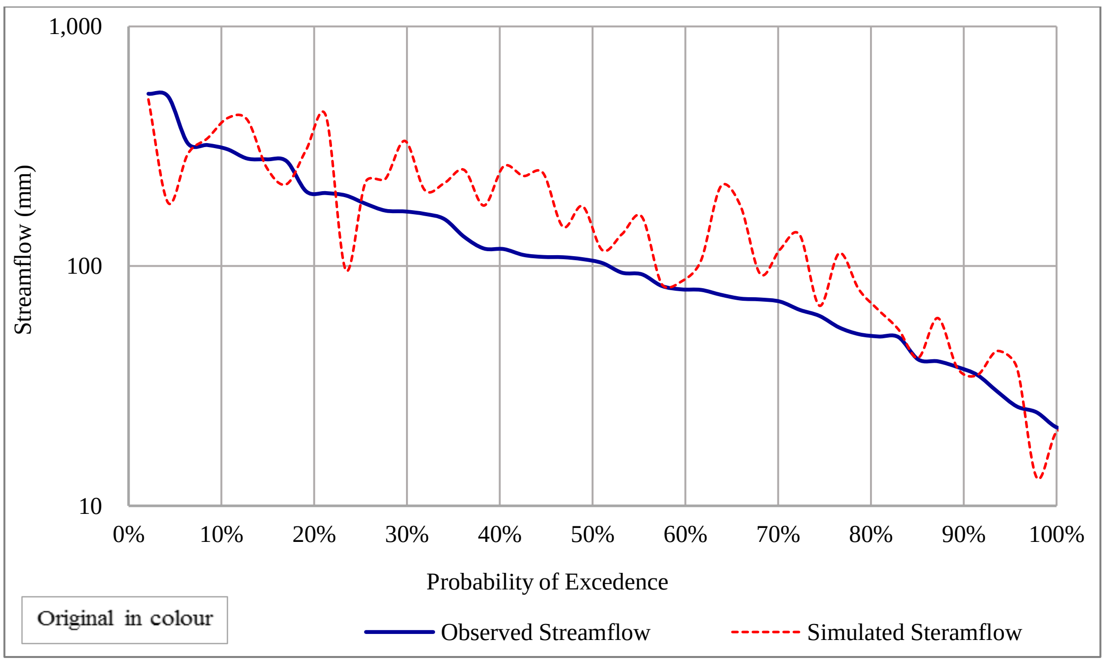

Figure 5-14: Flow duration curve of 2PM (Monthly Input) for Ellagawa Watershed – Calibration

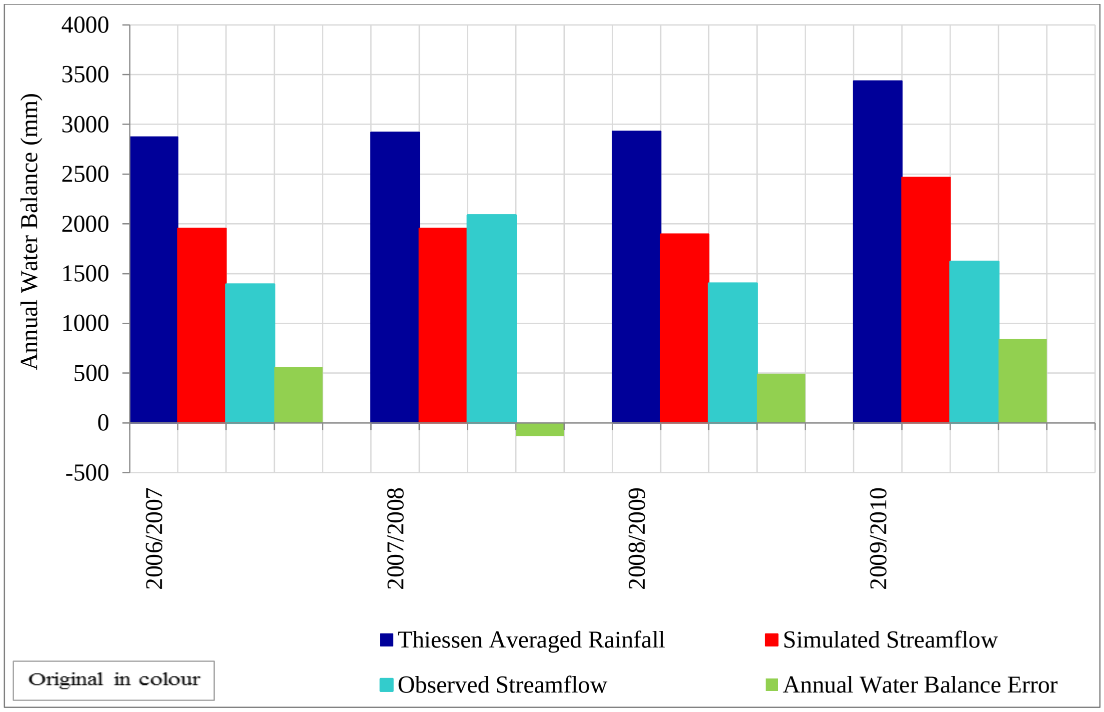

Figure 5-15: Annual Water Balance of 2PM (Monthly Input) for Ellagawa Watershed – Calibration

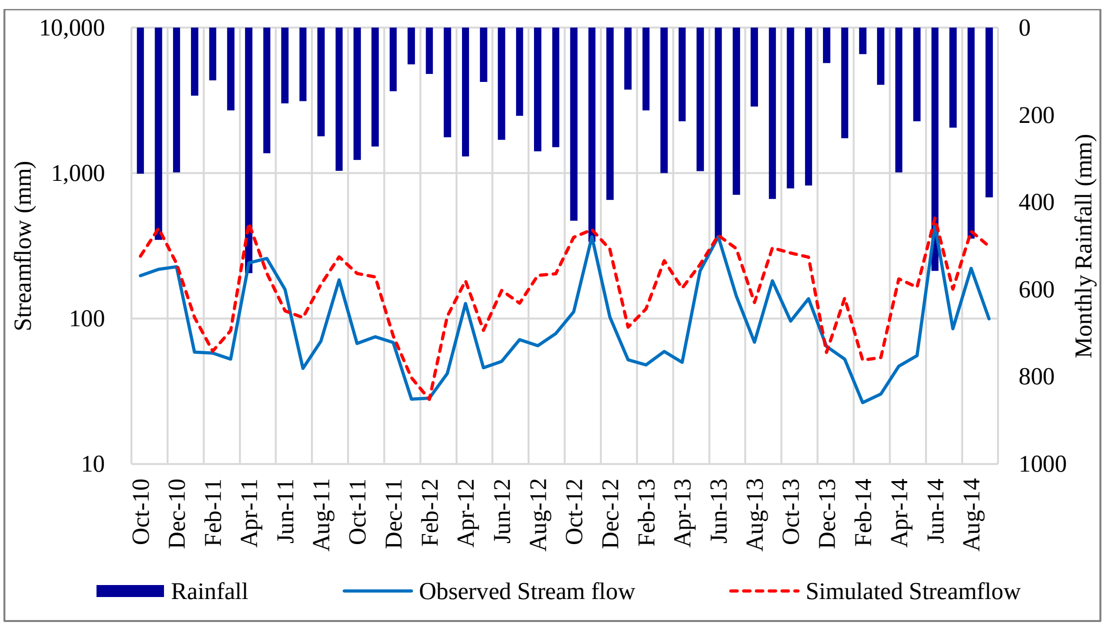

Figure 5-16: Hydrographs of 2PM (Monthly Input) for Ellagawa Watershed - Verification

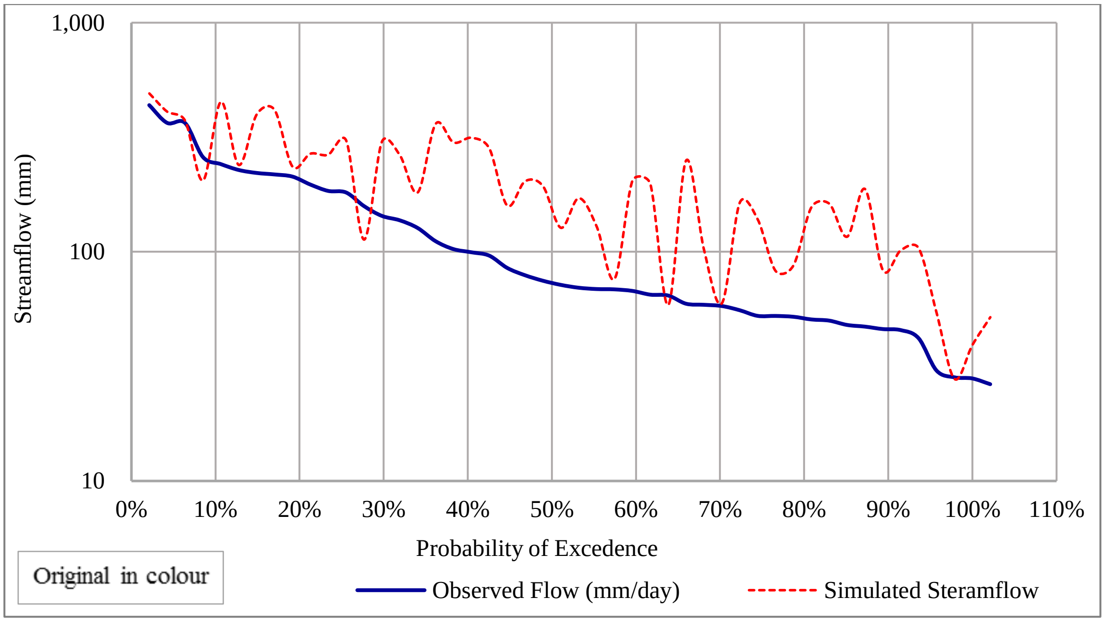

Figure 5-17: Flow duration curve of 2PM (Monthly Input) for Ellagawa Watershed – Verification

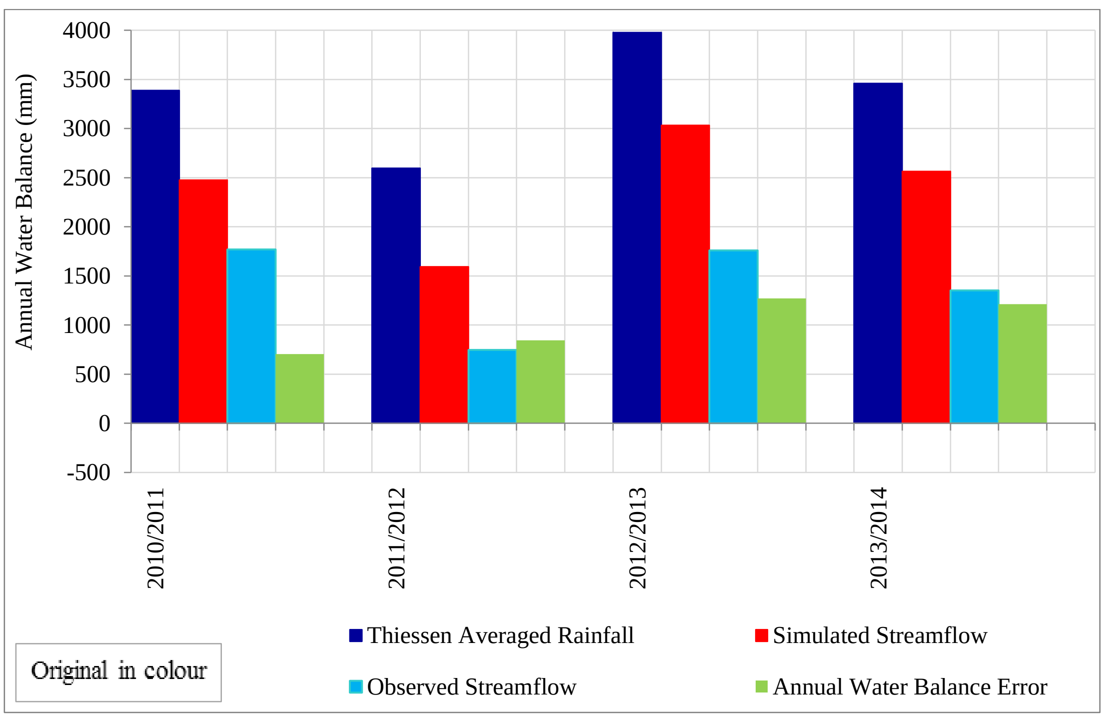

Figure 5-18: Annual Water Balance of 2PM (Monthly Input) for Ellagawa Watershed - Verification

5.6.3 Comparison of 2PM (Monthly Input) Performance

5.6.3.1 Ellagawa Watershed

Performance of 2PM (Monthly Input) with founder parameters and alternate parameters indicated a significant disparity (Table 5-8). The founder parameters showed a MRAE of 0.8066 with the calibration and verification MRAE for alternate data were 0.4848 and 1.0489 respectively. These values were much higher than those observed during founder model development.

Thiessen rainfall and observed streamflow hydrographs at data checking showed many streamflow observations that are not reflective of the areal rainfall input. After an investigation of major disparities (Figure 5-19), MRAE computations revealed that the alternate data set could produce a model with a reasonable accuracy (Table 5-10).

Table 5-10: Model performance and Data Disparities – Ellagawa Watershed

Description	Data Period	MRAE
Model with Founder Parameters – with Data disparities	2006 - 2014	0.8249
Model with Founder Parameters – without Data disparities	2006 - 2014	0.3943
Model Calibration with alternate data (with disparities)	2006 - 2010	0.4849
Model Calibration with alternate data (without disparities)	2006 – 2010	0.2863
Model Validation with alternate data (with disparities)	2010 - 2014	1.0489
Model Validation with alternate data (without disparities)	2010 - 2014	0.3993
Model with Founder Data (Calibration Period)	1983 - 1998	0.1446
Model with Founder Data (Validation Period)	1998 - 2013	0.1526

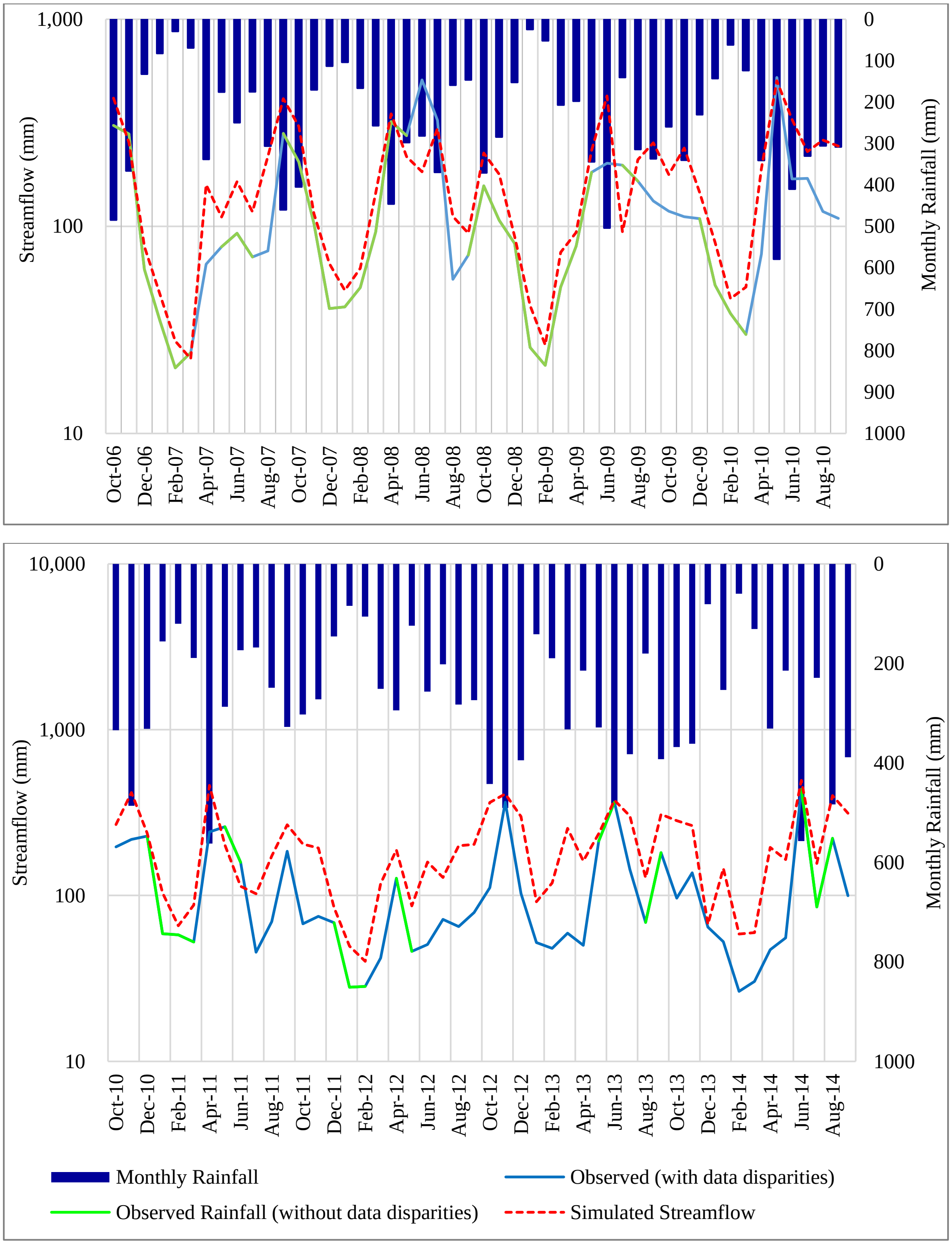

Figure 5-19**:** Comparison of Hydrographs – Monthly data (Year 2006/07- 2013/14) – Ellagawa Watershed

5.6.3.2 Tawalama Watershed

The same comparison was carried out in case of Tawalama watershed. Removal of points with incompatibility showed that the present alternate data produced a model with reasonable accuracy.

Table 5-11: Model performance and Data Disparities – Tawalama Watershed

Description	Data Period	MRAE
Model with Founder Parameters – with Data disparities	2000 - 2015	0.2393
Model with Founder Parameters – without Data disparities	2000 - 2015	0.1705
Model Calibration with alternate data (with disparities)	2000 - 2008	0.2067
Model Calibration with alternate data (without disparities)	2000 - 2008	0.1663
Model Validation with alternate data (with disparities)	2008 - 2015	0.2055
Model Validation with alternate data (without disparities)	2008 - 2015	0.1442
Model with Founder Data (Calibration Period)	1972 - 1992	0.0900
Model with Founder Data (Validation Period)	1992 - 2012	0.1158

5.6.4 Selected Parameters to the 2PM

Model performance at both watersheds demonstrated better results with founder models. The monthly data sets used for founder model (Khandu.D.,2016,unpubl and Sharifi.M.B.,2016,unpubl) were lengthier than the present alternate dataset. However, founder datasets did not contain values at a daily resolution. Since the comparison performed earlier showed reasonable results with the present data, and considering the daily time resolution, the present study used the model with parameters calibrated with alternate data. The parameters selected for the study are in Table 5-12.

Table 5-12: 2PM (Monthly Input) – Selected Parameters

Parameters	Tawalama	Ellagawa
C	1.42	1.29
SC	1,288.63	827.84

5.7 Daily Outflow Estimation with 2PM (Daily Input)

5.7.1 General

The two parameter alternate model (calibrated and verified with monthly inputs) was then used to estimate daily outputs using daily inputs. The Xiong. & Guo (1999) model equations do not indicate a relationship with a temporal resolution except the assumption that the equations represent conceptualization within any given time step. This model was identified as 2PM (Daily Inputs).

5.7.2 Performance of 2PM (Daily Input)

5.7.2.1 Tawalama Watershed

a) Calibration period (2000/01 – 2007/08)

Model outflow hydrographs (Figure 5 23, Figure 5-24, Figure D-12 and Figure D-13), flow duration curves (Figure 5-25 and Figure D-19), Annual water balance (Figure 5-26) and objective function values (Table 5-13) indicate a MRAE of approximately 0.43. Though this value appears as a reasonable estimation, the duration curves clearly reflect an over estimation in the low and medium flow with an under estimation in high flows. The scatter diagram in Figure 5-20 shows the behavior of simulated streamflow against observed streamflow.

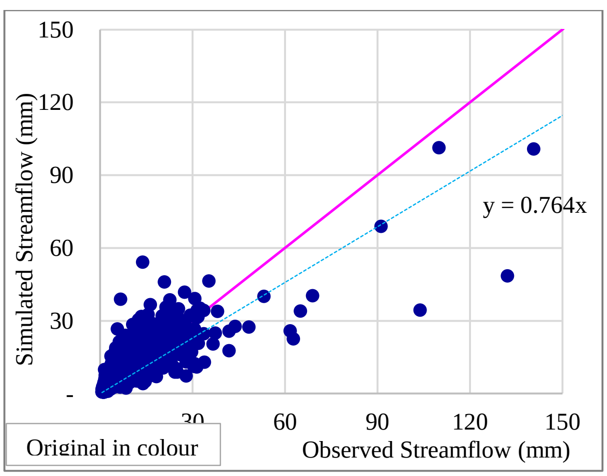

Figure 5-20: Streamflow comparison - 2PM (Daily Input) – Calibration Period – Tawalama Watershed

Daily outputs were summed to compare the estimation of monthly output (Figure 5-23). With monthly outputs from monthly inputs are in (Figure 5-22). Monthly estimate comparison indicated an almost equal performance.

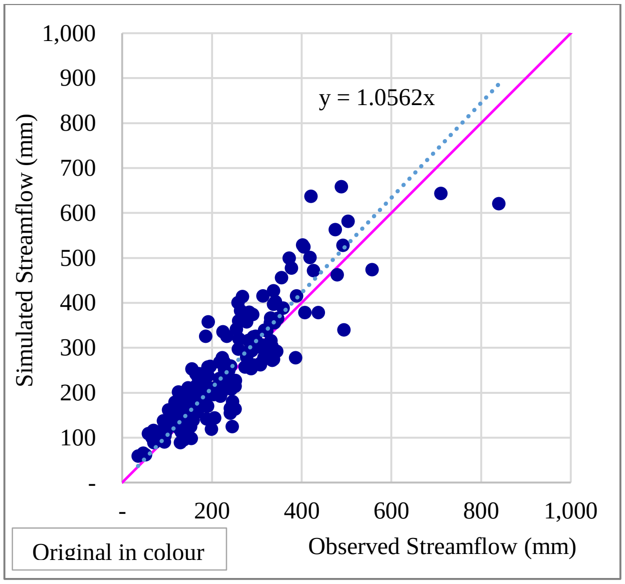

Figure 5-21: 2PM (Daily Input)– Monthly Streamflow Estimation – Calibration Period – Tawalama Watershed

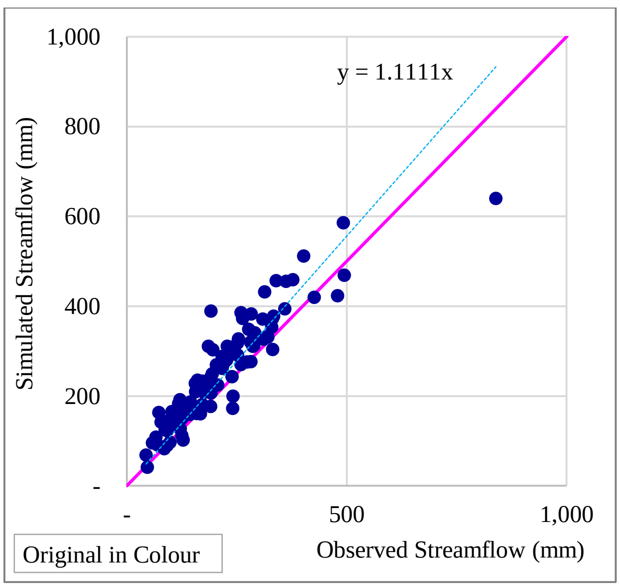

Figure 5-22: 2PM (Monthly Input) – Monthly Streamflow Estimation -– Calibration Period – Tawalama Watershed

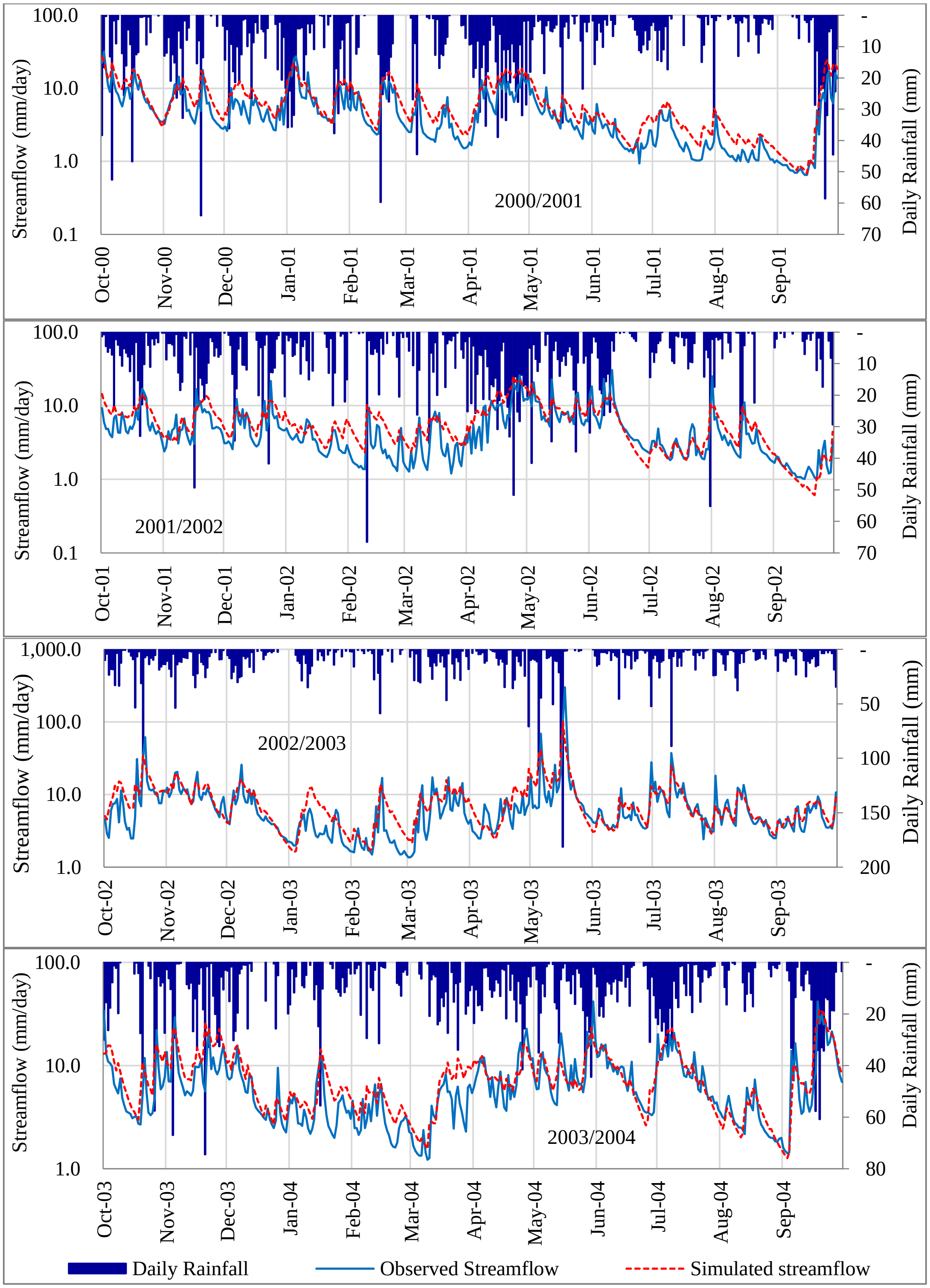

Figure 5-23: Output hydrographs – 2PM (Daily Input) – Calibration Period – Tawalama (Semi Logarithmic Plot) – Year 2000/01 – 2003/04

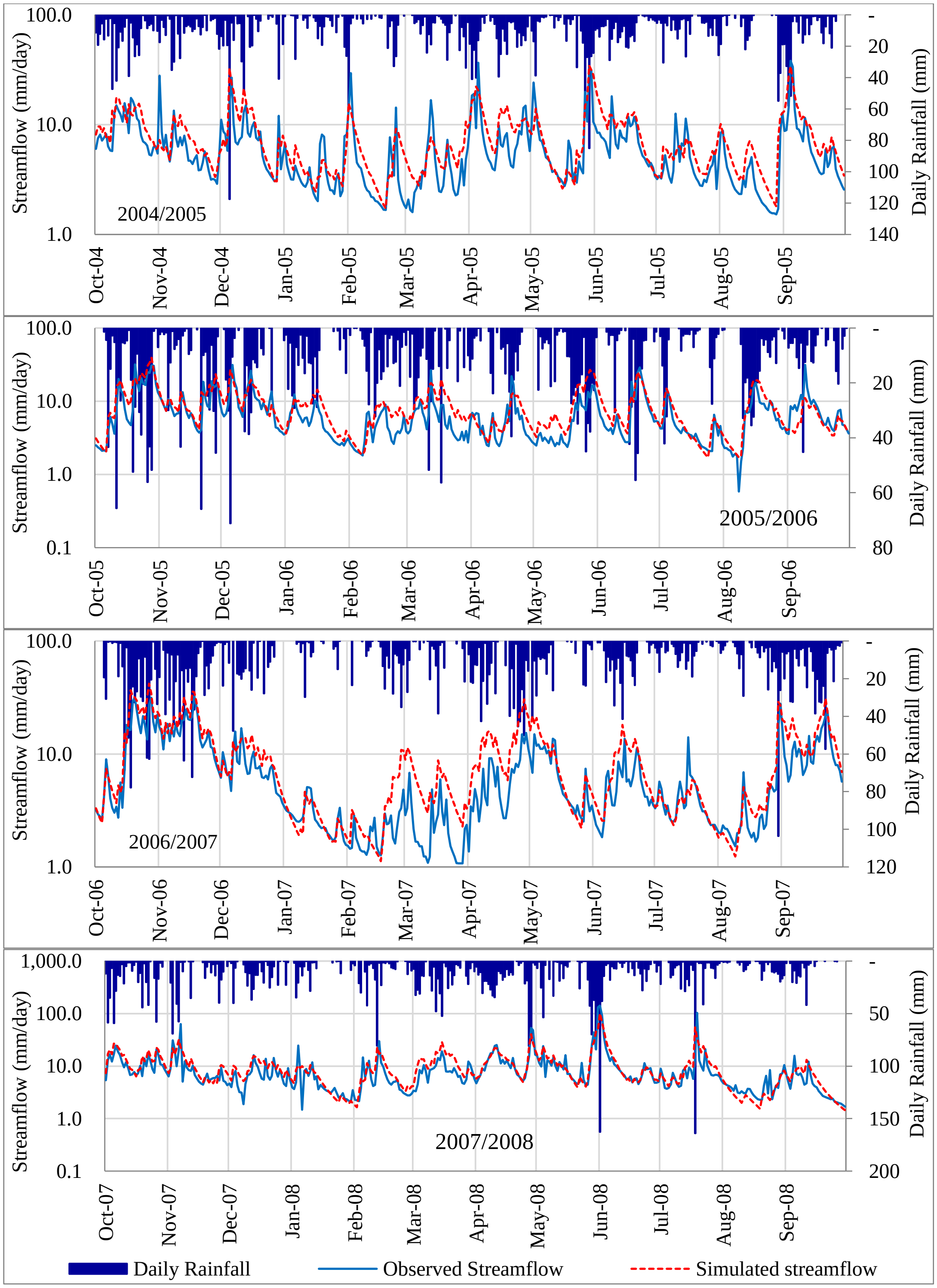

Figure 5-24: Output hydrographs from 2PM (Daily Input) – Calibration - Tawalama watershed (Semi Logarithmic Plot)

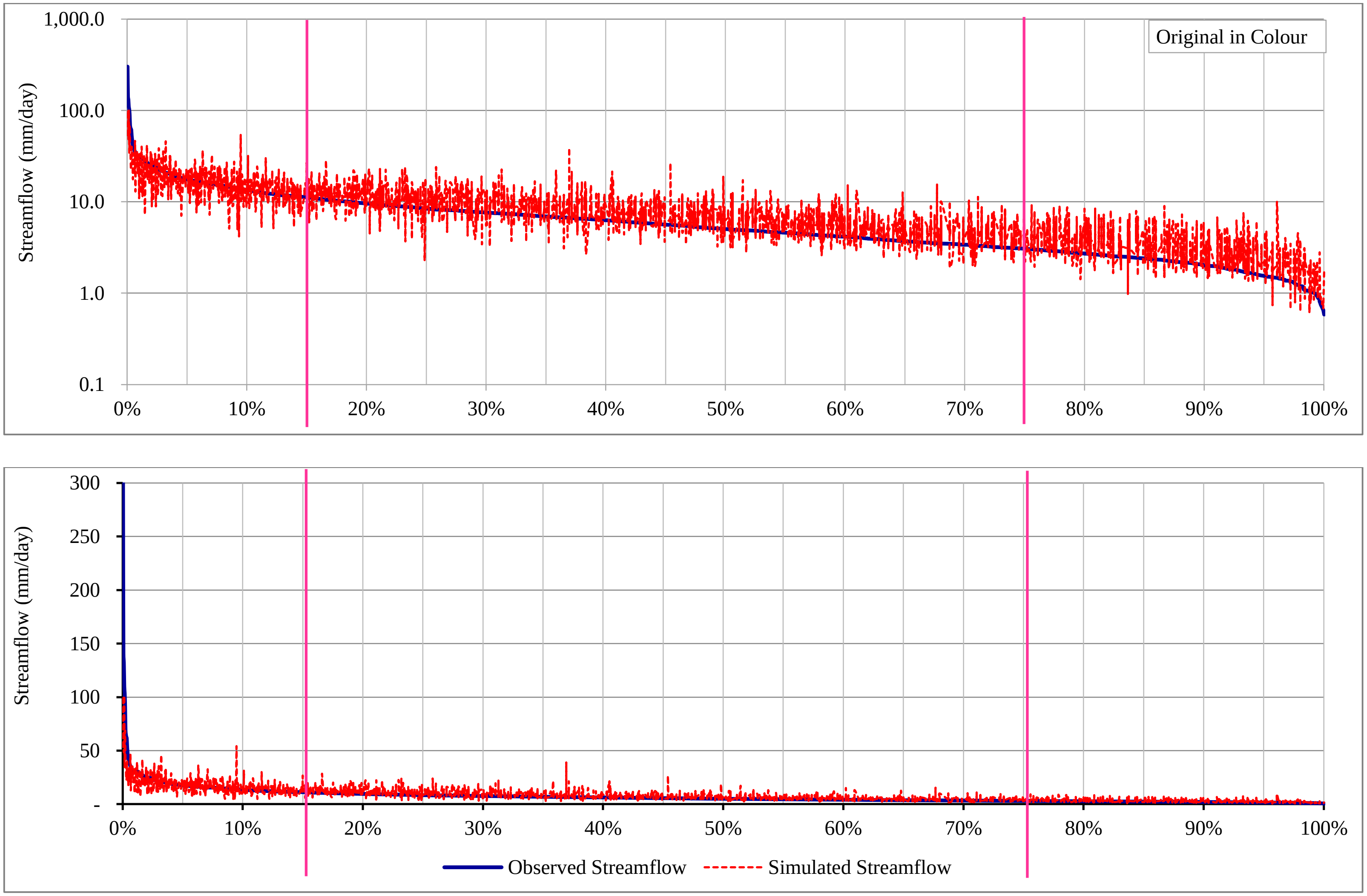

Figure 5-25: Flow Duration curve – 2PM (Daily Input - Calibration Period) - Tawalama Watershed

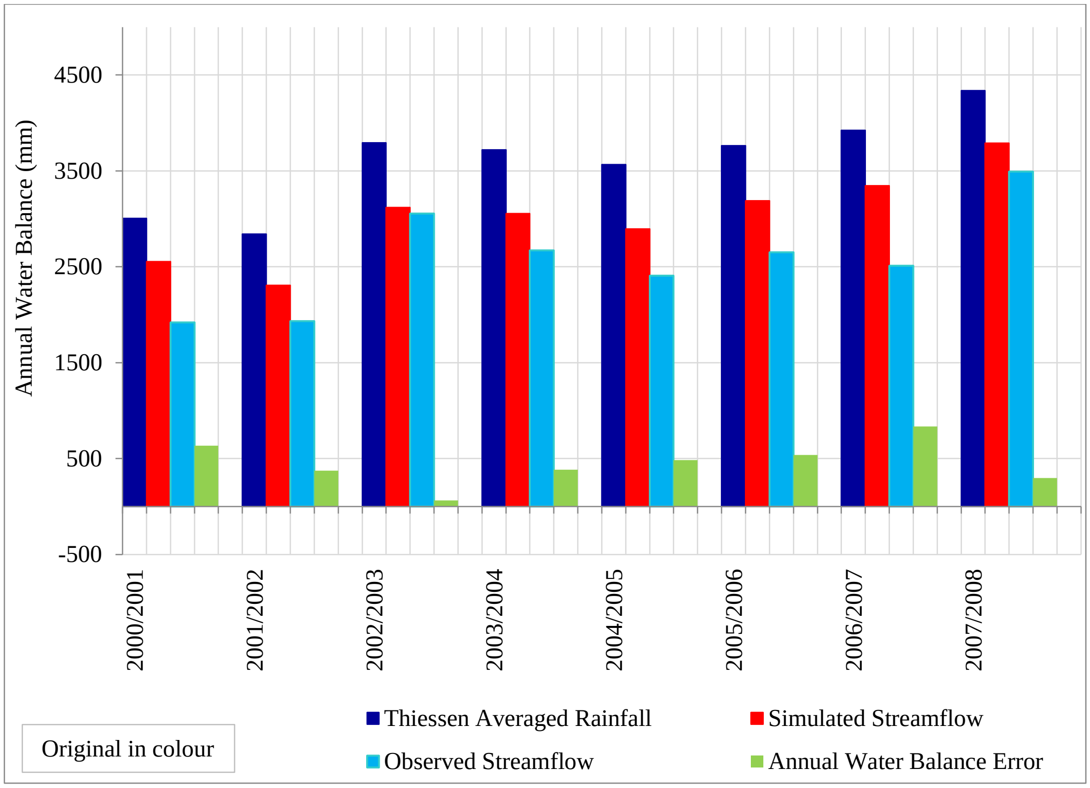

Figure 5-26: Annual Water Balance - 2PM (Daily Input) – Calibration Period – Tawalama Watershed

Table 5-13: Comparison of Model Performance 2PM (Daily Input) – Tawalama Watershed

Comparison of Model Performance	**2PM (Daily Input)**	
	Calibration	**Verification**
MRAE - Overall	0.4360	0.4039
MRAE - High	0.2849	0.2637
MRAE - Medium	0.4270	0.4168
MRAE - Low	0.6455	0.5458
Parameter - c	1.42	1.42
Parameter - Sc	1,288.63	1,288.63
Average WB difference	451.00	487.14
Data period	2000/01 – 2007/08	200809 – 2014/15
Nash-Sutcliffe	0.5102	0.6023

b) Verification Period (2008/09 – 2014/15)

Model outflow hydrographs (Figure 5-30, Figure 5-31 and Figure D-14,), flow duration curves (Figure 5-32), Annual water balance (Figure 5-33) and objective function values (Table 5-13) indicate a MRAE of approximately 0.40 which is better than that of calibration period. Duration curves show an over estimation. Figure 5-27 also clearly show the over estimation of low and medium flow by the model.

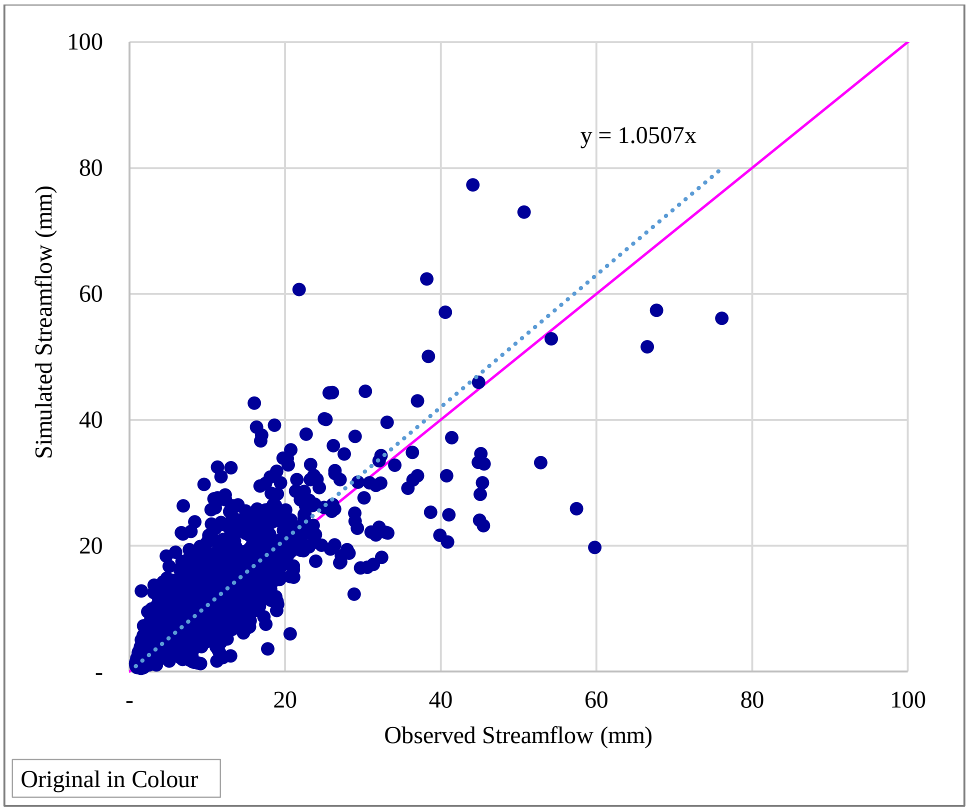

Figure 5-27: 2PM (Daily Input) – Daily Streamflow Estimation – Verification Period – Tawalama Watershed

Daily outputs were summed to compare the estimation of monthly outputs (Figure 5-28) with monthly outputs from monthly inputs (Figure 5-29). Results from daily inputs shows a clear over estimation of outputs.

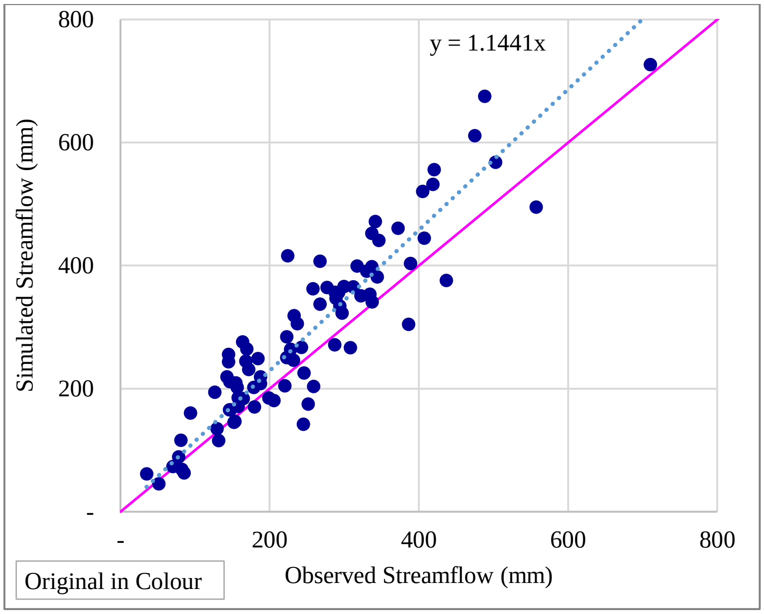

Figure 5-28: 2PM (Daily Input) – Monthly Streamflow Estimation – Verification Period – Tawalama Watershed

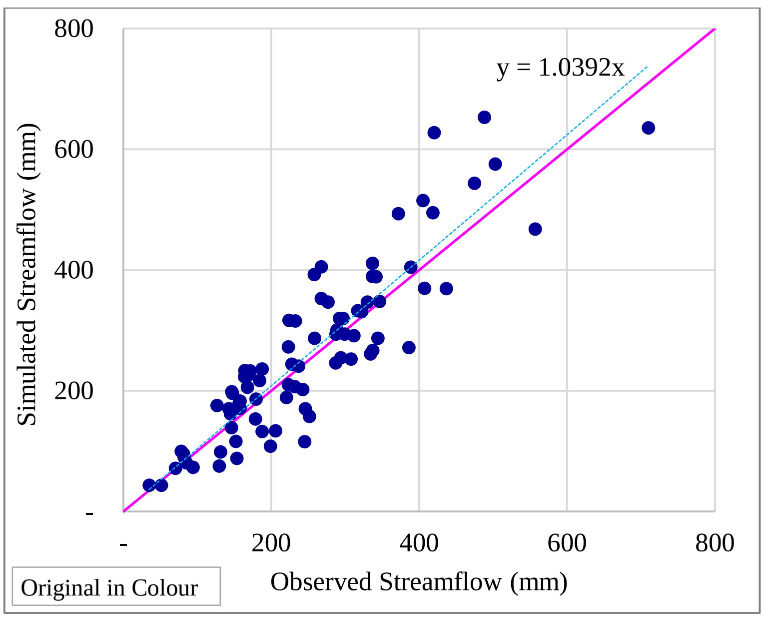

Figure 5-29: 2PM (Monthly Input) – Monthly Streamflow – Verification Period – Tawalama Watershed

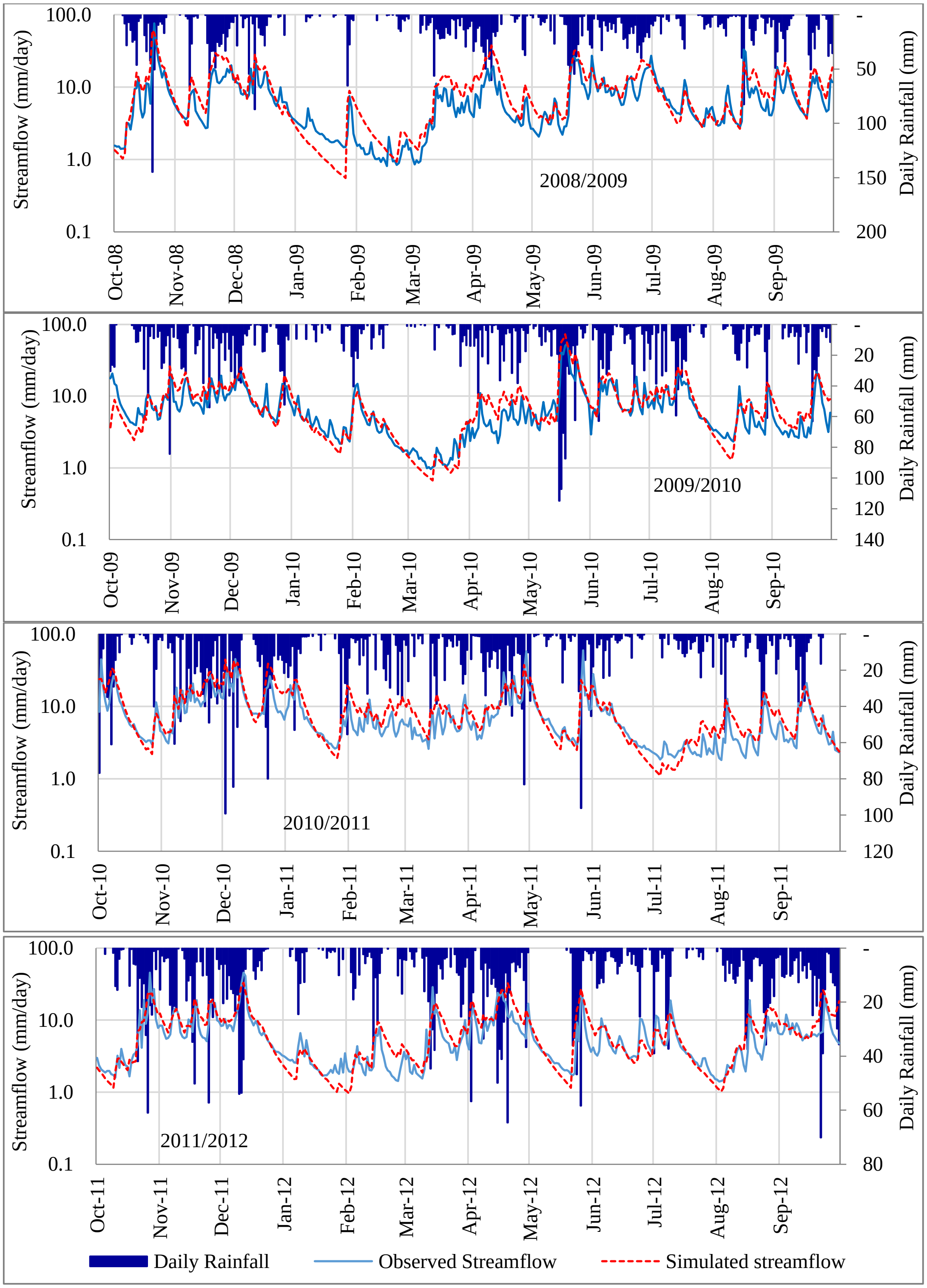

Figure 5-30: Output hydrographs – 2PM (Daily Input) – Verification Period – Tawalama Watershed (Semi Logarithmic Plot)

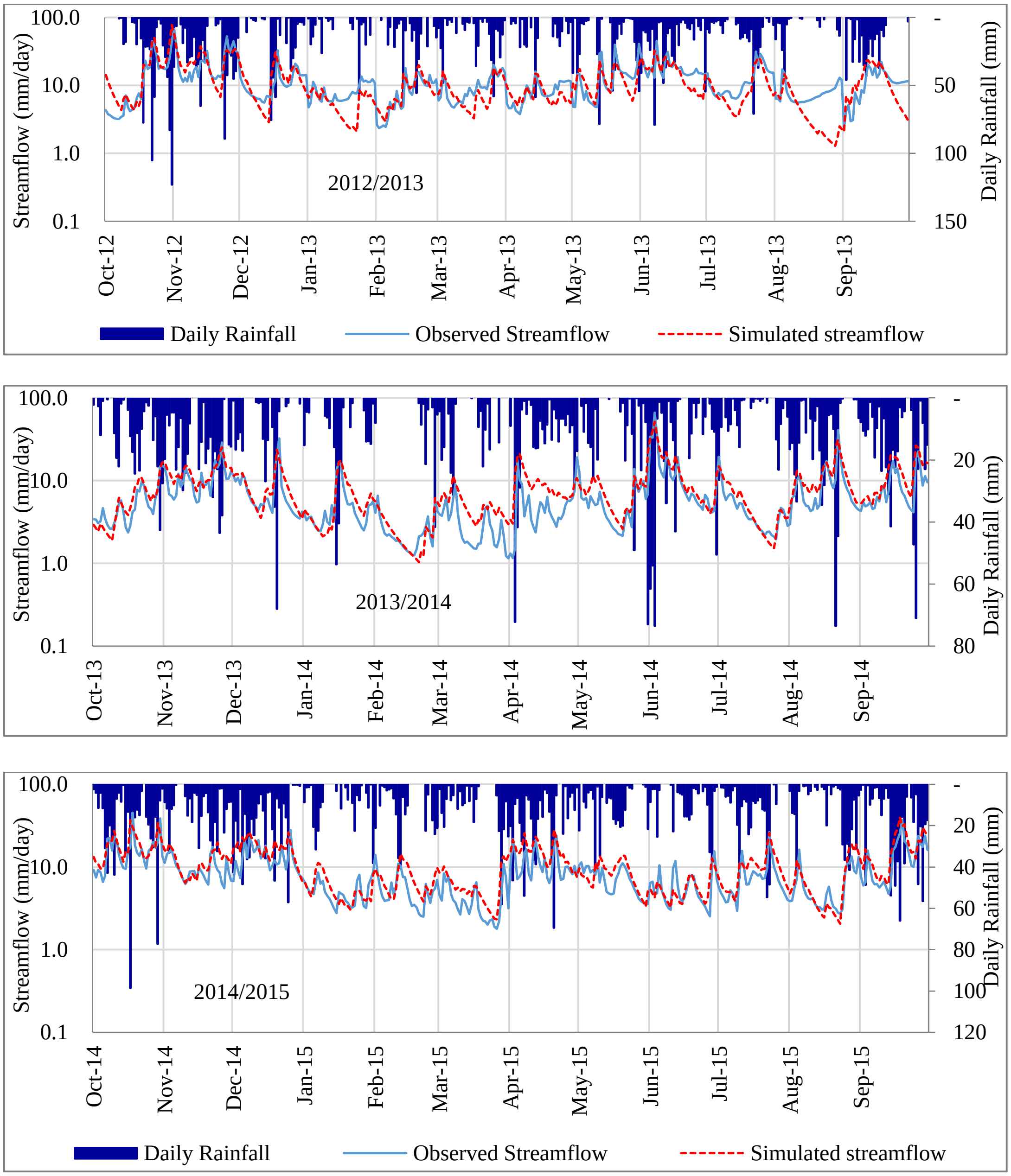

Figure 5-31: Output hydrographs – 2PM (Daily Input) – Verification Period – Tawalama Watershed (Semi Logarithmic Plot)

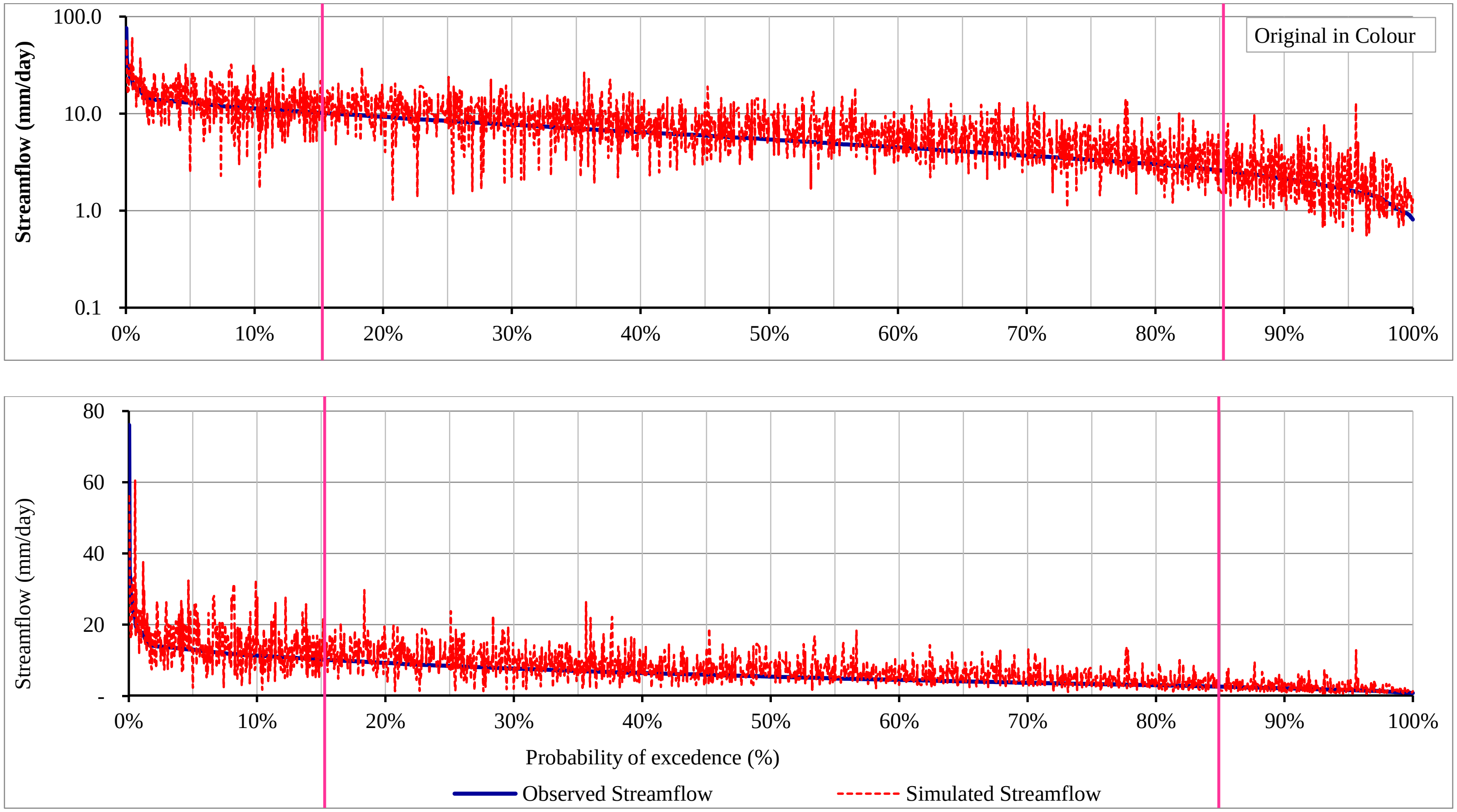

Figure 5-32: Flow Duration curve – 2PM (Daily Input) – Verification Period – Tawalama Watershed

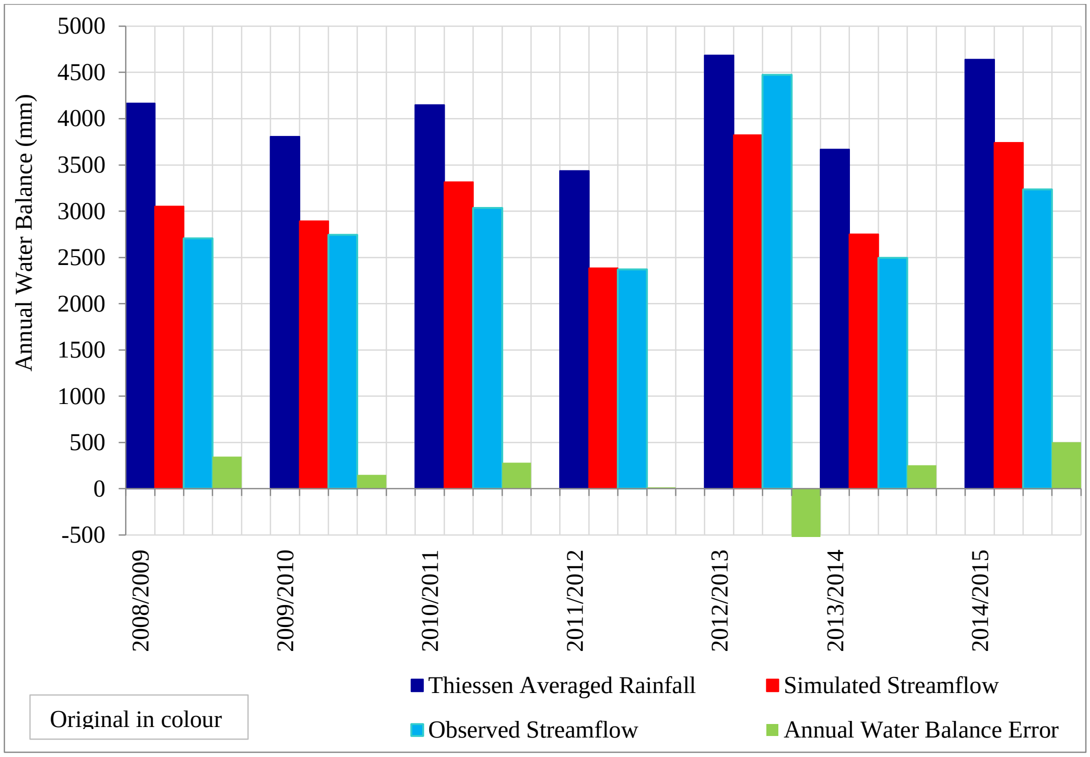

Figure 5-33: Annual Water Balance - 2PM (Daily Input) – Verification Period – Tawalama Watershed

5.7.2.2 Ellagawa Watershed

a) Calibration Period (2006/07 – 2009/10)

Model outflow hydrographs (Figure 5-37 and Figure D-28), flow duration curves (Figure 5-38 and Figure D-22), Annual water balance (Figure 5-39) and objective function values (Table 5-14) indicate a significant MRAE of 0.94. Though the reproduction of watershed response appear as in order and compatible with rainfall, the comparison with observations reflect a poor matching especially in high and medium flow (Figure 5-34). This may be due to the issues that were noted during data checking. Duration curves show a significant over estimation.

Daily outputs were summed to compare the estimation of monthly outputs. Comparison of monthly outputs from monthly inputs are in (Figure 5-35). Monthly estimates flow daily inputs show a higher over estimation when compared with the monthly input.

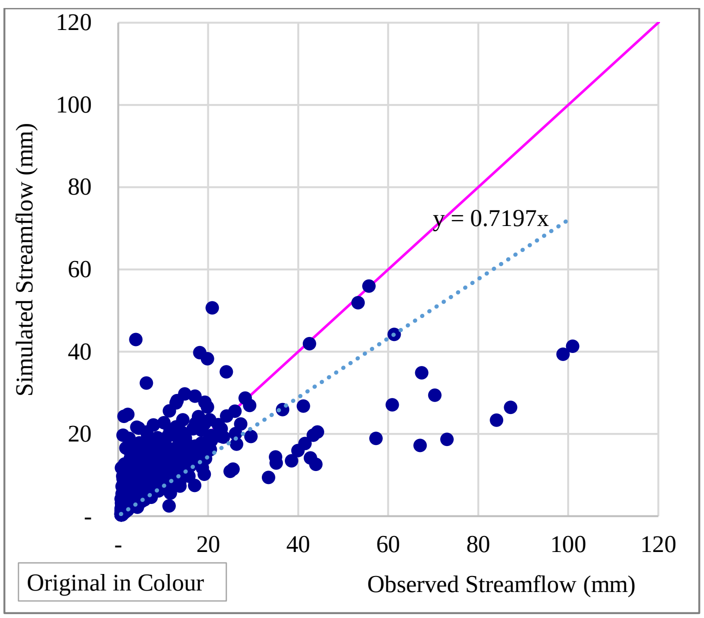

Figure 5-34: 2PM (Daily Input) – Daily Streamflow Estimation – Calibration Period – Ellagawa Watershed

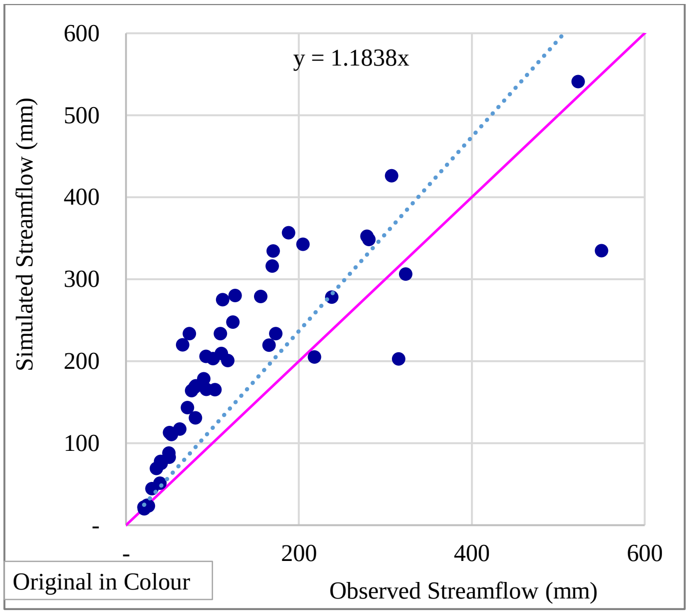

Figure 5-35: 2PM (Daily Input) – Monthly Streamflow Estimation – Calibration Period – Ellagawa Watershed

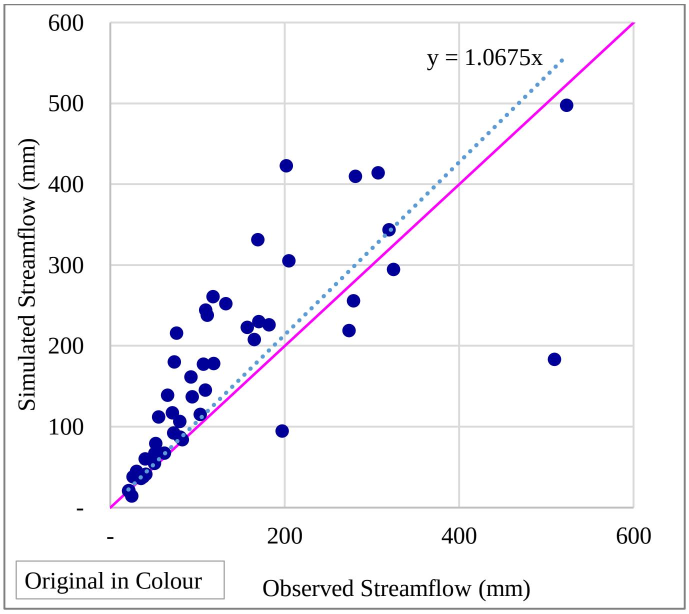

Figure 5-36: 2PM (Monthly Input) – Monthly Streamflow Estimation – Calibration Period – Ellagawa Watershed

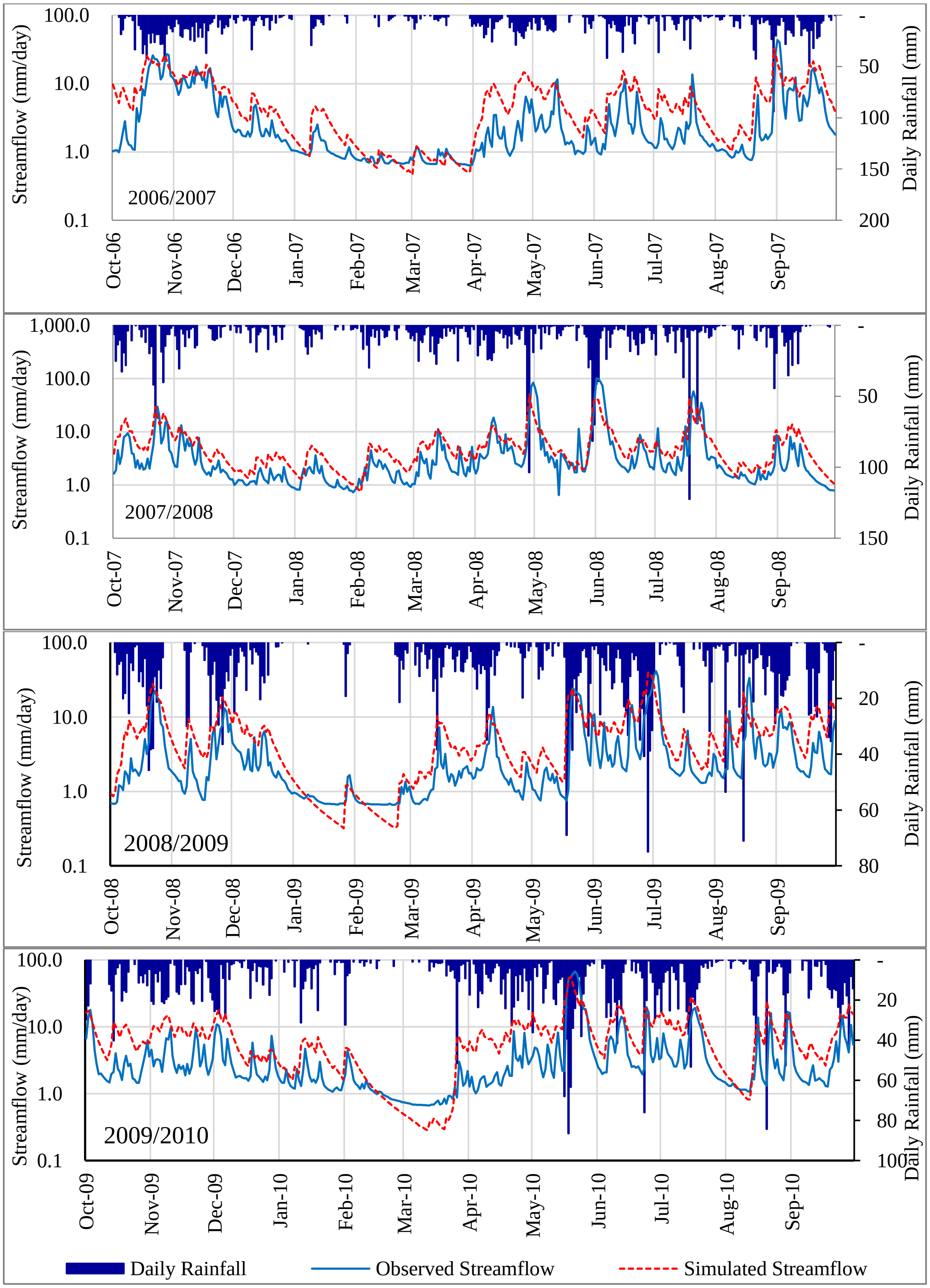

Figure 5-37: Output hydrographs – 2PM (Daily Input) – Calibration Period – Ellagawa Watershed (Semi Logarithmic Plot)

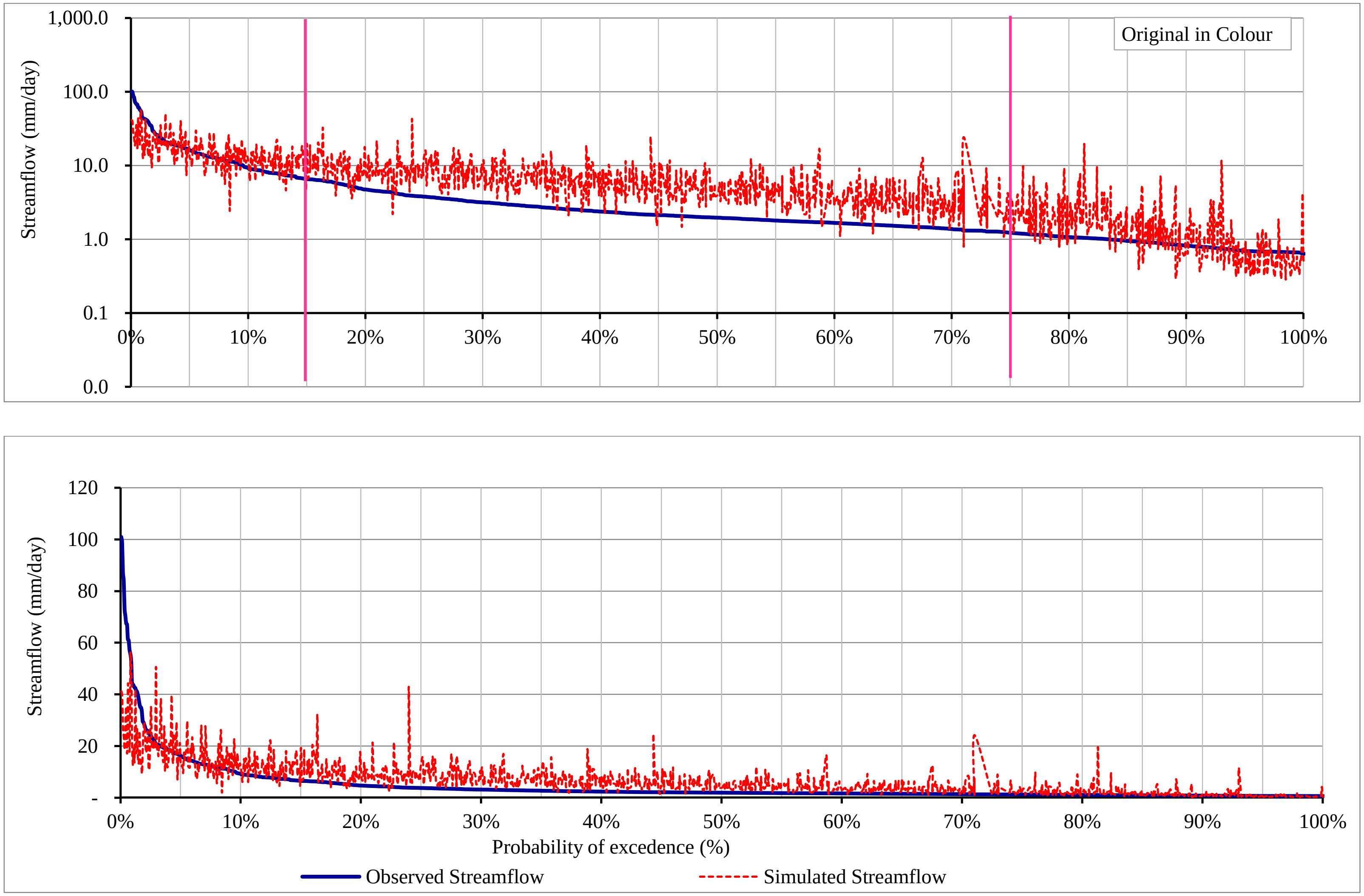

Figure 5-38: Flow Duration curve – 2PM (Daily Input) – Calibration Period - Ellagawa Watershed

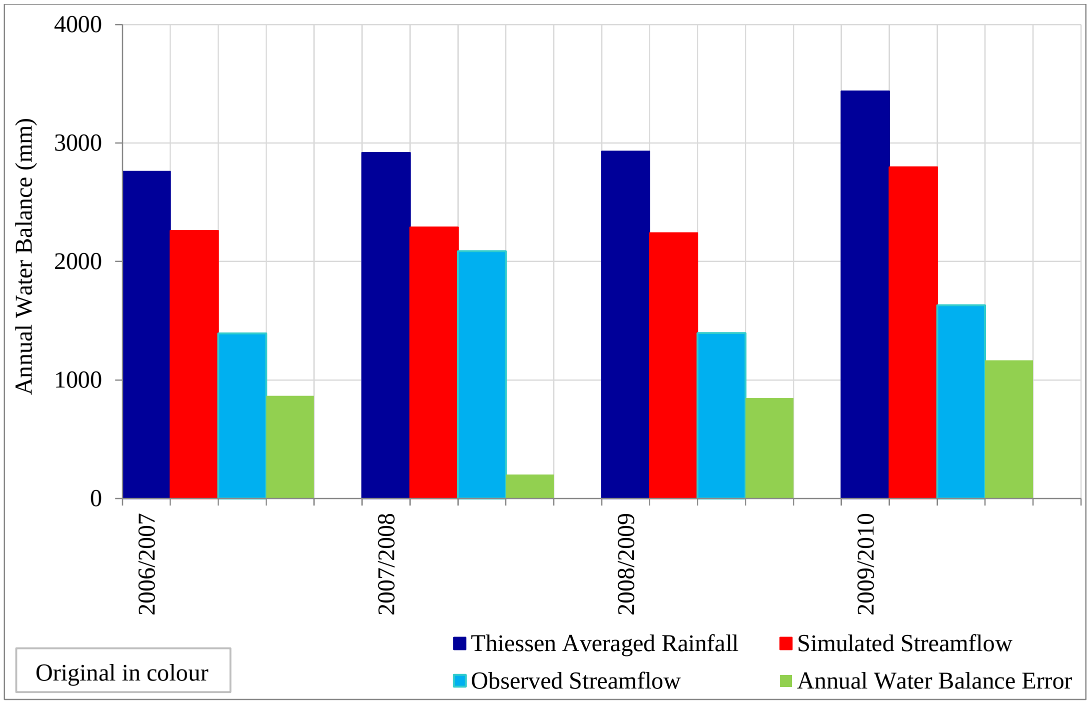

Figure 5-39: Annual Water Balance - 2PM (Daily Input) – Calibration Period – Ellagawa

Table 5-14: Comparison of Model Performance 2PM (Daily Input) – Ellagawa Watershed

Comparison of Model Performance	**2PM (Daily Input)**	
	Calibration	**Validation**
MRAE - Overall	1.2028	1.6963
MRAE - High	0.4394	0.6480
MRAE - Medium	1.4761	1.9976
MRAE - Low	0.6939	1.5058
Nash-Sutcliffe	0.4282	0.1025
Parameter - c	1.29	1.29
Parameter - Sc	827.84	827.84
Average WB difference	770.85	1,263.44
Data Duration	2006/07 – 2009/10	2010/11 – 2013/14

b) Verification Period (2010/11 – 2013/14)

Model outflow hydrographs (Figure 5-43 and Figure D-16), flow duration curves (Figure 5-44 and Figure D-23), annual water balance (Figure 5-45) and objective function values (Table 5-14) indicate a very poor matching of hydrographs. The duration curve shows a very significant over estimated model predictions. The scatter plots in Figure 5-40 also shows this character of model computations with respect to low and intermediate flows. The high flows are under estimated.

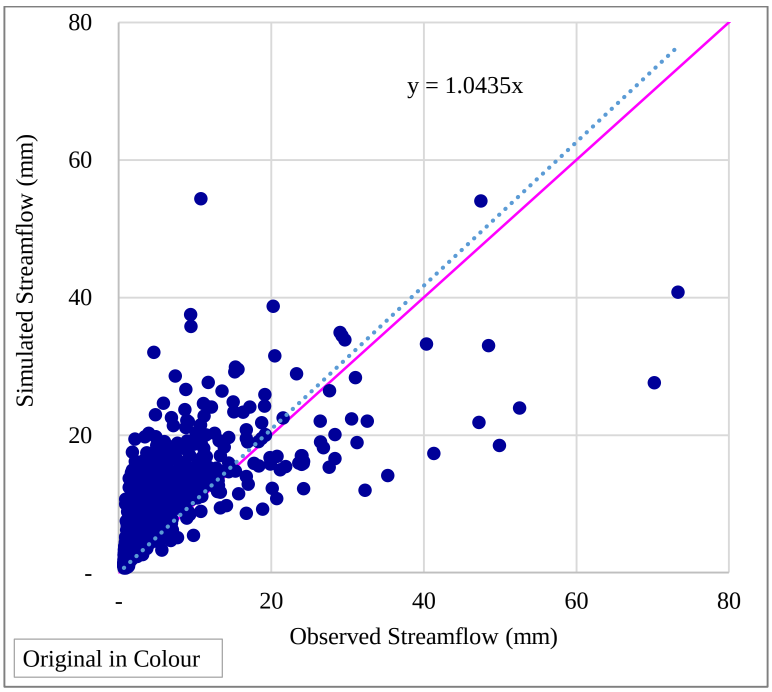

Figure 5-40: 2PM (Daily Input) – Daily Streamflow Estimation – Validation Period – Ellagawa Watershed

Daily outputs were summed to compare the estimation of monthly outputs (Figure 5-41) with monthly outputs from monthly inputs (Figure 5-42). Comparisons clearly show a higher over estimation when daily inputs are used. Computations clearly show a higher over estimation when daily inputs are used. Over estimation was also noted in the seasonal estimations (Figure D-37 and Figure D-52).

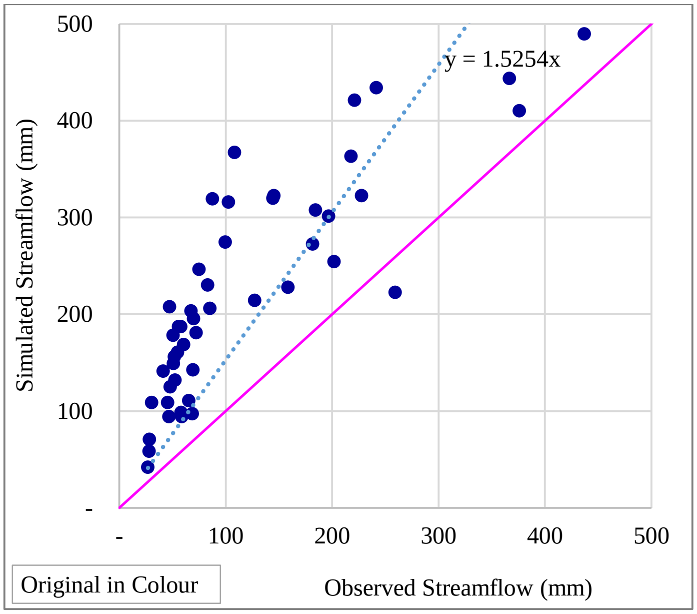

Figure 5-41: 2PM (Daily Input) – Monthly Streamflow Estimation – Validation Period – Ellagawa Watershed

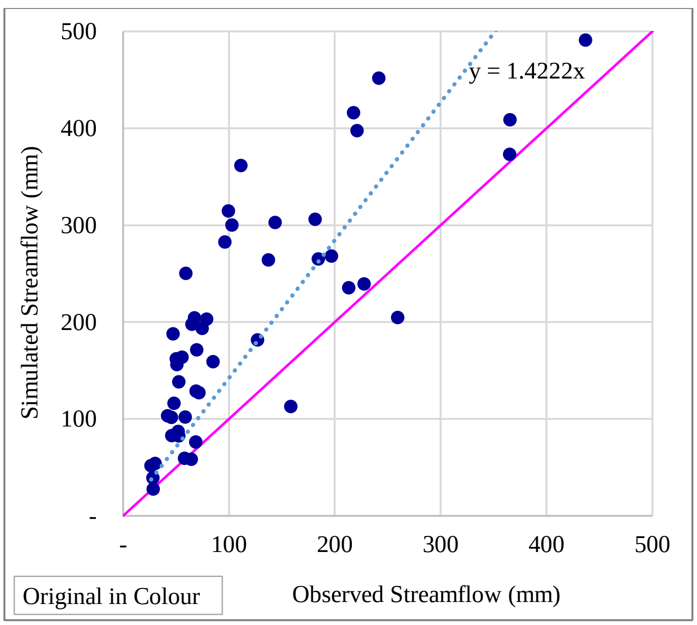

Figure 5-42: 2PM (Monthly Input) – Monthly Streamflow Estimation – Validation Period – Ellagawa Watershed

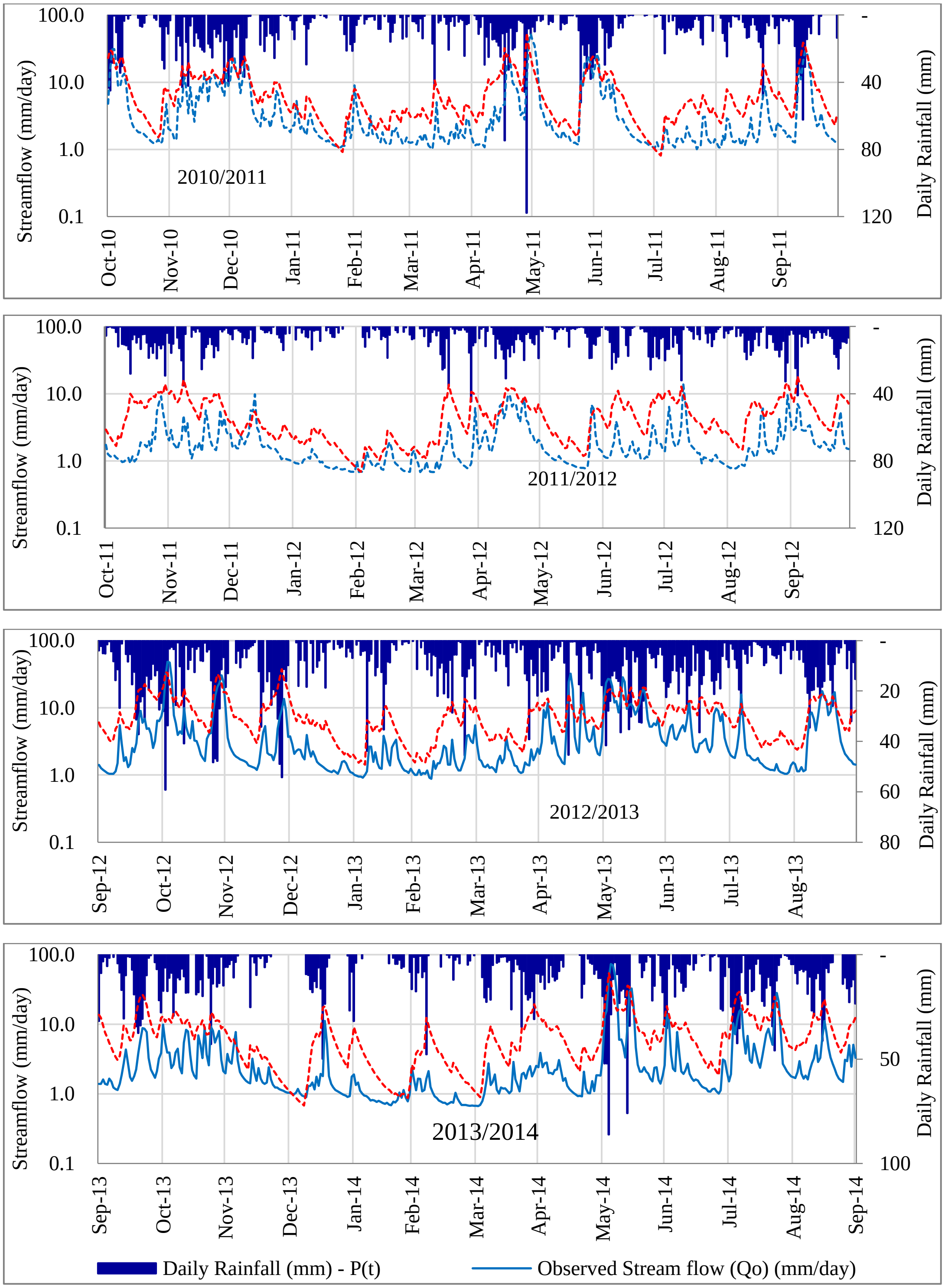

Figure 5-43: Output hydrographs – 2PM (Daily Input) – Verification Period – Ellagawa Watershed

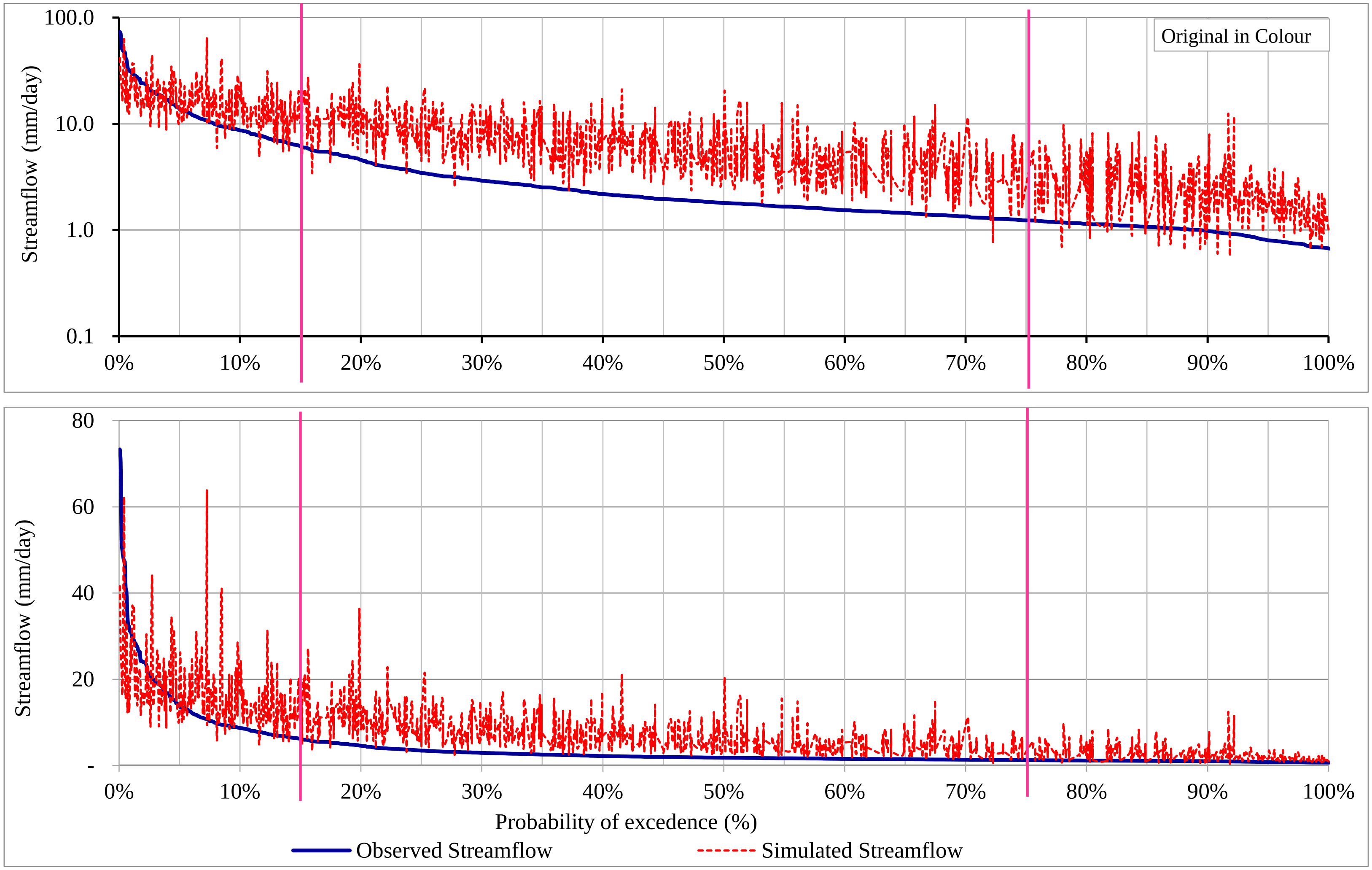

Figure 5-44: Flow Duration curve – 2PM (Daily Input) – Validation Period - Ellagawa Watershed

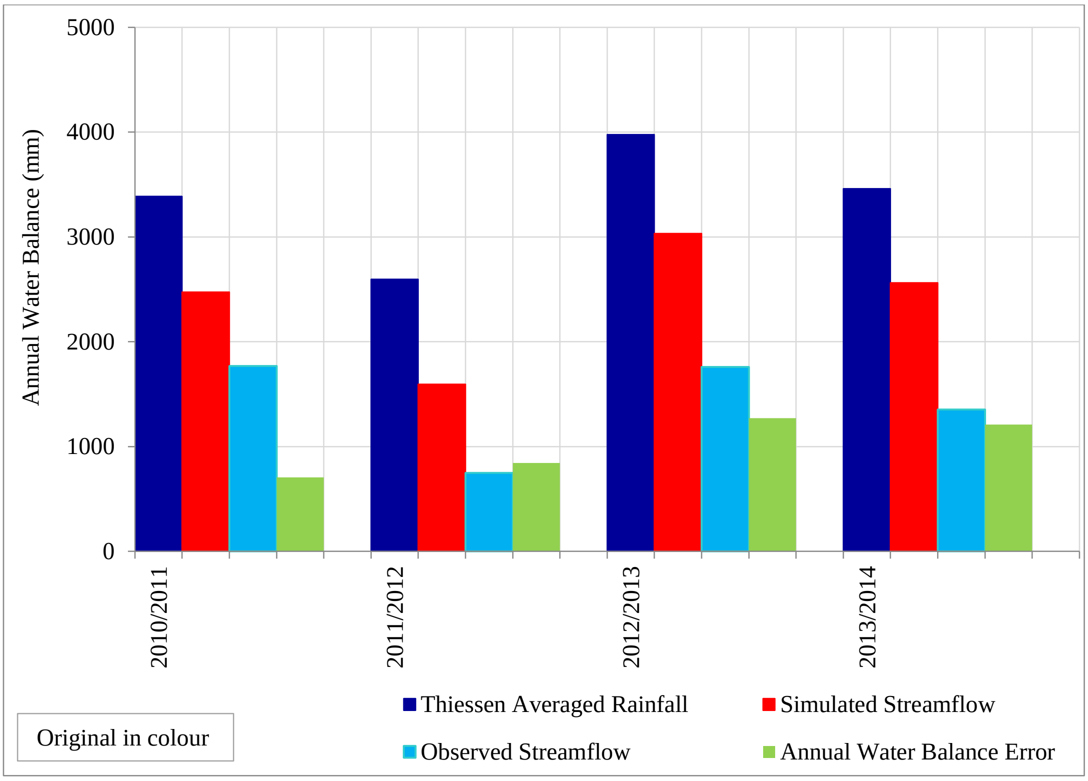

Figure 5-45: Annual Water Balance - 2PM (Daily Input) – Verification – Ellagawa

5.7.3 Summary of 2PM (Daily Input) Model Performance

In both watersheds the performance of two parameter model with daily data showed an over estimation of streamflow. In the case of Tawalama which had the best model reproductions, the over estimation was slight. In case of Ellagawa, the over estimation was probably exaggerated by the data disparities which were questioned during data checking.

Monthly flow estimations with daily inputs were also not at an acceptable level when compared with monthly flow estimates with monthly outputs. In both cases use of daily inputs reflected a clear over estimation.

Evaluation of both monthly and daily estimations reflects a similar, near uniform over estimation of streamflow estimation when compared with observed data.

5.8 Three Parameter Model (Monthly Input)

5.8.1 General

Evaluation of two parameter model (Xiong.,1999) with monthly inputs and daily inputs revealed the tendency of the model to overestimate the outflow. Over estimation in streamflow reflected a dependency on the rainfall input. For example low rainfall period over estimations were lesser than those in high rainfall periods. Hence, a three parameter model was conceptualized. The first two equations are the same as Equation 9 and 10. In addition a third parameter called 'AF' (Adjustment Factor) was introduced. The adjustment factor is to either cater to an increase or decrease of flow estimates by the model. Though the Xiong & Guo,(1999) model looks carefully at evapotranspiration and storage capacity of soil matrix, it does not indicate any consideration of land cover, slope, soil, depression storage etc. Hence the factor 'AF' would help to capture the flow transfer capacity of a catchment. The runoff coefficient of a catchment depends on many factors and the main factors are rain, slope, soil and land cover (Perera.K.R.S. & WIjesekara.N.T.S.,2003).

Accordingly the three parameter model, equations are shown as 9, 10, 11 and 12. In order to enable the consideration of runoff transfer factors such as slope, soil, land cover, depression storage etc., the Adjustment factor 'AF' was considered as a parameter to be calibrated.

$$E(t)/ EP(t) = C \times \tanh [P(t)/ EP(t)] \quad (16)$$

$$Q(t) = S(t-1) + \tanh\{(S(t-1)+P(t)-E(t)/Sc)\} \quad (17)$$

$$(Q_{calculated})_t = AF \times Q(t) \quad (18)$$

5.8.2 Calibration of Three Parameter Model

Similar to calibrating two parameter models (described earlier), the tool for optimization was 'solver' in MS Excel.

Optimization initially carried out a coaser search technique to capture the region of Global minimum. Then a more intense search was carried out by using finer initial parameters. Details of search range and corresponding MRAE values are in Table D-13 and Table D-14 respectively for Tawalama and Ellagawa watersheds. Optimized parameters are shown in Table 5-15.

Table 5-15: Optimized Parameters - 3PM (Monthly Input)

Parameter	Tawalama	Ellagawa
c	1.02	0.52
SC	1,292.00	975.20
AF	0.83	0.46

5.8.3 Tawalama Watershed

5.8.3.1 Calibration

Calibration results of Tawalama watershed are in Table 5-16. Results indicated a marked improvement in the MRAE value from 0.2 in 2PM (Monthly input) to 0.17. The flow duration curve indicated that the improvements were in the intermediate and low flow prediction. The high flow matching status deteriorated from MRAE 0.178 to 0.214. Outflow hydrographs (Figure 5-46), flow duration curve (Figure 5-47), and annual water balance (Figure 5-48) showed the improved performance of the three parameter model during calibration.

Table 5-16: Objective Function values - 3PM (Monthly Input) – Tawalama Watershed

Comparison of performance	3PM (Monthly Input)	
	Calibration	Validation
Parameter - c	1.02	1.02
Parameter - Sc	1,292.00	1,292.00
Parameter - AF	0.83	0.83
MRAE - Overall	0.1733	0.1807
MRAE - High	0.2140	0.1720
MRAE - Medium	0.1658	0.1895
MRAE - Low	0.1368	0.1647
Nash-Sutcliffe	0.6949	0.7272
Average WB difference	(316.18)	(263.19)
Data Duration	2000/01 – 2007/08	2008/09 – 2014/15

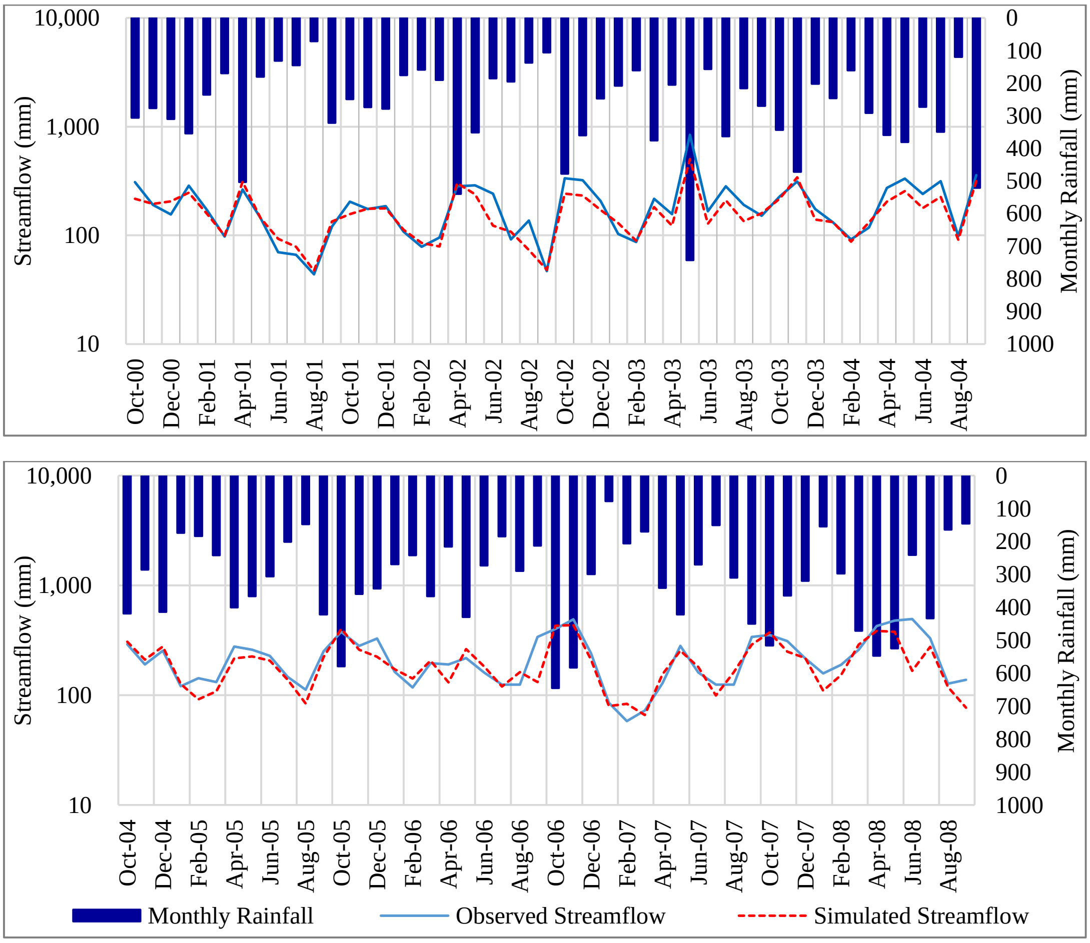

Figure 5-46: Output hydrographs – 3PM (Monthly Input) – Calibration – Tawalama Watershed

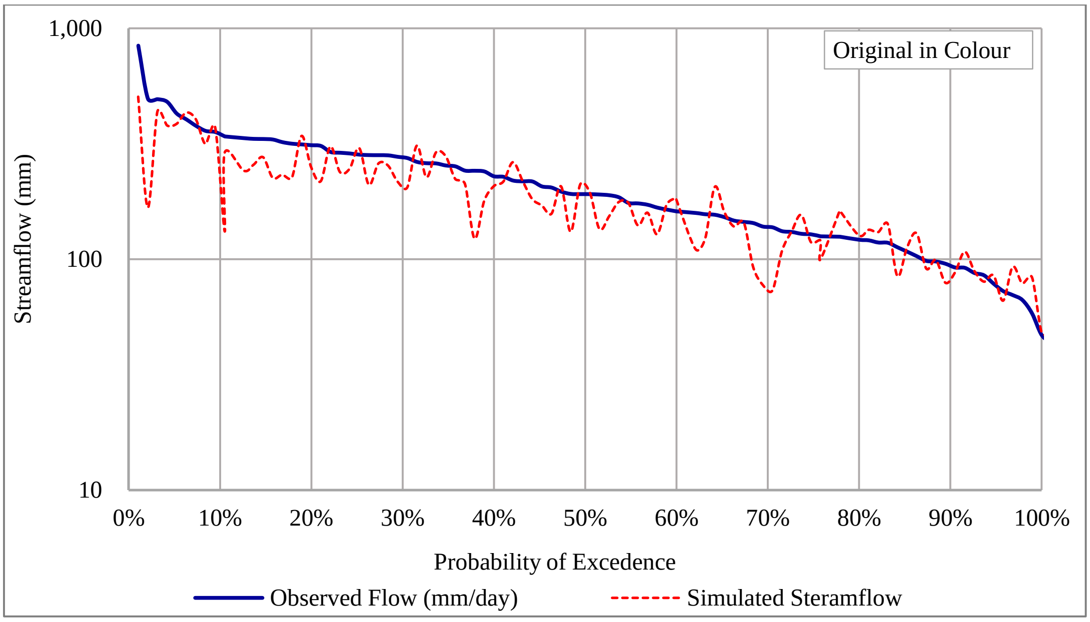

Figure 5-47: Flow duration curve – 3PM (Monthly Input) – Calibration – Tawalama Watershed

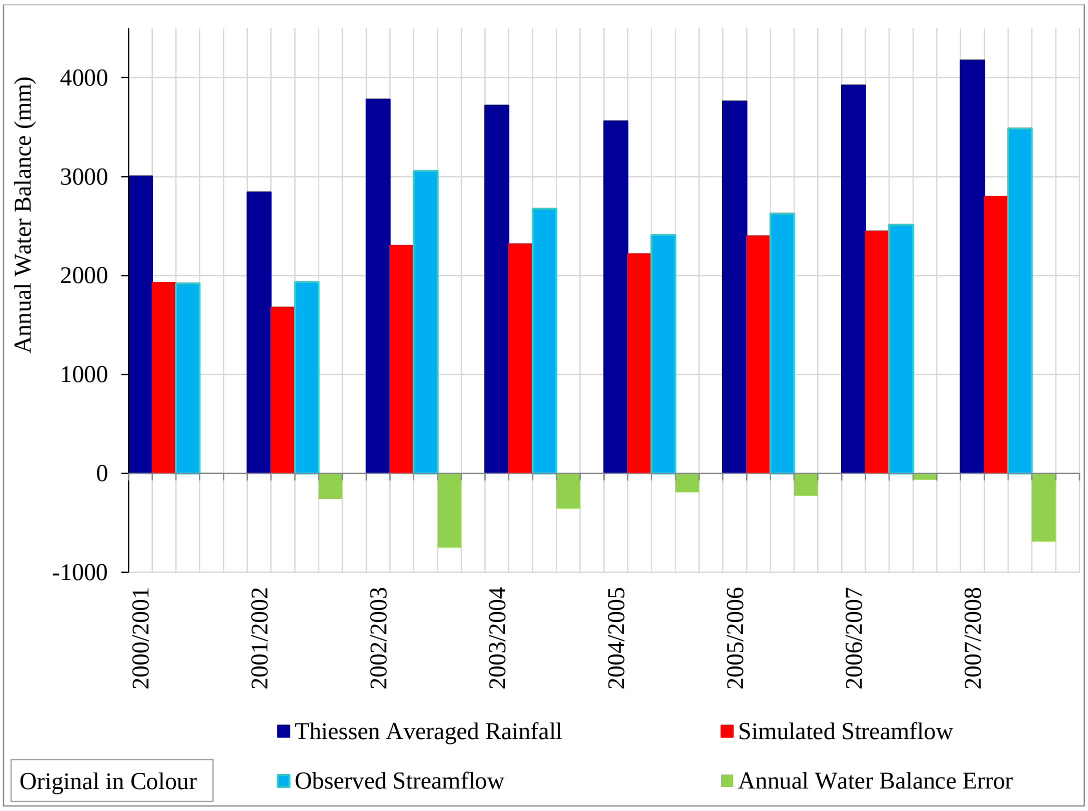

Figure 5-48: Annual Water Balance – 3PM (Monthly Input) – Calibration – Tawalama Watershed

5.8.3.2 Verification

Verification results (Table 5-16) also showed the improved MRAE from a value of 0.2 in 2PM (Monthly) to 0.18. Flow duration curve showed an improvement in both high flow and medium flow regions but the MRAE for low flows were slightly higher than in the case of 2PM (Monthly). Outflow hydrographs (Figure 5-49), flow duration curve (Figure 5-50) and annual water balance (Figure 5-73) reflected the improved performance during verification.

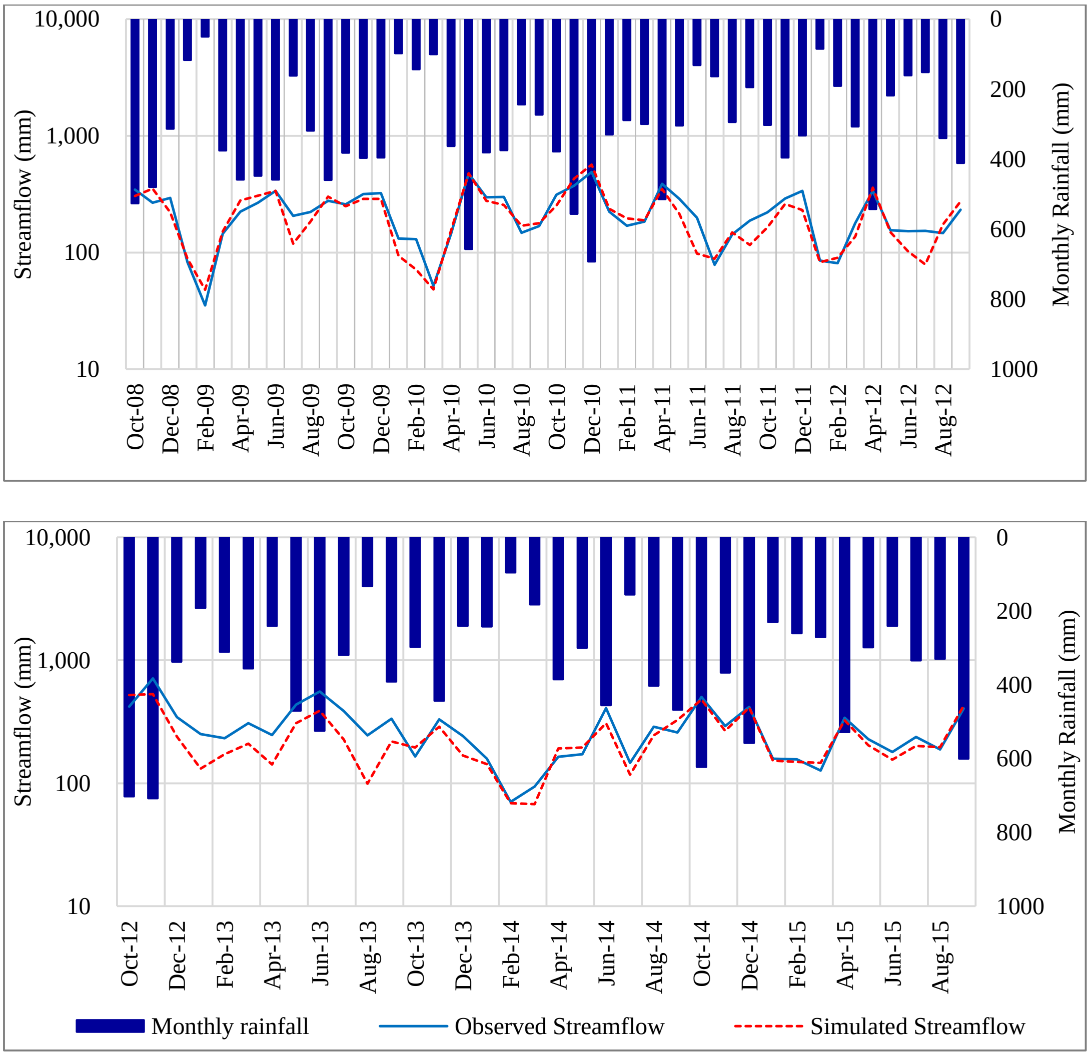

Figure 5-49: Output hydrographs – 3PM (Monthly Input) – Verification – Tawalama

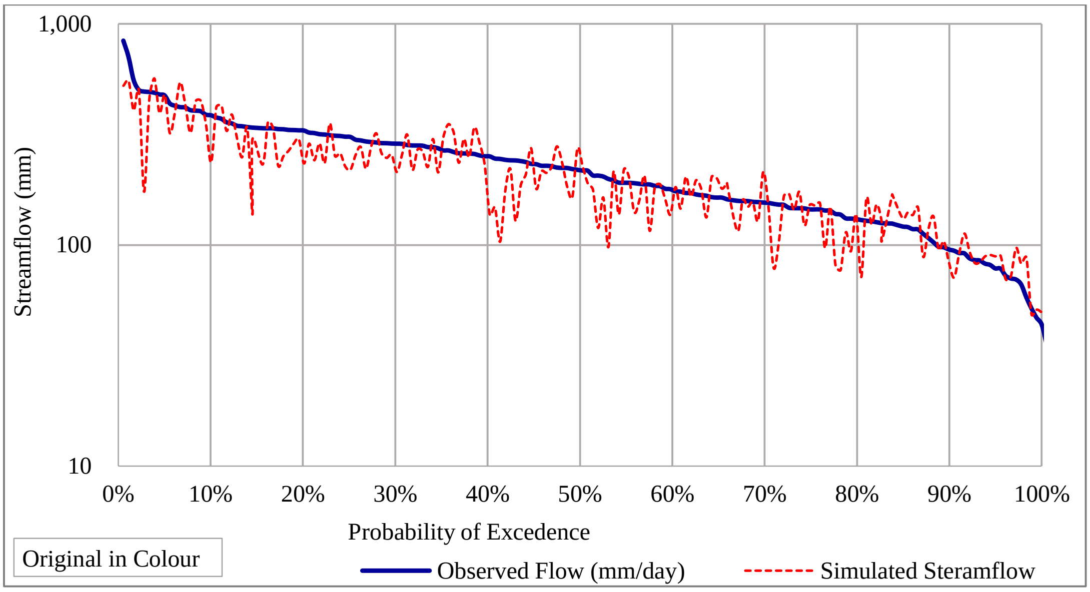

Figure 5-50: Flow duration curve – 3PM (Monthly Input) – Verification Period – Tawalama Watershed

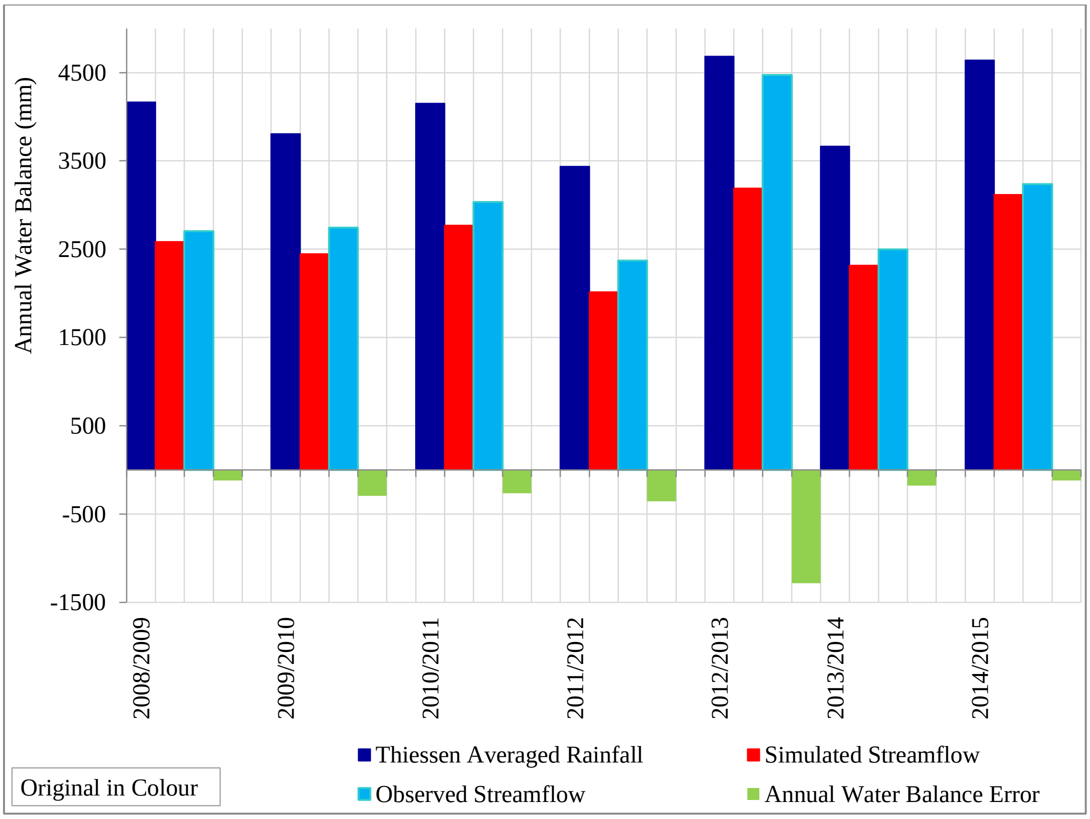

Figure 5-51: Annual Water Balance – 3PM (Monthly Input) – Verification Period – Tawalama Watershed

5.8.4 Ellagawa Watershed

5.8.4.1 Calibration

Calibration results of Ellagawa watershed are in Table 5-17. Three parameter model (Monthly Input) calibration was carried out while keeping the data disparities detected previously. Calibration of 3PM (Monthly Input) showed a marked improvement of MRAE from 0.48 to 0.22. The medium and low flow improvements were much greater than the high flows.

Table 5-17: Comparison of Model Performance 3PM (Monthly Input) – Ellagawa Watershed

Comparison of Model Performance	3PM (Monthly Input)	
	Calibration	Validation
Parameter - c	0.52	0.52
Parameter - Sc	974.67	974.67
Parameter - AF	0.46	0.46
MRAE - Overall	0.2254	0.4016
MRAE - High	0.33	0.31
MRAE - Medium	0.18	0.39
MRAE - Low	0.11	0.55
Average WB difference	(441.10)	(70.44)
Data period	2006 - 2010	2010 - 2014

Outflow hydrographs (Figure 5-52), flow duration curve (Figure 5 53) and annual water balance (Figure 5-54) showed the vast improvement in the model estimations.

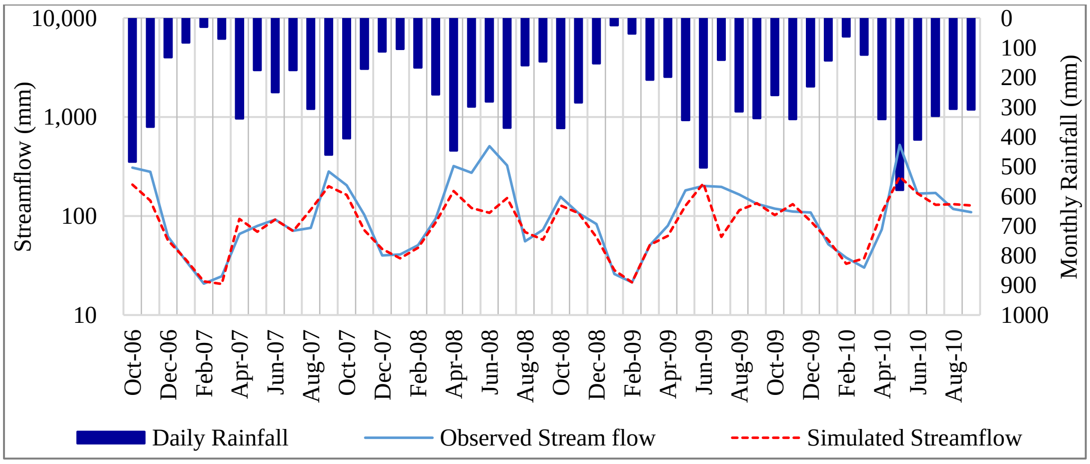

Figure 5-52: Output hydrographs – 3PM (Monthly Input) – Calibration – Ellagawa

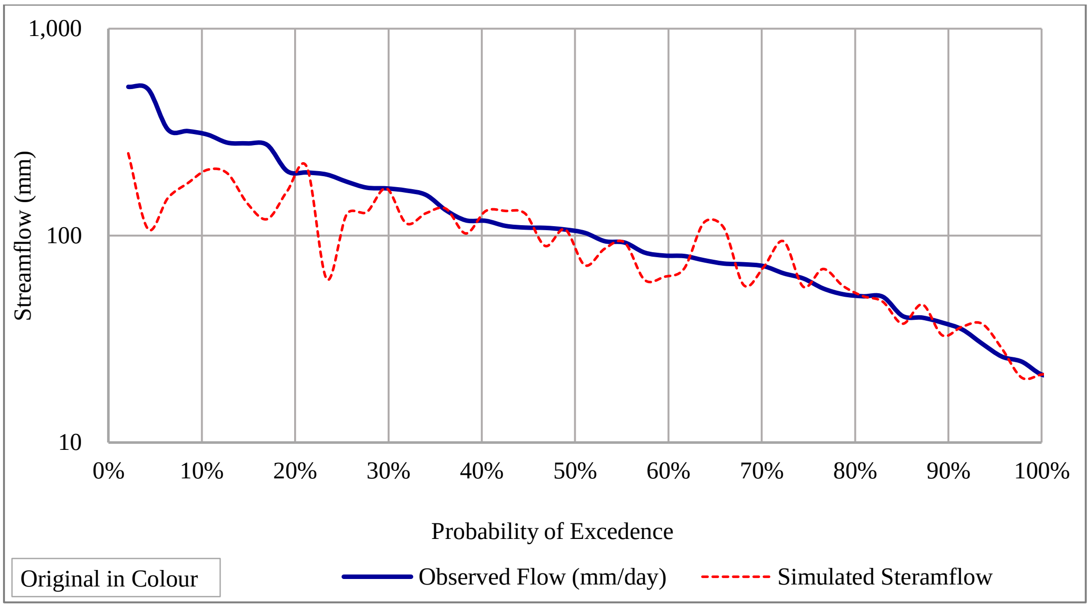

Figure 5-53: Flow duration curve – 3PM (Monthly Input) – Validation Period – Ellagawa

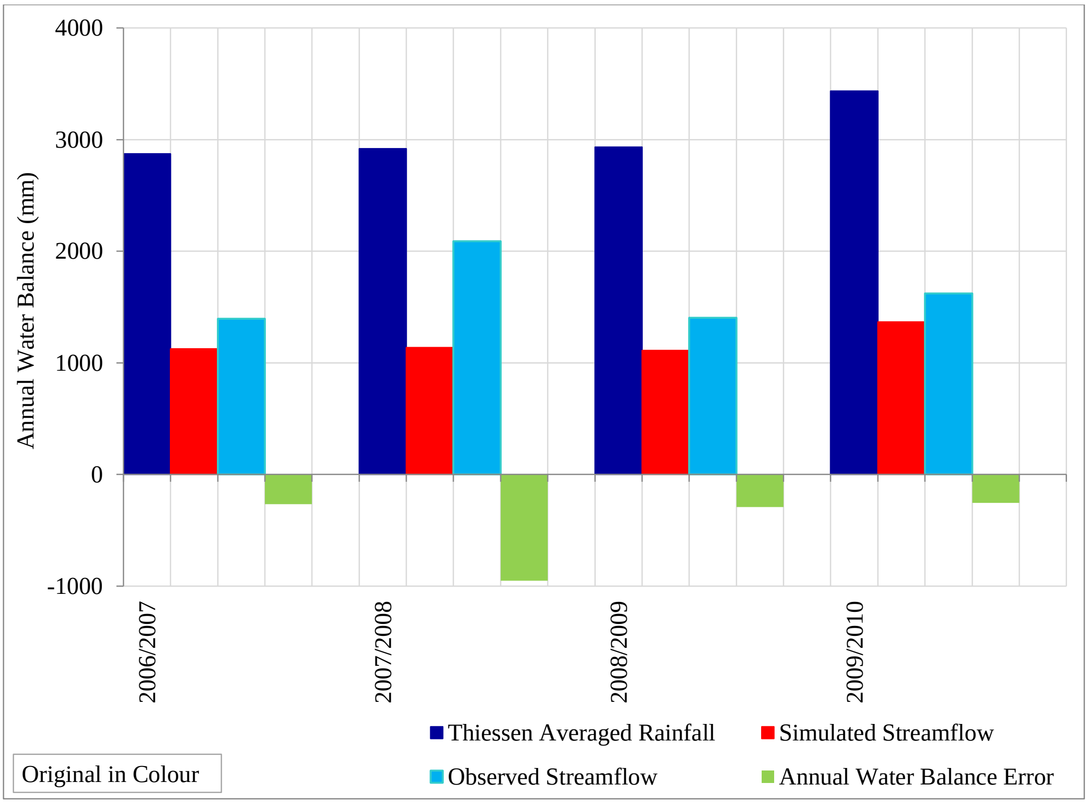

Figure 5-54: Annual Water Balance – 3PM (Monthly Input) – Calibration Period – Ellagawa

5.8.4.2 Verification

Verification results of Ellagawa watershed also showed a vast improvement in the MRAE value from 1.049 in 2PM (Monthly Input) to the present 3PM (Monthly Input). The medium flow estimations has largely contributed to this MRAE improvement. The hydrographs produced by the 3PM (Monthly Input) also show a much improved reflection of watershed rainfall.

Outflow hydrographs for the verification period (Figure 5-55), flow duration curve (Figure 5-56) and Annual water balance (Figure 5-57) indicate the performance status change due to the added parameter.

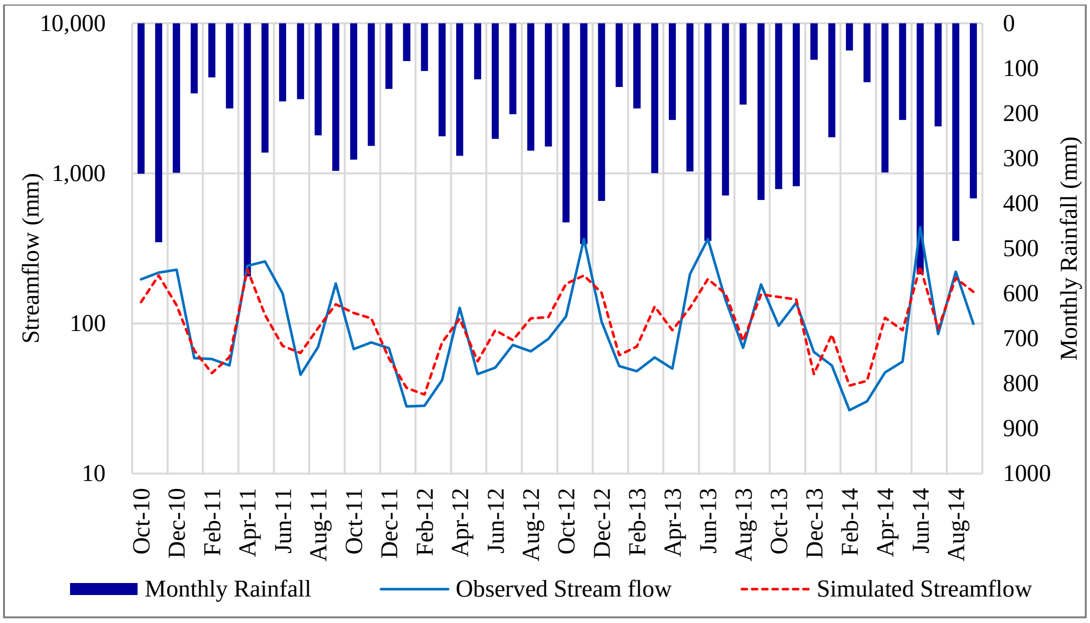

Figure 5-55: Output hydrographs – 3PM (Monthly Input) – Verification – Ellagawa

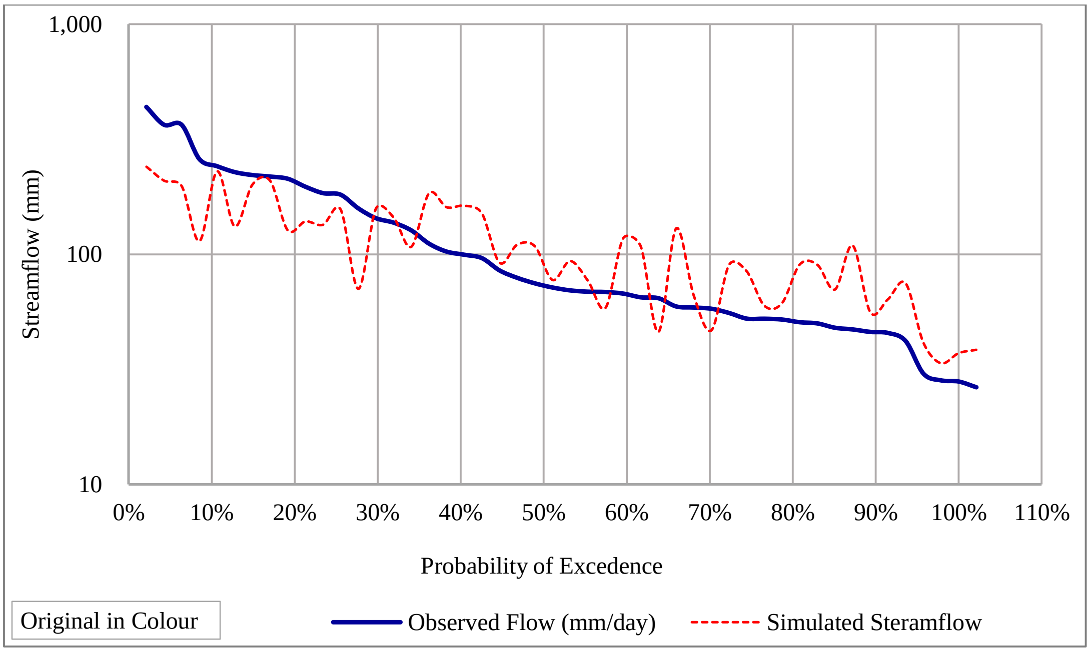

Figure 5-56: Flow duration curve – 3PM (Monthly Input) – Verification Period – Ellagawa

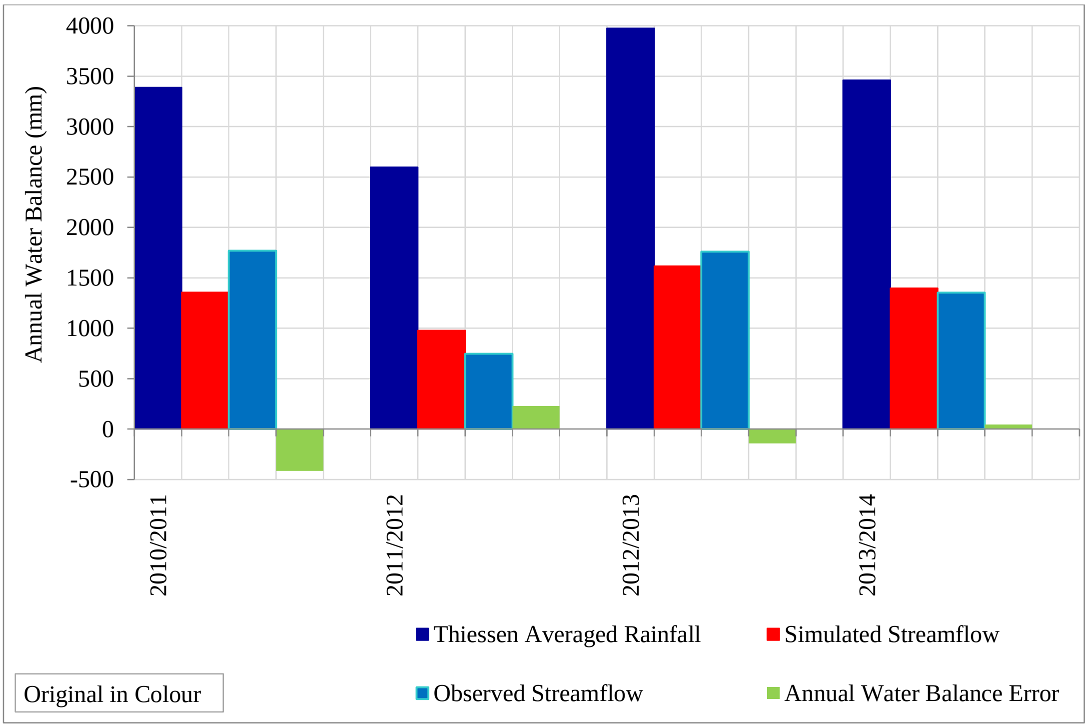

Figure 5-57: Annual Water Balance – 3PM (Monthly Input) – Verification Period – Ellagawa

5.9 Three Parameter Model (Daily Input)

5.9.1 General

Objective of the present work is to identify an easy to use rainfall-streamflow model which is capable of providing soil moisture indications. The proposed three parameter model calibrated and verified in this work is also an easy to use model when compared with the two parameter model proposed by Xiong & Guo, (1999). The three parameter model has performed very well in both watersheds when estimating monthly outputs from monthly inputs. Next, the three parameter model was tested with daily inputs to check its capability to make daily estimations. In this exercise no new effort was taken for parameter calibration and verification. The model used for this evaluation was the same 2 PM with parameters calibration using monthly data. However, estimations were carried out for the calibration and verification datasets of each watershed for the ease of comparison.

5.9.2 Tawalama watershed

5.9.2.1 Calibration Period

Performance corresponding to daily flow estimation showed an improvement in estimations from 0.4360 (Table 5-13) to 0.3202 (Table 5-18) when compared with the same from 2PM (Monthly Input) with daily inputs. However, the MRAE value showed a deterioration from 0.1733 to 0.3202 when compared with the 3PM monthly estimations. Table 5-18 show the indicators and parameter values for the calibration dataset.

Table 5-18: Indicators and Parameter values – 3PM (Daily Input) - Tawalama

Comparison of performance	3PM (Daily Input)	
	Calibration	Validation
Parameter - c	1.02	1.02
Parameter - Sc	1,292.00	1,292.00
Parameter - AF	0.83	0.83
MRAE - Overall	0.3202	0.3185
MRAE - High	0.2629	0.2551
MRAE - Medium	0.2997	0.3119
MRAE - Low	0.4811	0.4575
Nash-Sutcliffe	0.5127	0.6687
Average WB difference	(21)	(63.63)
Data period	2000 - 2008	2008 - 2015

Outflow hydrographs (Figure 5-58 and Figure 5-59), flow duration curve (Figure 5-59) and annual water balance (Figure 5-61) for calibration data set reflect a much improved model performance when producing daily data.

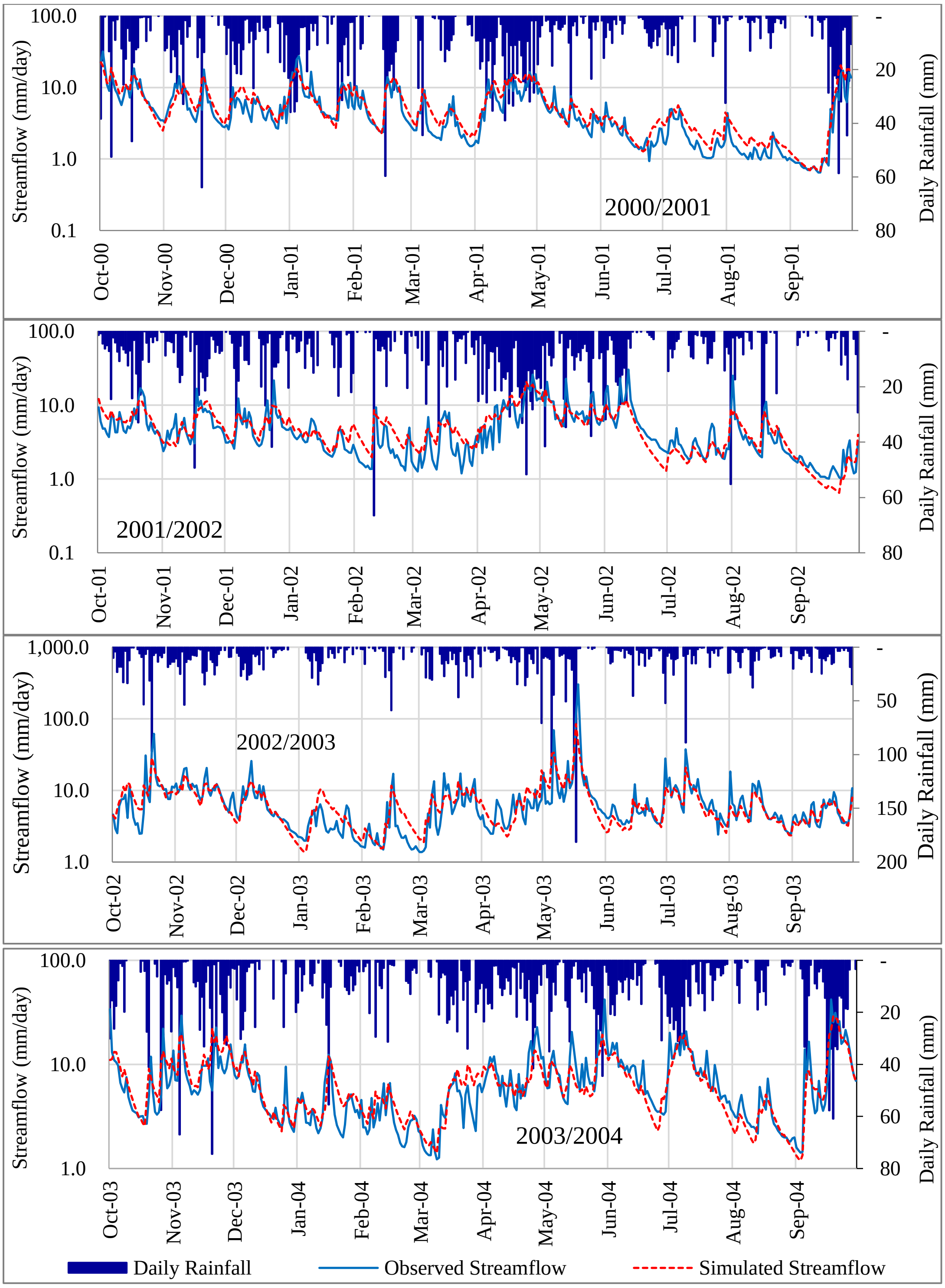

Figure 5-58: Output hydrographs – 3PM (Daily Input) – Calibration Period – Tawalama Watershed (Semi Logarithmic Plot)

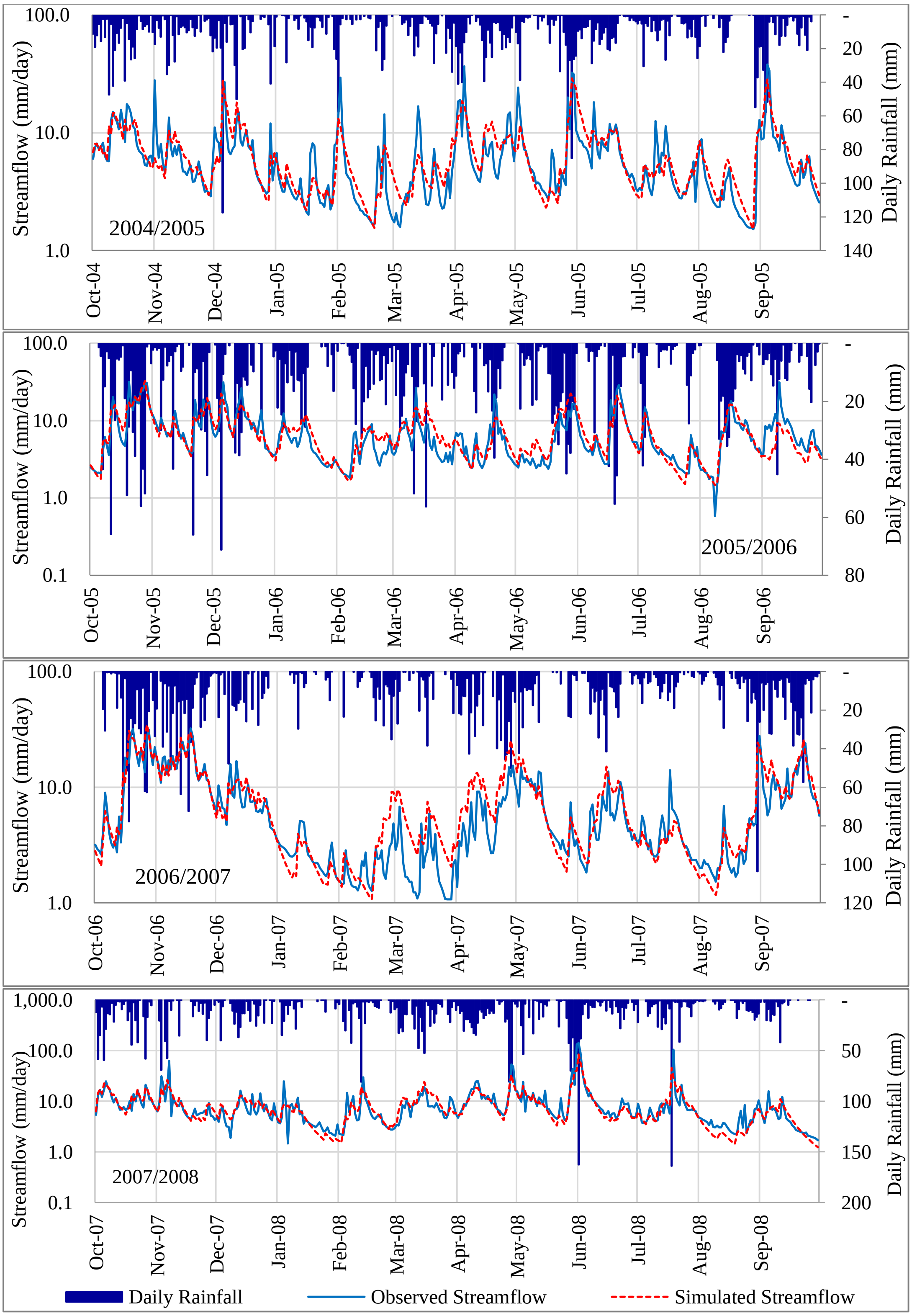

Figure 5-59: Output hydrographs – 3PM (Daily Input) – Calibration Period – Tawalama Watershed (Semi Logarithmic Plot)

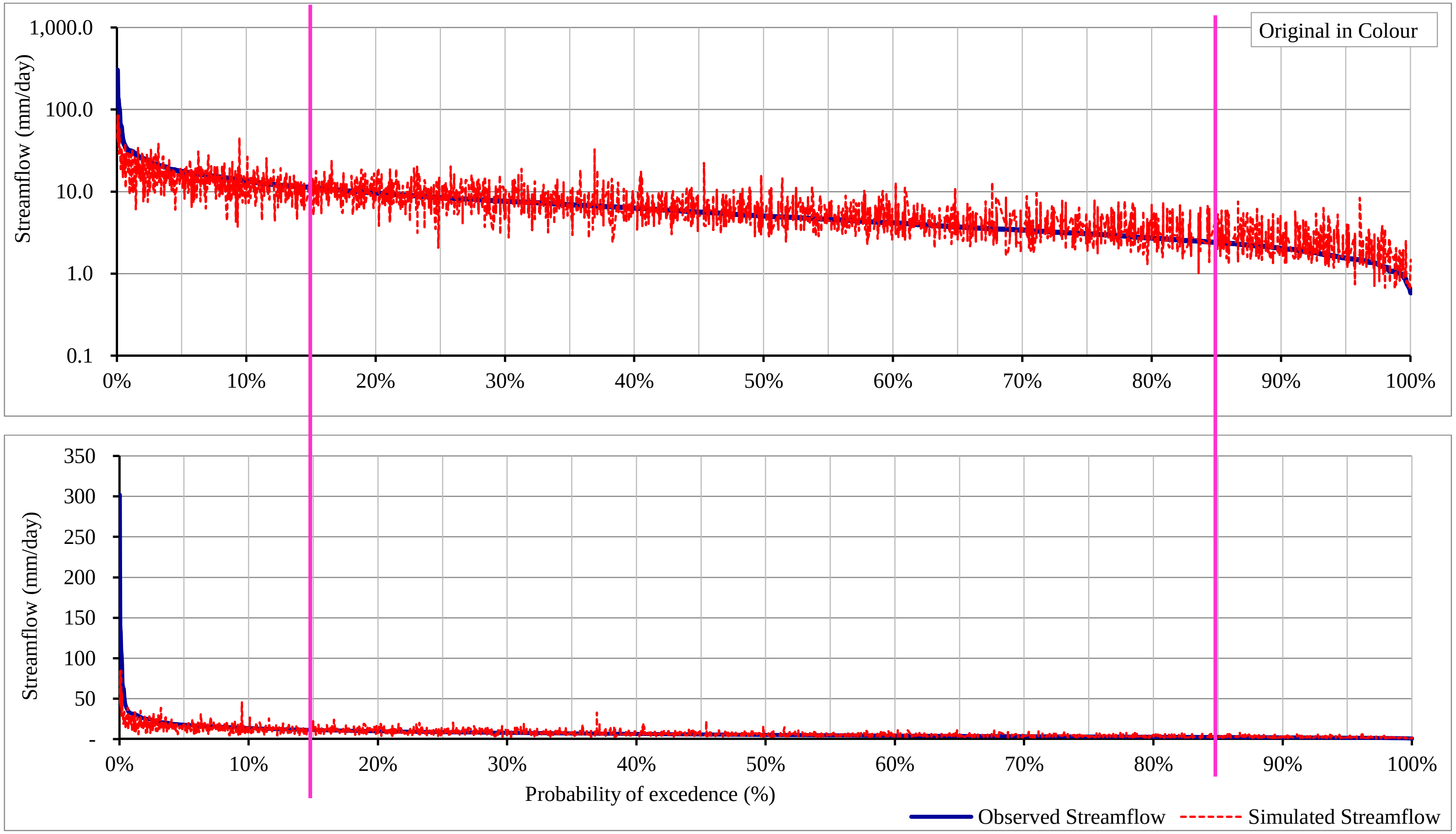

Figure 5-60: Flow duration curve – 3PM (Daily Input) — Calibration Period – Tawalama

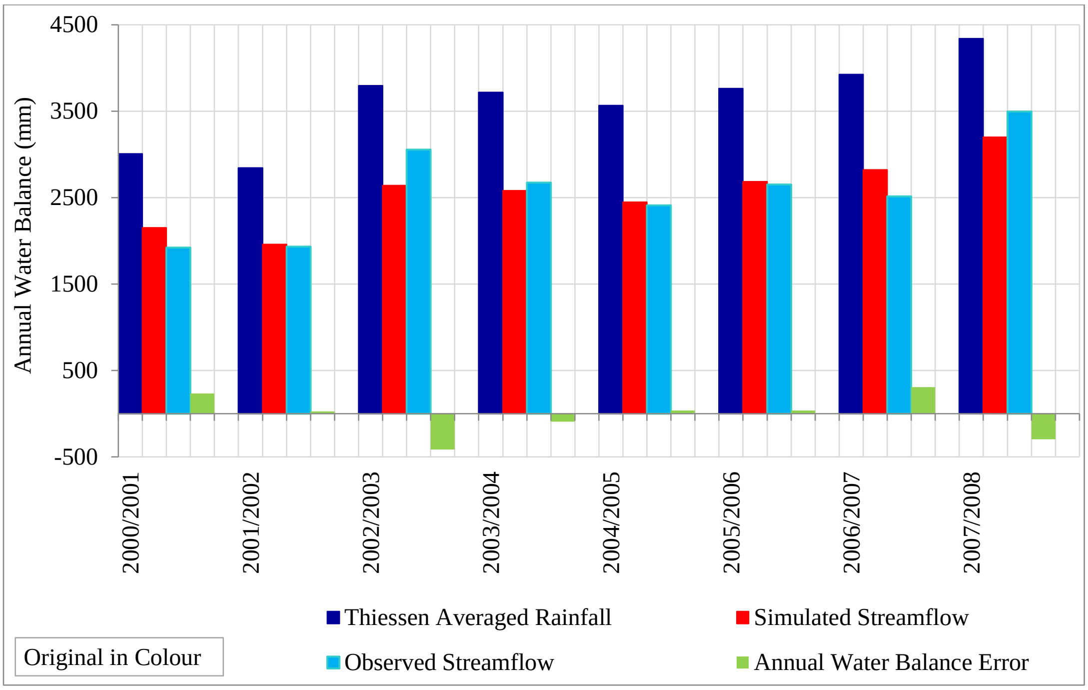

Figure 5-61: Annual Water Balance – 3PM (Daily Input) –– Calibration Period – Tawalama

The comparison of observed and computed daily streamflow also reflects the improved matching of low and medium flow by the 3PM (Figure 5-62). The high flow were under estimated.

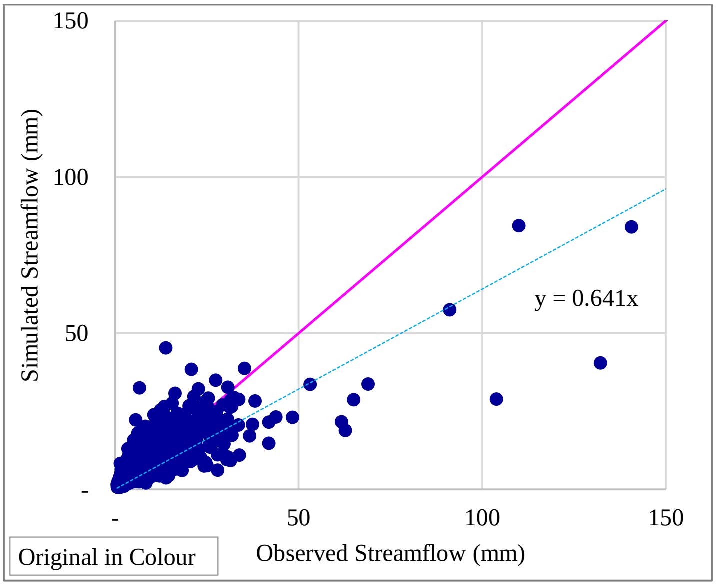

Figure 5-62: 3PM (Daily Input) – Daily Streamflow Estimation ––– Calibration Period – Tawalama

5.9.2.2 Verification period

Performance corresponding to daily flow estimation showed an improvement of MRAE from 0.4039 for the two parameter monthly model to 0.3185 for the present three parameter monthly model. However the MRAE values for verification period showed a deterioration from 0.1807 to 0.1385, when compared with the three parameter monthly estimations. Table 5-18 show the indicators and parameter values corresponding to the verification data set. Outflow hydrographs (Figure 5-63), flow duration curve (Figure 5-64) and annual water balance (Figure 5-65) for verification data set reflect a much improved model performance.

Comparison of observed and computed streamflow also reflected an improved matching of hydrograph by the three parameter model (Figure 5 66). The under estimation of highflows could be noted.

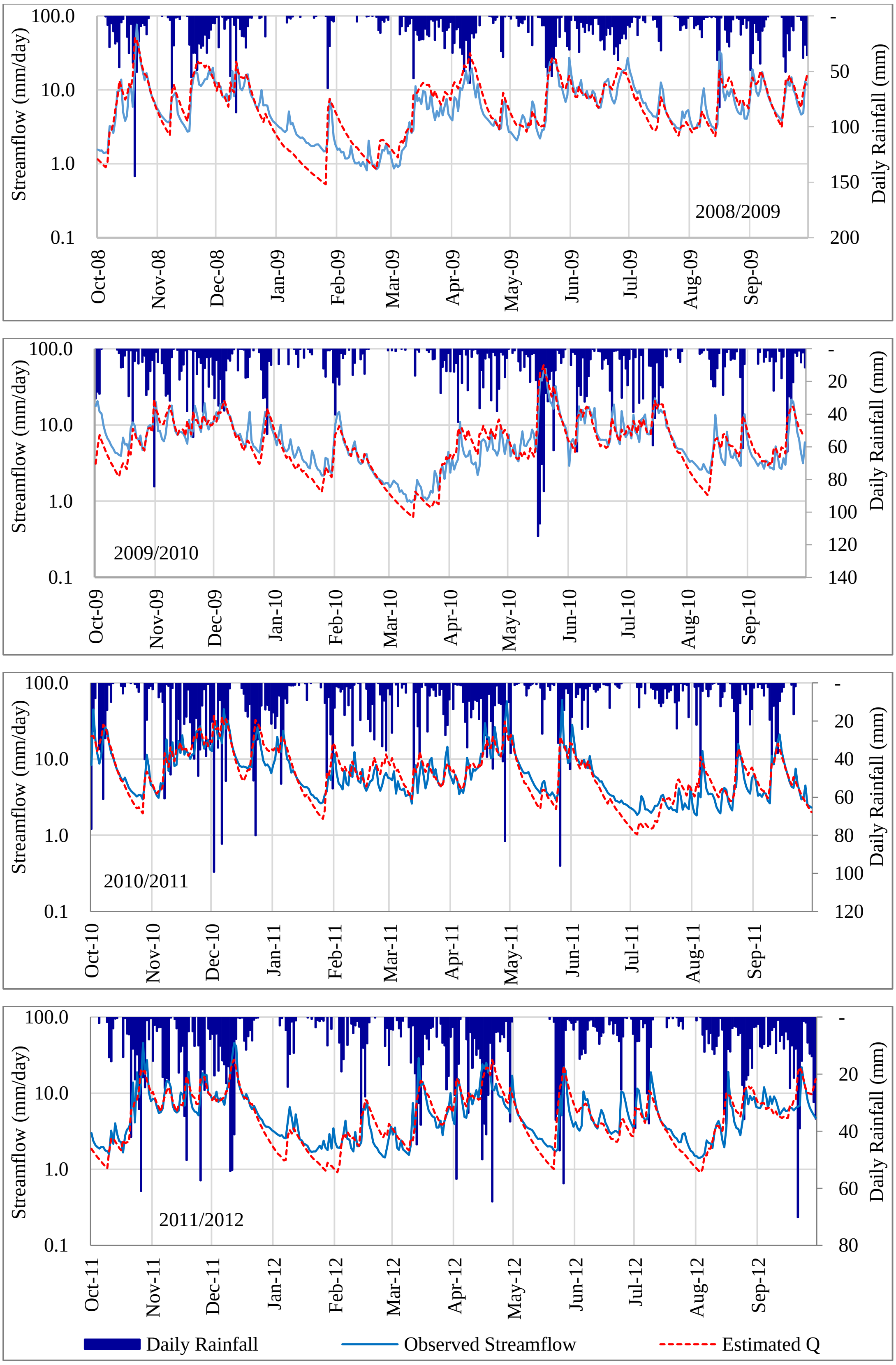

Figure 5-63: Output hydrographs – 3PM (Daily Input) – Verification Period – Tawalama

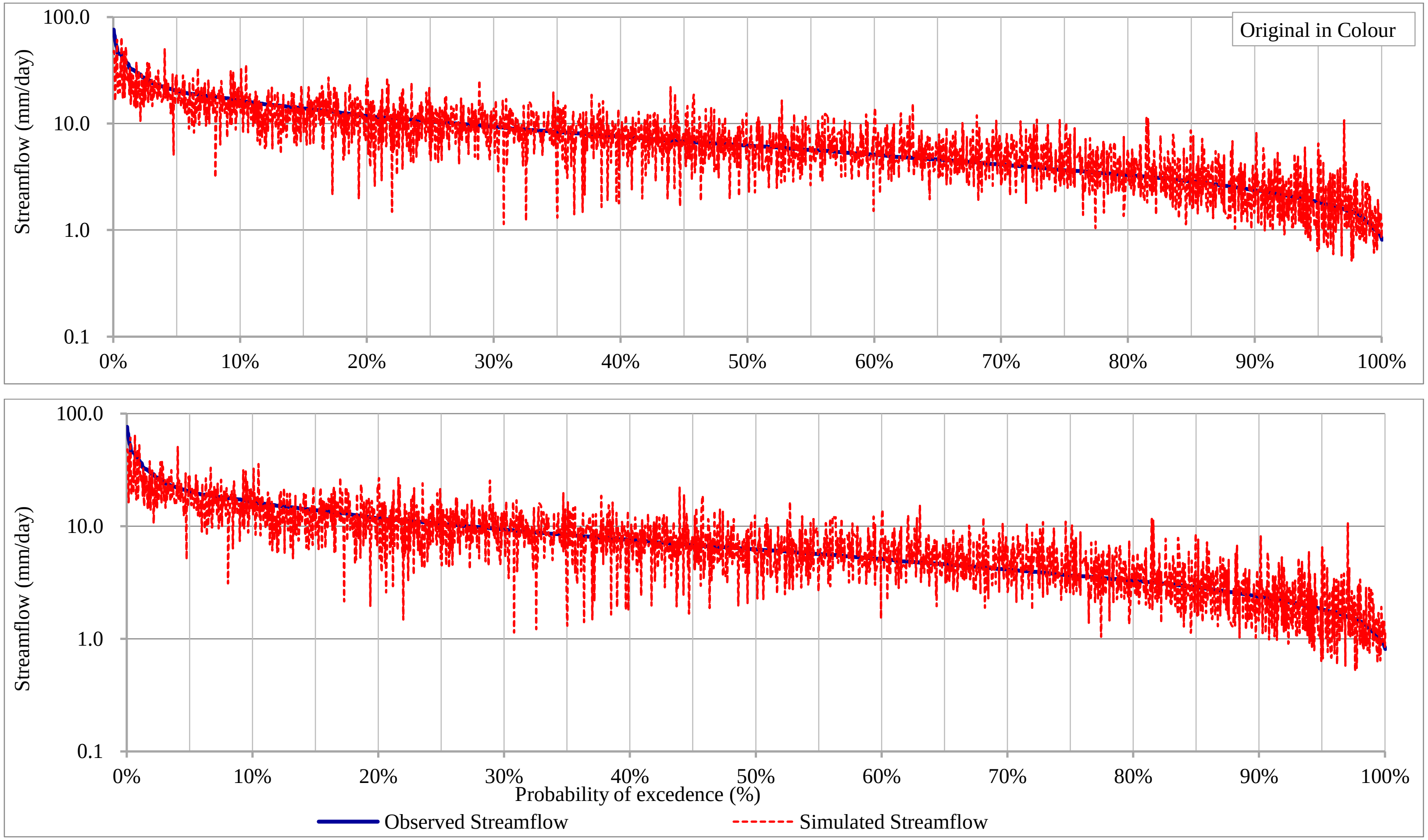

Figure 5-64: Flow duration curve – 3PM (Daily Input) — Verification – Tawalama Watershed

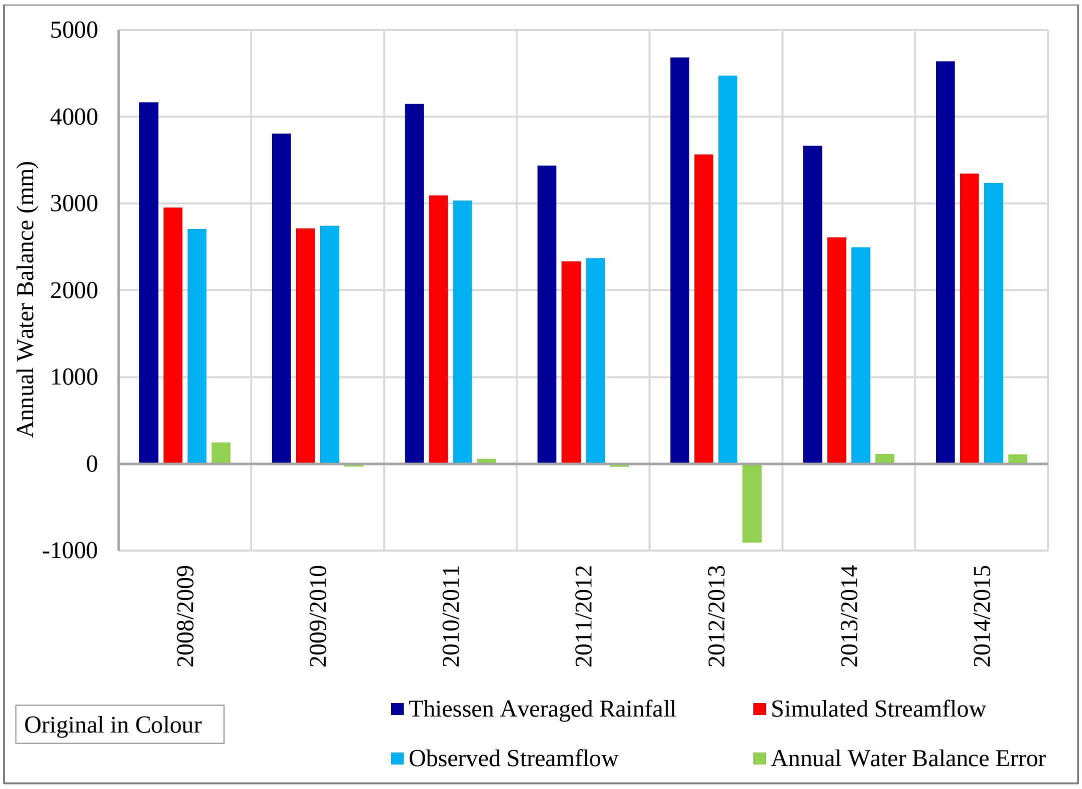

Figure 5-65: Annual Water Balance – 3PM (Daily Input) — Verification – Tawalama Watershed

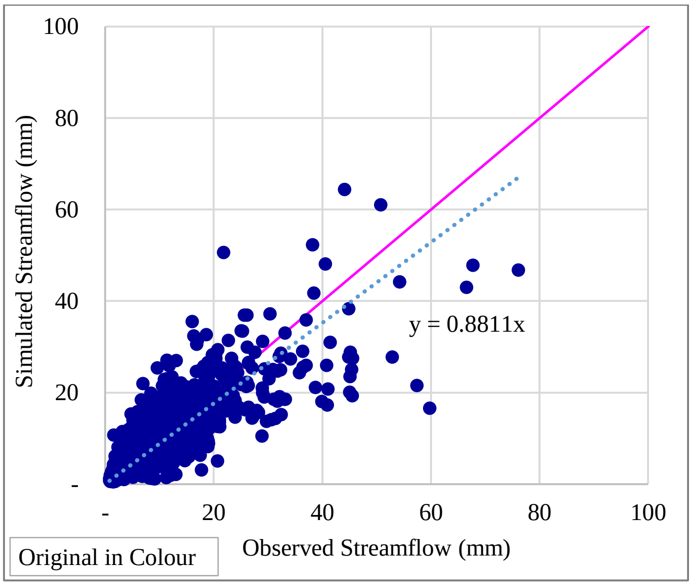

Figure 5-66: 3PM (Daily Input) – Daily Streamflow Estimation —– Verification Period – Tawalama

5.9.3 Ellagawa Watershed

5.9.3.1 Calibration Period

Performance of model in Ellagawa watershed corresponding to daily flow estimations showed a very high improvement in the MRAE from 1.2028 (Table 5-14) for the two parameter monthly model with daily inputs to 0.4573 of three parameter model. The MRAE value of three parameter monthly model showed a better value of 0.2254 than the 0.4573 of three parameter model (monthly input). Table 5-19 shows the outputs for calibration period. Outflow hydrographs (Figure 5-67), flow duration curve (Figure 5-68) and annual water balance (Figure 5-69) for calibration data set reflect a significant improvement in all high, intermediate and low flow values.

Table 5-19: Parameters and indicators of 3PM (Daily Input) - Ellagawa

Comparison of performance	3PM (Daily Input)	
	Calibration	**Verification**
Parameter - c	0.52	0.52
Parameter - Sc	974.67	974.67
Parameter - AF	0.46	0.46
MRAE - Overall	0.4573	0.6206
MRAE - High	0.4245	0.3762
MRAE - Medium	0.4629	0.6695
MRAE - Low	0.4654	0.6205
Average WB difference	(367.86)	(5.17)
Data period	2006 - 2010	2010 - 2014
Nash Sutcliffe	0.3549	0.4455

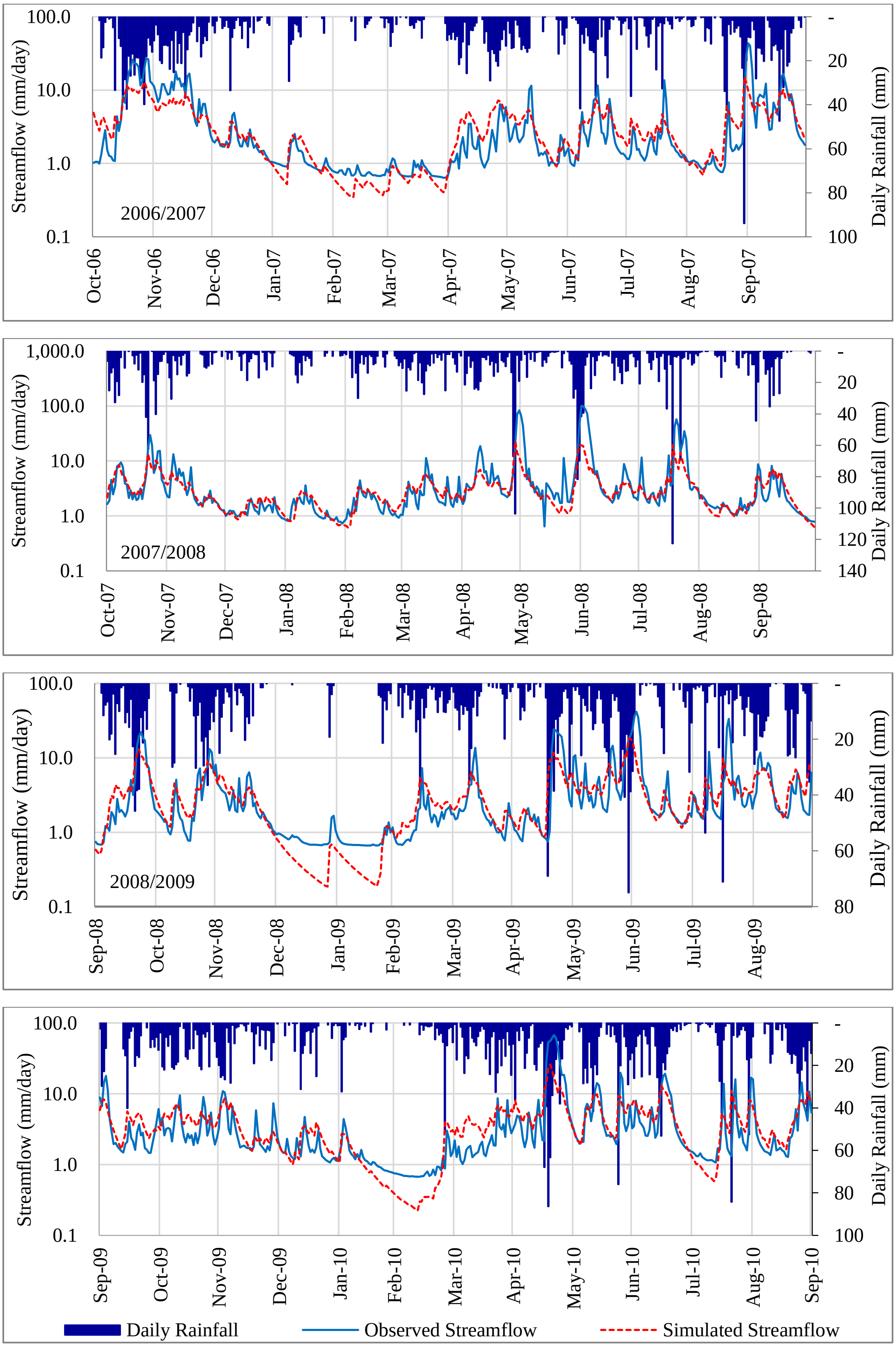

Figure 5-67: Output hydrographs – 3PM (Daily Input) – Calibration Period – Ellagawa

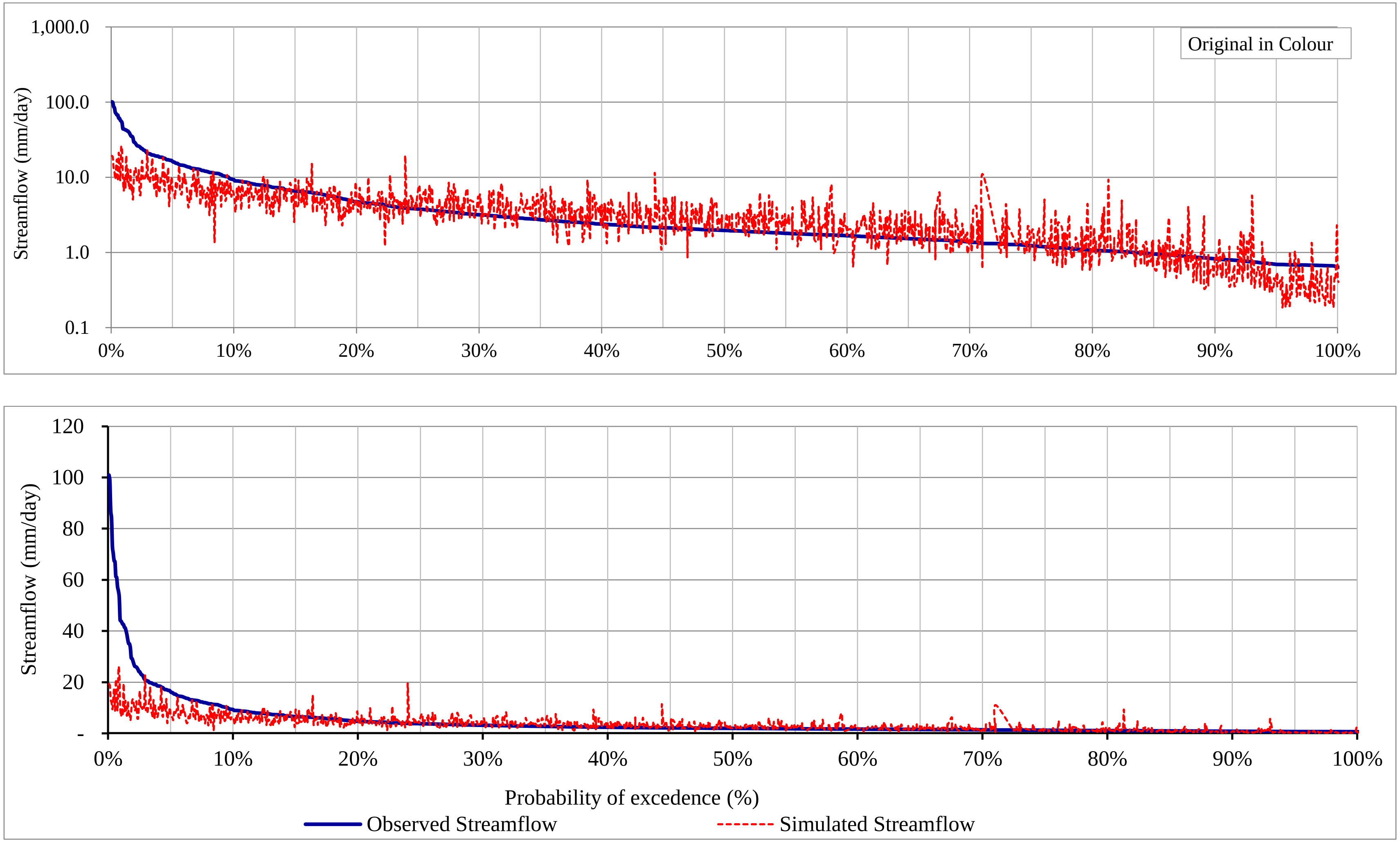

Figure 5-68: Flow duration curve – 3PM (Daily Input) — Calibration Period – Ellagawa watershed

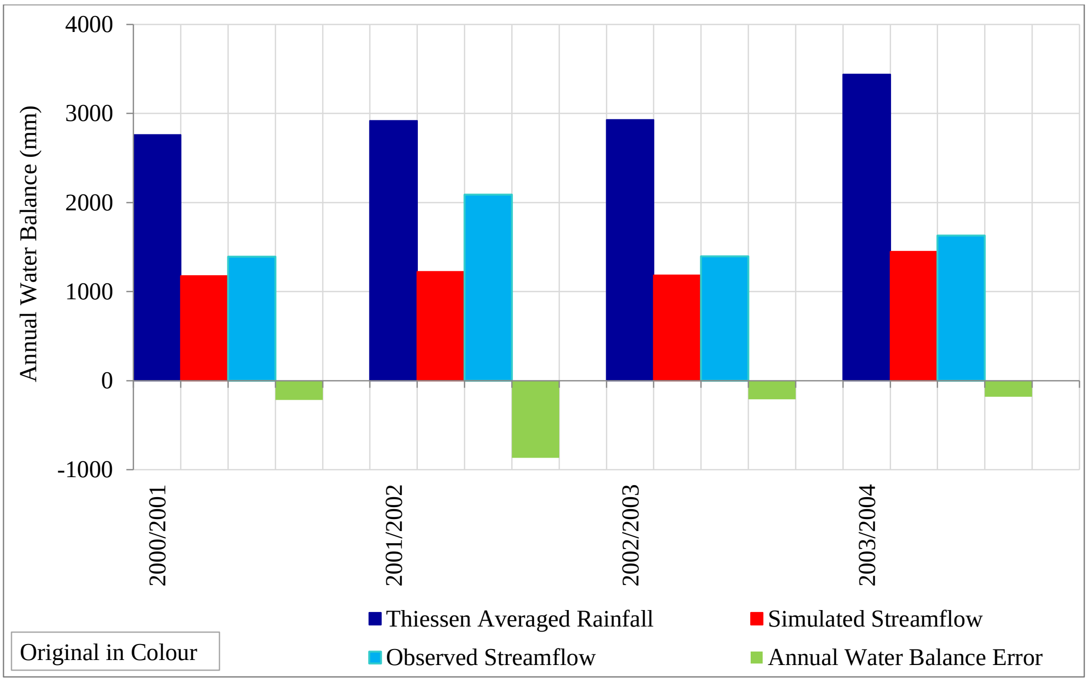

Figure 5-69: Annual Water Balance – 3PM (Daily Input) – Calibration Period — Ellagawa

Though the comparison of observed and computed streamflow scatter diagram reflects an under estimation of high flows, the water balance error shows that the mis matching is significant in the year 2001/2002.

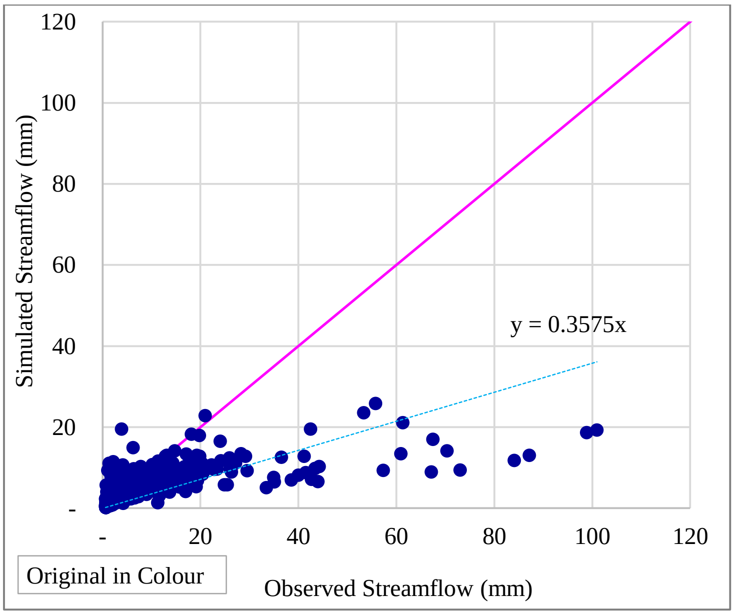

Figure 5-70: 3PM (Daily Input) – Daily Streamflow Estimation— Calibration Period — Ellagawa Watershed

5.9.3.2 Verification

Performance corresponding to daily flow estimation showed an improvement of MRAE from 1.6965 for the two parameter monthly model with daily inputs to 0.6206 for the three parameter model. However the MRAE value showed a deterioration from 0.4106 to 0.6206 when compared with monthly estimations from three parameter model. Table 5-19 shows the outputs for the verification period.

Outflow hydrographs (Figure 5-71), flow duration curve (Figure 5-72) and annual water balance (Figure 5-73) for verification data set reflect a much improved model performance relative to the previous modelling attempts.

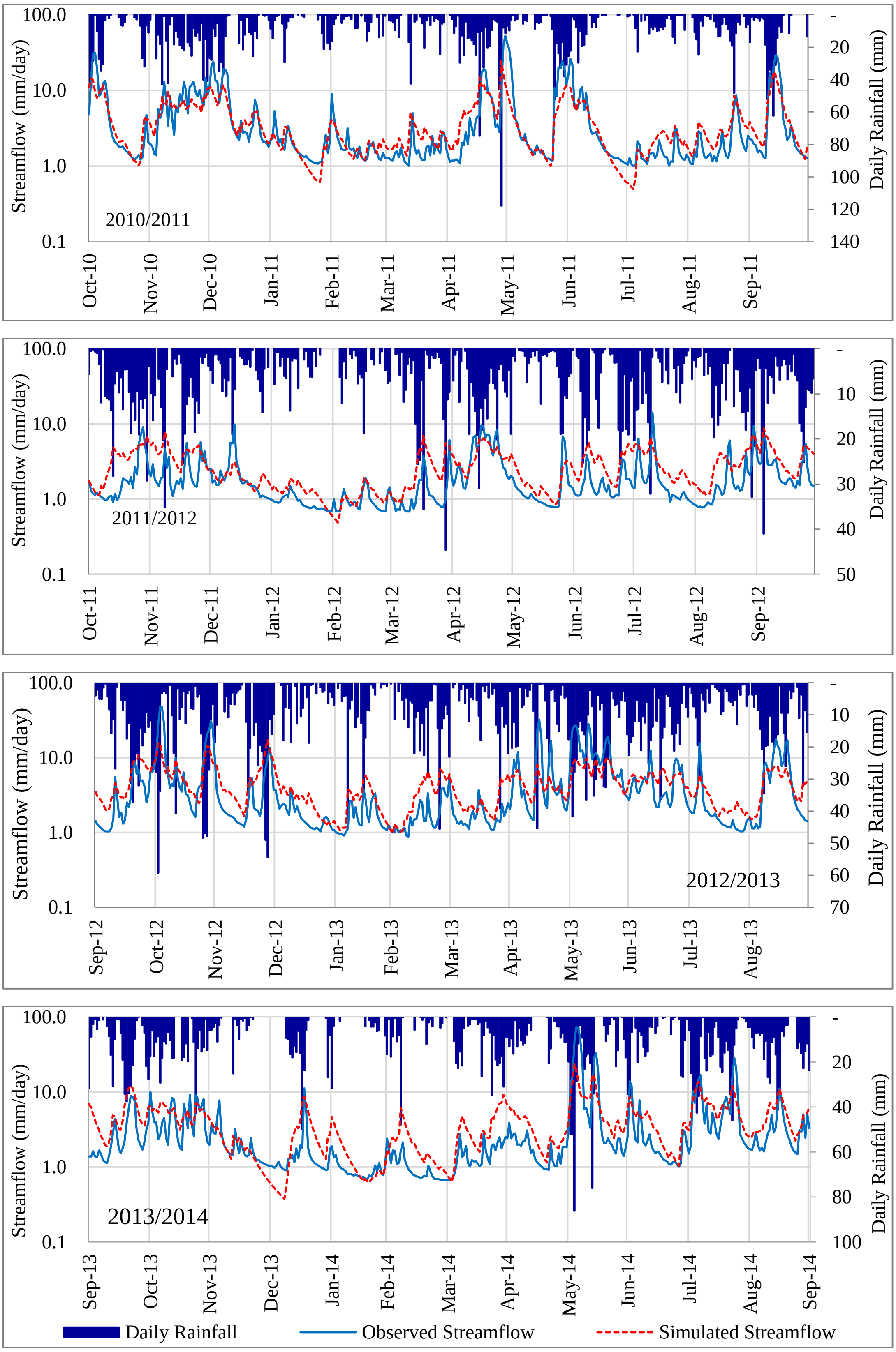

Figure 5-71: Output hydrographs – 3PM (Daily Input) – Verification Period– Ellagawa

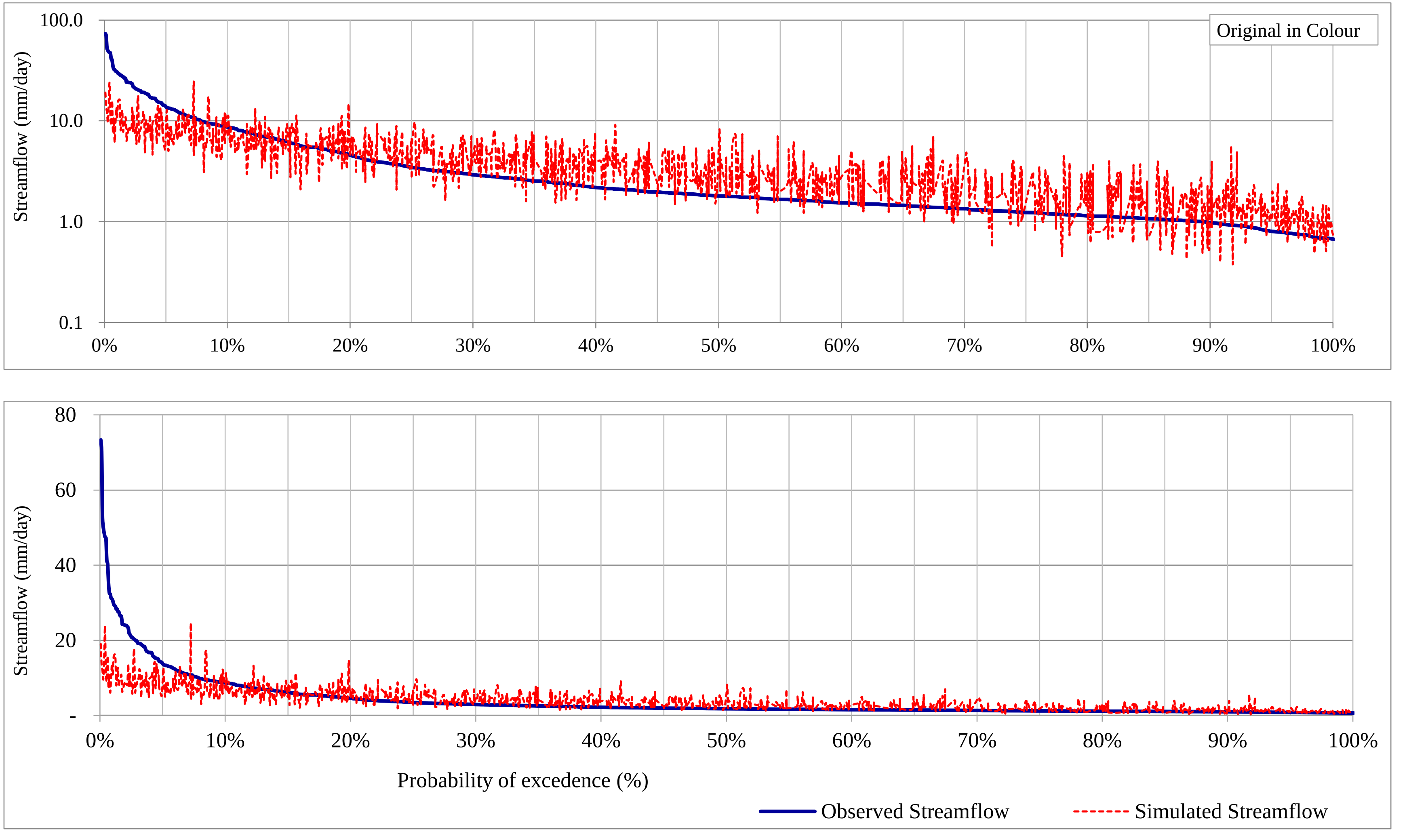

Figure 5-72: Flow duration curve – 3PM (Daily Input) — Verification Period – Ellagawa Watershed

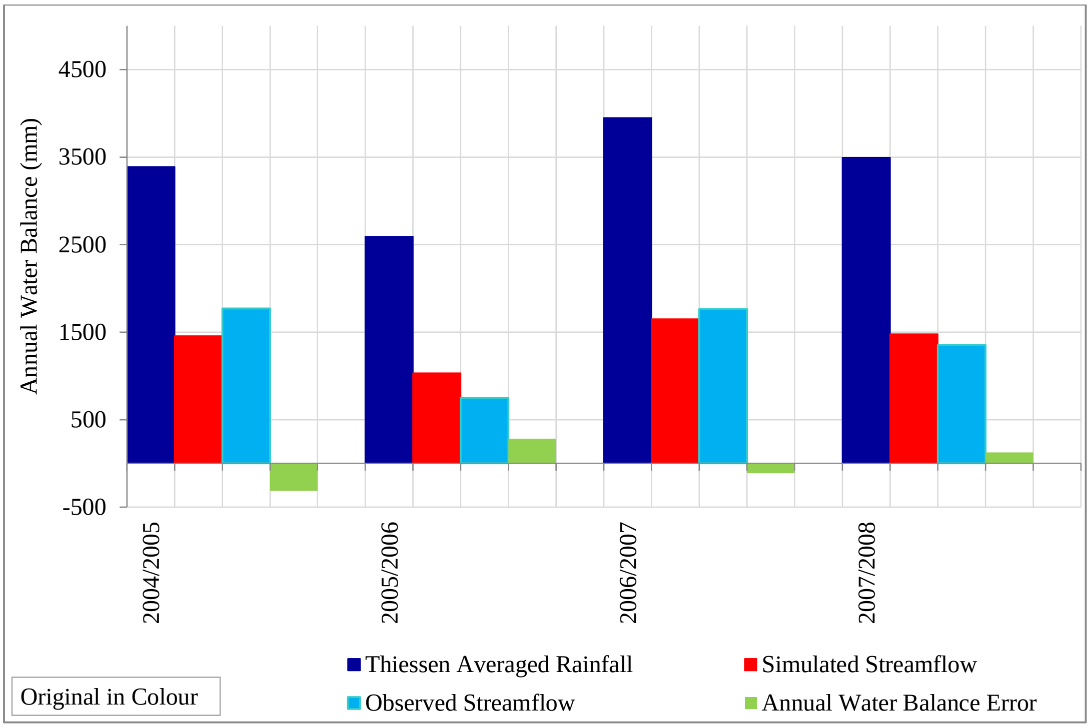

Figure 5-73: Annual Water Balance – 3PM (Daily Input) — Verification – Ellagawa

Though the comparison of observed and computed streamflow reflects an underestimation of high flows, the water balance computations do not reflect significant effect when considered annually (Figure 5-74).

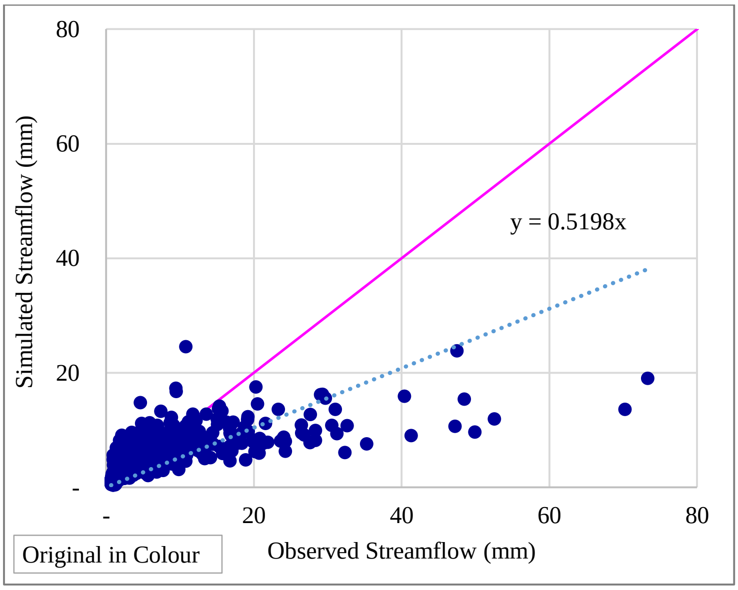

Figure 5-74: Streamflow Comparison – 3PM (Daily Input) — Verification Period – Ellagawa Watershed

5.9.4 Comparison of Monthly Estimates

a) Tawalama Watershed

Monthly estimates with monthly inputs and daily inputs were compared for both watersheds. Comparison for Tawalama watershed in calibration and verification periods are in Figure 5-75 and Figure 5-76 respectively. In both data periods, monthly outputs from daily inputs shared comparatively better results.

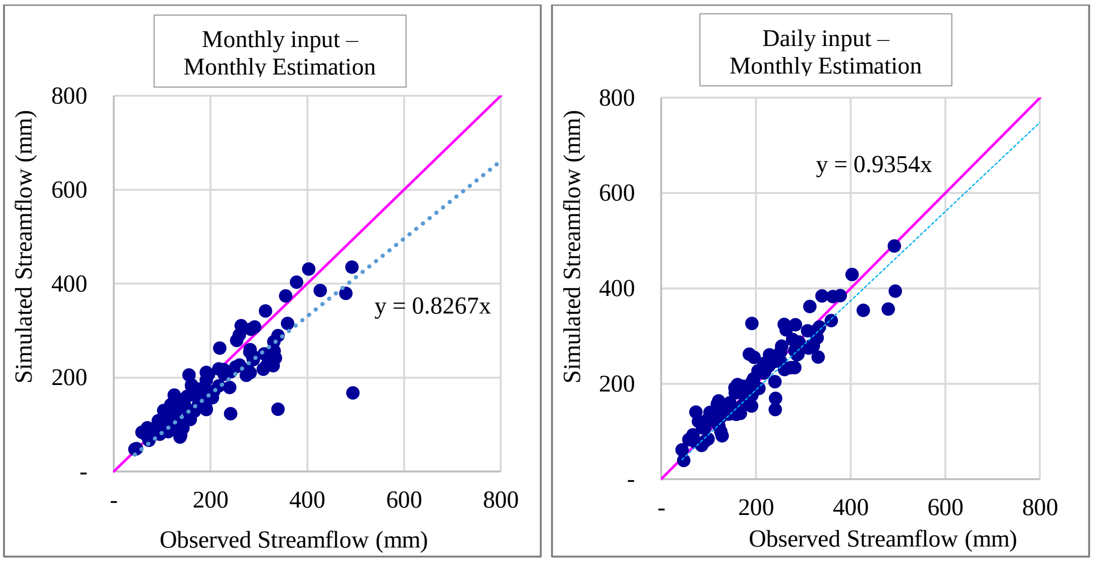

Figure 5-75: 3PM (Monthly Input & Daily Input) - Monthly Streamflow Estimation – — Calibration Period – Tawalama Watershed

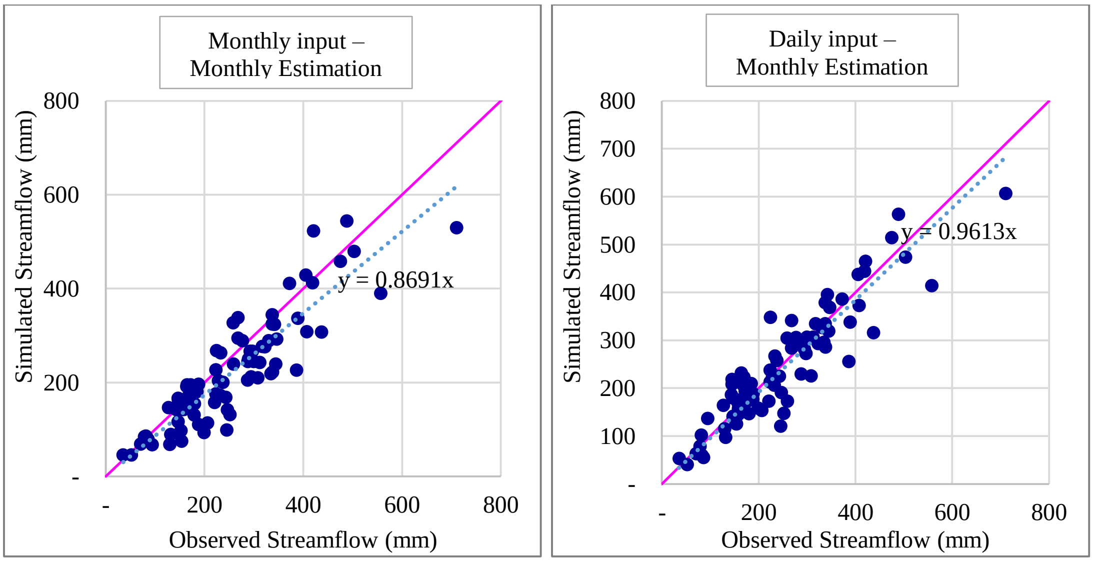

Figure 5-76: 3PM (Monthly Input & Daily Input) - Monthly Streamflow Estimation – — Verification Period – Tawalama Watershed

b) Ellagawa Watershed

Results for Ellagawa watershed are in (Figure 5-77 and Figure 5-78). In this case also the monthly outputs obtained by using the model with daily inputs were relatively better.

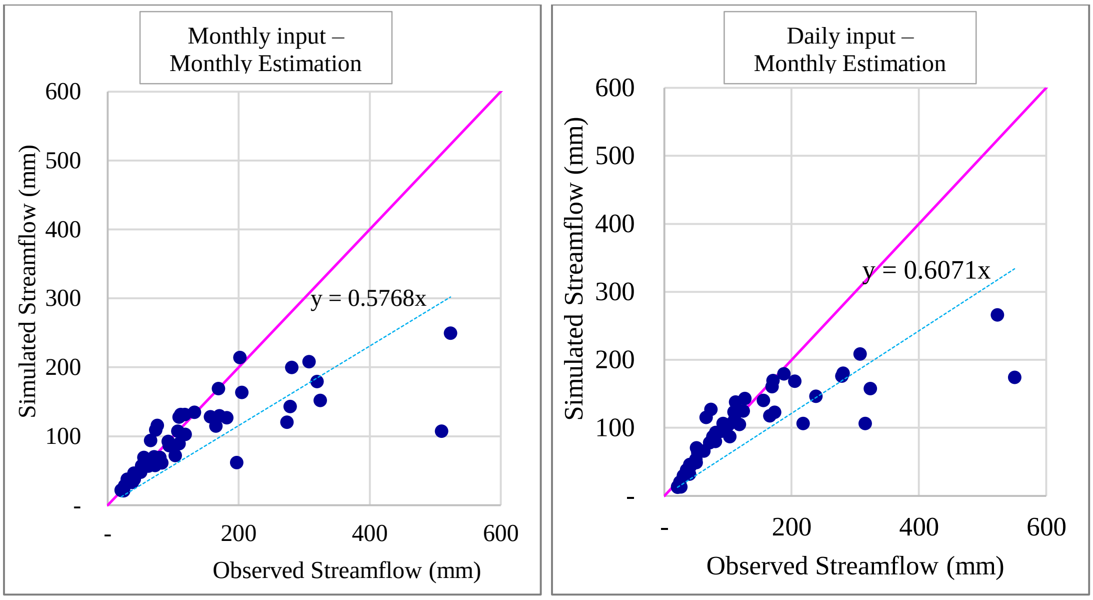

Figure 5-77: Monthly estimation Comparison – 3PM (Monthly Input & Daily Input) — Calibration Period – Ellagawa Watershed

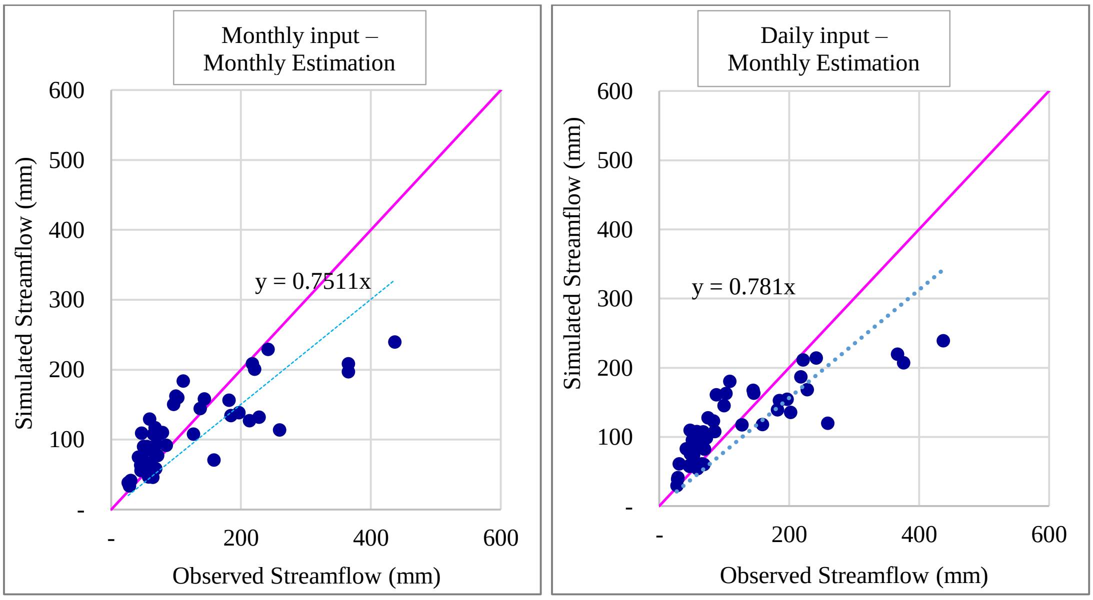

Figure 5-78: Monthly estimation Comparison – 3PM (Monthly Input & Daily Input) — Verification Period – Ellagawa Watershed

6. DISCUSSION

6.1 Model Identification

Model identification required a suitable initial soil moisture value. As recommended in literature, a cyclic warm up period of 5 years was used to ensure a representative value. The present work identified that a five cycle warm up period is satisfactory for determination of initial soil moisture level.

6.2 Two Parameter Monthly Model (Monthly Input)

The performance of two parameter founder models with monthly data in both watersheds were significantly different for the alternate present datasets. Calibrated parameters for the alternate data set also differed in both watersheds. This could be due to difference in data or due to the spatial variability of data or could be due to the data duration used for parameter estimation. The present work revealed that founder models with longer datasets showed better fitting of monthly values in case of the two parameter monthly model. The c and Sc parameters and initial soil moisture levels for both watersheds are in Table 6-1.

Table 6-1: Model parameters and initial soil moisture values for two parameter monthly model

Watershed	c	Sc	Initial soil Moisture - S_0 (mm)	Average MRAE	Remarks
Tawalama	0.89	1,292.00	325	0.1030	Founder Model
	1.42	1,288.63	315	0.2061	Alternate Model
Ellagawa	1.0	800	195	0.1853	Founder Model
	1.29	829.84	199	0.7668	Alternate Model (with data disparity)
	1.29	829.84	199	0.3428	Alternate Model (without data disparity)

Value of c varied considerably with the two data sets but the Sc and S_0 values reflected values of same order of magnitude. This shows that parameter c has a significant influence on the dataset used for calibration.

6.3 Two Parameter Model (Daily Input)

Two parameter model with daily inputs showed a reasonably good matching with acceptable MRAE values of 0.4360 (calibration) and 04039 (validation) in Tawalama watershed. However, detailed investigations with duration curve, scatter diagrams and daily rainfall-streamflow graphs showed clear over estimations in both watersheds. This over estimation was more in case of high flows where as low in low flow periods. This was confirmed when scatter diagrams were investigated. As such it was evident that a simple linear coefficient which has the flexibility to adjust with the rainfall, evaporation and soil moisture status data would enhance the estimation potential of the Xiong,(1999) monthly model.

6.4 Three Parameter Model (Monthly Input)

The three parameter model with monthly inputs showed significant improvement in the model estimations of monthly flow for both catchments.

Table 6-2: Model parameters and initial soil moisture values for two parameter monthly model

Watershed	c	Sc	AF	Initial soil Moisture - S_0 (mm)	Average MRAE	Remarks
Tawalama	1.02	1,292	0.83	359.03	0.1657	Alternate Model
Ellagawa	0.52	975.2	0.46	271.41	0.3135	Alternate Model

MRAE values for both watersheds were very low and other indicators such as flow duration, log and normal plots also showed significantly improved matching. Lesser over prediction in the case of two parameter model in Tawalama was well demonstrated by the AF coefficient of 0.83 while the significant over estimations were very well handled by the parameter AF with an optimized parameter value of 0.46.

This reflected the versatile nature of the third AF parameter when making monthly flow estimations. It is important to test this model on other watersheds to confirm the findings of this case study.

6.5 Three Parameter Model (Daily Input)

The three parameter model calibration for monthly data produced very representative streamflow estimations in the daily time scale. Three parameter model daily outputs reflected a very good estimate of the flow duration curve and a highly compatible streamflow hydrographs for both watersheds. This average MRAE values which were 0.3193 and 0.5389 respectively for Tawalama and Ellagawa watersheds, demonstrated the goodness of fit. The high flow and low flow estimates on extreme situations did not perform well but in general the medium flows which are the key to water resources management were very well estimated.

The hydrograph matching showed a very high potential of the three parameter model calibration with monthly data to perform very well and reproduce daily streamflows.

6.6 Importance Of Three Parameter Model

The present work demonstrated an immense value of three parameter model developed by the current research. In Sri Lanka, monthly data are available at an affordable price to be bought from the state agencies which collect rainfall and streamflow data. Therefore this monthly model can be developed calibrated and verified very easily with the use of those monthly data.

Once developed the model can then be safely used to study watersheds at a finer daily time resolution. As an example, if climate change impacts due to rainfall change need to monitored at a daily resolution then the three parameter model developed for a particular catchment using monthly data can be used to obtain satisfactory daily results for an evaluation by the input of daily resolution rainfall and streamflow.

6.7 Data Disparity

Present study, at the point of data checking, recognized many data disparities when thiessen rainfall was compared with the observed streamflow. This was quite noticeable in Ellagawa watershed than in the Tawalama watershed. At the initial stages occasionally the disparities were considered for output evaluations. However during main modeling efforts which are the parameter optimization for two parameter and three parameter monthly models, the data disparities were kept without interference.

Results during the model computations with two parameter monthly model indicated hydrograph matching problems when handling such dubious data points. At that point of modelling it was most likely that the data were erroneous. However the three parameter monthly model showed very good performance with improved model estimations even at the points that reflected data disparities. This indicated that data checking and cleaning efforts need to carefully consider the data, models and their conceptualizations prior to concluding about the quality of data.

6.8 Model conceptualization

Results of the present work showed that the model conceptualization in the two parameter model (Xiong & Guo,1999) was not adequate to conceptualize catchment processes at both monthly and daily scales with the two governing equations that had been proposed by the Auther. The inclusions of a third parameter as ‘AF’ to reflect the watershed runoff transfer characteristic clearly demonstrated that the three parameter model can be treated as a model which had captured the governing watershed response at both monthly and daily temporal resolutions. This is a great advantage for watershed modeling because the present work encourages watershed modelers to investigate possibilities of understanding catchment behavior with simpler governing equations than with parameter laden micro level physics assumed to exist at macro level conceptualizations presently used for basin level assessments. The three parameter model demonstrated the importance of rational inclusion of parameters that enable easy hydrologic modeling across two temporal resolutions with the strength moving from coarser data to finer estimations.

7. CONCLUSIONS

1. Two parameter (monthly model) performed well in Tawalama and Ellagawa watersheds demonstrating the capability to estimate monthly streamflows to a satisfactory level with respective average MRAE values of 0.2061 and 0.3428.

2. The two parameter model calibrations in both watersheds showed a significant variation of c parameter with temporal variation of data but showed a relatively little variation in the Sc values and initial soil moisture level with the same temporal variation.

3. In case of two parameter monthly model the c and Sc values for Tawalama watershed with alternate data were 1.42 and 1,289 respectively while the same for Ellagawa watershed were 1.29 and 828.

4. Three parameter monthly model proposed in this study produced superior results than the two parameter model of Xiong & Guo, (1999) when estimating both monthly and daily streamflows.

5. Third parameter 'AF' enabled the very satisfactory estimation of streamflow at Tawalama and Ellagawa watersheds with respective average MRAE values of 0.1657 and 0.3135.

6. Conceptualization extended in the three parameter model demonstrates the potential of successful catchment process conceptualization fitting both monthly and daily temporal resolutions.

7. Hydrologic modelers when dealing with data disparities should exercise more care when carrying out data corrections because the disparity may have been due to approximations made in the modeling effort.

8. Three parameter model can be strongly recommend for future water resources planning actions on similar watersheds

8. RECOMMENDATIONS

1. The three parameter model should be applied to many other watersheds to investigate the improvements and possibility of recognizing the modeling concept and the associated parameters.

2. Further research should investigate not only on the conceptualization of watershed heterogeneity but also the identification of optimum rainfall averaging methods that could enlighten more on data quality.

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ANNEX A - DATA

Table A-1: Thiessen Average Rainfall Data – Tawalama Watershed

Year	Monthly rainfall (mm/month)			Annual rainfall (mm/year)
	Maximum	Mean	Minimum	
2000/01	503.77	251.68	71.13	3,020.14
2001/02	539.91	236.94	105.37	2,843.23
2002/03	596.33	313.20	160.37	3,758.38
2003/04	521.52	309.89	119.69	3,718.64
2004/05	306.75	202.80	127.01	2,433.60
2005/06	578.93	313.62	184.89	3,763.39
2006/07	645.45	332.43	77.93	3,989.19
2007/08	546.88	361.58	145.53	4,338.95
2008/09	526.26	347.22	50.50	4,166.66
2009/10	451.88	259.15	95.08	3,109.82
2010/11	692.34	345.51	131.77	4,146.10
2011/12	526.06	285.31	84.51	3,423.78
2012/13	580.93	359.43	91.87	4,313.12
2013/14	483.75	306.86	95.66	3,682.29
2014/15	641.36	387.07	185.69	4,644.82

Table A-2: Streamflow Data – Tawalama Watershed

Year	Monthly Streamflow (mm/month)			Annual Streamflow (mm/year)
	Maximum	Mean	Minimum	
2000/01	308.81	159.95	43.62	1,919.37
2001/02	288.58	161.14	46.84	1,933.63
2002/03	839.41	254.47	86.99	3,053.69
2003/04	358.88	222.74	91.88	2,672.82
2004/05	290.79	200.69	112.37	2,408.31
2005/06	377.39	203.61	58.08	2,443.29
2006/07	492.15	209.36	58.08	2,512.28
2007/08	494.30	290.56	127.92	3,486.77
2008/09	346.30	225.44	35.16	2,705.34
2009/10	474.87	228.61	51.70	2,743.34
2010/11	488.47	252.80	78.32	3,033.66
2011/12	337.46	197.50	81.22	2,370.06
2012/13	710.37	331.34	163.83	3,976.06
2013/14	407.28	207.98	70.56	2,495.75
2014/15	503.11	269.64	126.78	3,235.66

Table A-3: Evaporation Data – Rathnapura Station

Year	Monthly Evaporation (mm/month)			Annual Evaporation (mm/year)
	Maximum	Mean	Minimum	
2000/01	92.04	64.10	48.62	769.18
2001/02	107.55	79.45	48.06	953.43
2002/03	99.17	76.71	56.84	920.50
2003/04	100.39	76.10	44.14	913.19
2004/05	104.44	77.00	50.61	924.05
2005/06	91.70	76.77	58.89	921.26
2006/07	123.66	82.84	57.01	994.03
2007/08	97.09	77.01	61.70	924.07
2008/09	114.14	88.38	66.42	1,060.59
2009/10	103.19	78.67	57.01	944.03
2010/11	88.86	72.43	48.51	869.18
2011/12	113.70	82.83	65.20	994.01
2012/13	98.43	72.52	52.98	870.27
2013/14	107.35	74.91	54.51	898.86
2014/15	96.47	74.80	48.39	897.63

Table A-4: Thiessen Average Rainfall Data – Ellagawa Watershed

Year	**Monthly rainfall (mm/month)**			**Annual rainfall (mm/year)**
	Maximum	**Mean**	**Minimum**	
2006/07	484.76	261.48	29.63	3,137.81
2007/08	446.31	265.57	113.21	3,186.81
2008/09	504.15	235.07	24.87	2,820.80
2009/10	579.33	290.35	62.10	3,484.24
2010/11	562.23	281.85	120.31	3,382.20
2011/12	442.50	228.08	84.27	2,736.95
2012/13	490.91	325.11	141.68	3,901.29
2013/14	557.49	290.07	60.22	3,480.89

Table A-5: Streamflow Rainfall Data – Ellagawa Watershed

Year	**Monthly Streamflow (mm/month)**			**Annual Streamflow (mm/year)**
	Maximum	**Mean**	**Minimum**	
2006/07	307.18	116.17	20.74	1,394.02
2007/08	509.39	174.06	40.08	2,088.69
2008/09	201.72	116.90	21.28	1,402.81
2009/10	523.21	135.11	30.02	1,621.34
2010/11	259.33	147.50	45.50	1,769.99
2011/12	127.08	62.83	27.99	754.01
2012/13	365.57	146.76	47.93	1,761.13
2013/14	436.91	112.70	26.42	1,352.37

ANNEX B - DATA CHECKING (ELLAGAWA BASIN)

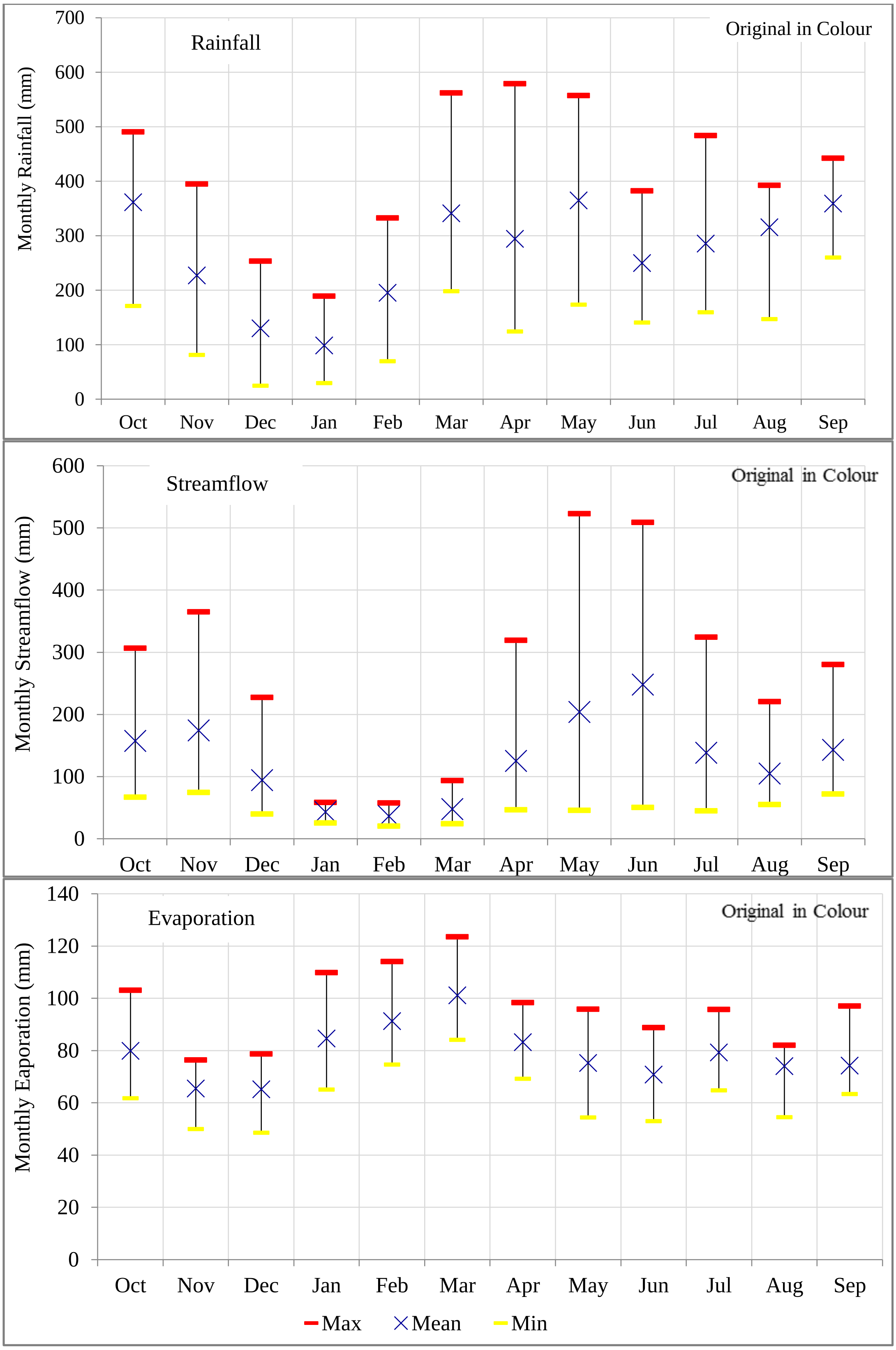

Figure B-1: Variation of Maximum, Mean and average monthly rainfall, streamflow & evaporation

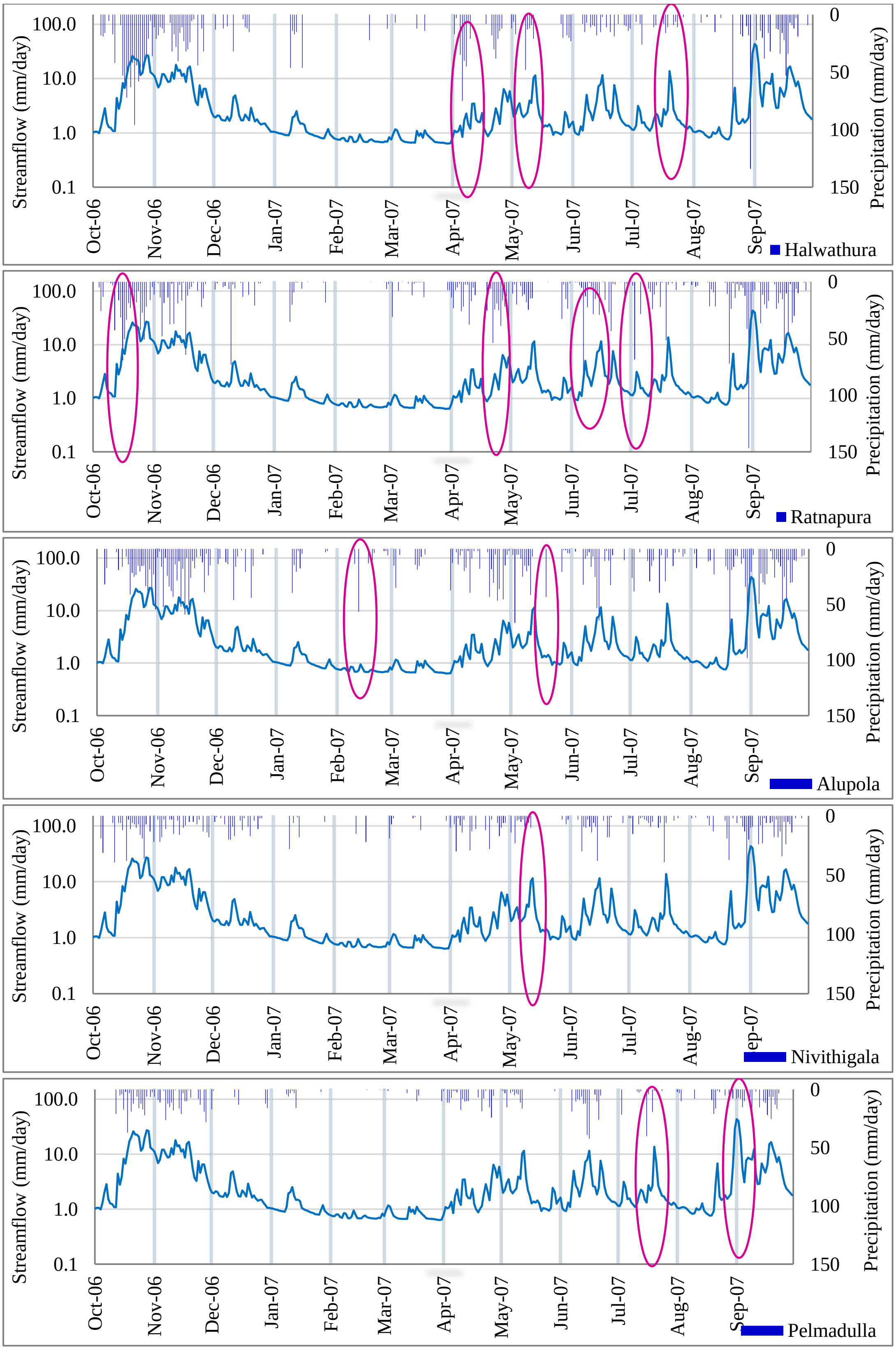

Figure B-2 : Rainfall response to Ellagawa Streamflow in year 2006/2007- Semi Logarithmic scale

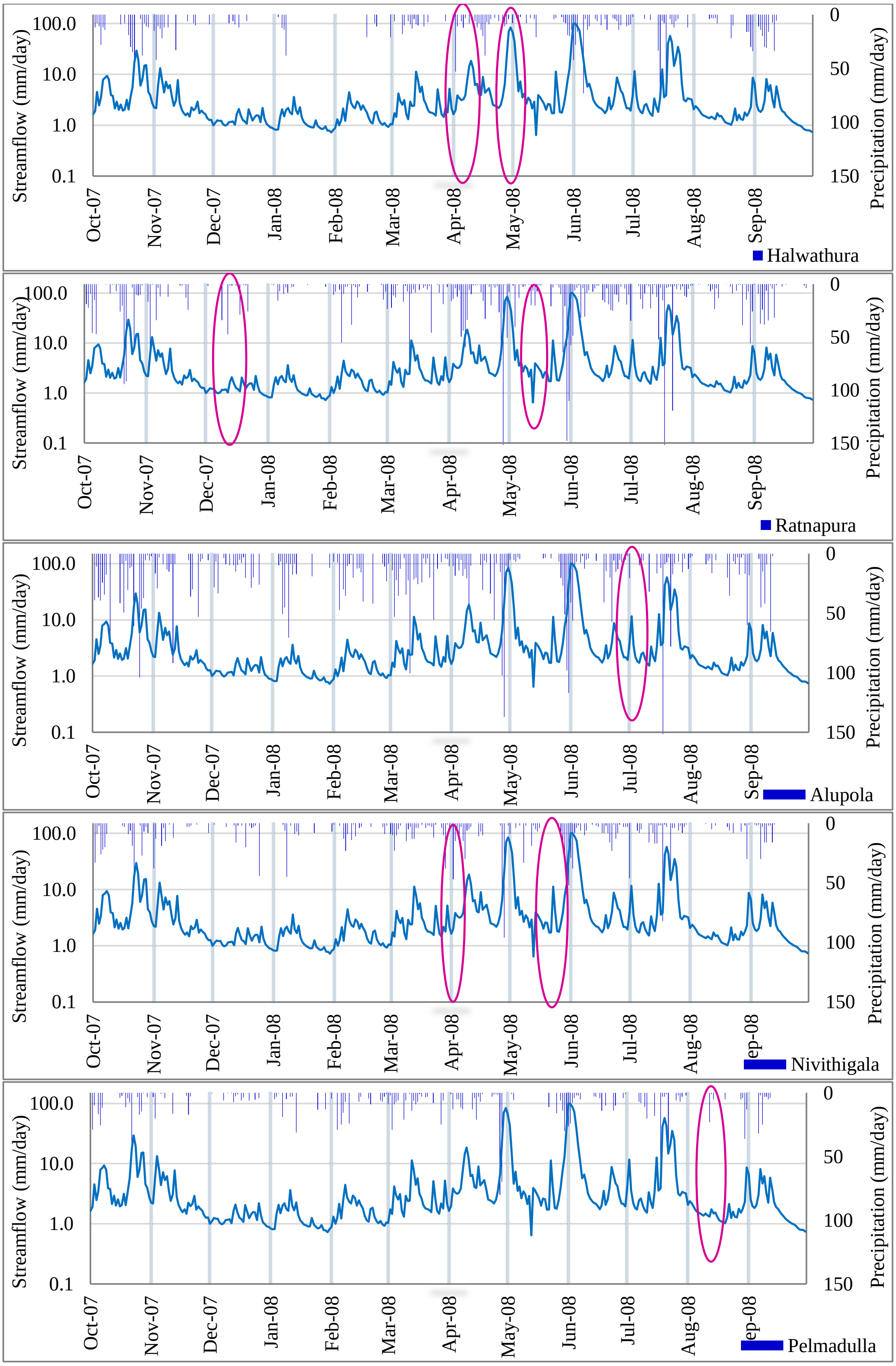

Figure B-3 : Rainfall response with Ellagawa Streamflow in 2007/2008 - Semi Logarithmic scale

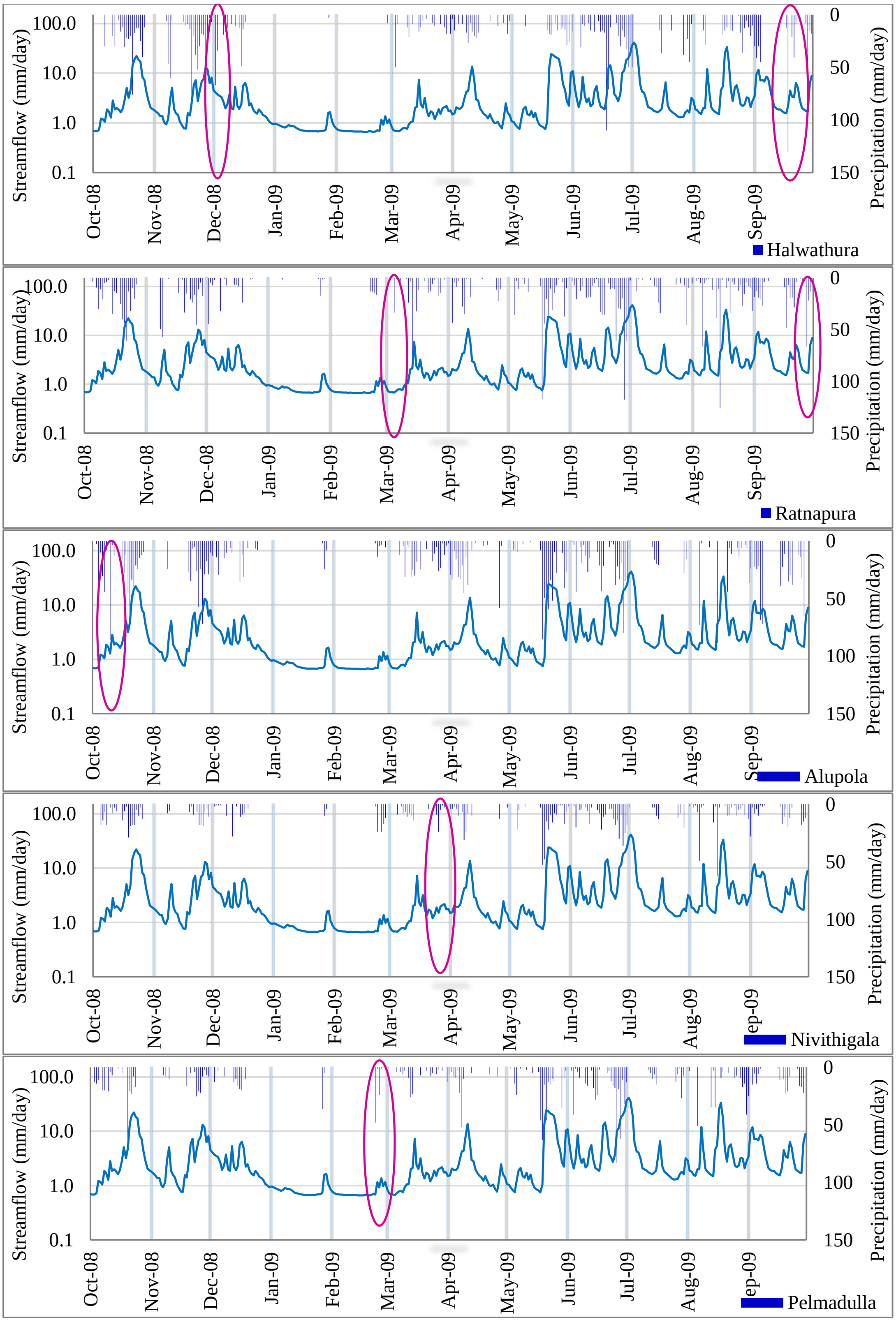

Figure B -4 : Rainfall response with Ellagawa Streamflow in 2008/2009 - Semi Logarithmic scale

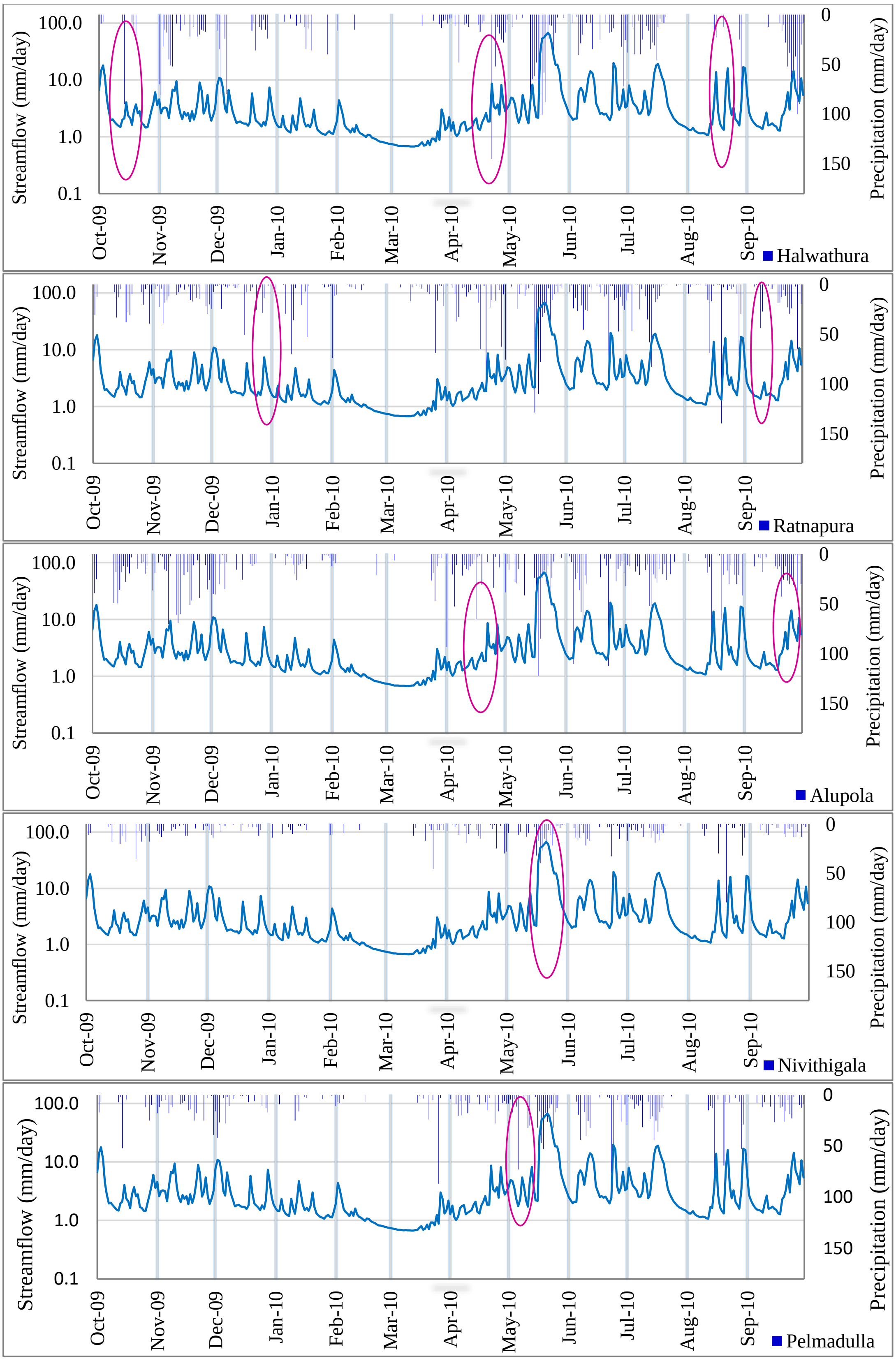

Figure B -5: Rainfall response with Ellagawa streamflow in 2009/2010- Log scale

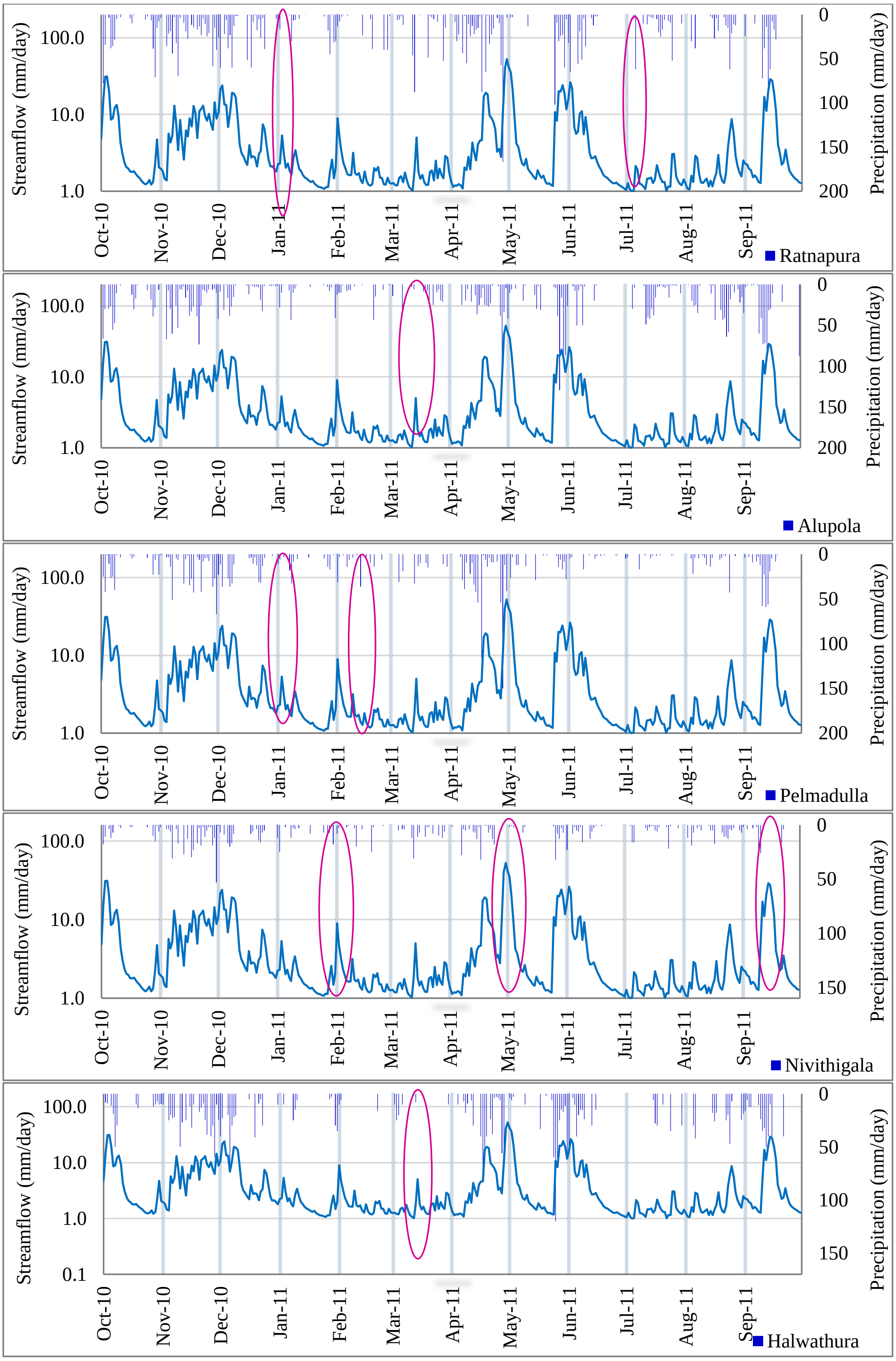

Figure B -6: Rainfall response with Ellagawa streamflow in 2010/2011- Log scale

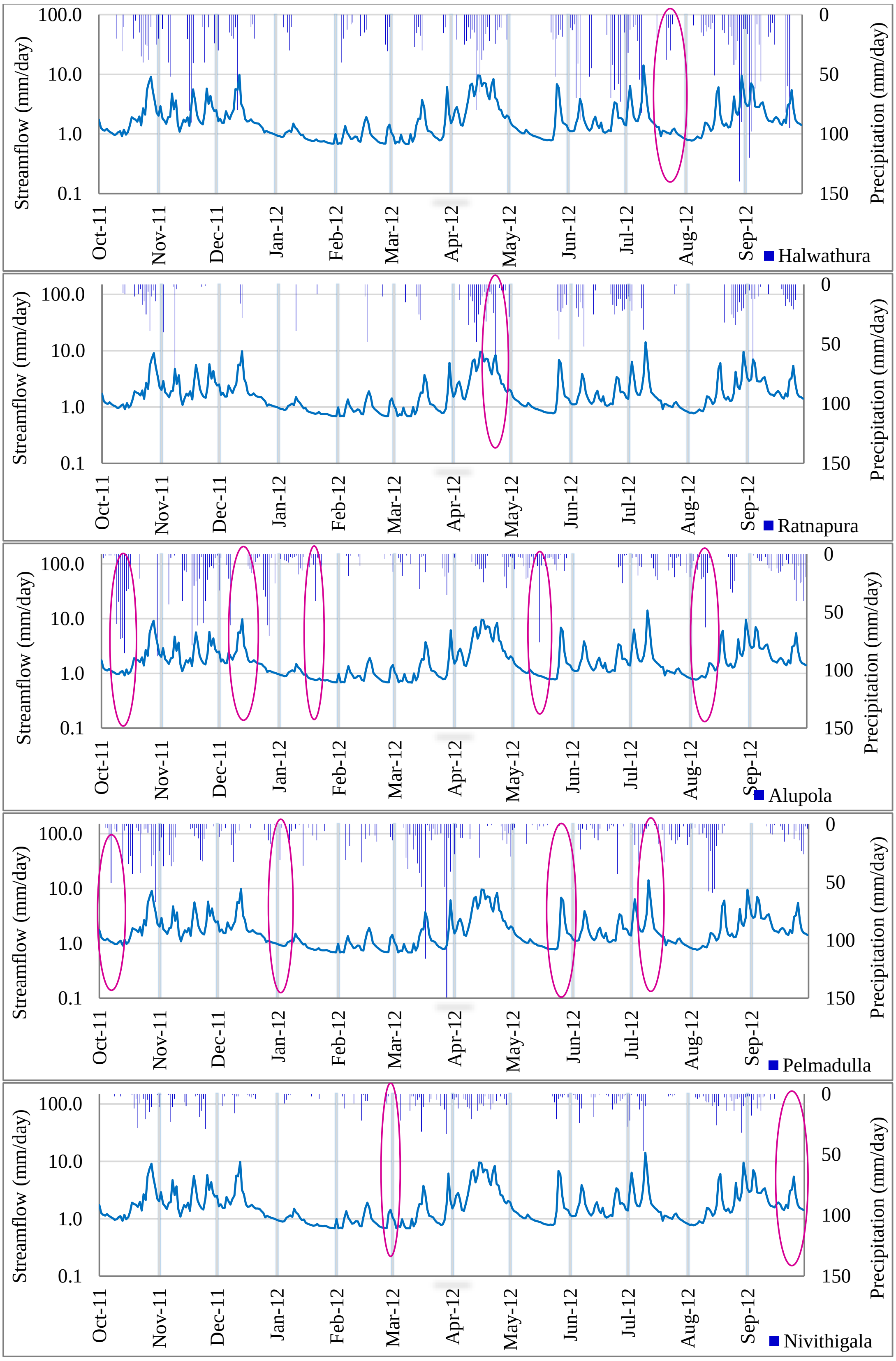

Figure B -7: Rainfall response with Ellagawa stream flow in 2011/2012- Log scale

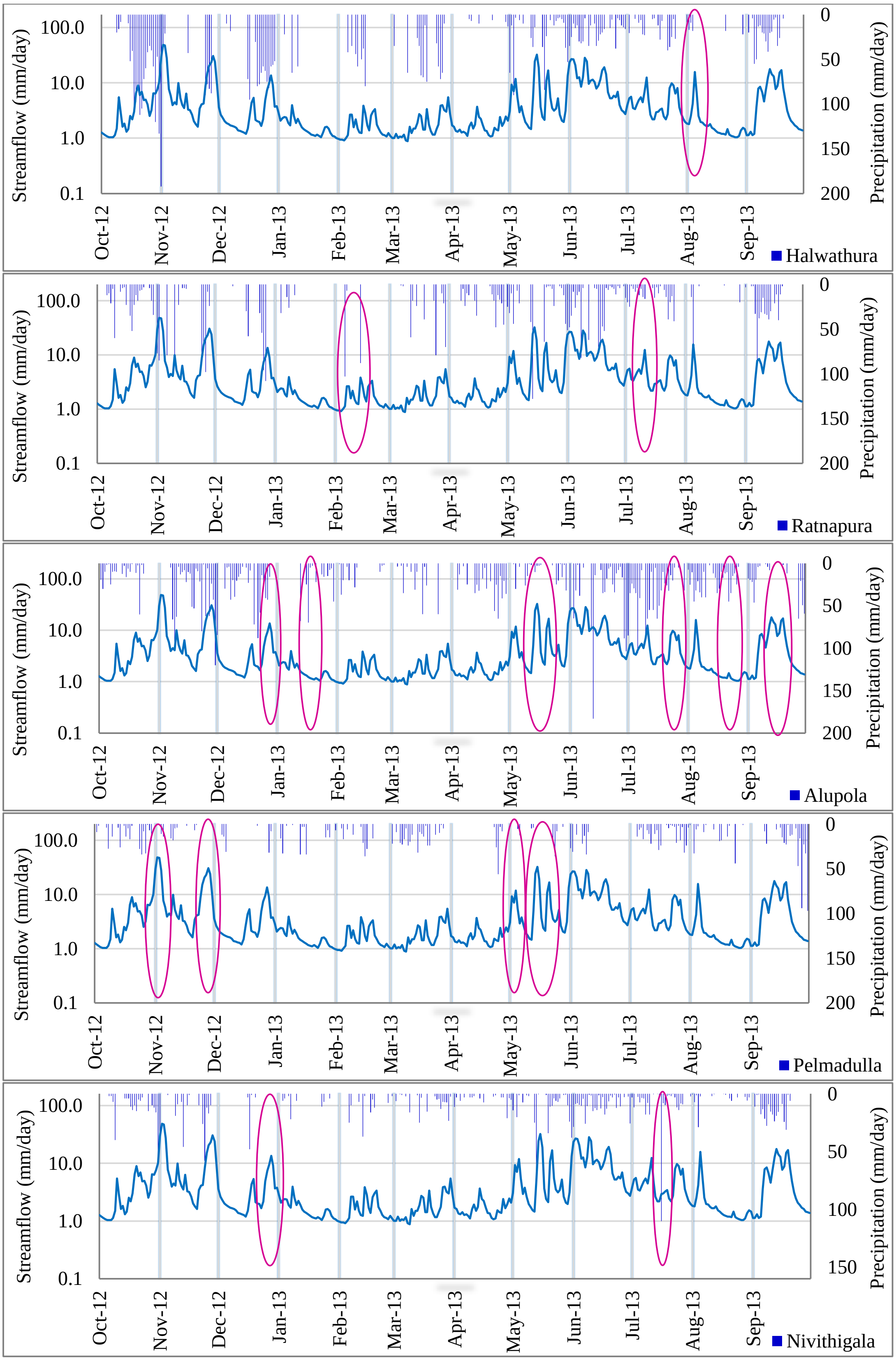

Figure B -8: Rainfall response with Ellagawa stream flow in 2012/2013- Log scale

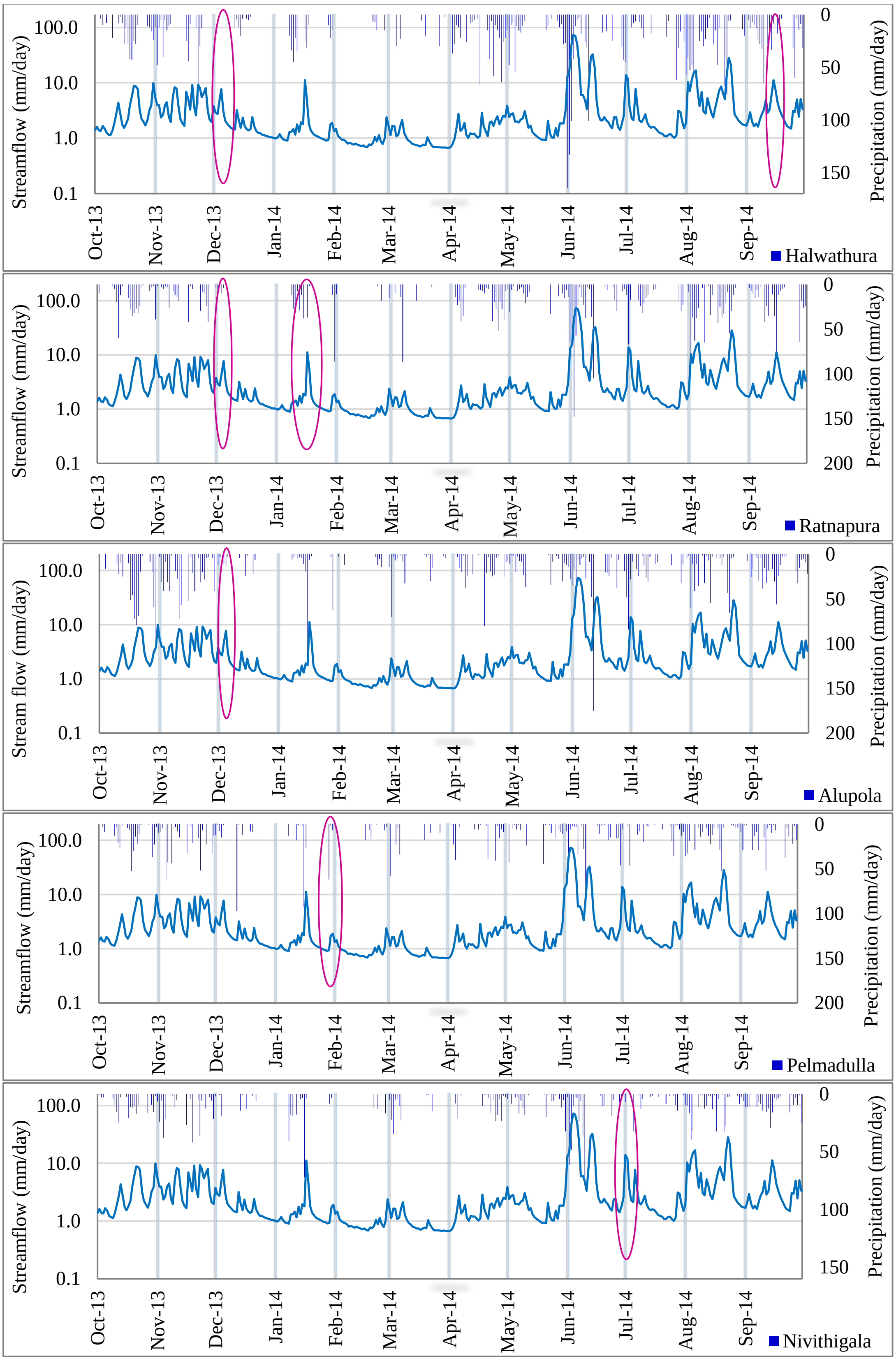

Figure B -9: Rainfall response with Ellagawa stream flow in 2013/2014- Log scale

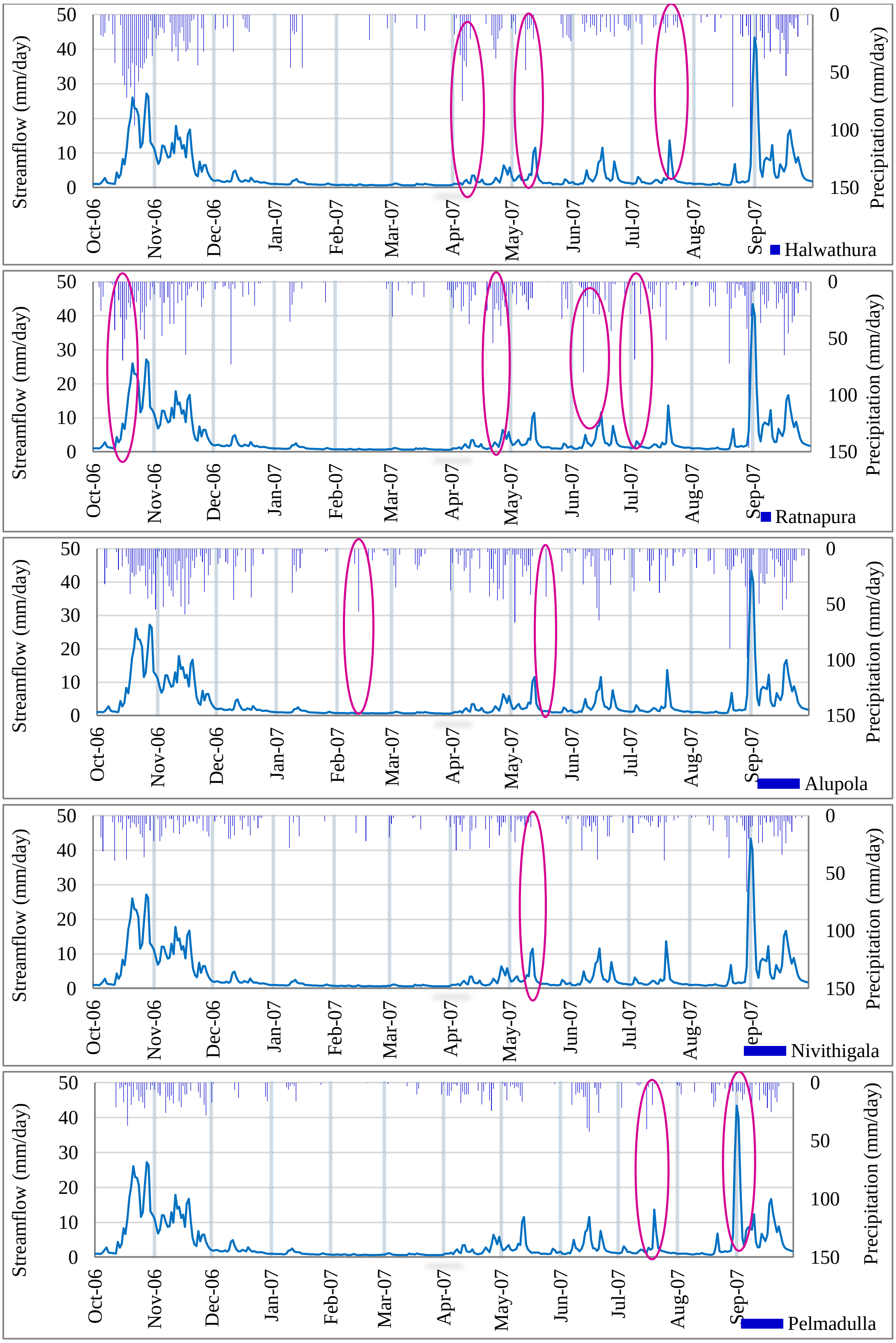

Figure B -10 : Rainfall response to Ellagawa Streamflow in year 2006/2007- Normal scale

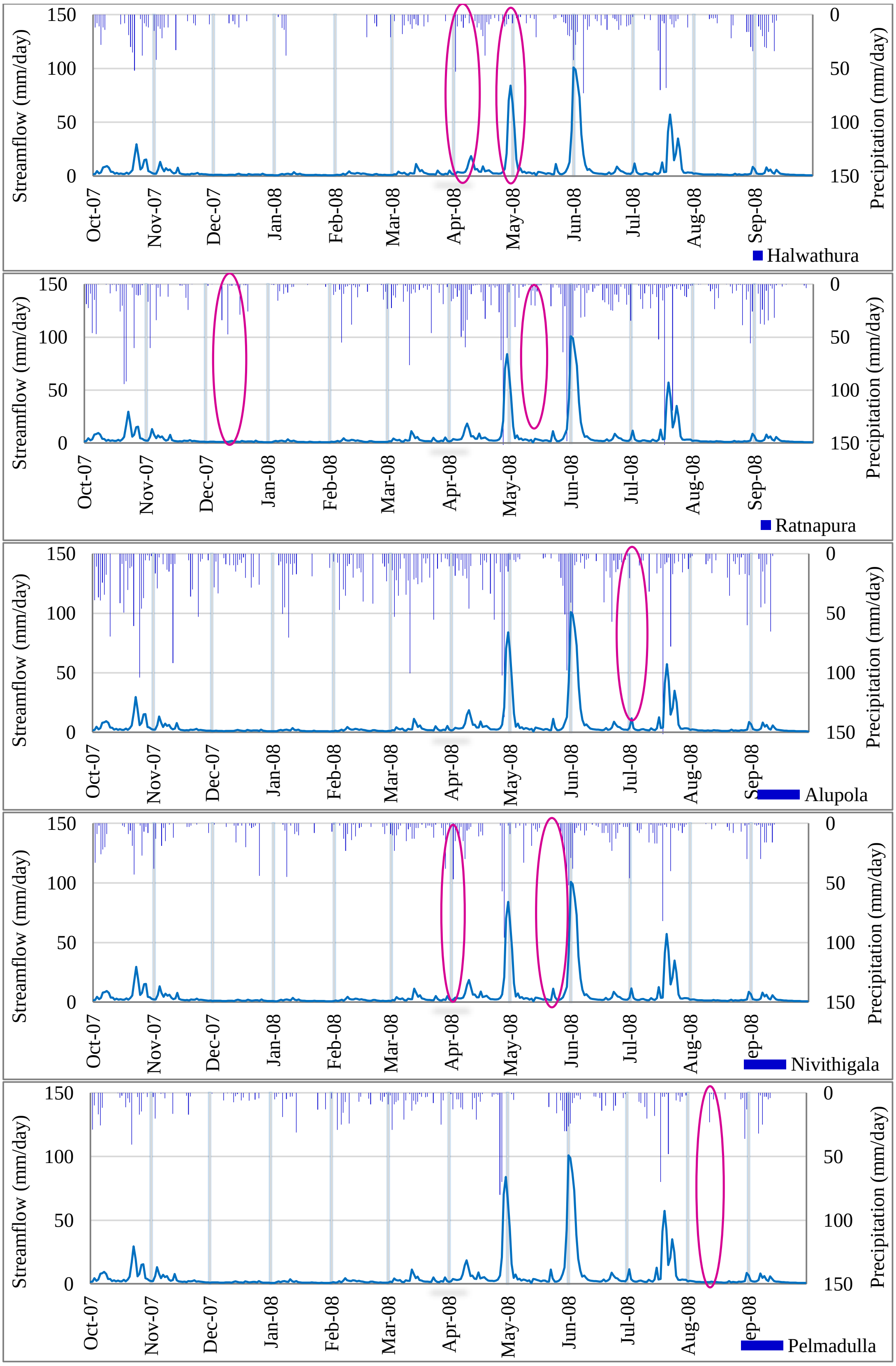

Figure B -11 : Rainfall response with Ellagawa Streamflow in 2007/2008 - Normal scale

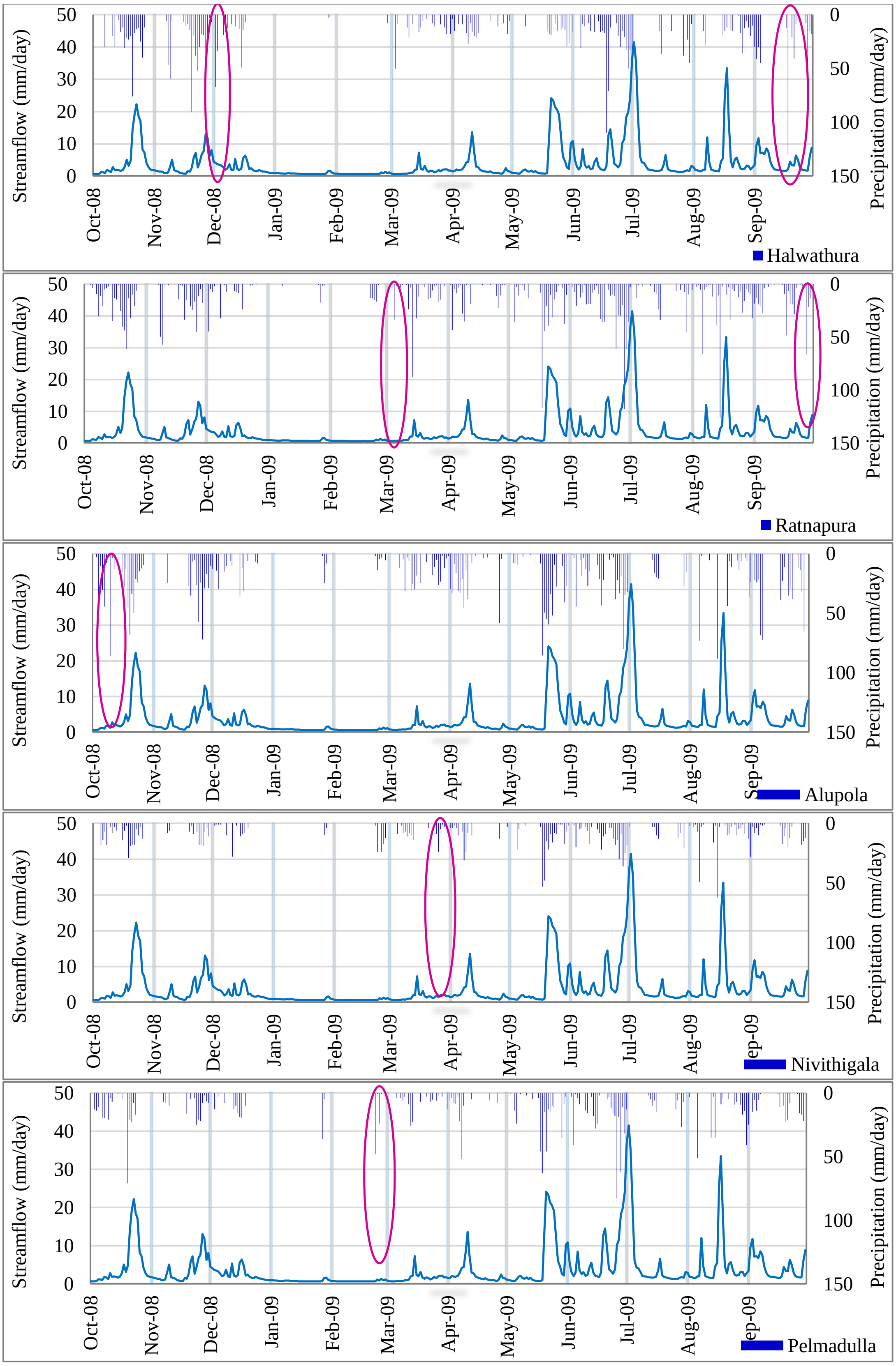

Figure B -12 : Rainfall response with Ellagawa Streamflow in 2008/2009- Log scale

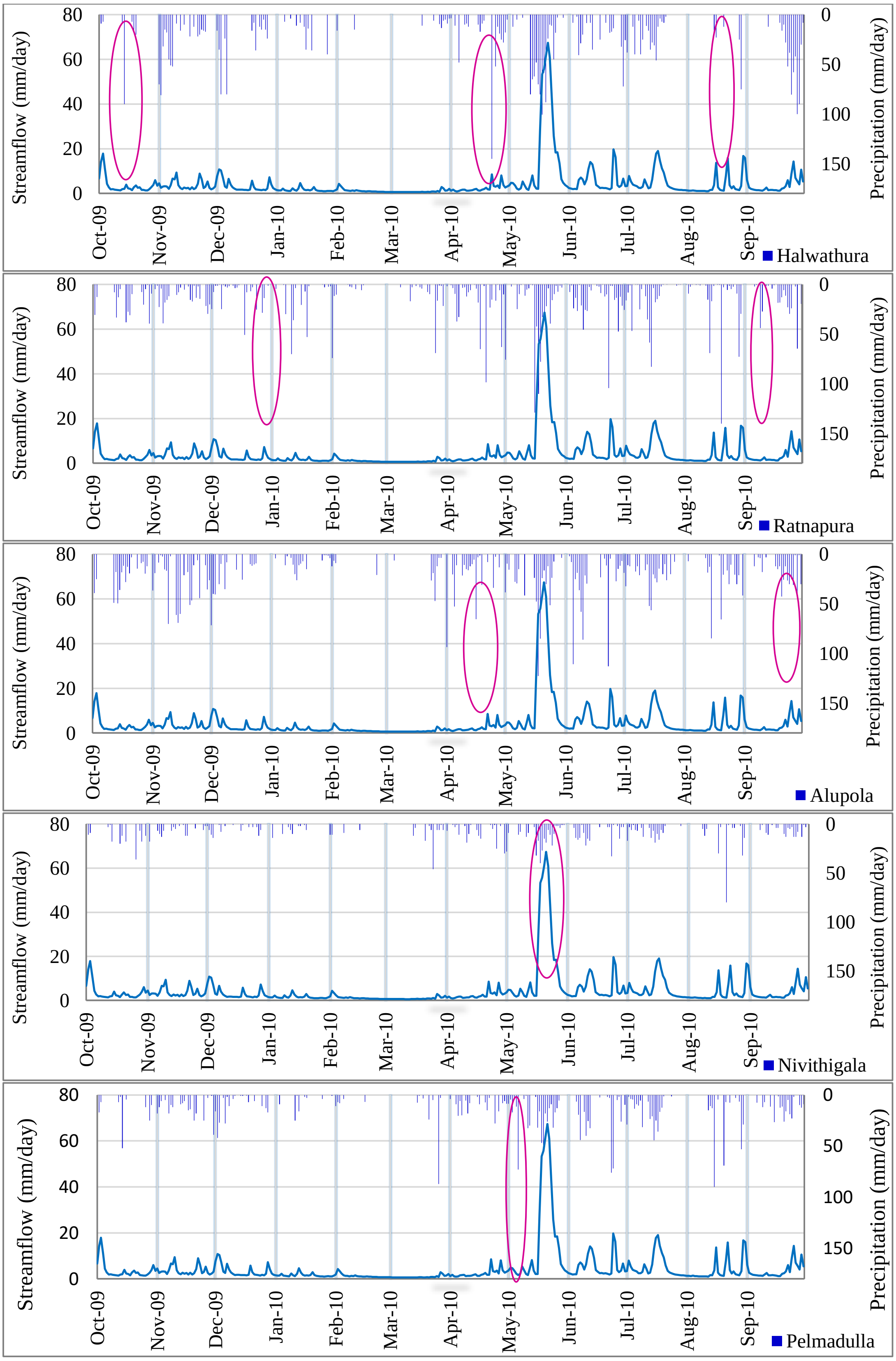

Figure B -13: Rainfall response with Ellagawa streamflow in 2009/2010 - Normal scale

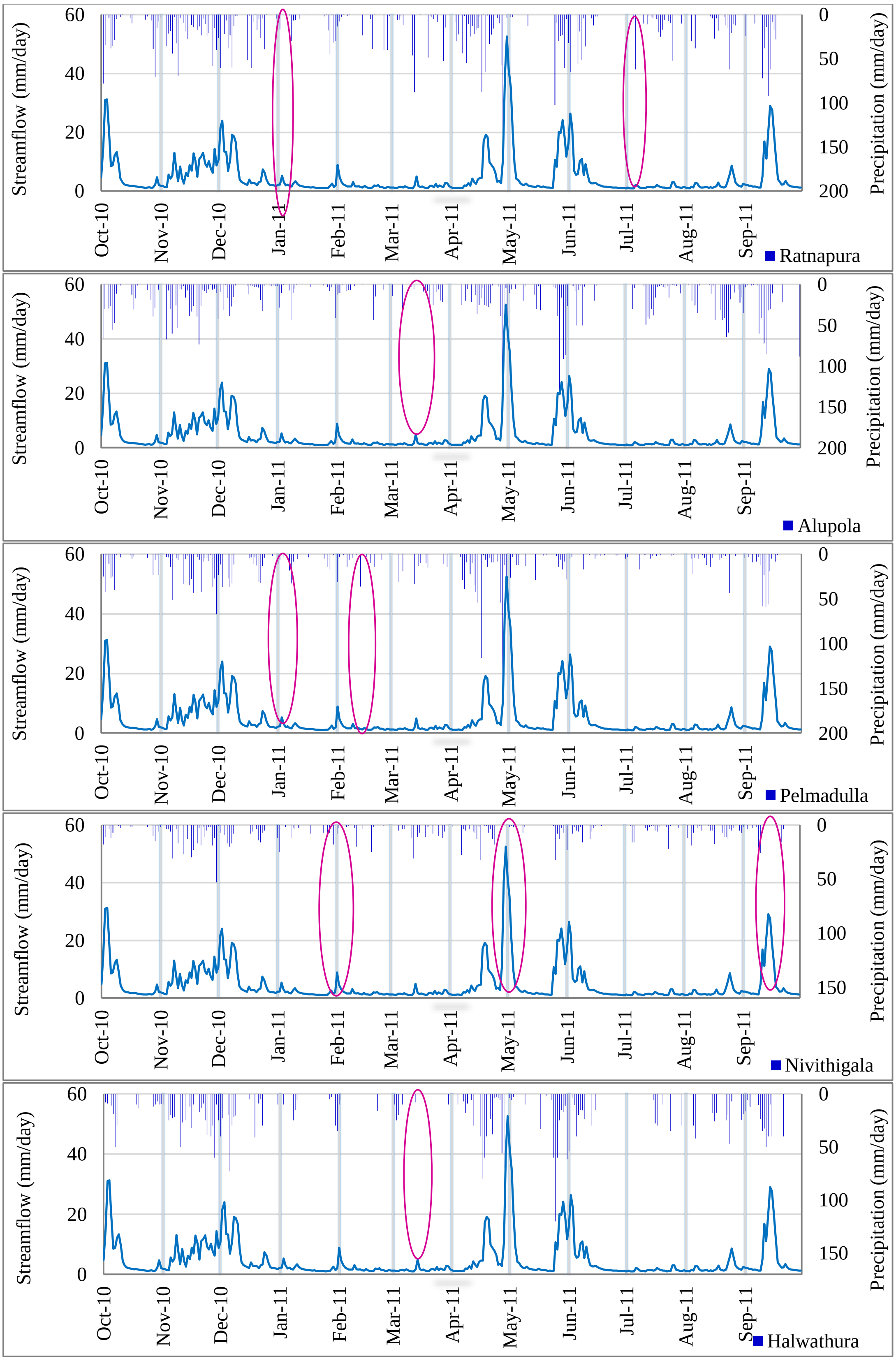

Figure B -14: Rainfall response with Ellagawa streamflow in 2010/2011- Normal scale

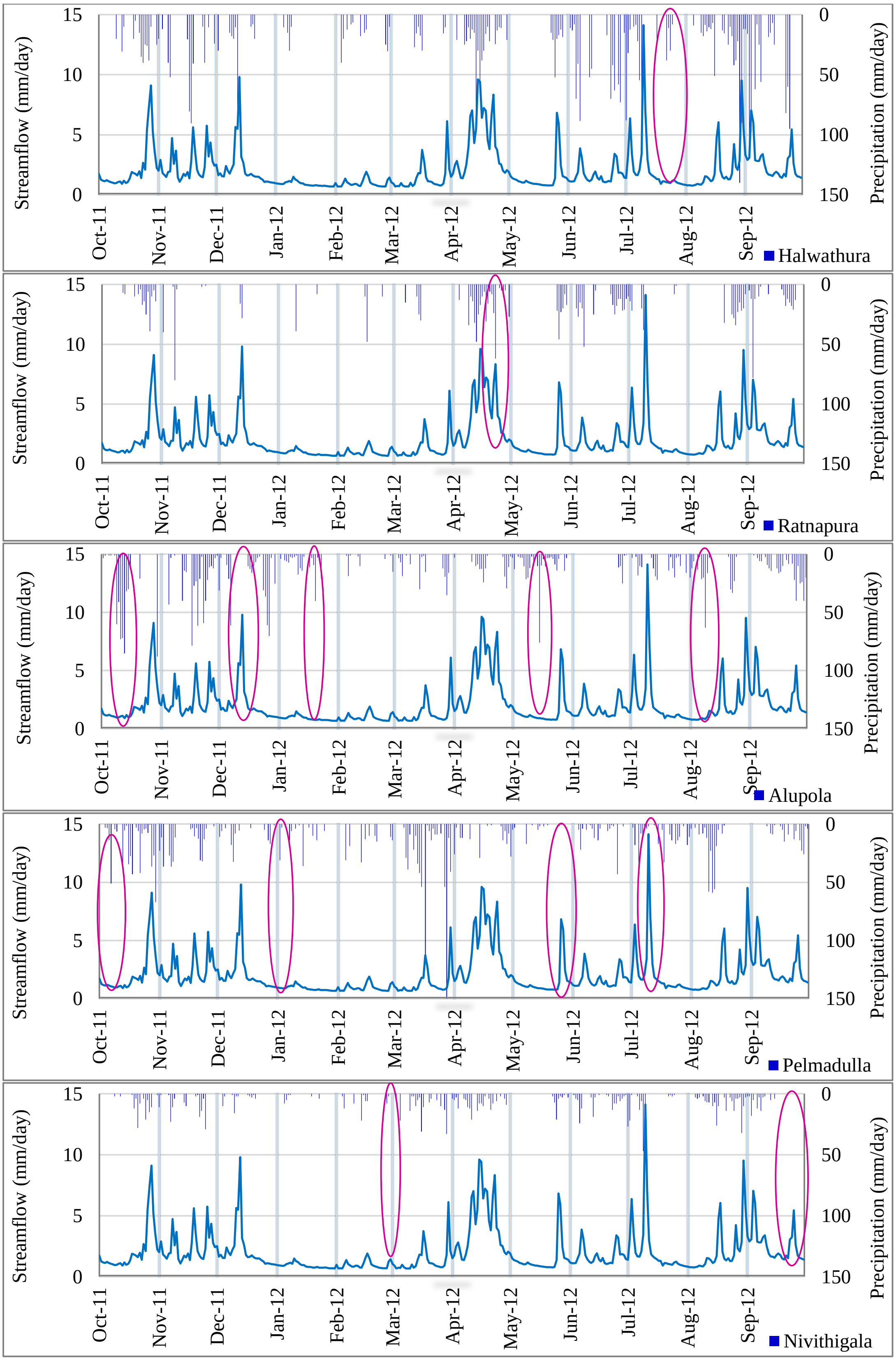

Figure B -15: Rainfall response with Ellagawa stream flow in 2011/2012 - Normal scale

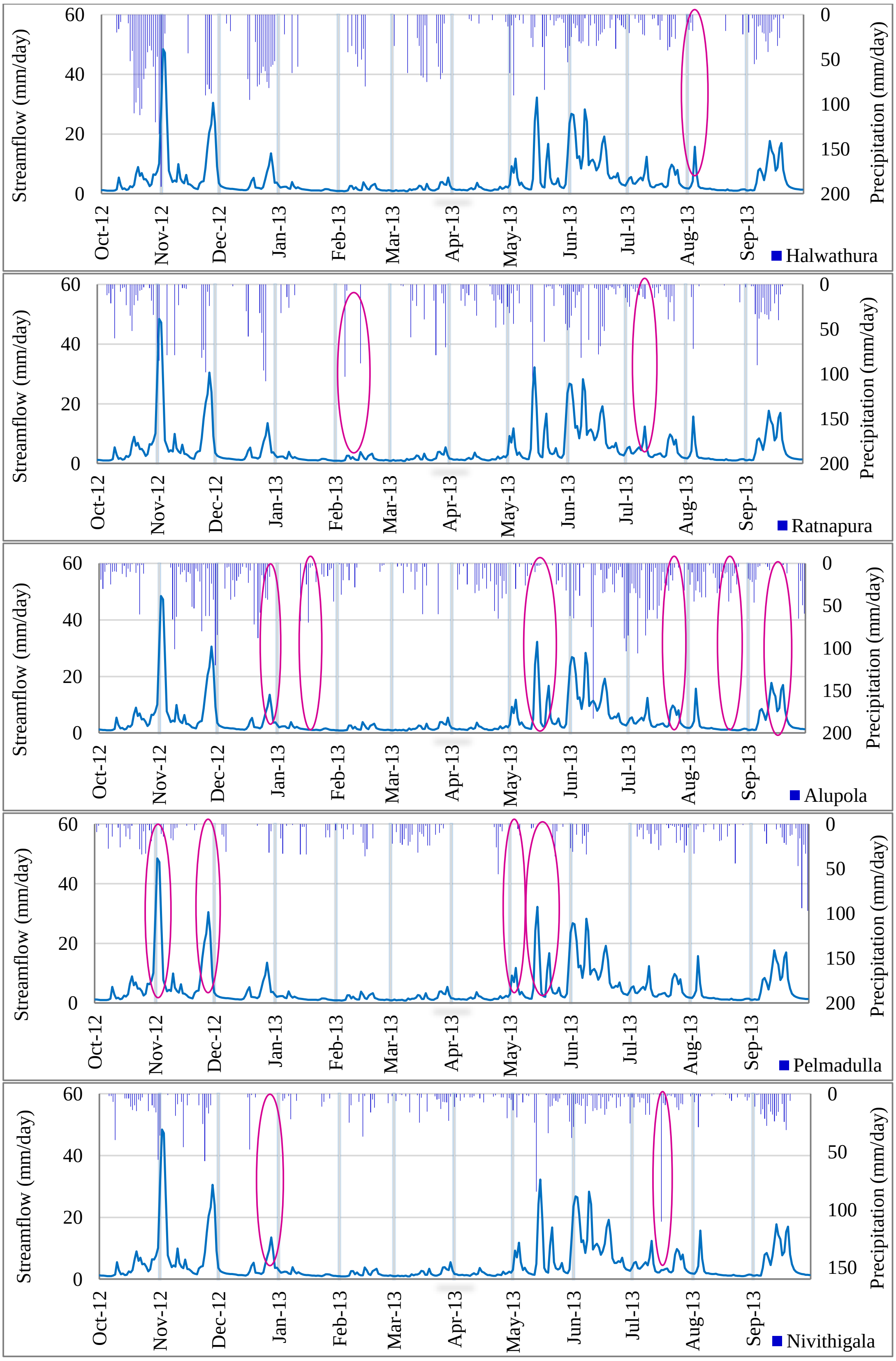

Figure B -16: Rainfall response with Ellagawa stream flow in 2012/2013- Log scale

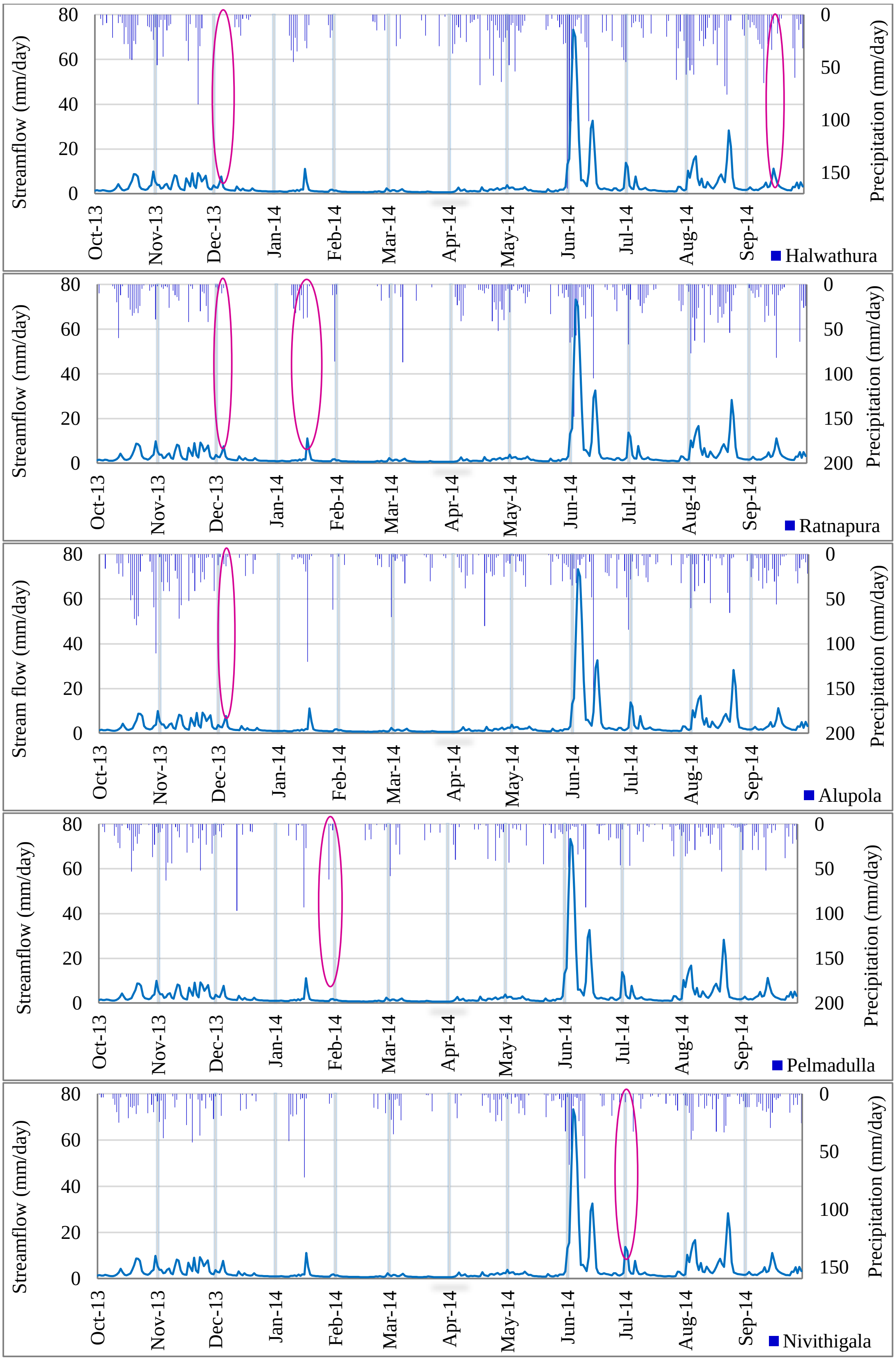

Figure B -17: Rainfall response with Ellagawa stream flow in 2013/2014 - Normal scale

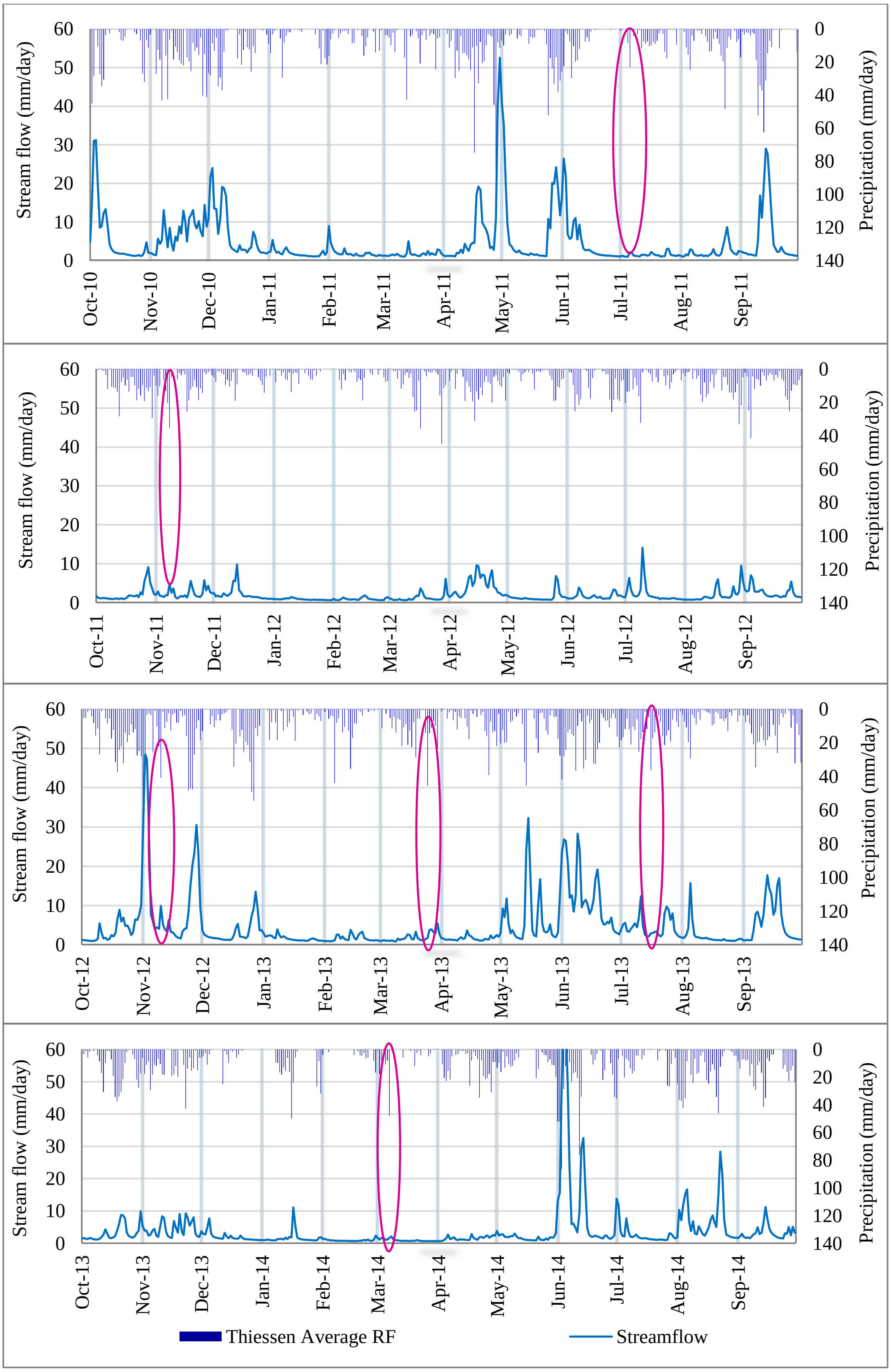

Figure B -18: Theissen Average Rainfall response with Ellagawa stream flow in 2010-2014- Normal scale

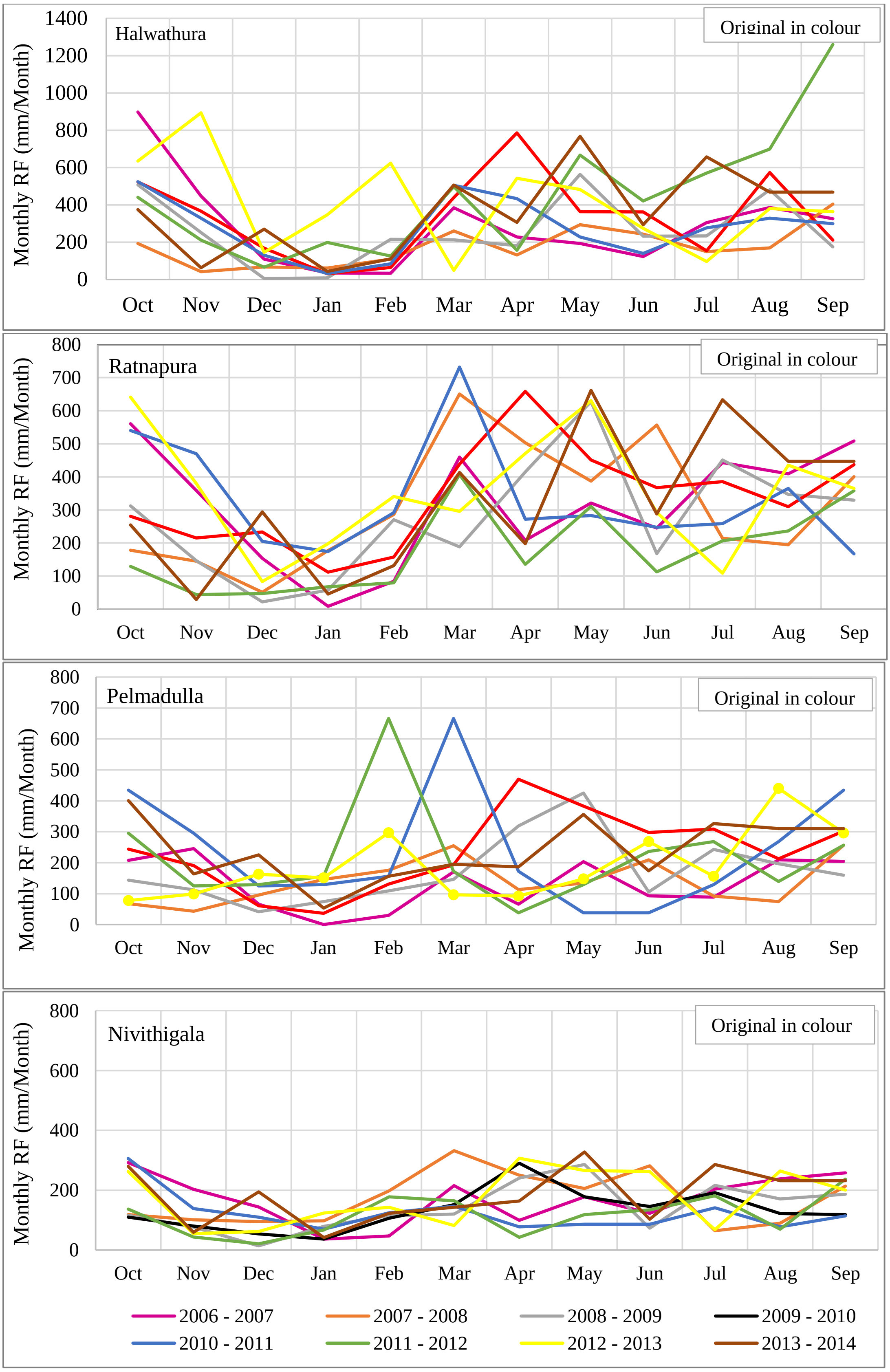

Figure B -19: Monthly Rainfall Comparison – Ellagawa Watershed

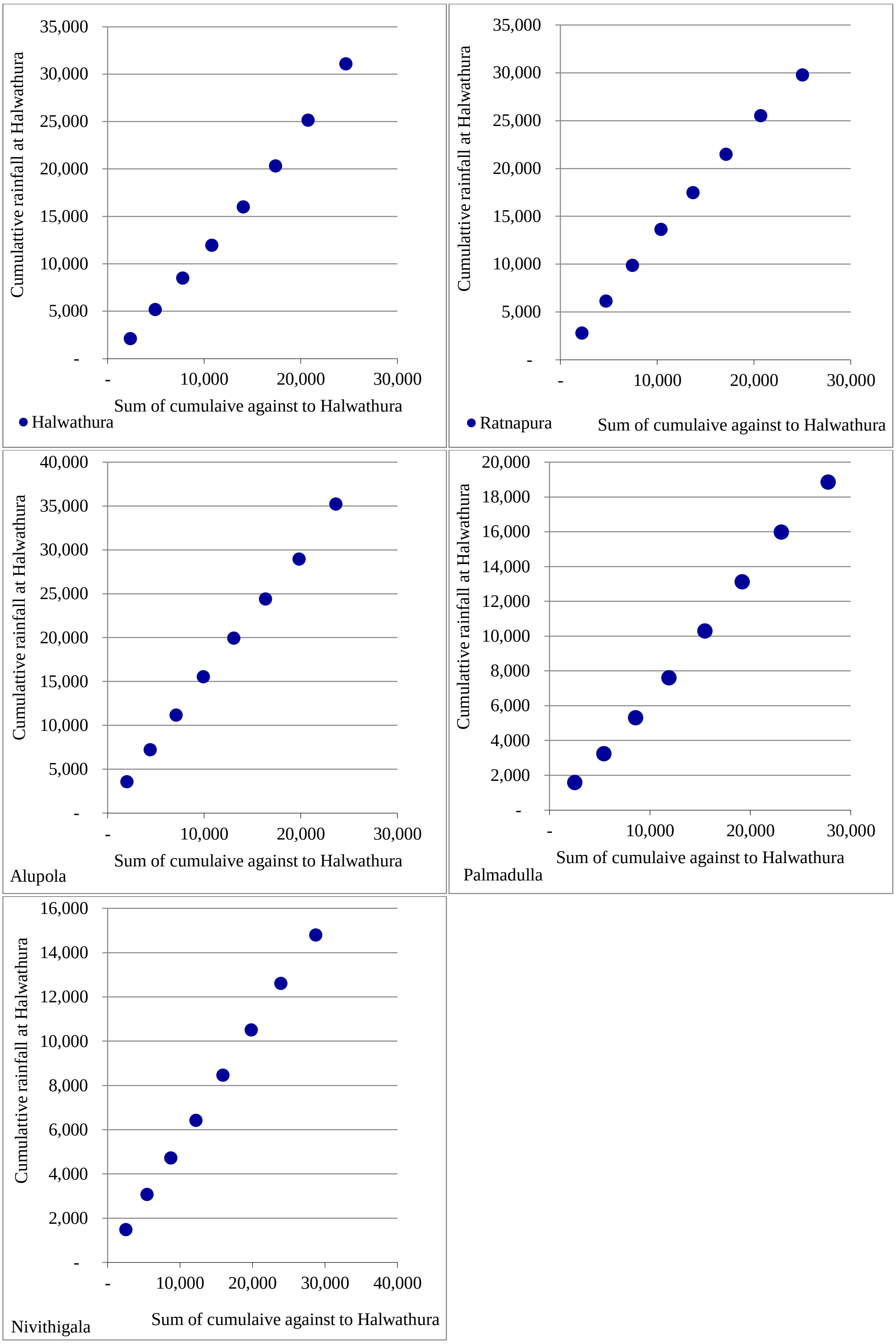

Figure B -20: Double Mass Curve for Rainfall Data – Ellagawa basin

Table B -1: Cumulative Average Rainfall for Double Mass Curve – Ellagawa Watershed

Water Year	For Halwathura	For Ratnapura	For Alupola	For Pelmadulla	For Nivithigala
2006 / 2007	2,958	2,883	2,712	3,427	3,314
2007 /2008	5,925	5,444	5,107	6,509	6,299
2008 / 2009	8,601	8,051	7,649	9,433	9,317
2009/ 20010	11,854	11,301	10,774	12,987	13,183
2010 / 2011	15,039	14,310	13,695	16,277	16,823
2011 / 2012	17,732	17,796	16,962	19,785	20,588
2012 / 2013	21,455	21,665	20,326	24,144	24,995
2013 / 2014	24,662	24,994	23,630	27,719	28,737

Table B -2: Cumulative Average Rainfall for Double Mass Curve – Tawalama Watershed

Water Year	For Tawalama	For Neluwa	For Aningkanda	For Deniyaya
2000 - 2001	-	-	2,685	2,101
2001 - 2002	3,136	1,464	5,530	4,478
2002 - 2003	7,082	4,684	8,402	7,098
2003 - 2004	11,171	7,938	11,305	9,968
2004 - 2005	15,510	11,669	14,221	12,998
2005 - 2006	19,877	15,404	17,259	16,151
2006 - 2007	24,269	19,290	20,365	19,341
2007 - 2008	28,685	23,192	23,597	22,604
2008 - 2009	33,143	27,202	26,875	26,142
2009 - 2010	37,711	31,300	30,305	29,825
2010 - 2011	42,389	35,406	33,736	33,754
2011 - 2012	47,114	39,685	37,240	37,721
2012 - 2013	51,916	44,032	40,752	41,780
2013 - 2014	56,932	48,422	44,811	45,958
2014 - 2015	62,084	53,972	49,124	50,311

ANNEX C - DATA CHECKING (TAWALAMA WATERSHED)

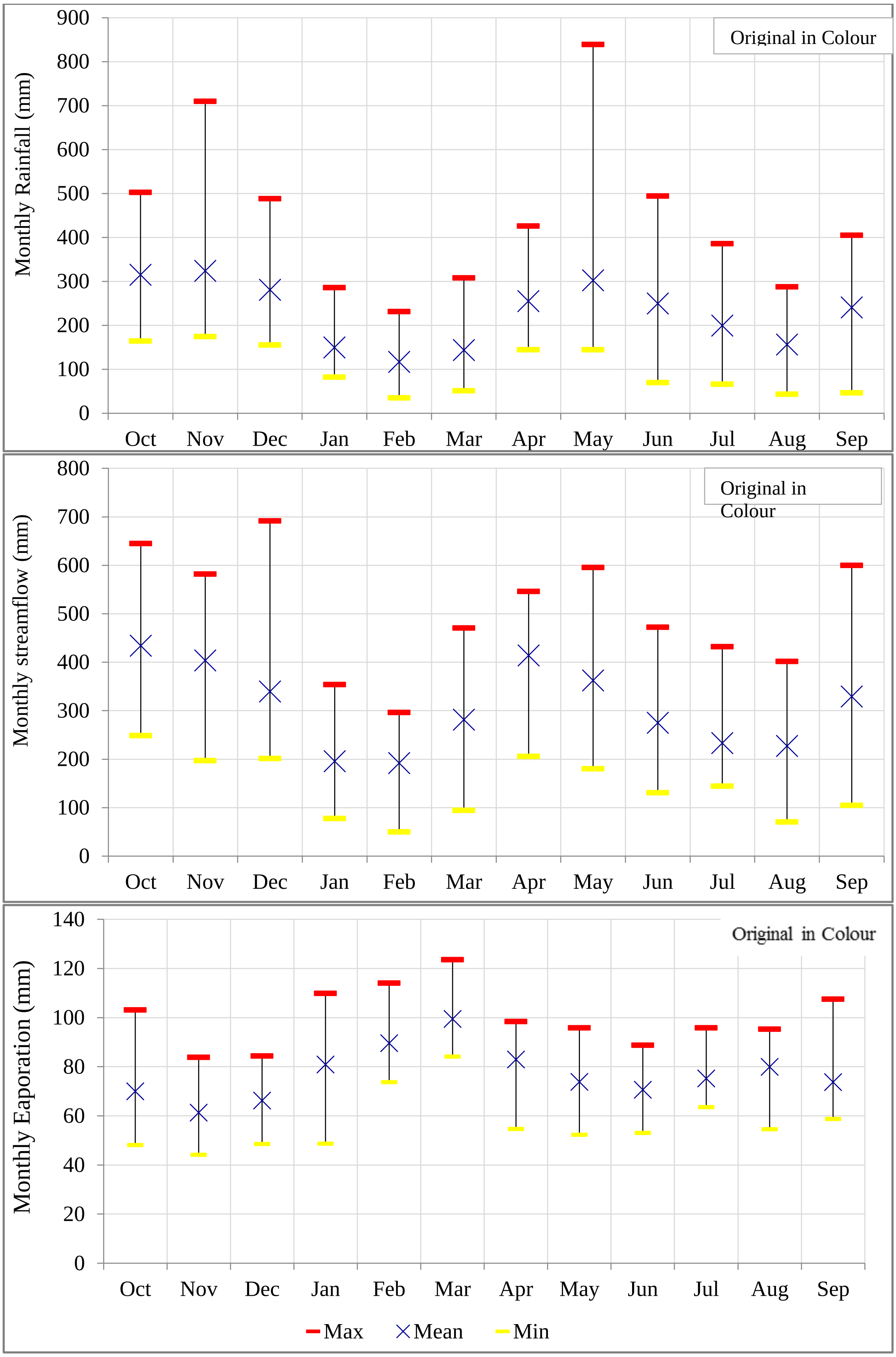

Figure C-1: Variation of high, medium and minimum flows – Tawalama Watershed

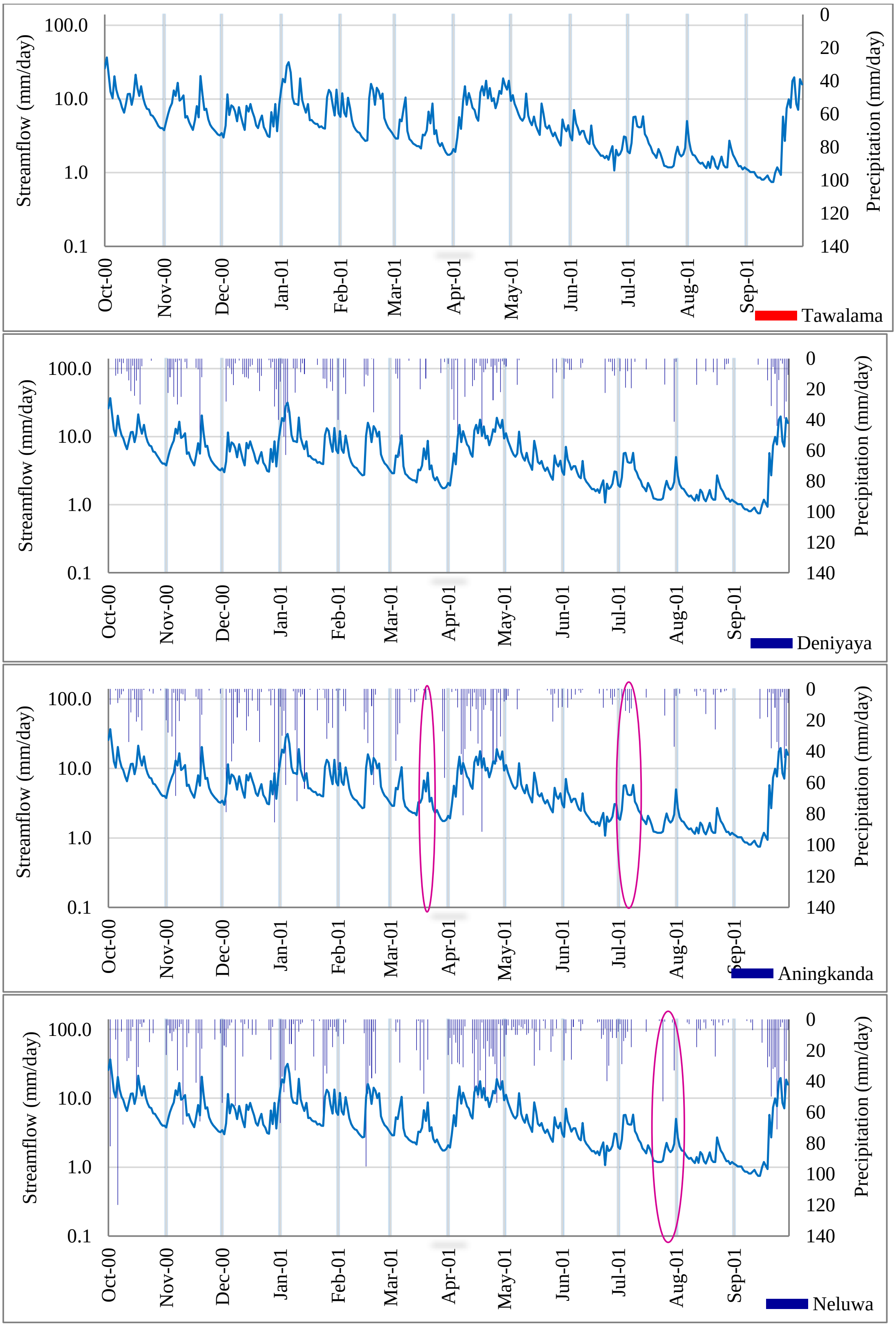

Figure C-2: Rainfall response to Tawalama Stream flow in year 2000/2001 –Log scale

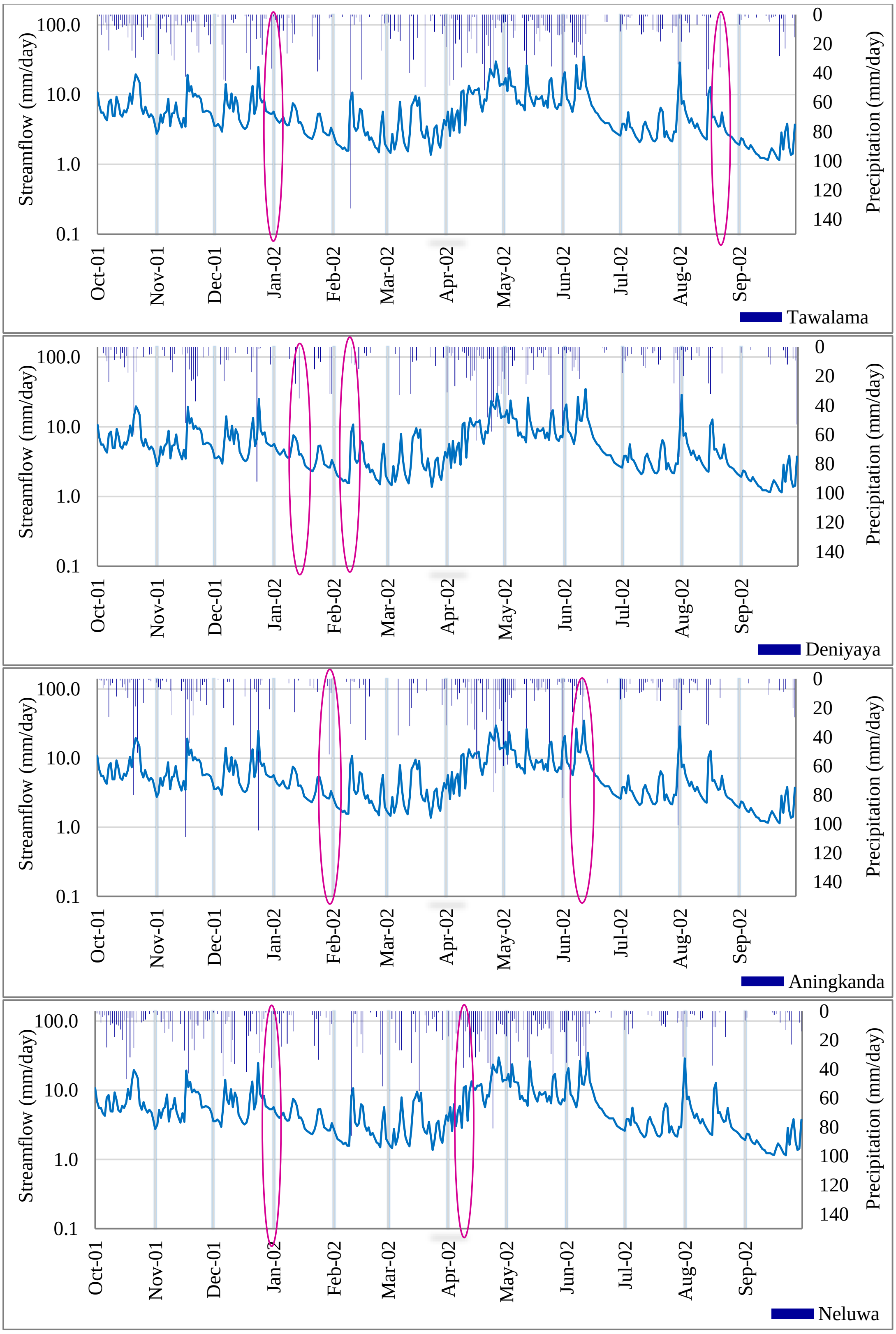

Figure C -3: Rainfall response to Tawalama Stream flow in year 2001/2002 – Log scale

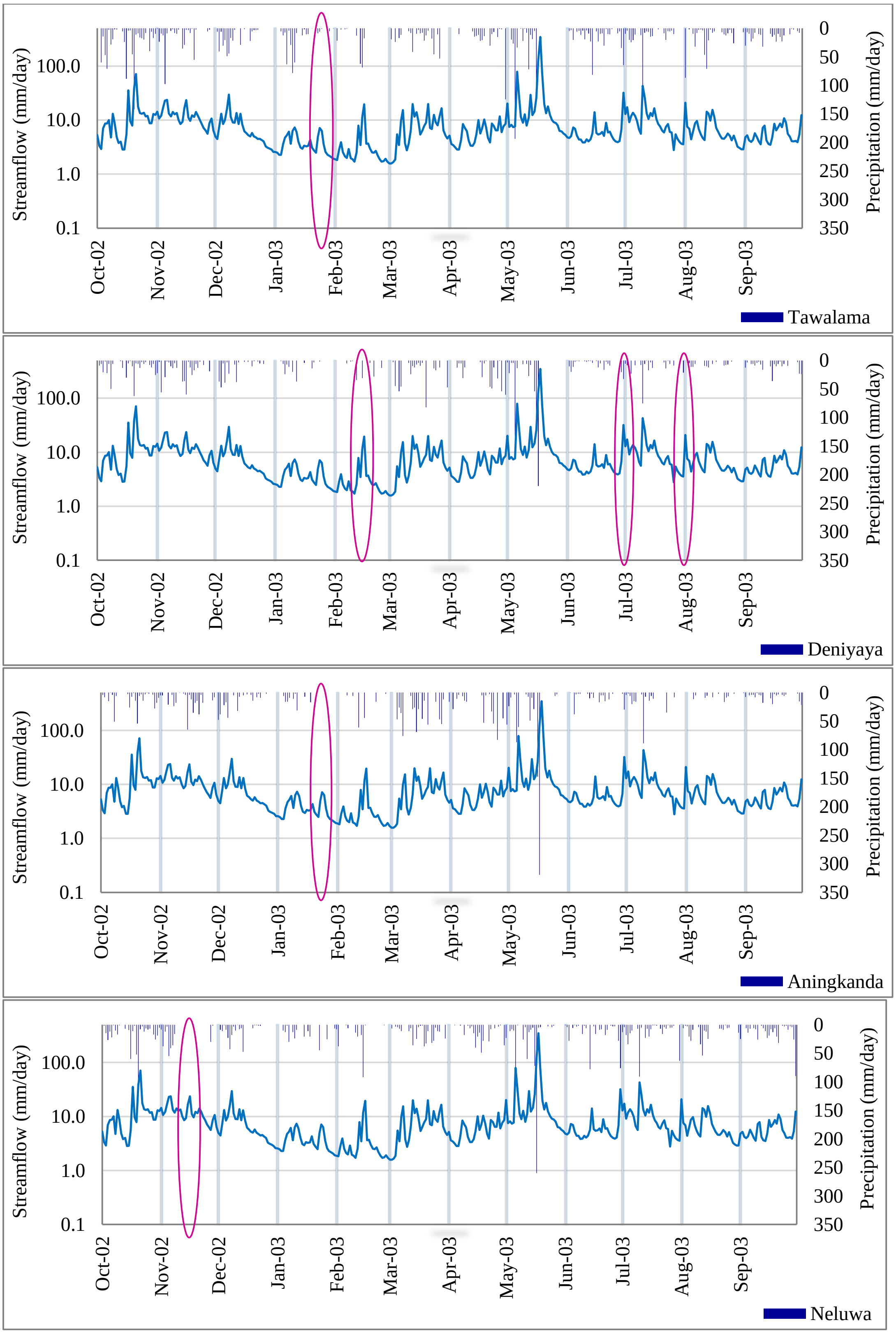

Figure C -4: Rainfall response to Tawalama Stream flow in year 2002/2003 – Log scale

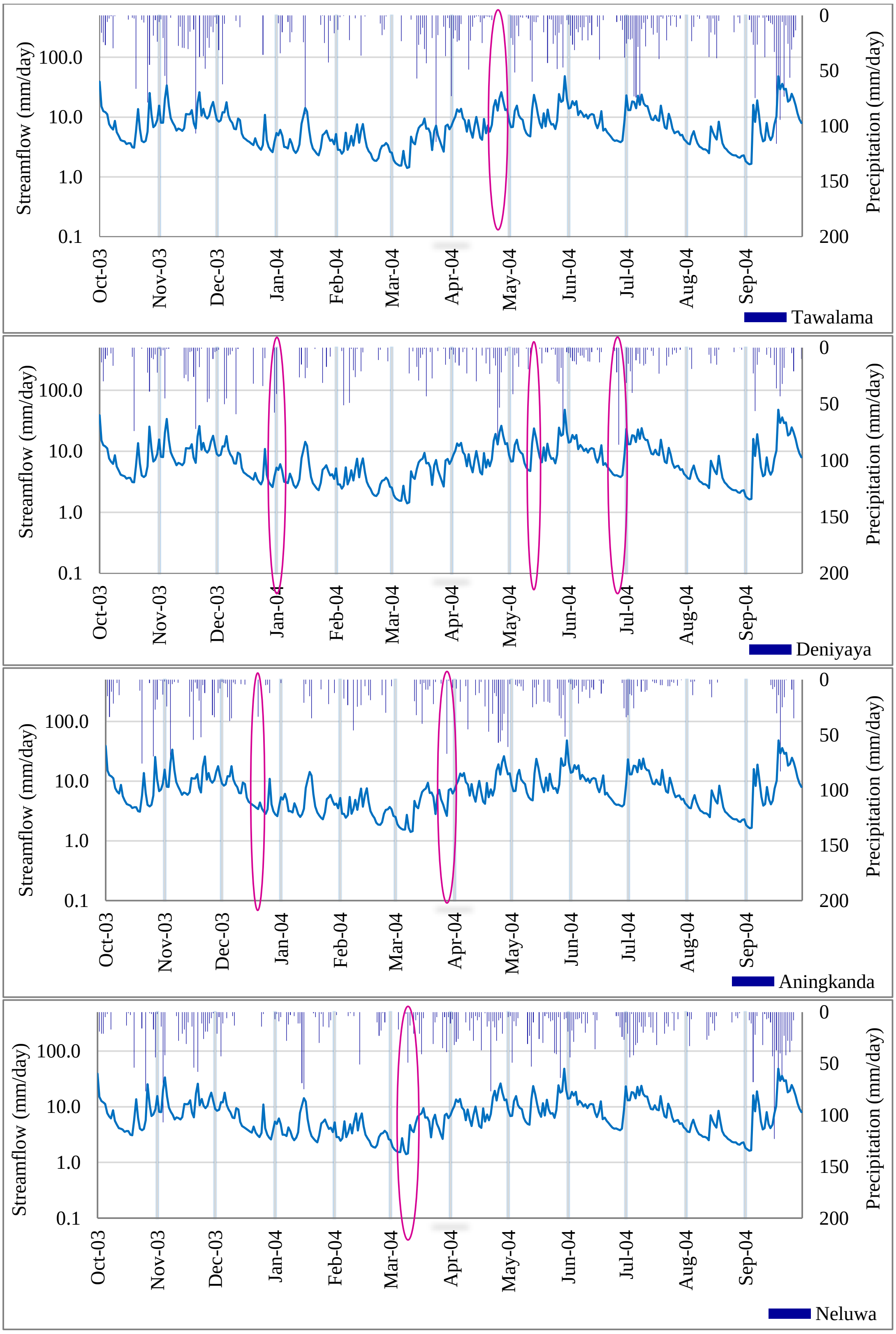

Figure C -5: Rainfall response to Tawalama Stream flow in year 2003/2004– Log scale

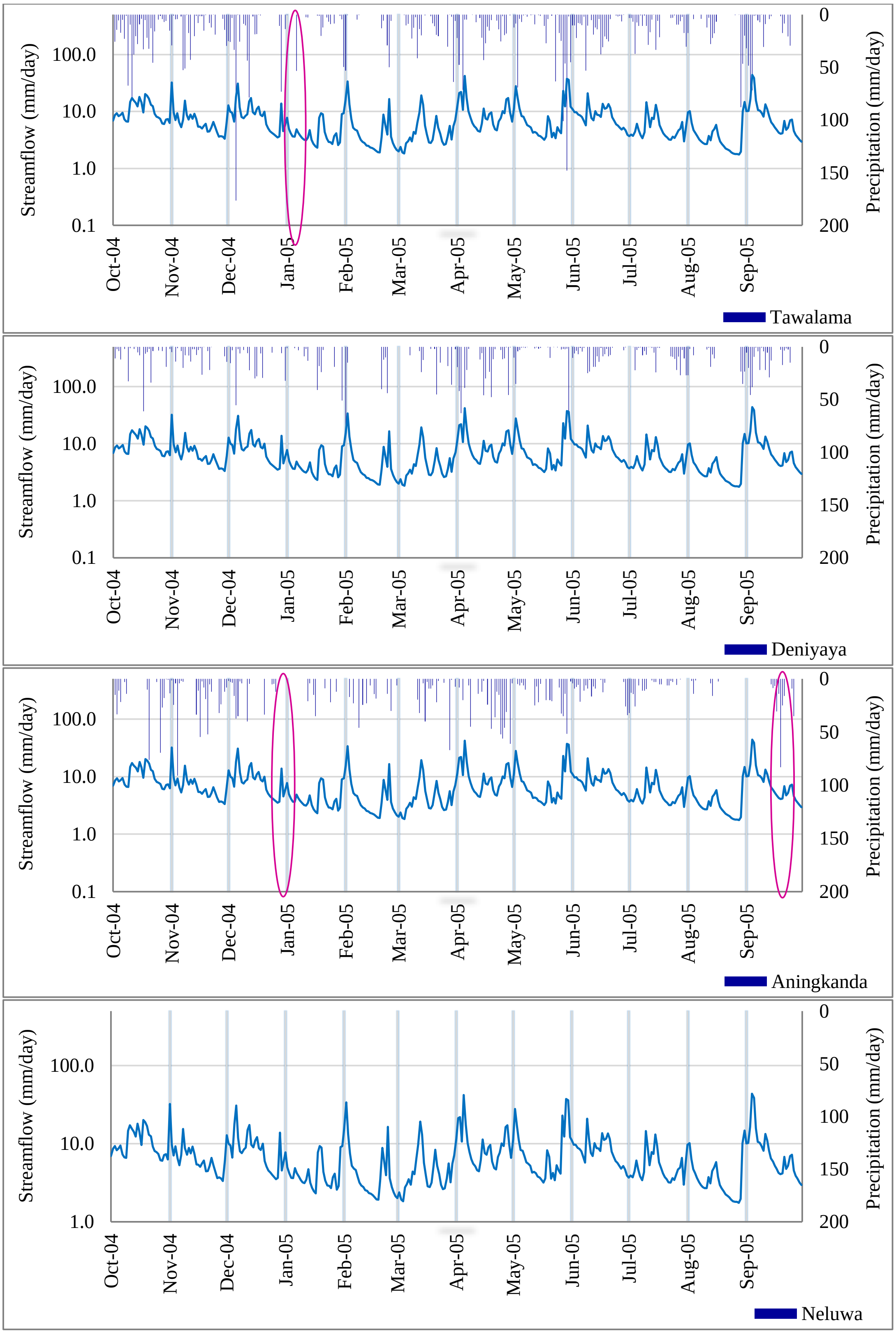

Figure C -6: Rainfall response to Tawalama Stream flow in year 2004/2005– Log scale

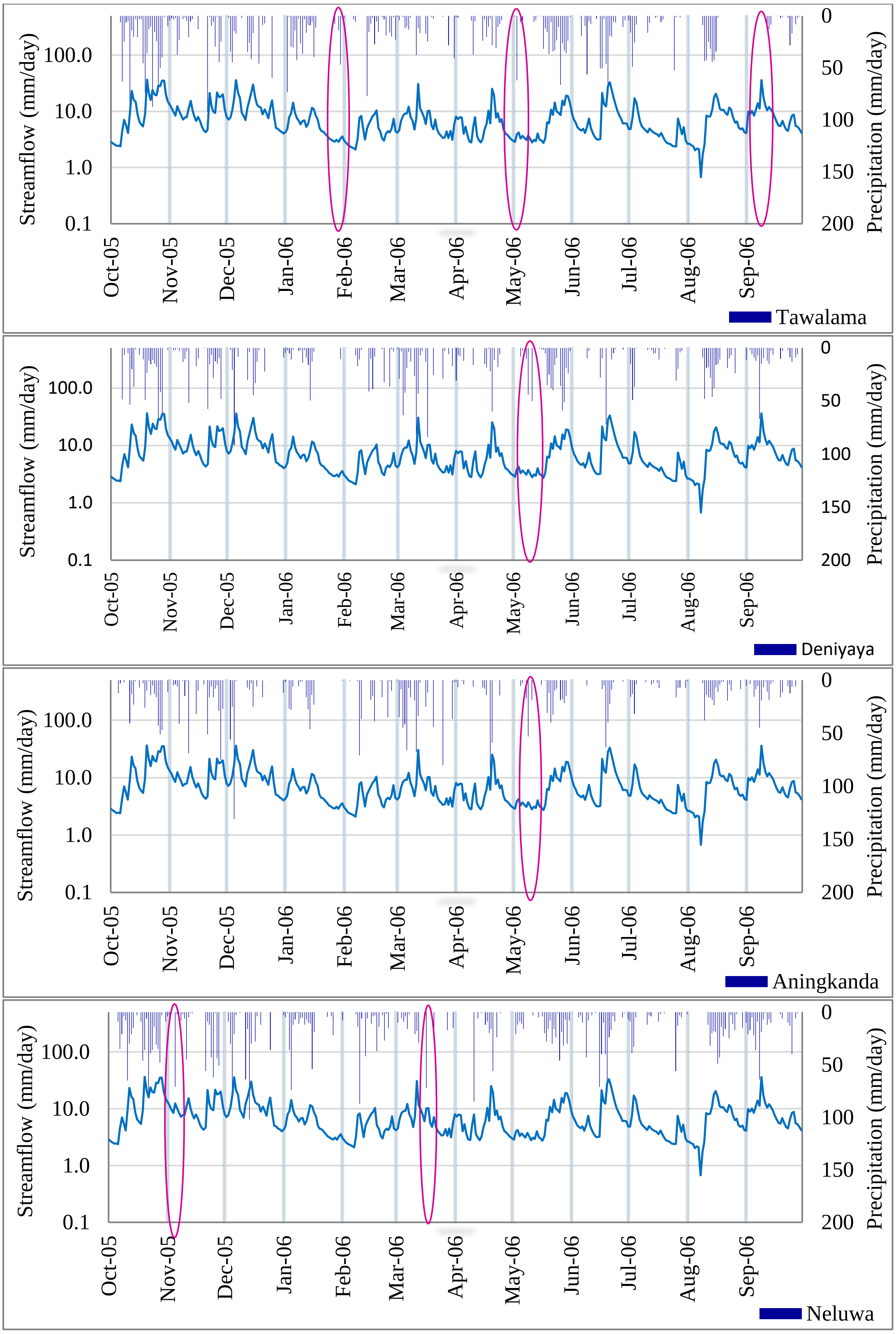

Figure C -7: Rainfall response to Tawalama Stream flow in year 2005/2006 – Log scale

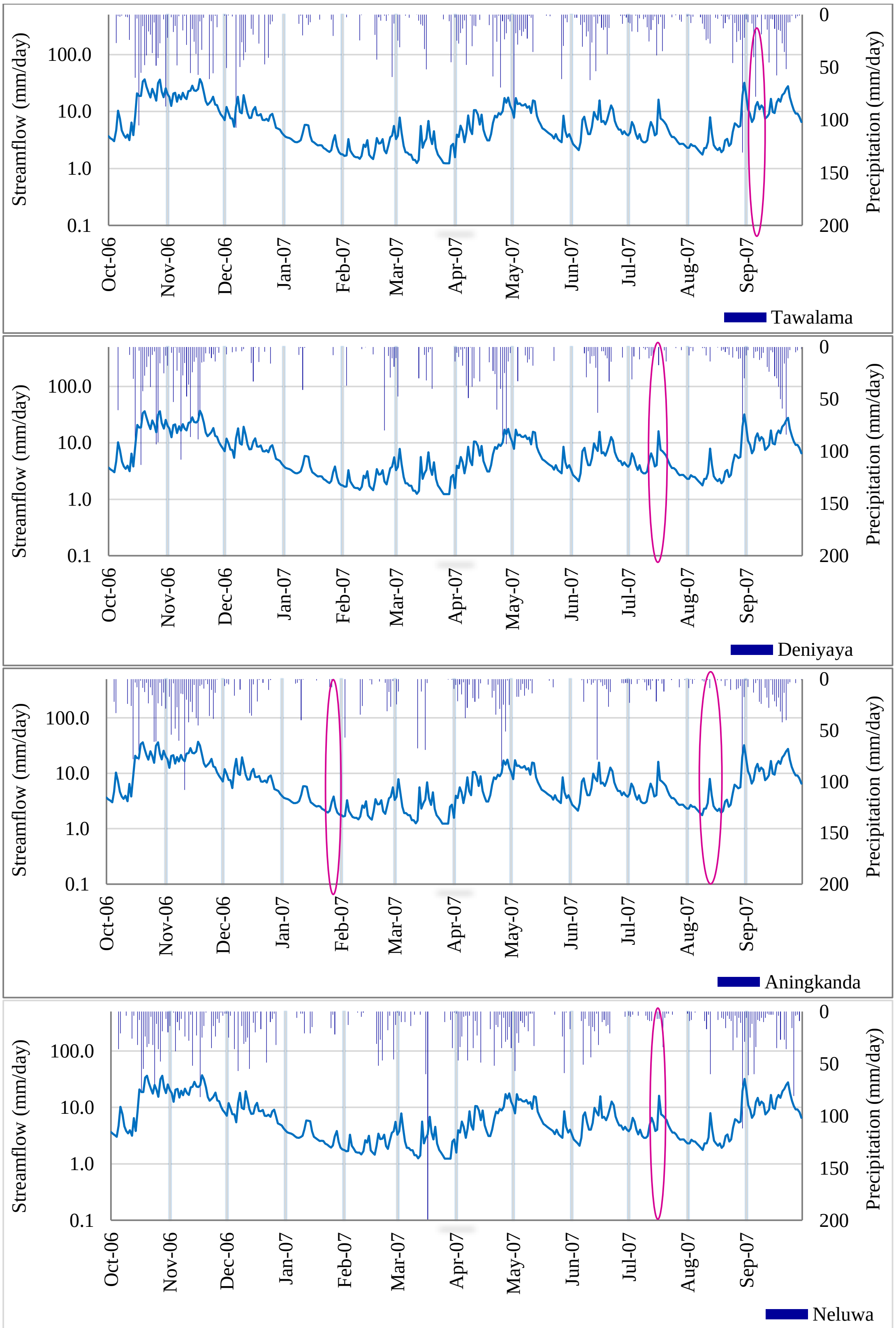

Figure C -8: Rainfall response to Tawalama Stream flow in year 2006/2007– Log scale

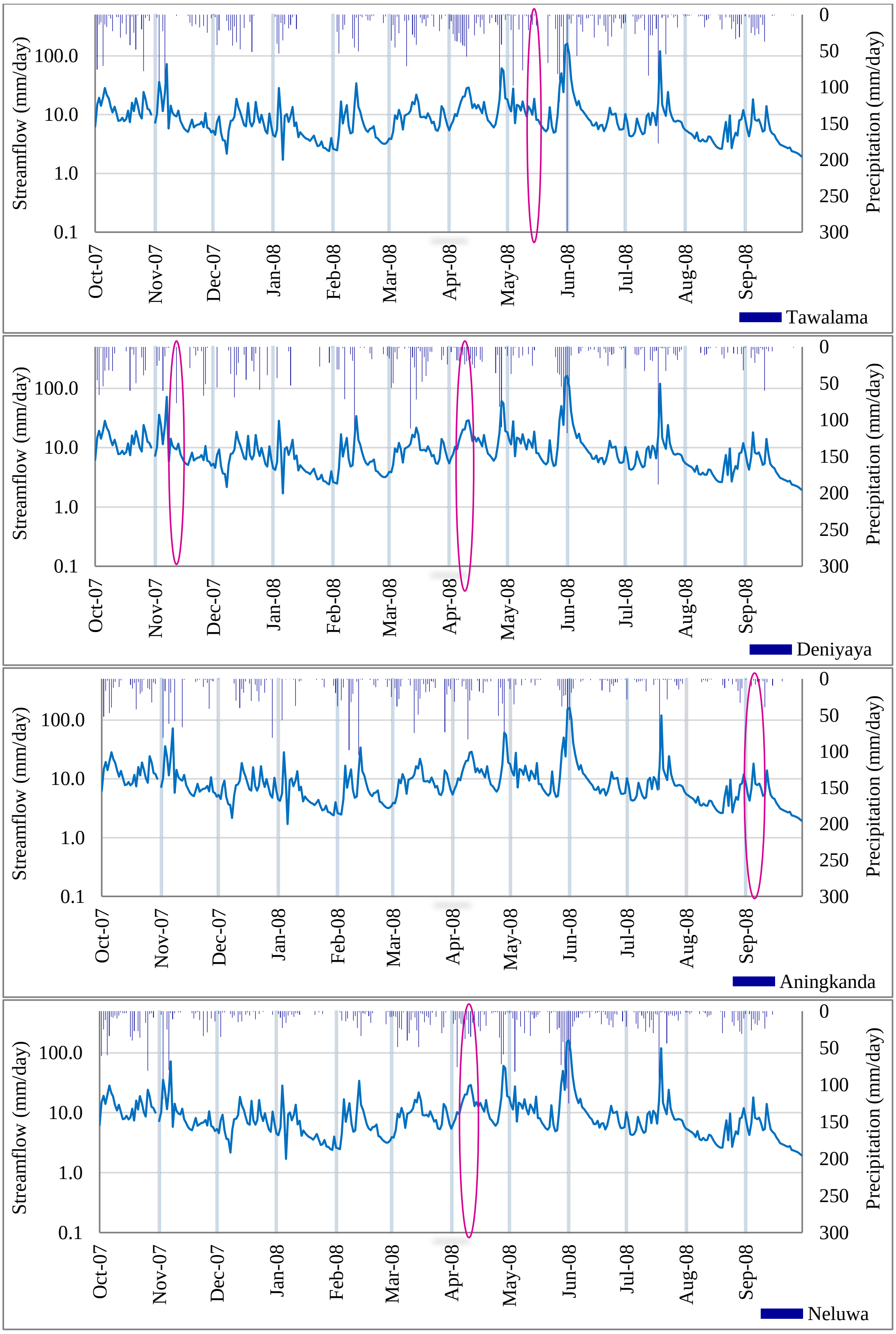

Figure C -9: Rainfall response to Tawalama Stream flow in year 2007/2008– Log scale

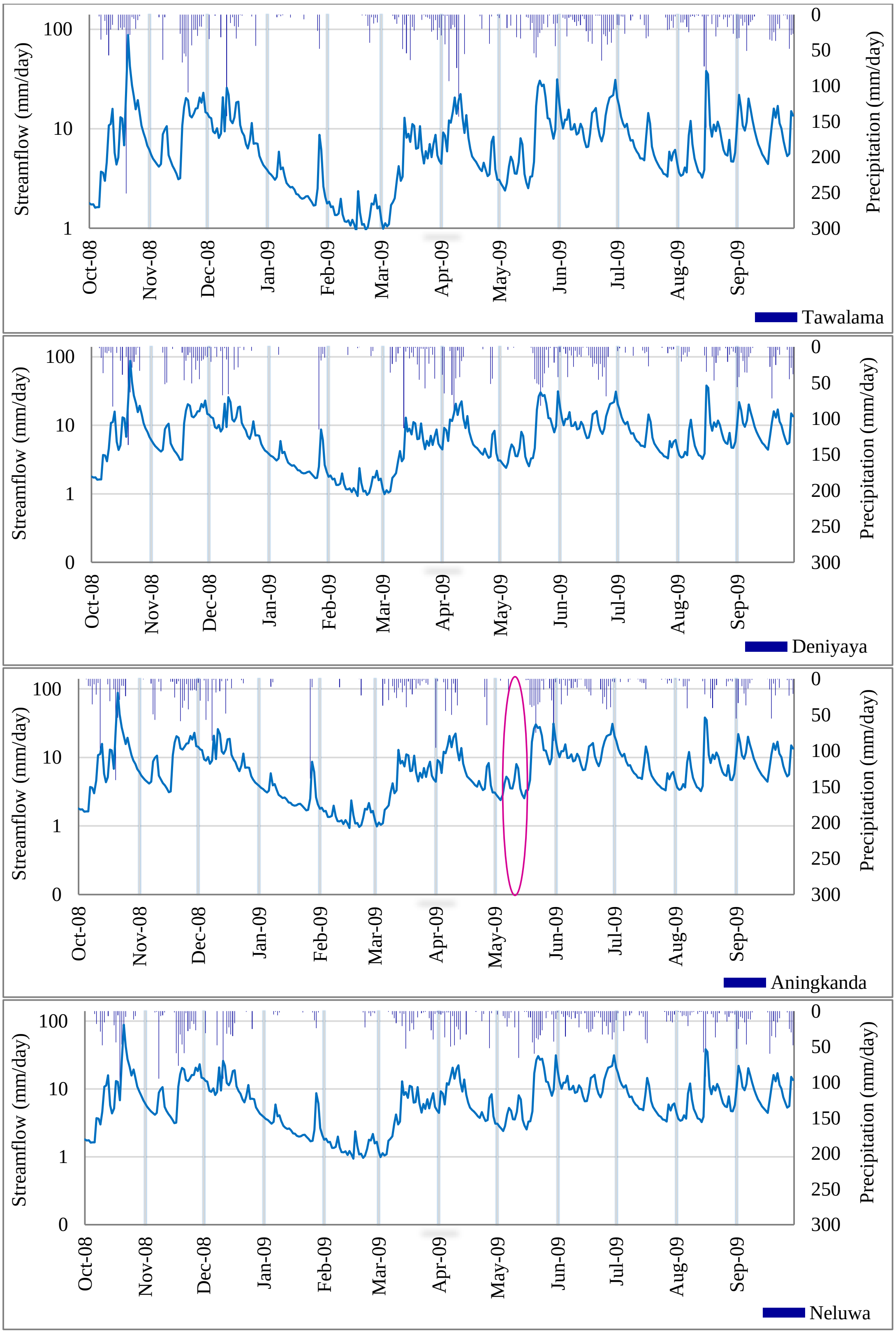

Figure C -10: Rainfall response to Tawalama Stream flow in year 2008/2009– Log scale

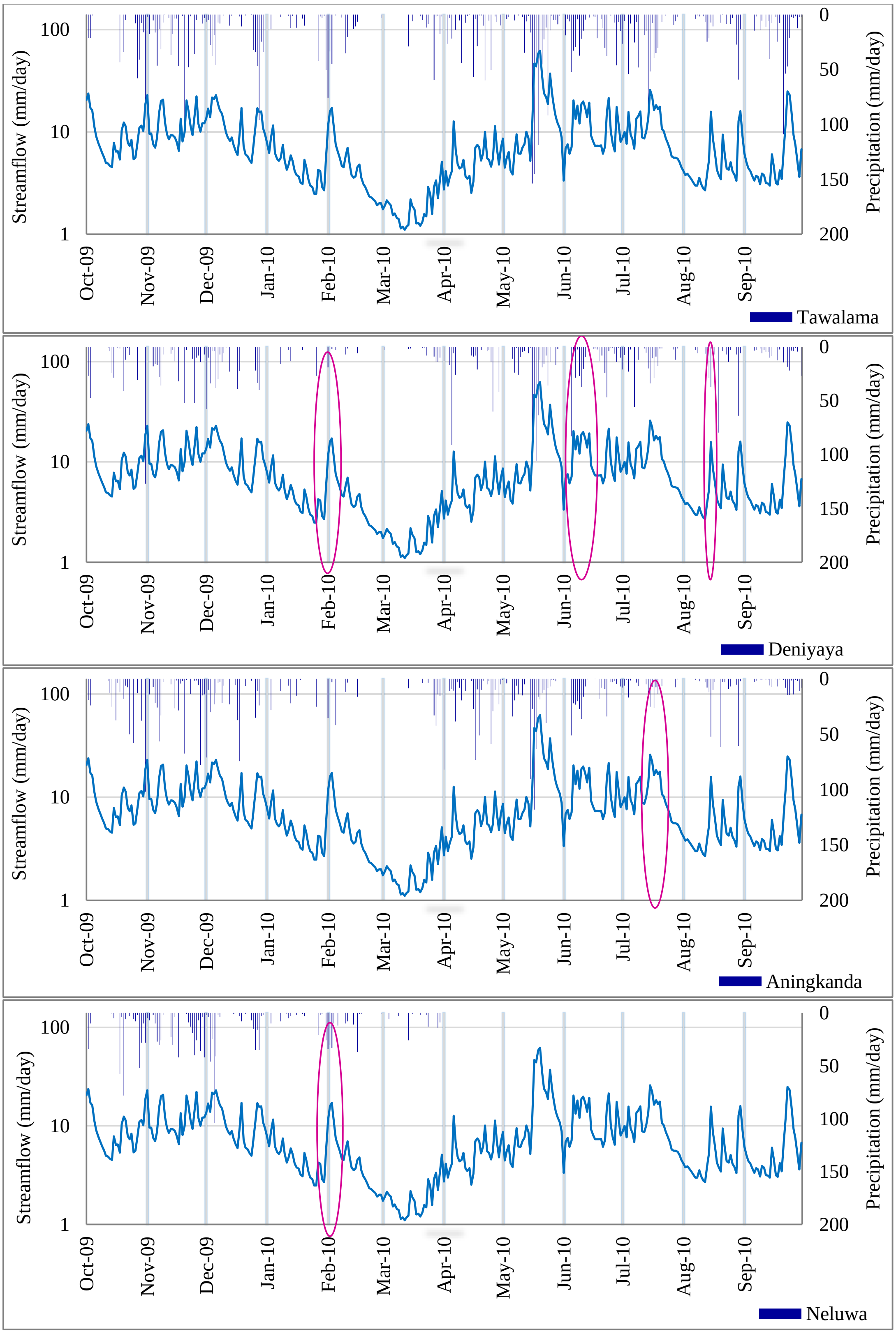

Figure C -11: Rainfall response to Tawalama Stream flow in year 2009/2010– Log scale

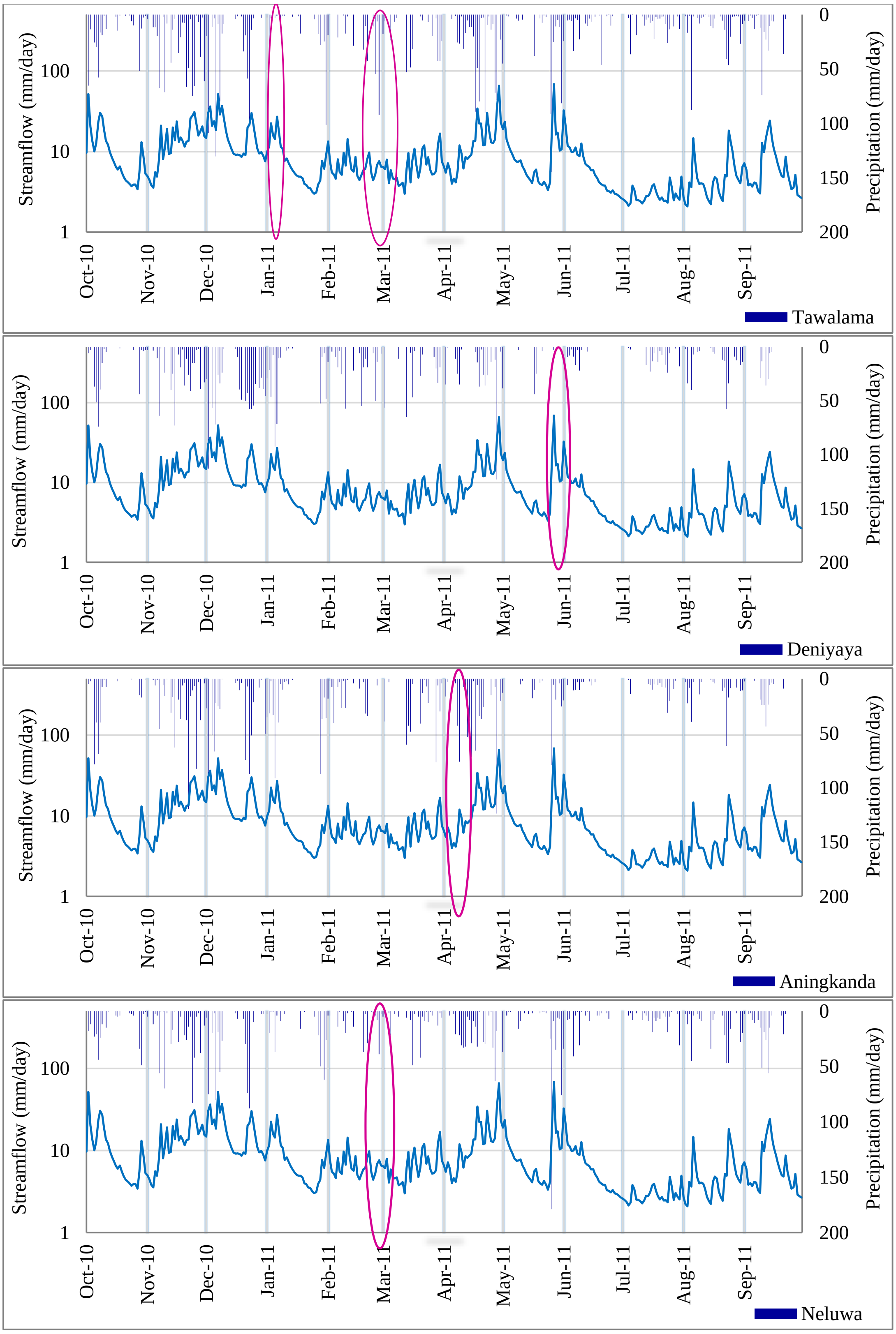

Figure C -12: Rainfall response to Tawalama Stream flow in year 2010/2011– Log scale

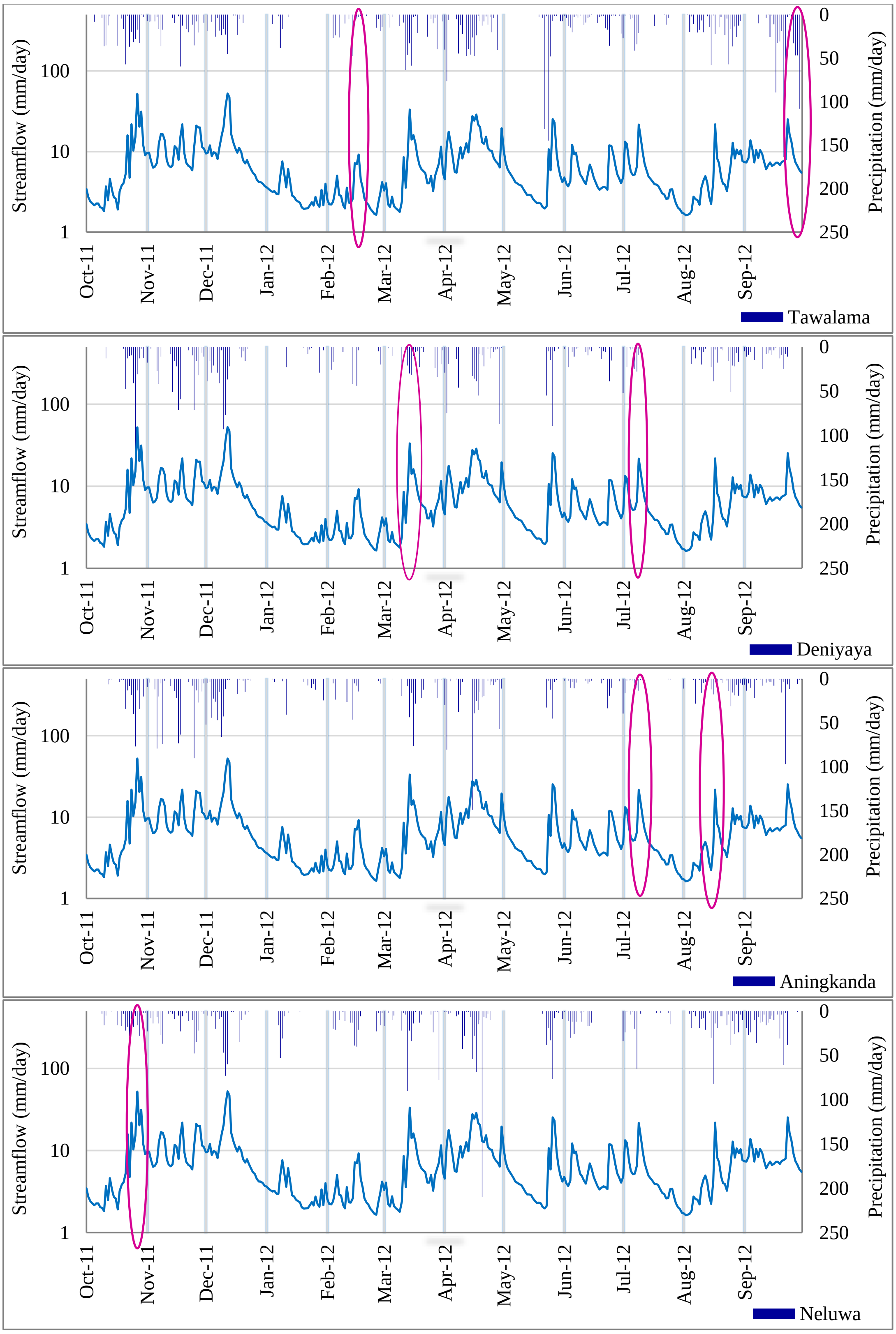

Figure C -13: Rainfall response to Tawalama Stream flow in year 2011/2012– Log scale

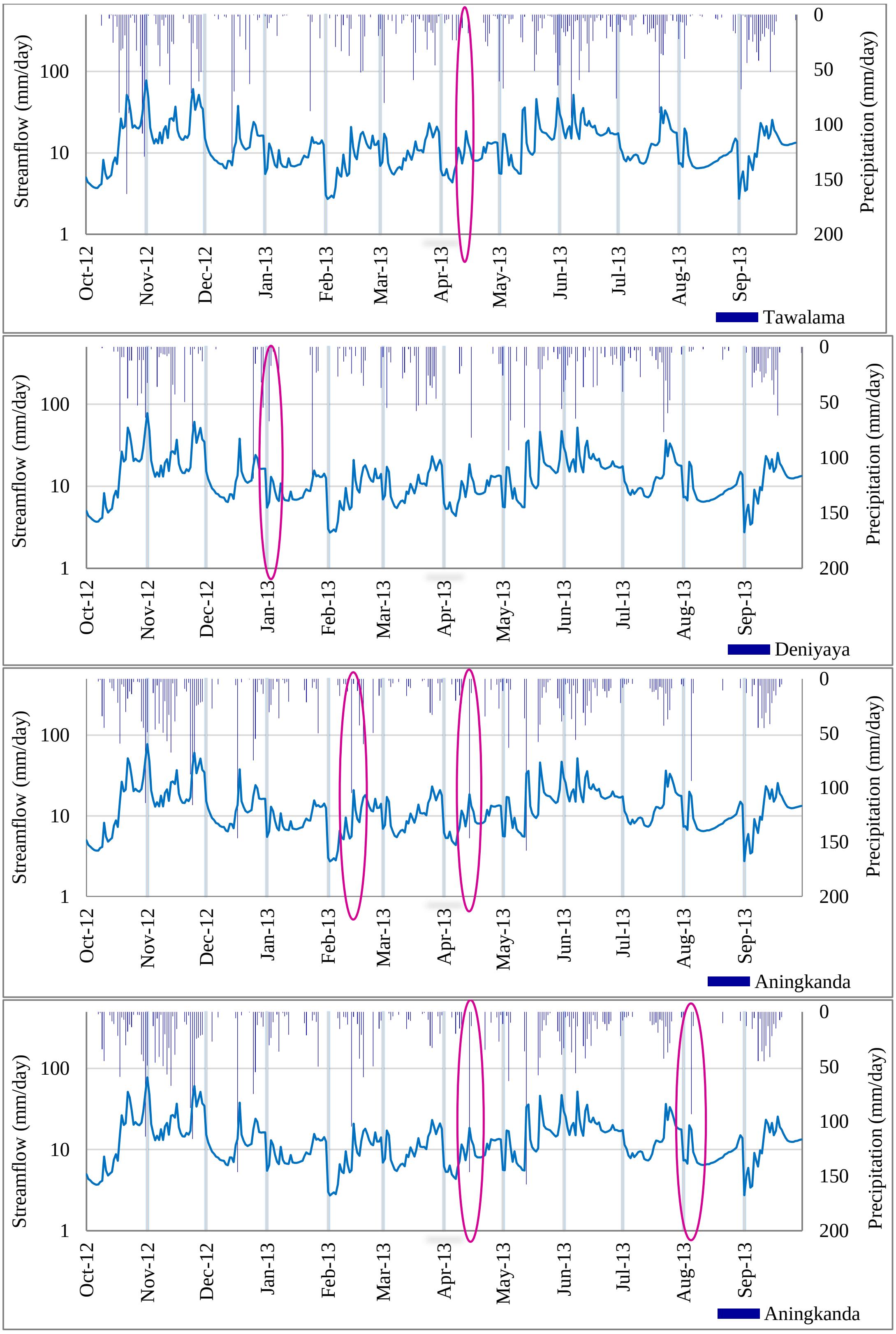

Figure C -14: Rainfall response to Tawalama Stream flow in year 2012/2013 – Log scale

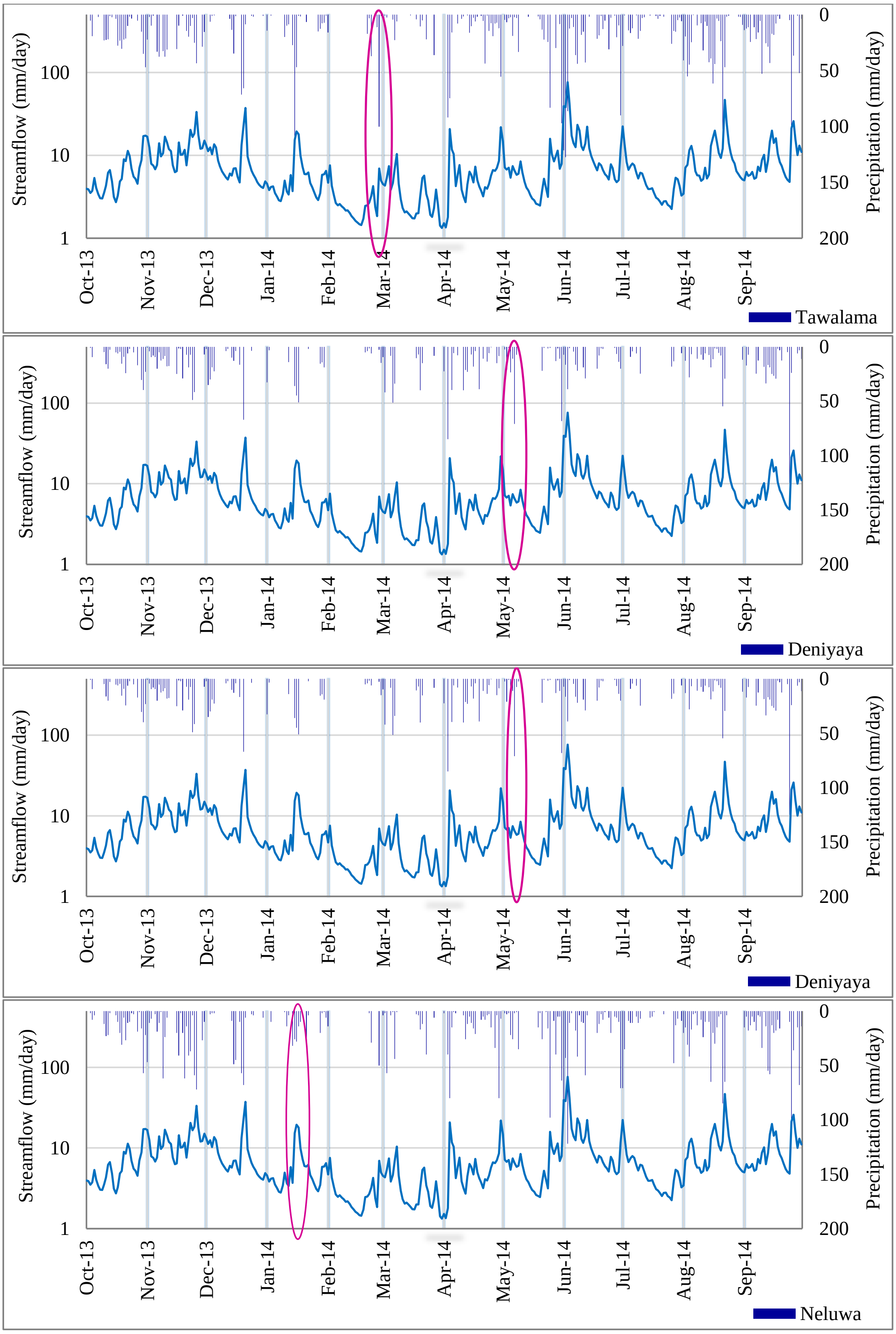

Figure C -15: Rainfall response to Tawalama Stream flow in year 2013/2014 – Log scale

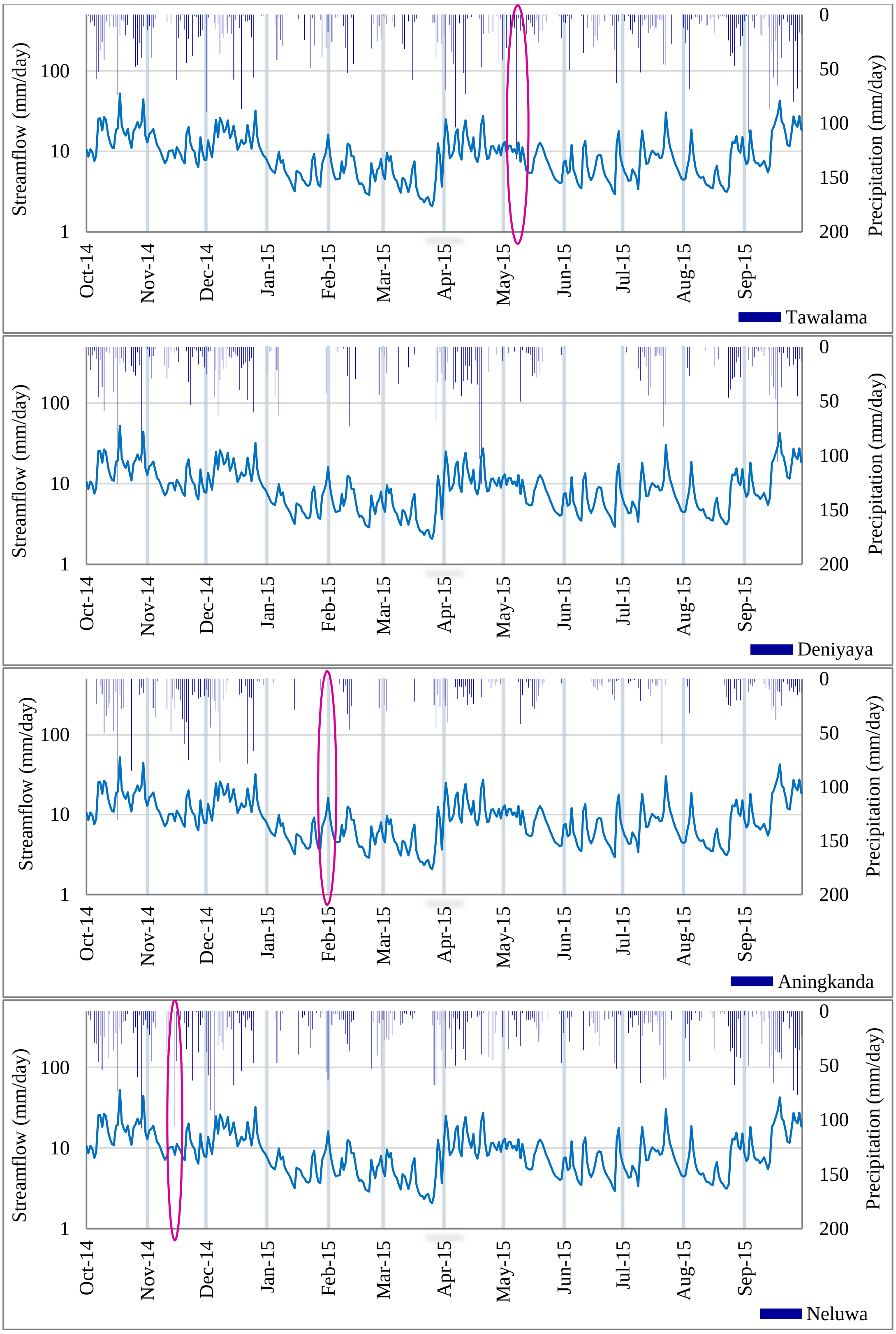

Figure C -16: Rainfall response to Tawalama Stream flow in year 2014/2015– Log scale

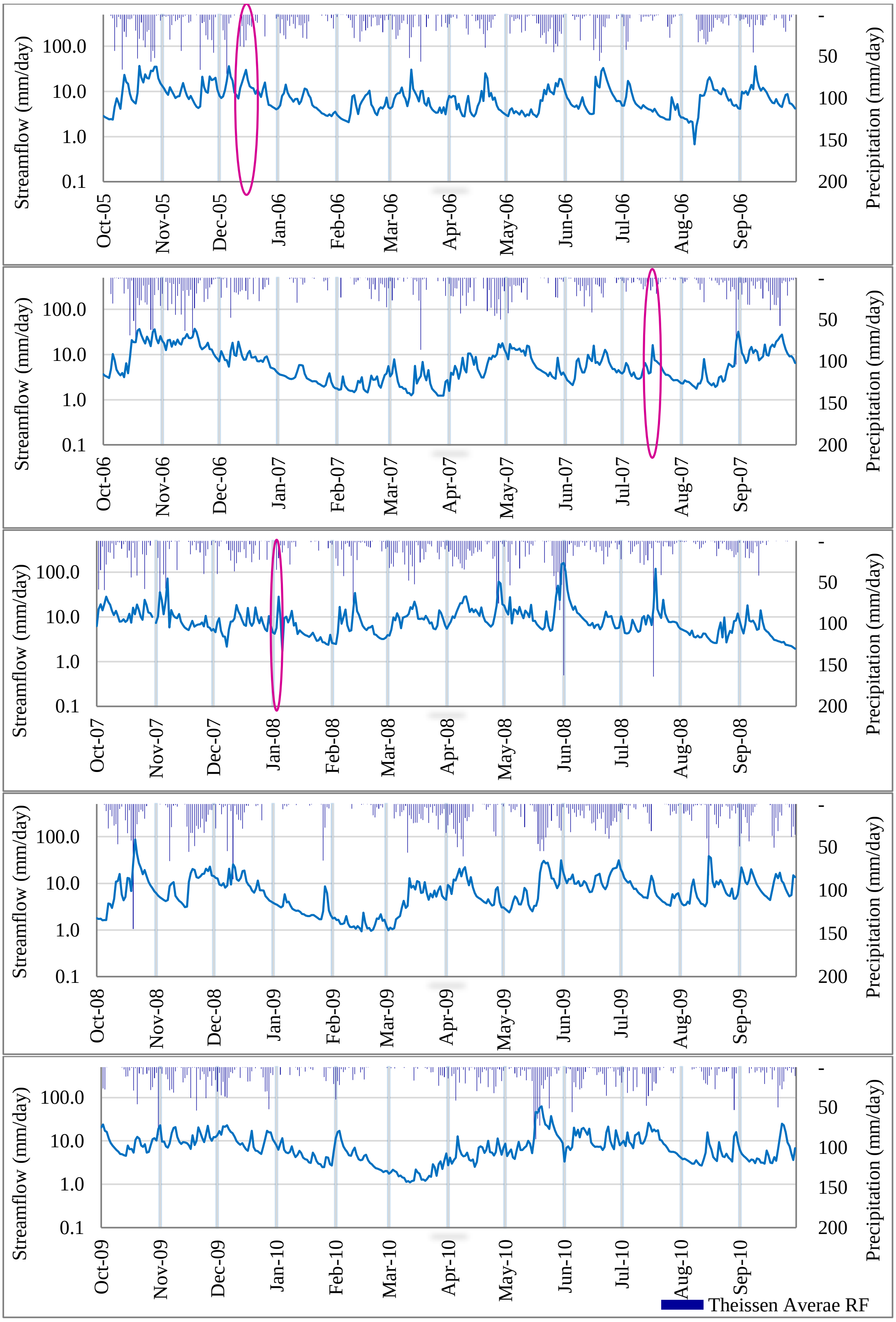

Figure C -17: Thiessen Average Rainfall response to Tawalama Stream flow 2005~2010– Log scale

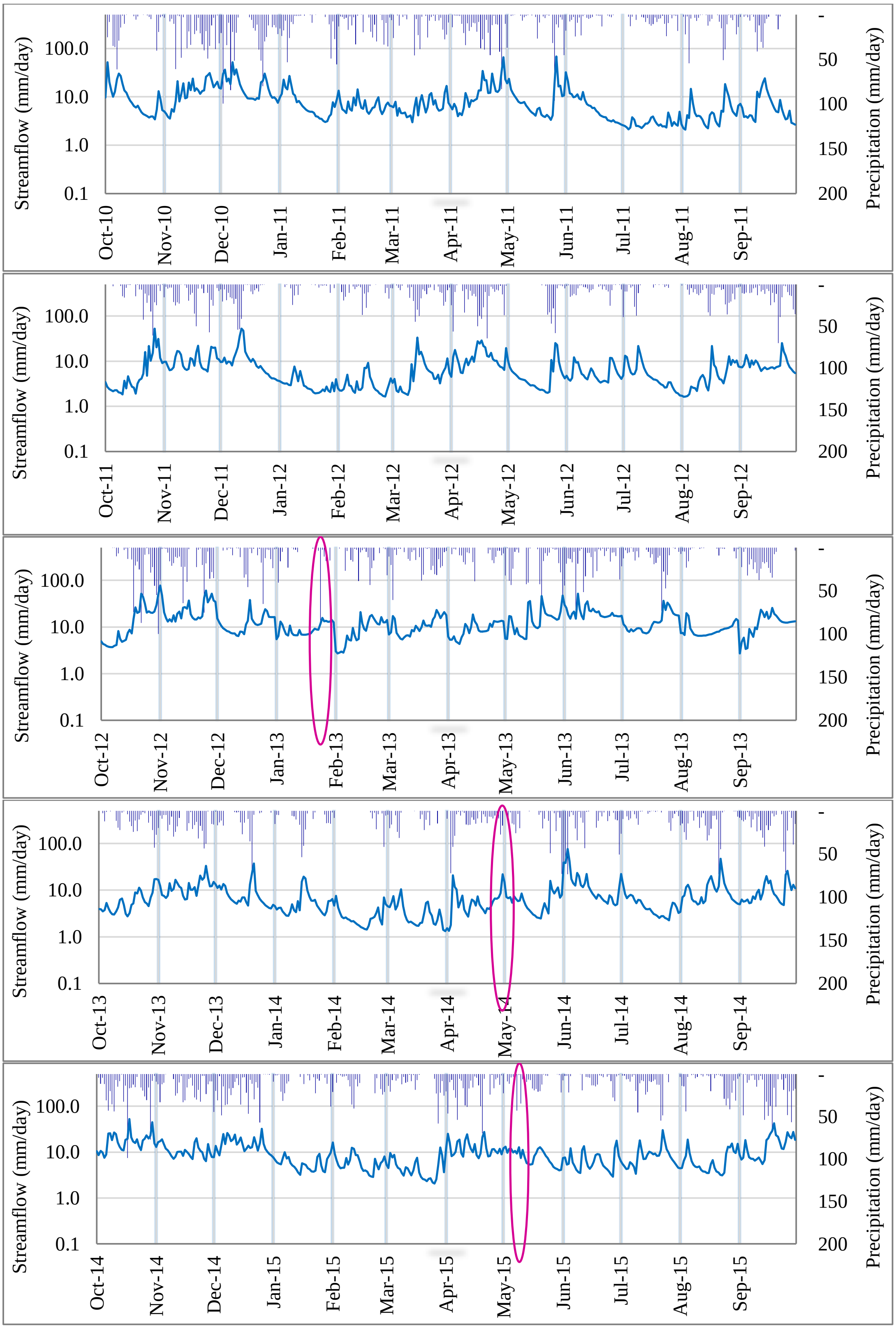

Figure C -18: Thiessen Average Rainfall response to Tawalama Stream flow 2010~2015– Log scale

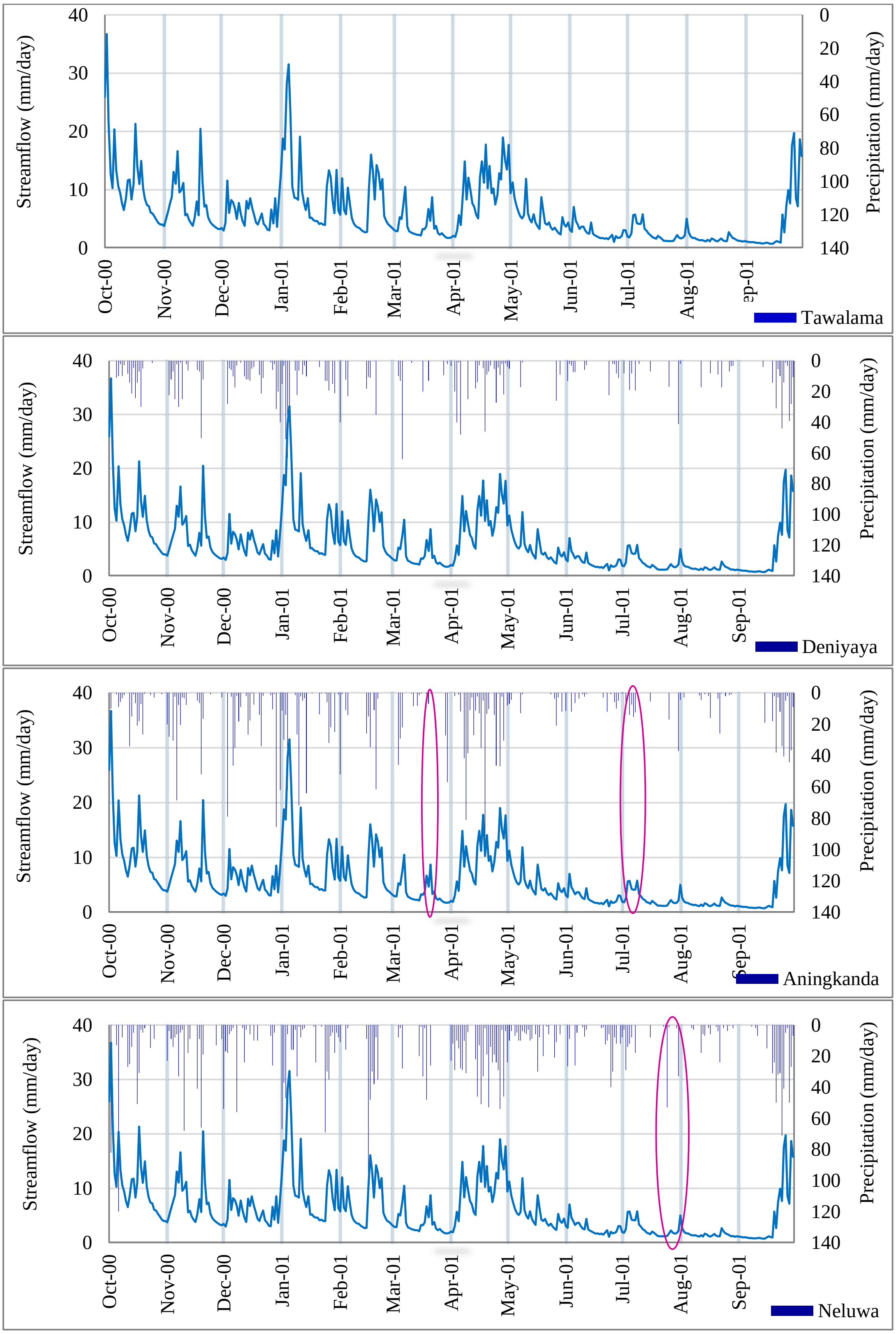

Figure C -19: Rainfall response to Tawalama Stream flow in year 2000/2001 – Normal scale

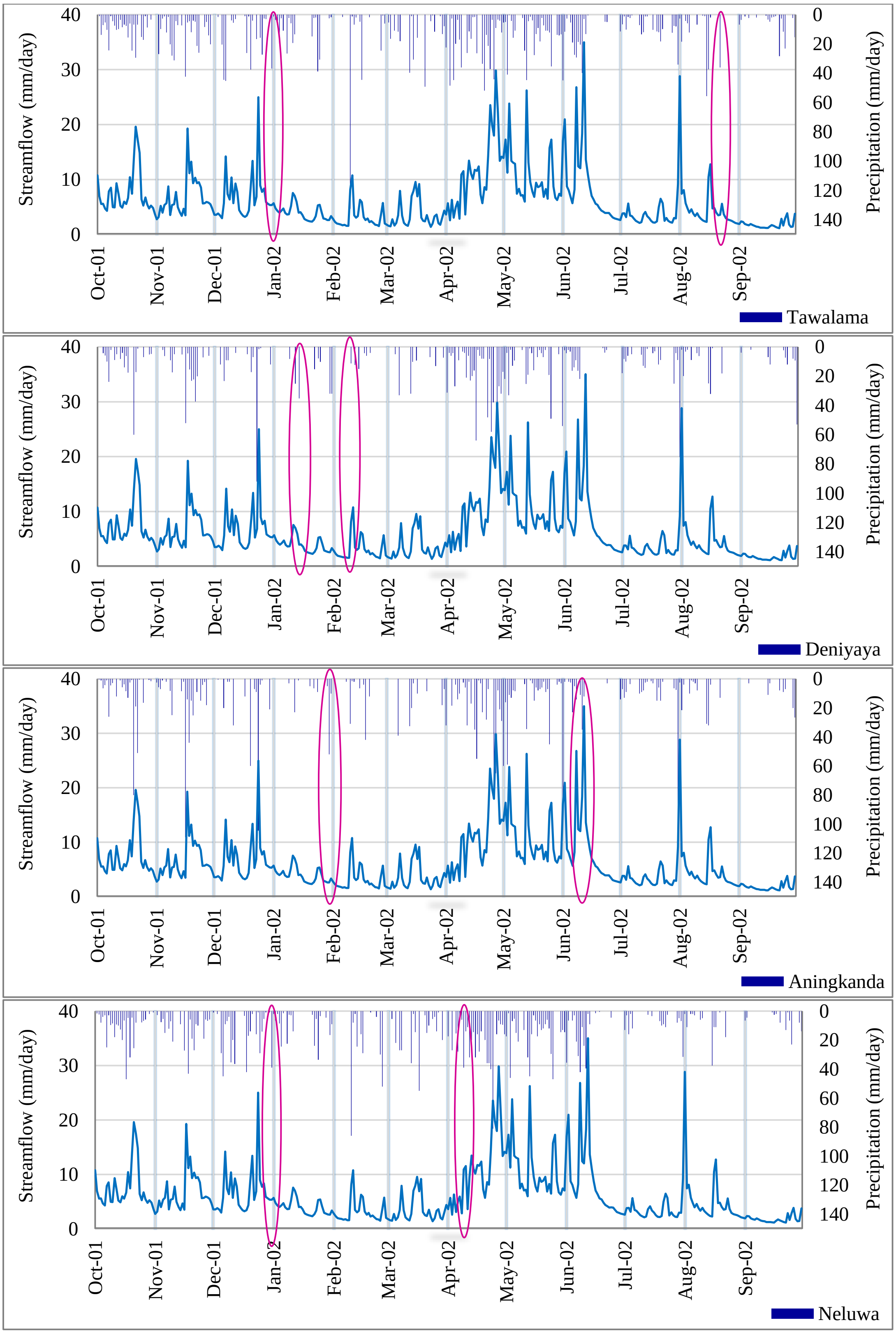

Figure C -20: Rainfall response to Tawalama Stream flow in year 2001/2002 – Normal scale

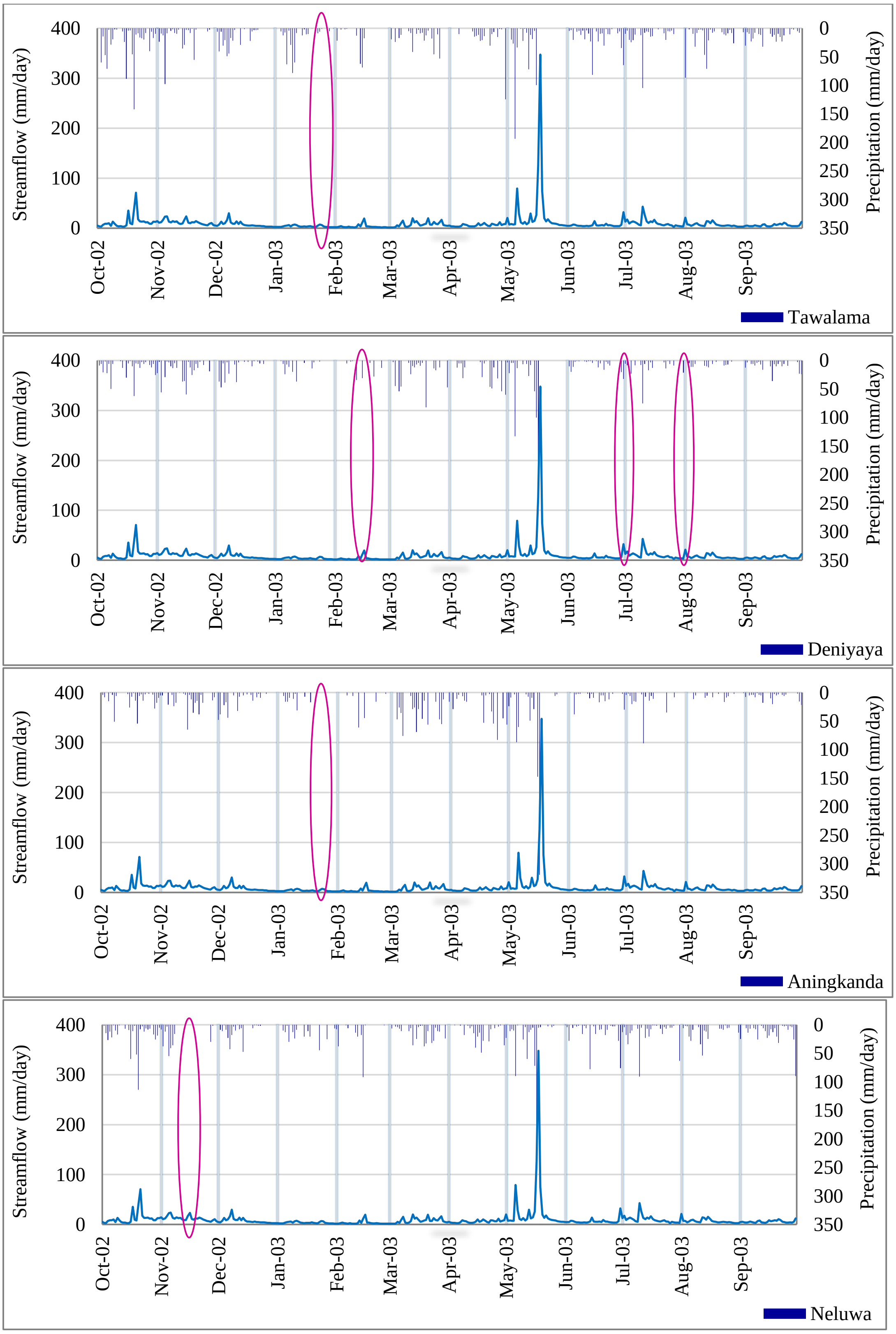

Figure C -21: Rainfall response to Tawalama Stream flow in year 2002/2003 – Normal scale

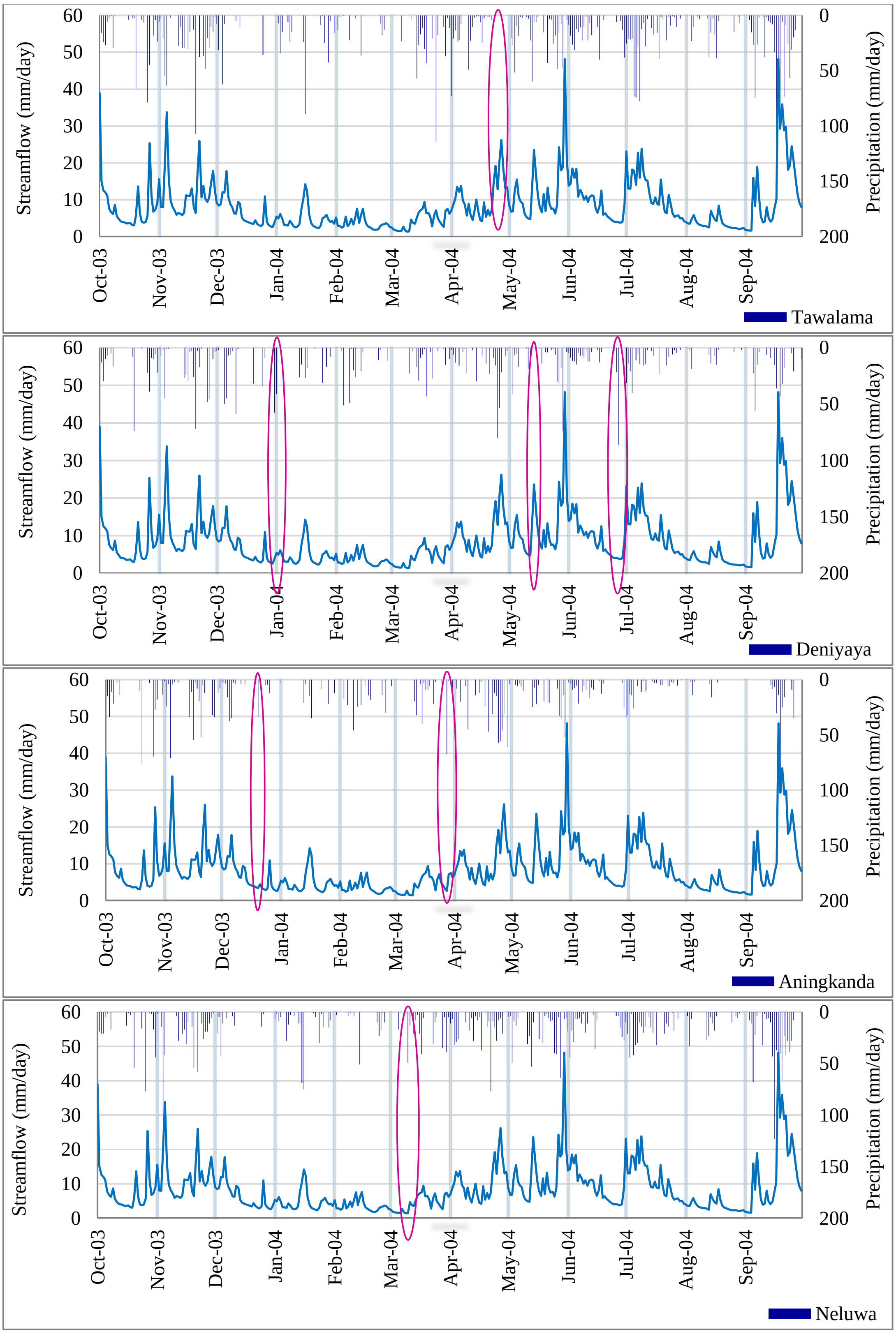

Figure C -22: Rainfall response to Tawalama Stream flow in year 2003/2004 – Normal scale

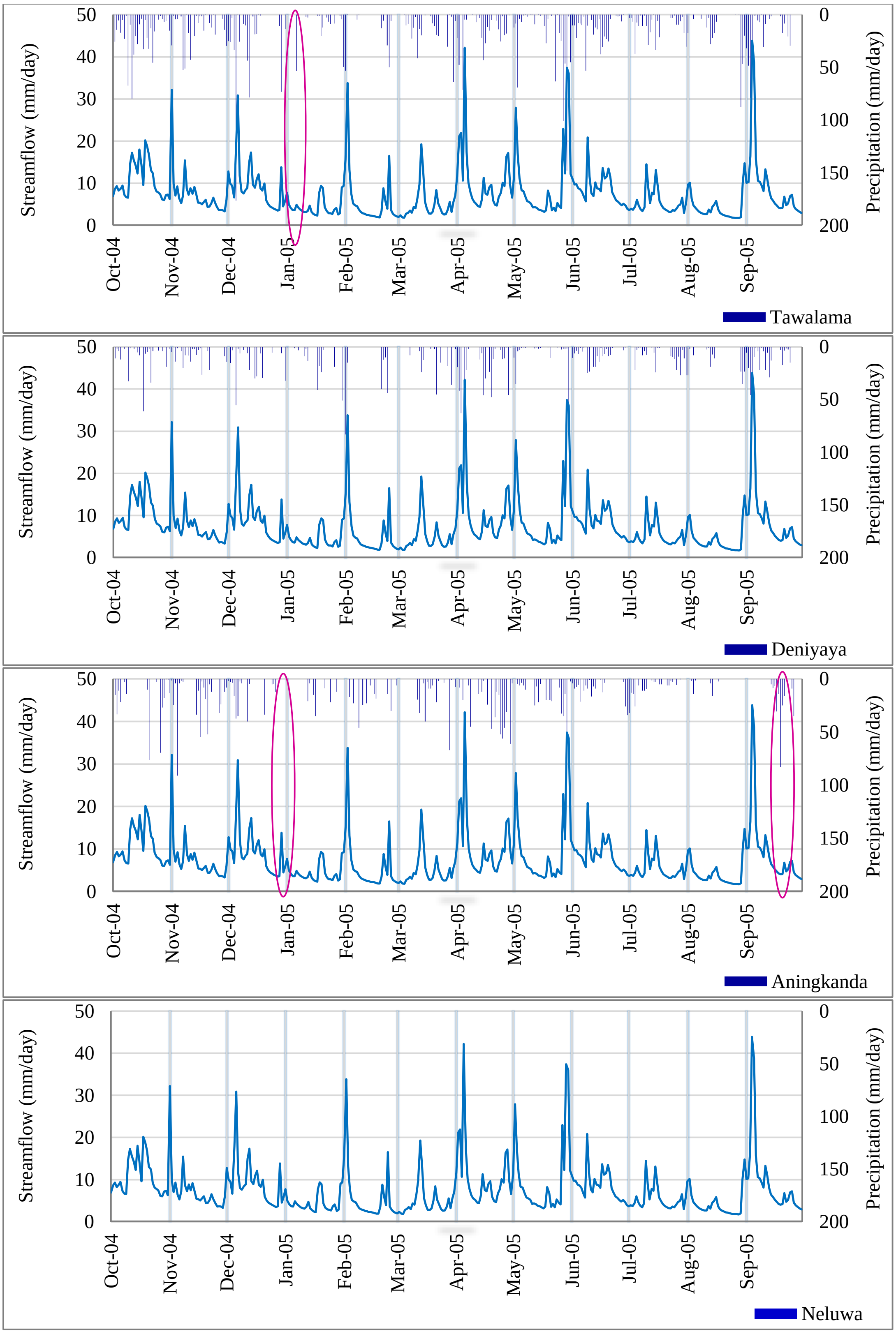

Figure C -23: Rainfall response to Tawalama Stream flow in year 2004/2005 – Normal Log scale

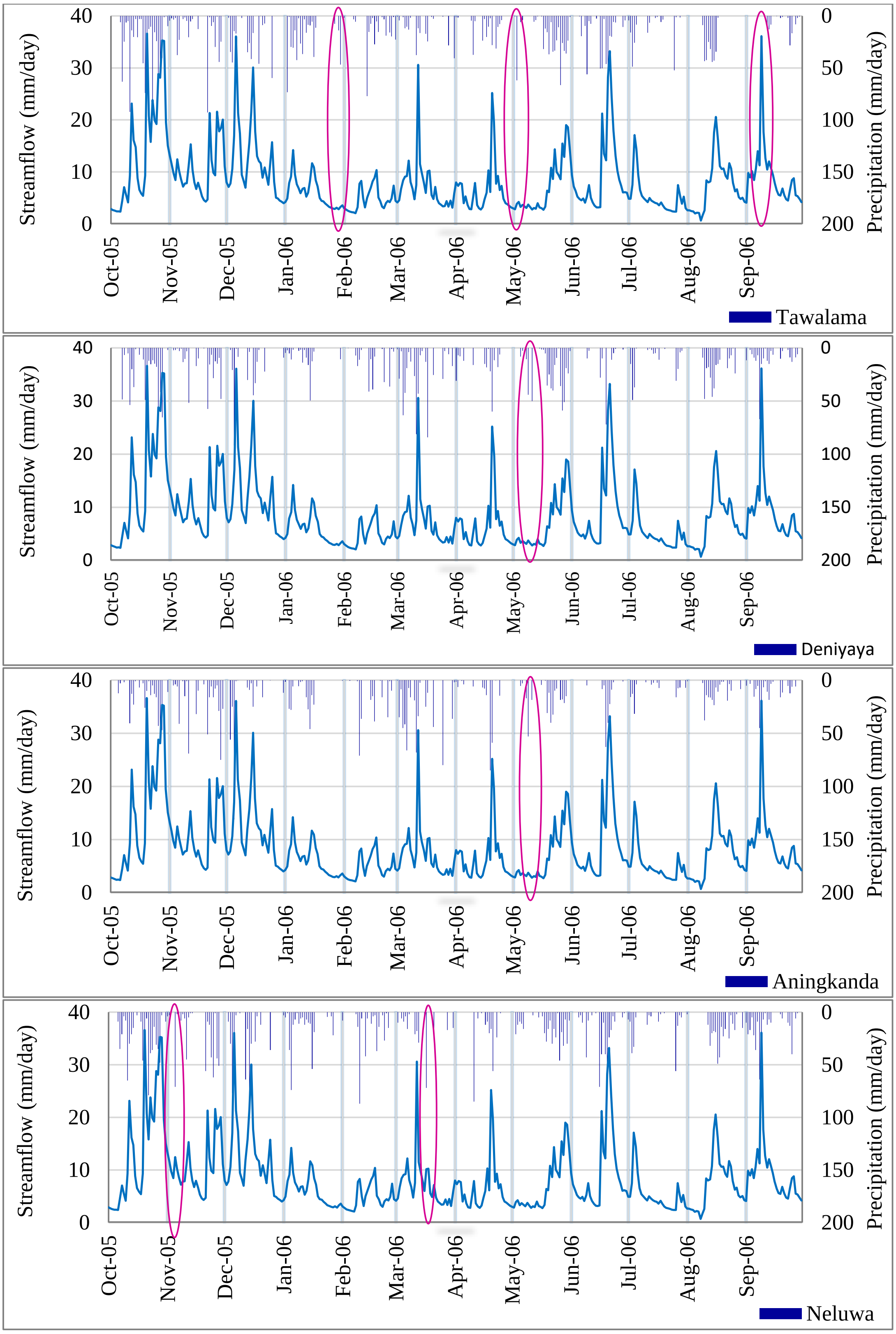

Figure C -24: Rainfall response to Tawalama Stream flow in year 2005/2006 – Normal scale

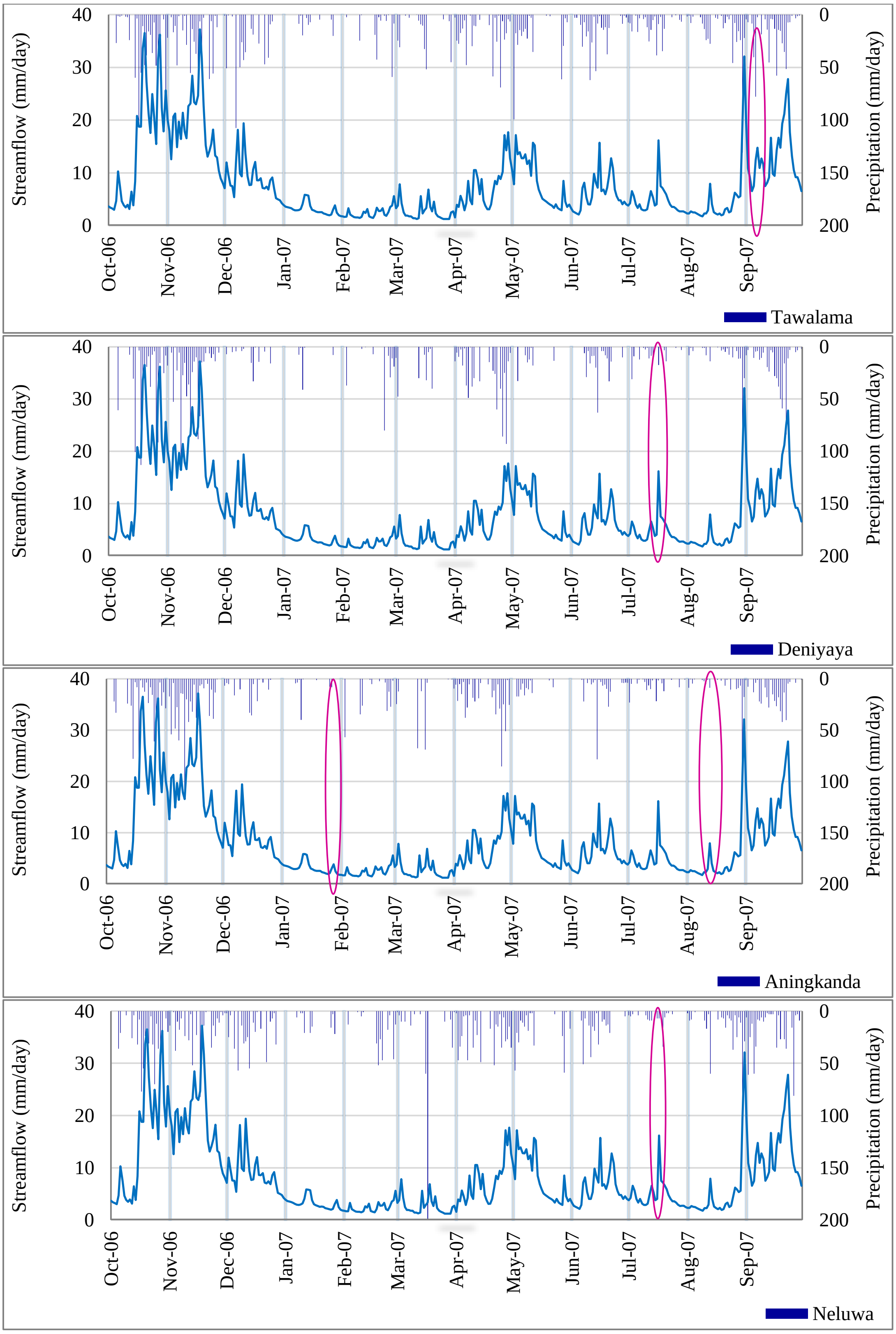

Figure C -25: Rainfall response to Tawalama Stream flow in year 2006/2007– Normal scale

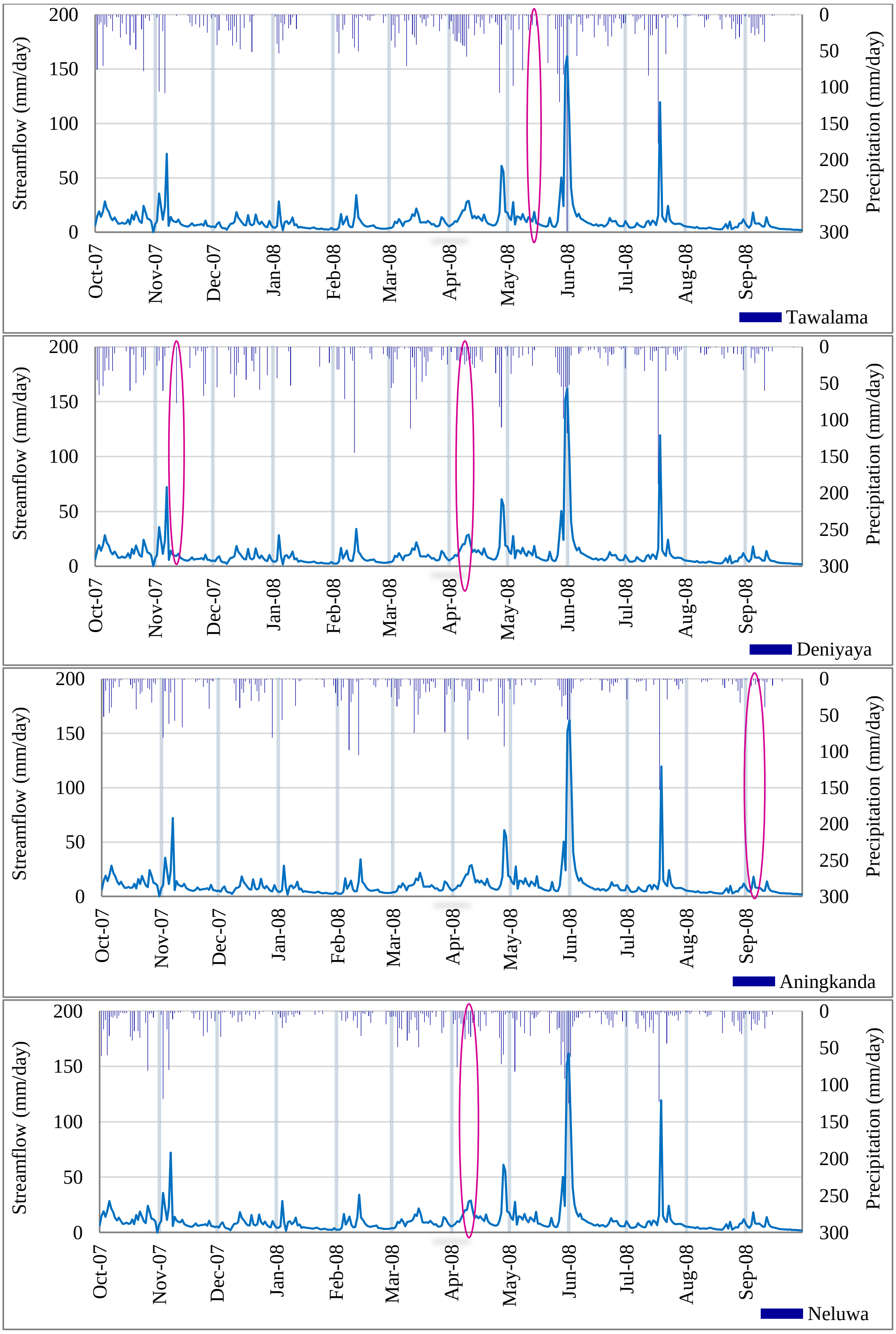

Figure C -26: Rainfall response to Tawalama Stream flow in year 2007/2008 – Normal scale

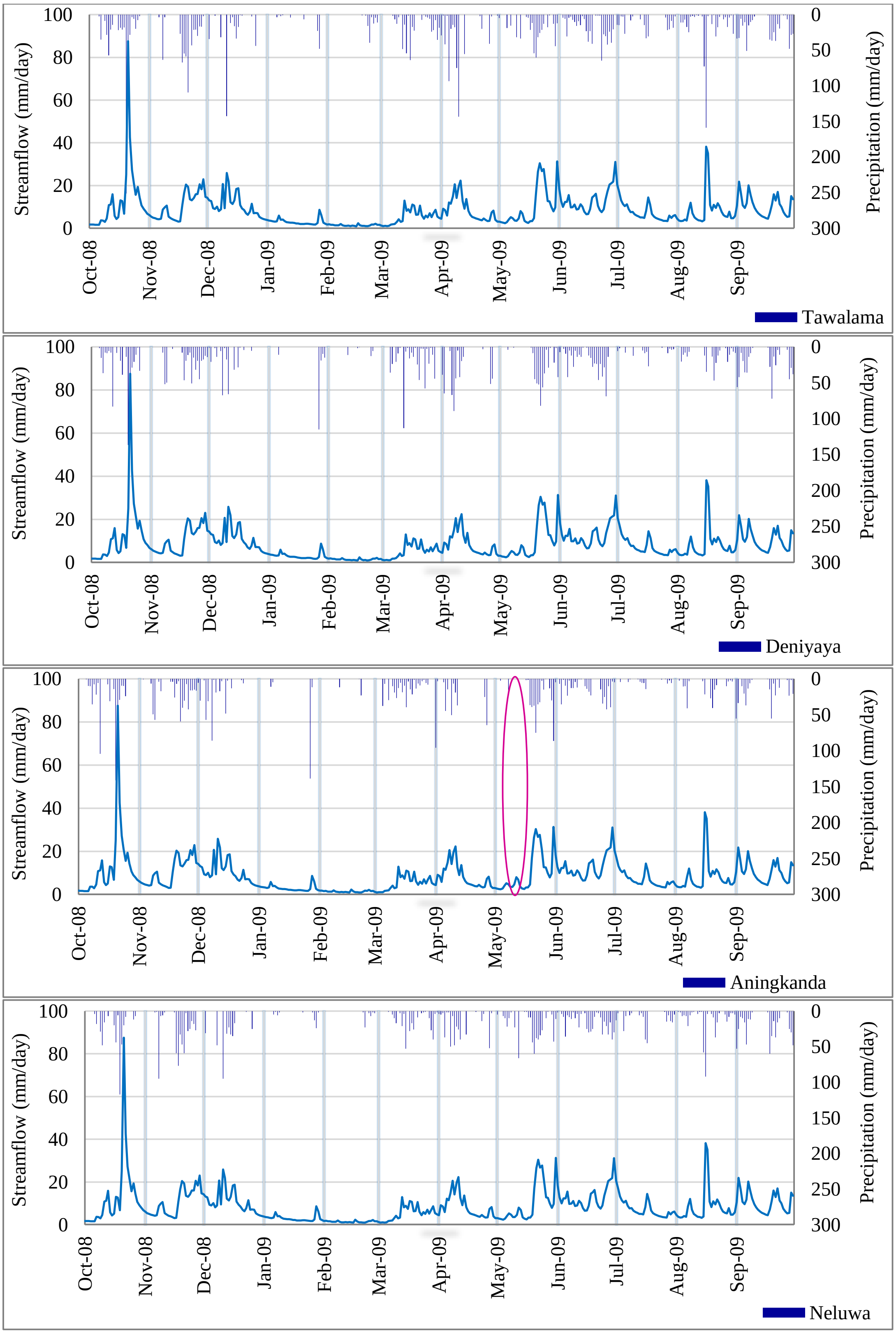

Figure C -27: Rainfall response to Tawalama Stream flow in year 2008/2009 – Normal scale

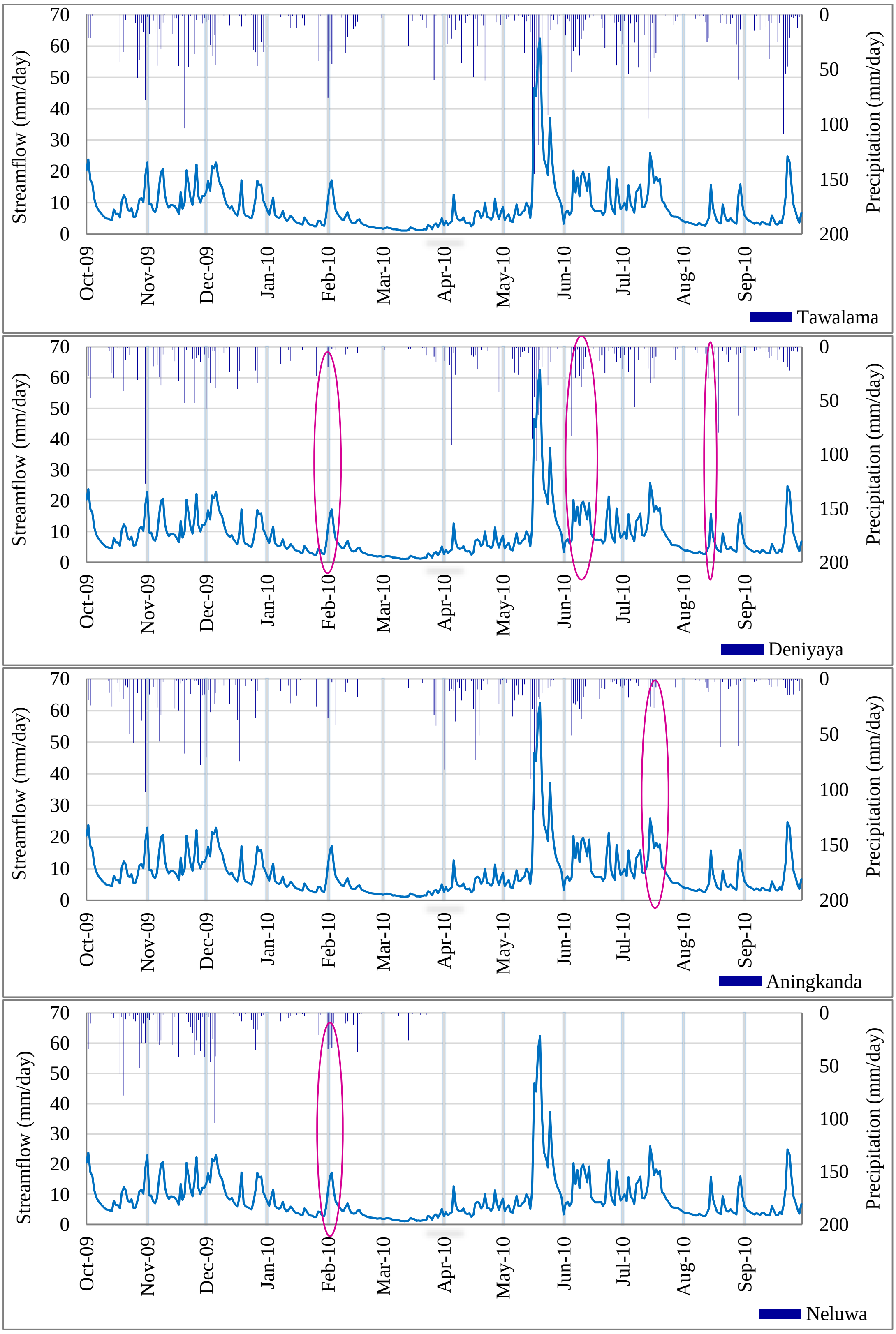

Figure C -28: Rainfall response to Tawalama Stream flow in year 2009/2010 – Normal scale

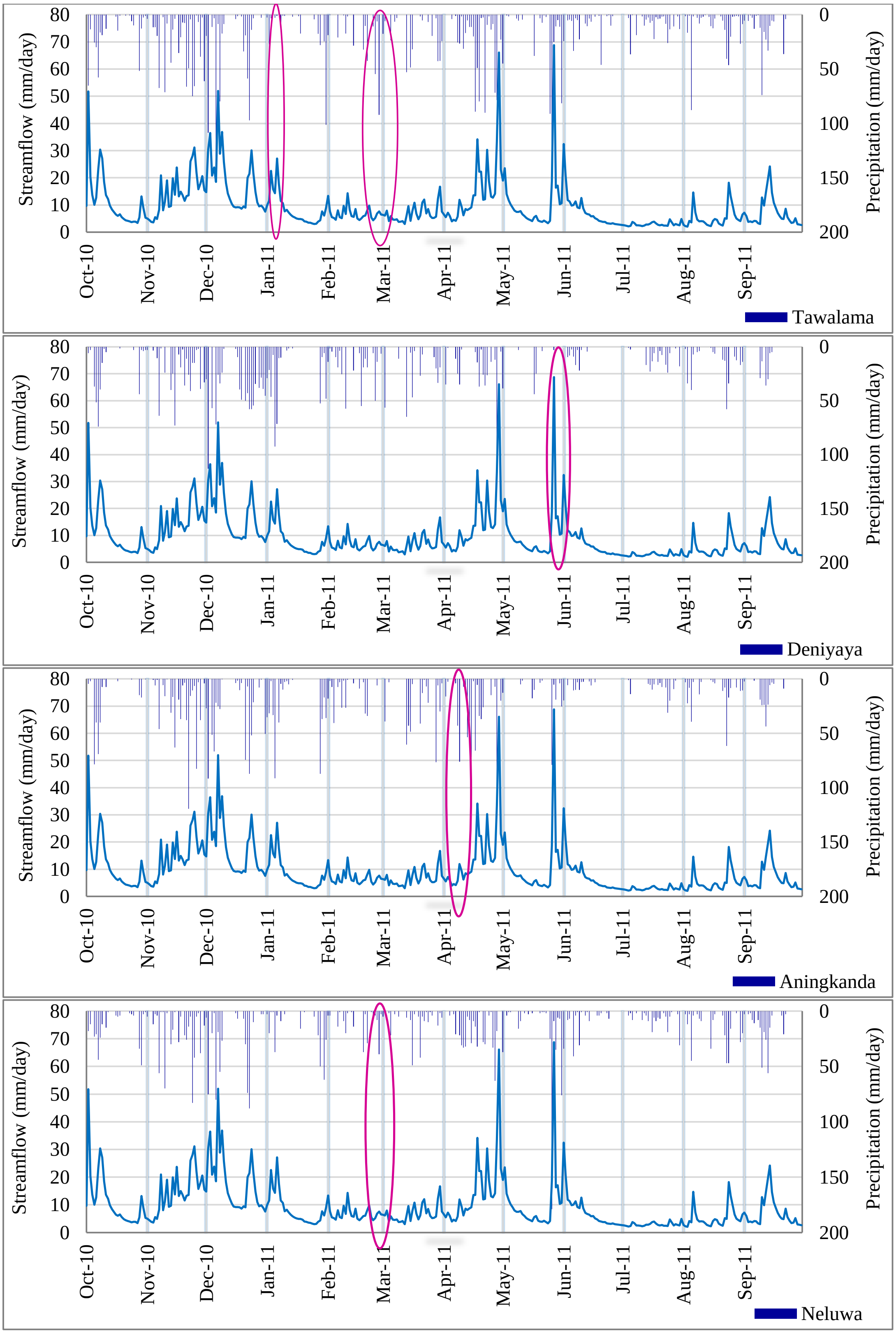

Figure C -29: Rainfall response to Tawalama Stream flow in year 2010/2011– Normal scale

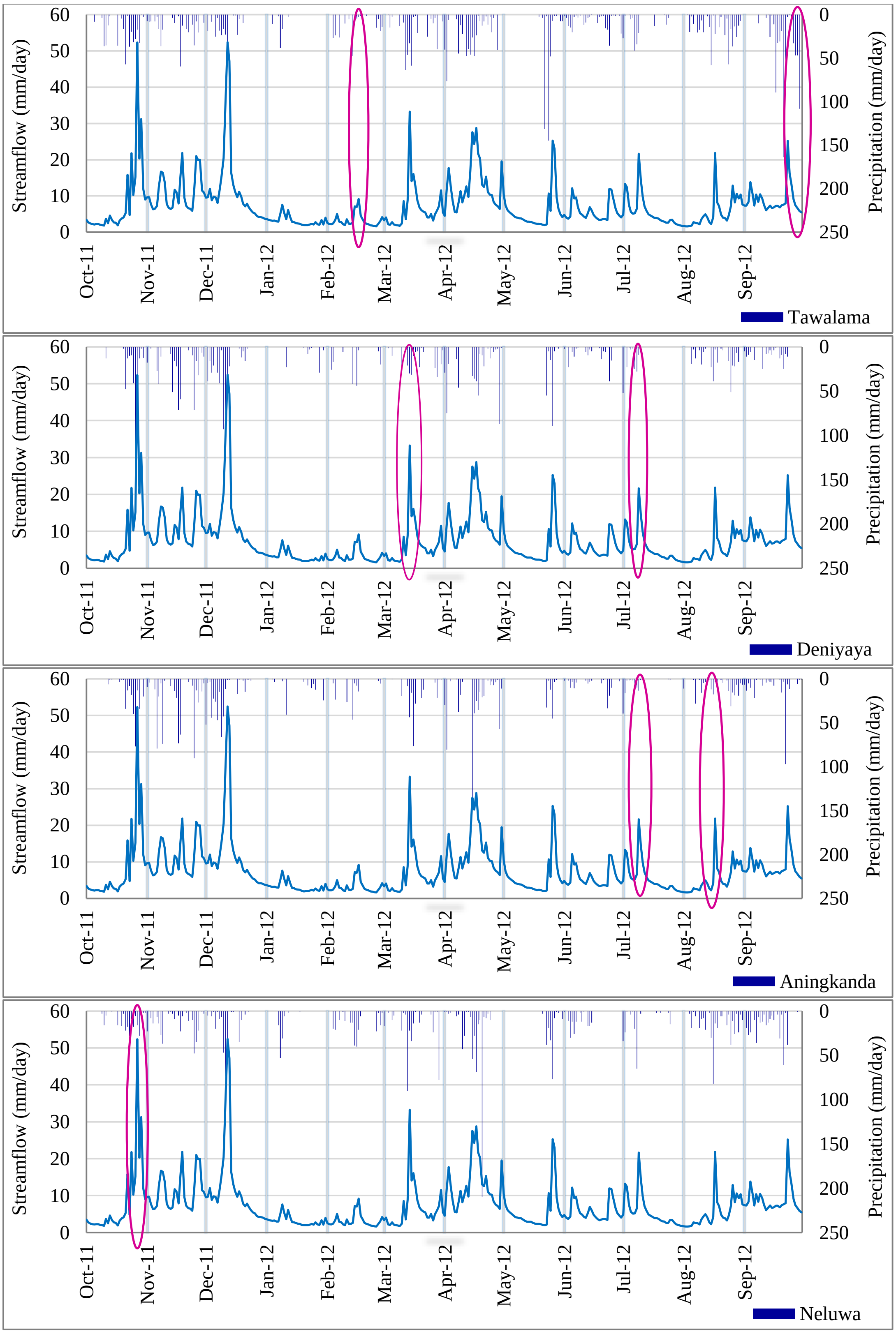

Figure C -30: Rainfall response to Tawalama Stream flow in year 2011/2012– Normal scale

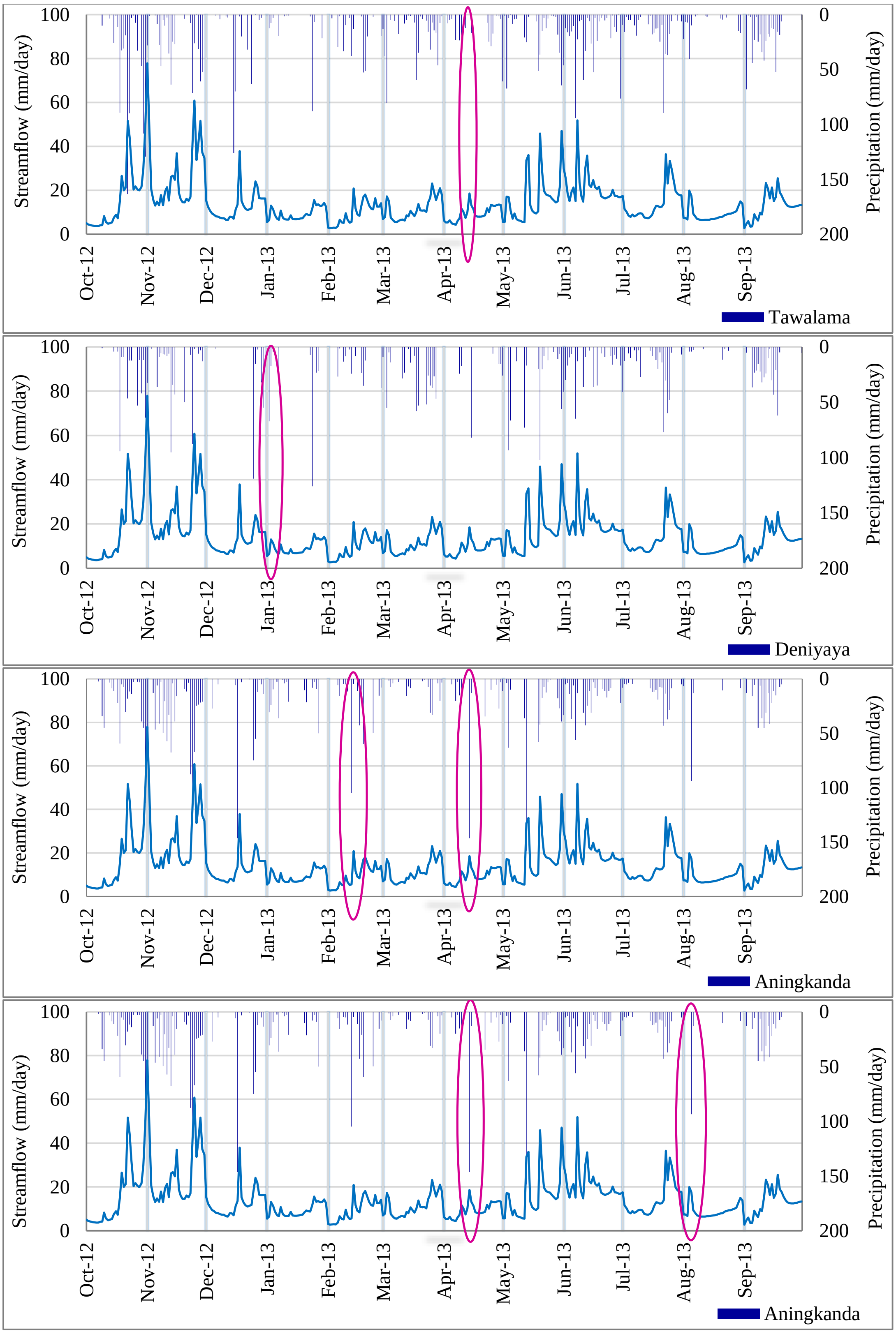

Figure C -31: Rainfall response to Tawalama Stream flow in year 2012/2013 – Normal scale

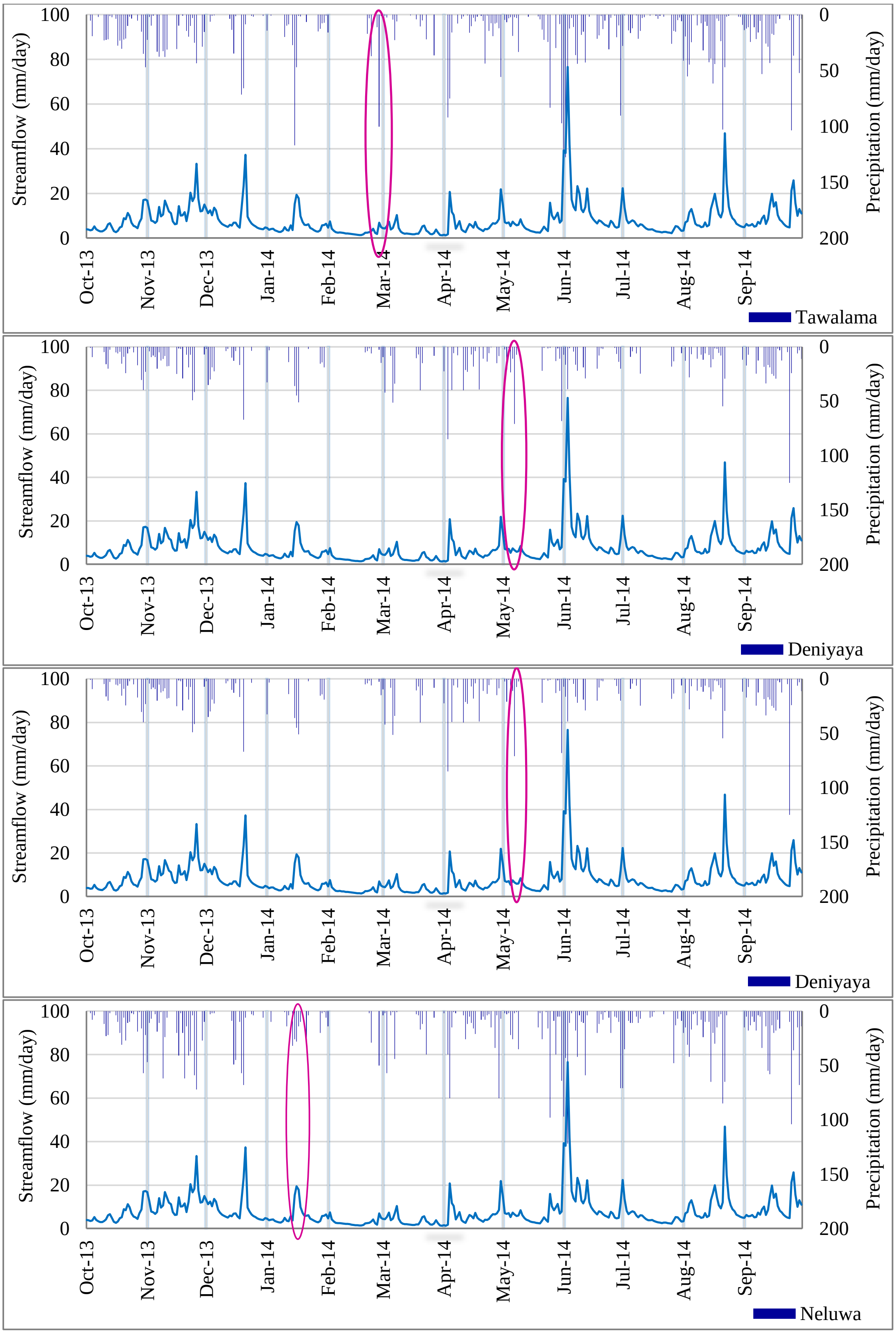

Figure C -32: Rainfall response to Tawalama Stream flow in year 2013/2014 – Normal scale

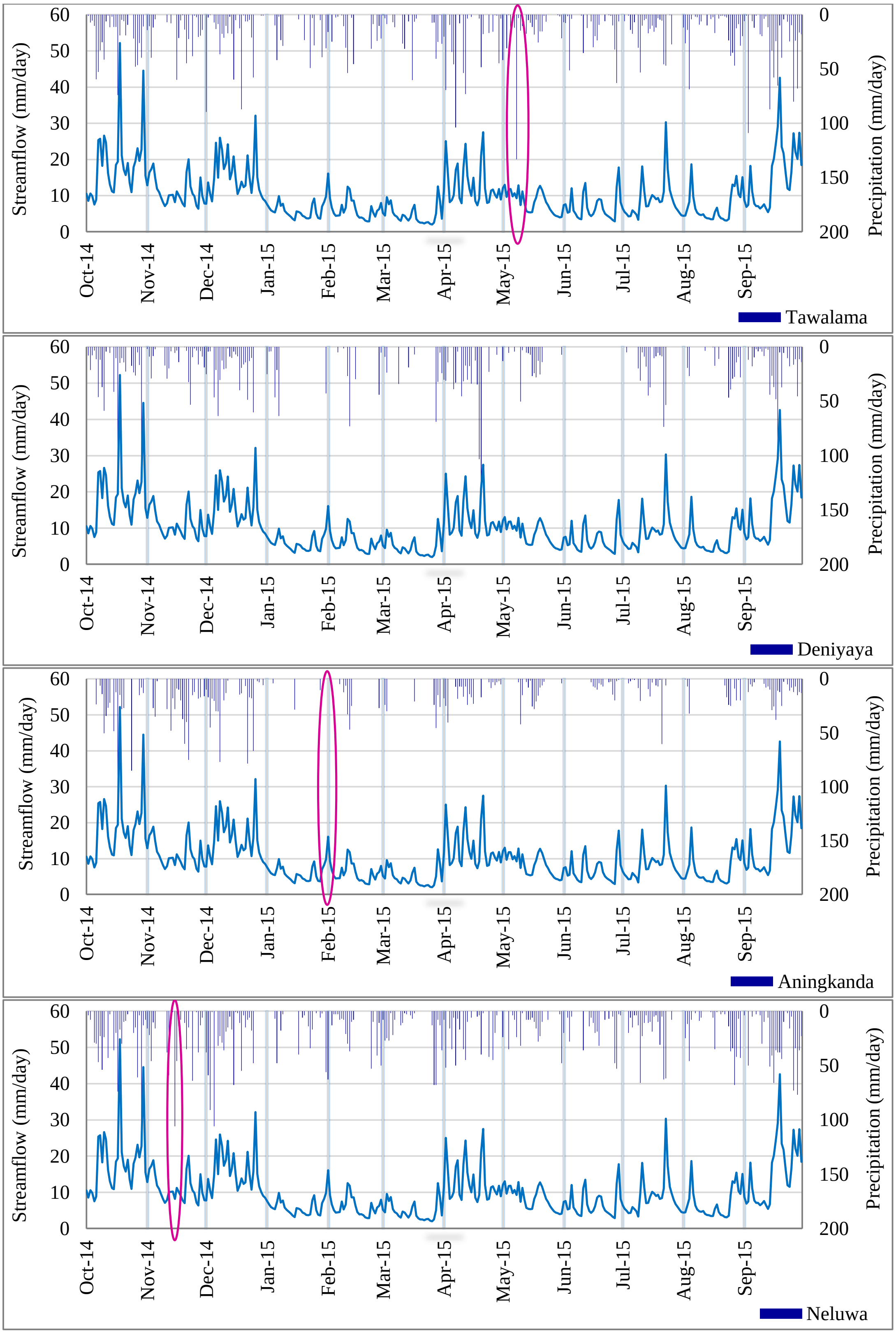

Figure C-33: Rainfall response to Tawalama Stream flow in year 2014/2015 – Normal scale

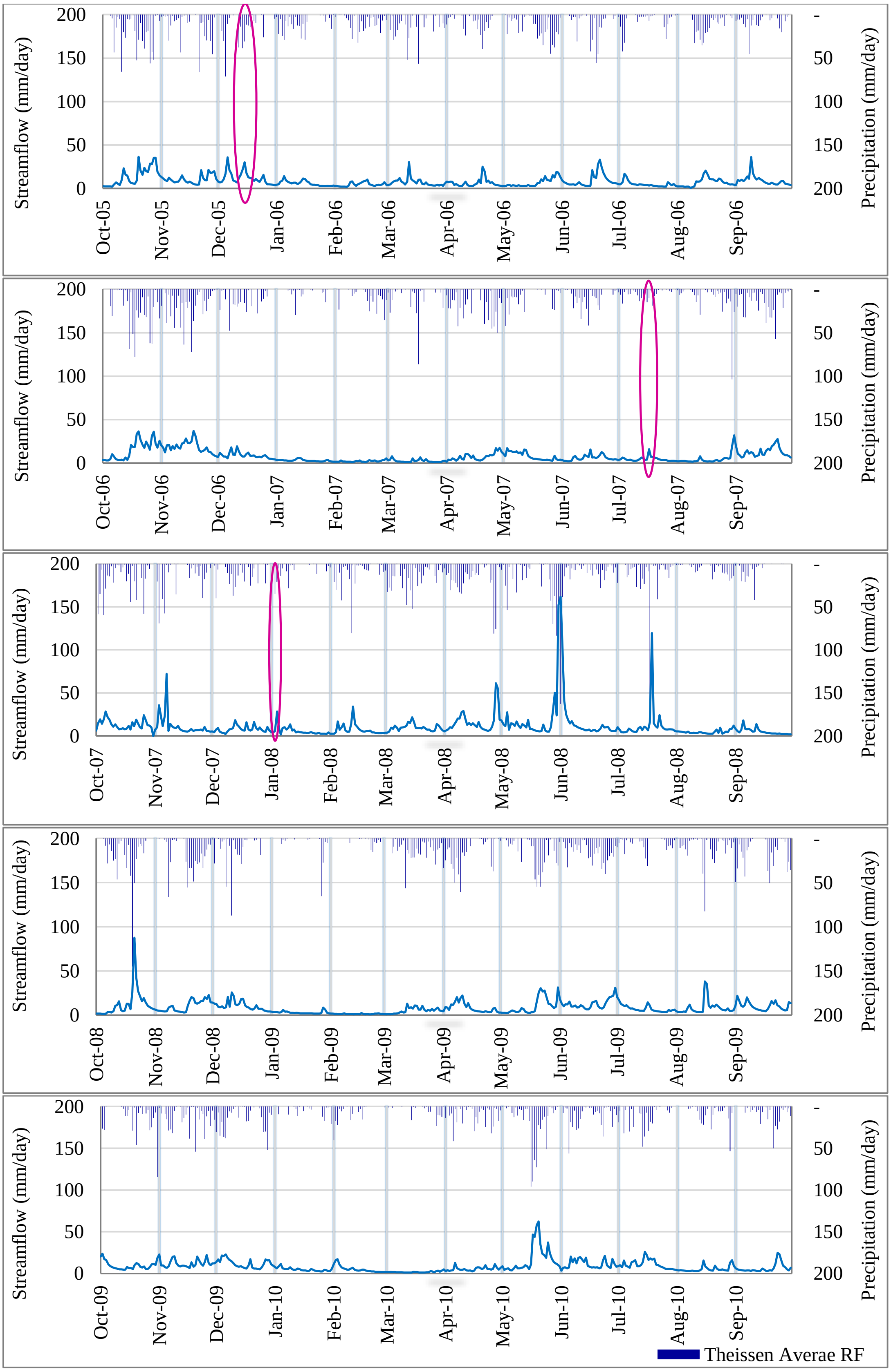

Figure C-34: Thiessen Average Rainfall response to Tawalama Stream flow 2005~2010 – Normal scale

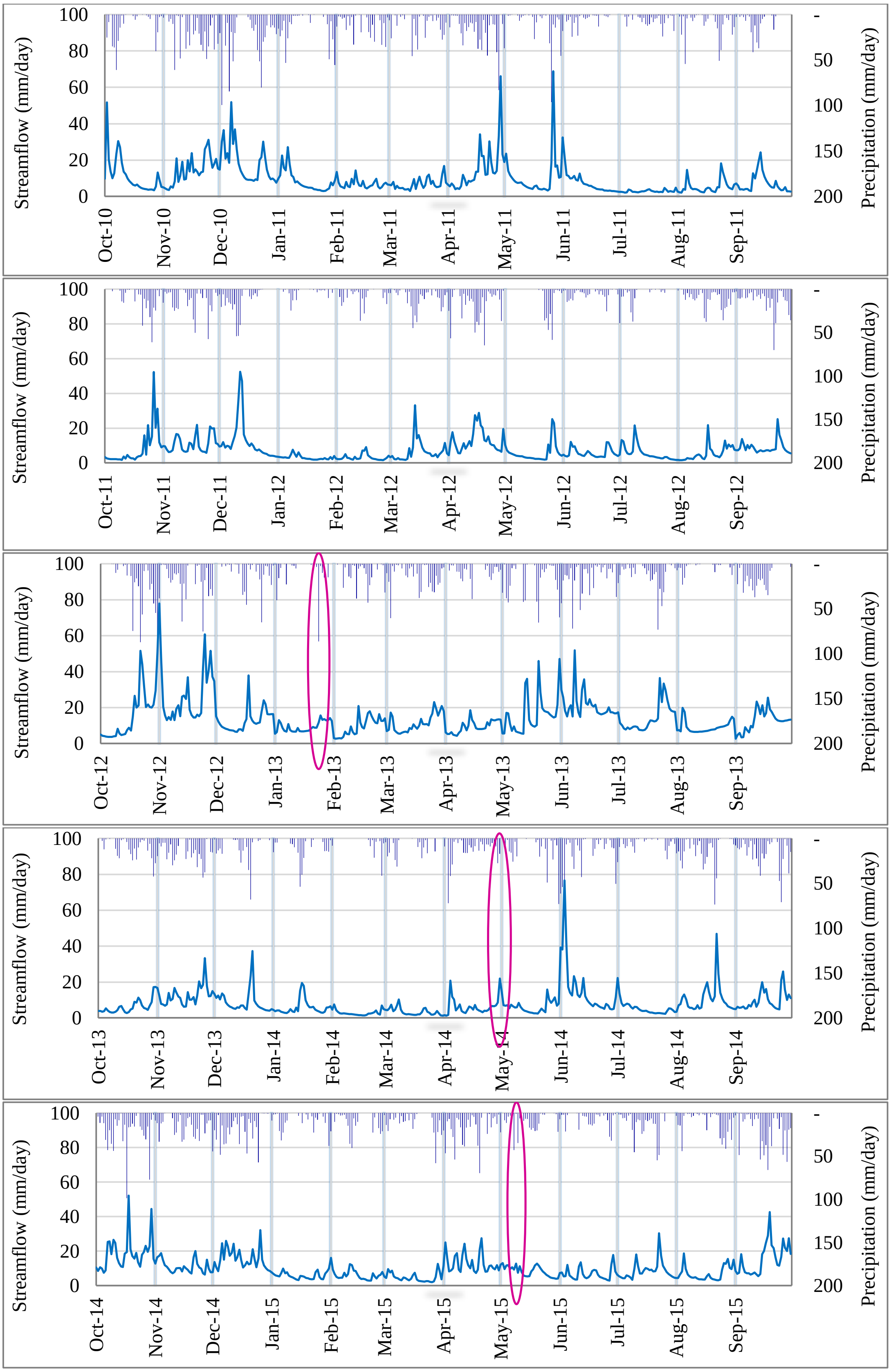

Figure C-35: Thiessen Average Rainfall response to Tawalama Stream flow 2010~2015 – Normal scale

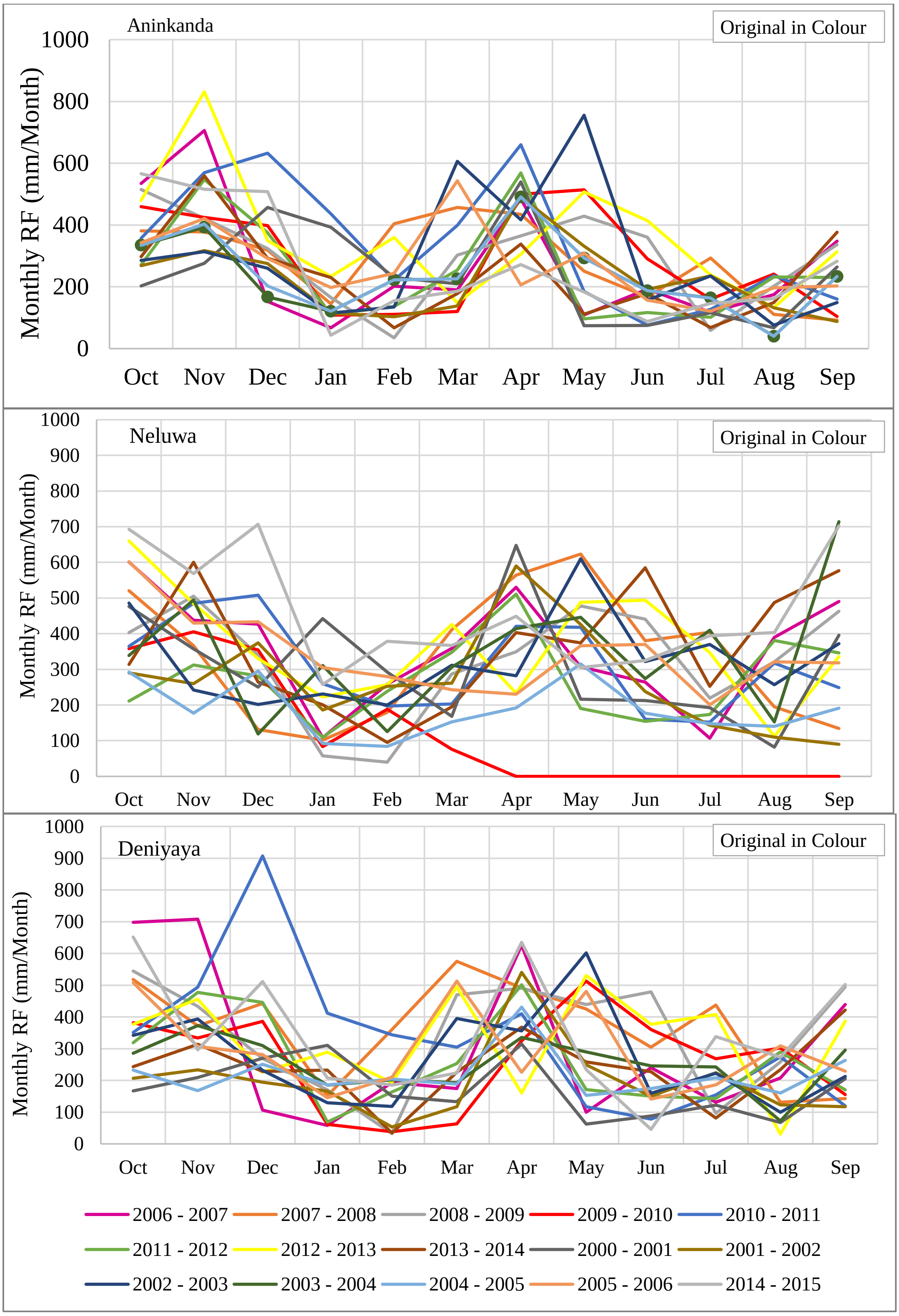

Figure C-36: Comparison of Annual Rainfall Pattern

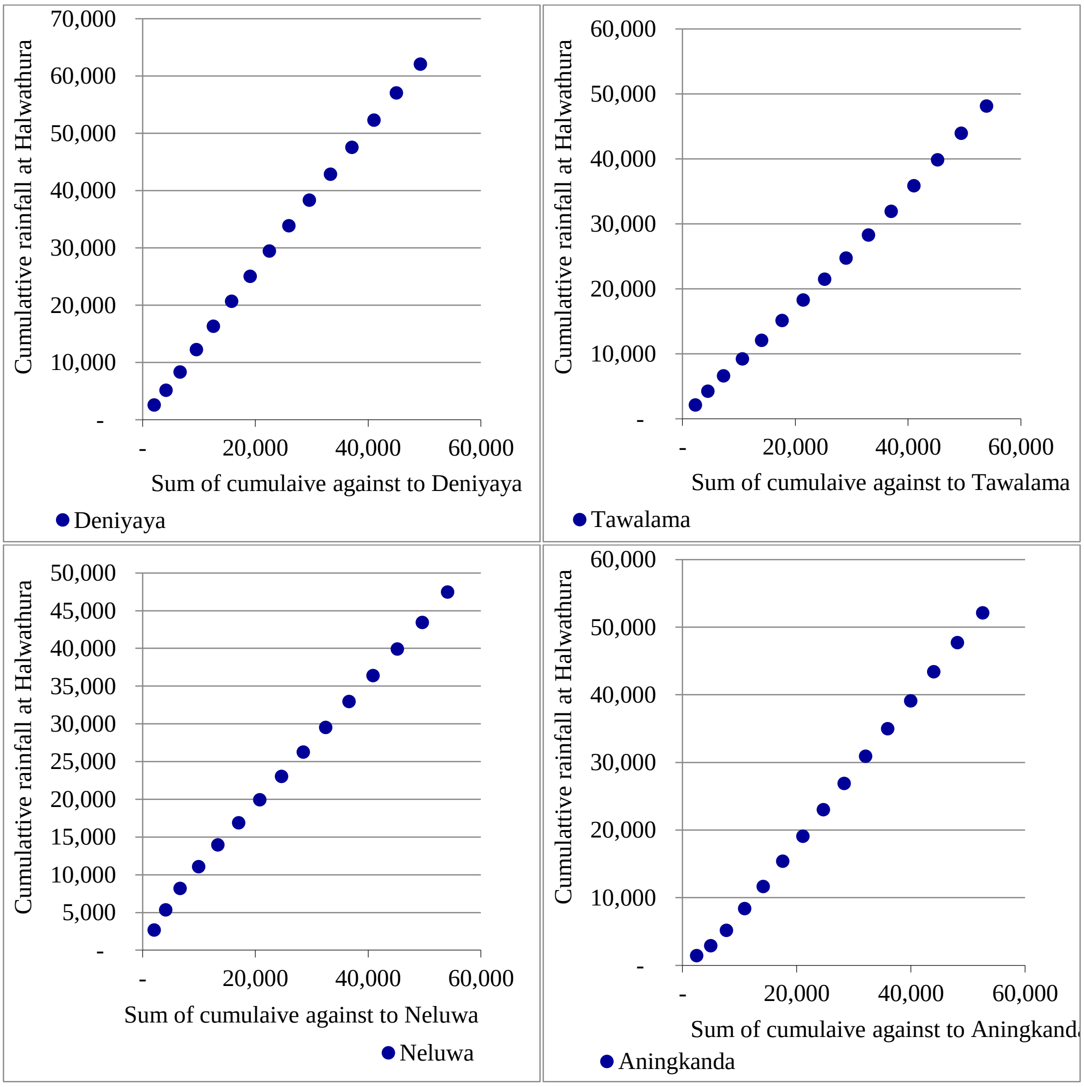

Figure C-37: Double Mass Curve for Rainfal data - Tawalama Basin

ANNEX D - ANALYSIS AND RESULTS

Specimen Calculation for Ellagawa basin

Consider 2006/Oct/04

Thiessen average rainfall P(t) = 2.07 mm/day

Daily pan Evaporation EP(t) = 3.45 mm/day

Model Parameter

Parameter c = 2.5 (Assumed)

Parameter Sc = 700 mm

Actual Evapotranspiration is given by,

$$E(t) = c \times EP(t) \times \tanh\{(P(t)/EP(t)\} \quad (1)$$

E(t) = 3.79 mm/day

Condition Applied,

1. Actual Evaporation should not be less than zero.
2. Actual Evaporation should not be more than pan evaporation.
3. The water content at the end of the day, S(t-1) is obtained from hydrologic cycle and next day value S(t-1) is equal to S(t) of the first day.

S(t-1) = 34 mm

Monthly runoff can be calculated by,

$$Q(t) = S(t-1) + \tanh\{(S(t-1) + P(t) - E(t)/Sc)\} \quad (2)$$

Q(t) = 1.45 mm/day

Condition Applied,

1. Runoff should not be less than zero.
2. The water content at the t^{th} month can be computed by,

$$S(t) = S(t-1) + P(t) - E(t) - Q(t) \quad (3)$$

S(t) = 30.39 mm

Condition Applied,

1. Soil moisture content should not be less than zero.

Runoff coefficient can be calculated as,

C = Q(t)/P(t) (4)

= 0.89

The average runoff in the calibration period is the average value in calibration data set

C avg = 2.6

Catchment Area = 1372.4 km^2

Estimated streamflow can be calculated as

$$Q = Q(t) \times Cavg \times A \times 106/(1000 \times 24 \times 60 \times 60) \quad (5)$$

Q = 1.33 m^3/s

Error Estimation & Parameter Optimization

Mean Ratio of Absolute Error (MRAE)

$$MRAE = (1/n) \times \sum_i [Abs(Q0 - Qs)/Q0] \quad (6)$$

MRAE = 0.46

Model was developed with excel using based on literatures (Xiong, 1999). First equation of the model is as below.

E(t)/ EP(t) = c×tanh [P(t)/ EP(t)]

(19)

Where, E(t) – Model developed evaporation

EP(t) – Pan evaporation

P(t) – Rainfall

C – First parameter of the model (Pan Evaporation coefficient)

According to the basic concepts, E(t) can not be negative. Hence, condition was applied to the model as,

If E(t) < 0, then E(t) = 0

When P(t)/EP(t) is greater than 1, tanh [P(t)/ EP(t)] is approaching to 1. Then E(t) ⇒ c× EP(t)

When c is greater than to the 1, E(t) > EP(t)

But, theoretically EP(t) should be greater than the E(t). Hence, second condition incorporated as, If, $E(t) > EP(t)$, then $E(t) = EP(t)$

Second equation of the model is,

$$Q(t)=S(t-1)+\tanh\{(S(t-1)+P(t)-E(t)/Sc)\} \quad (20)$$

According to the basic concepts, Q(t) can not be negative. Hence, condition incorporated to the model as,

If, $Q(t) < 0$, then $Q(t) = 0$

The third equation of the model was used the continuity equation and modified equation is as below.

$$S(t) = S(t-1)+P(t)-E(t)-Q(t) \quad (21)$$

The condition incorporated to the model as,

If, $S(t)<0$, then $S(t) = 0$

Finally, model developed with while incorporating those conditions and then optimization done.

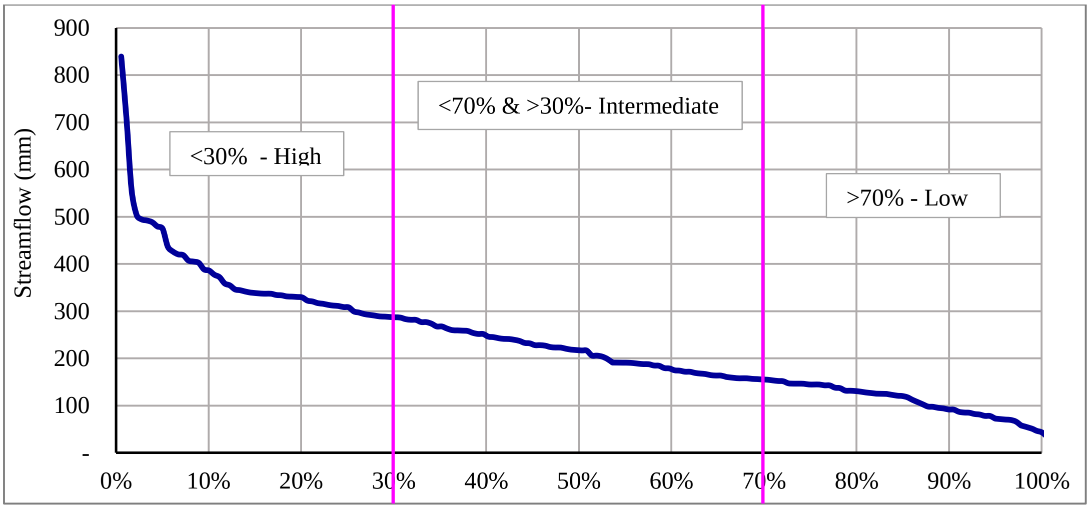

Figure D-1: Flow Duration Curve – Monthly Scale - Tawalama Watershed (Normal Scale)

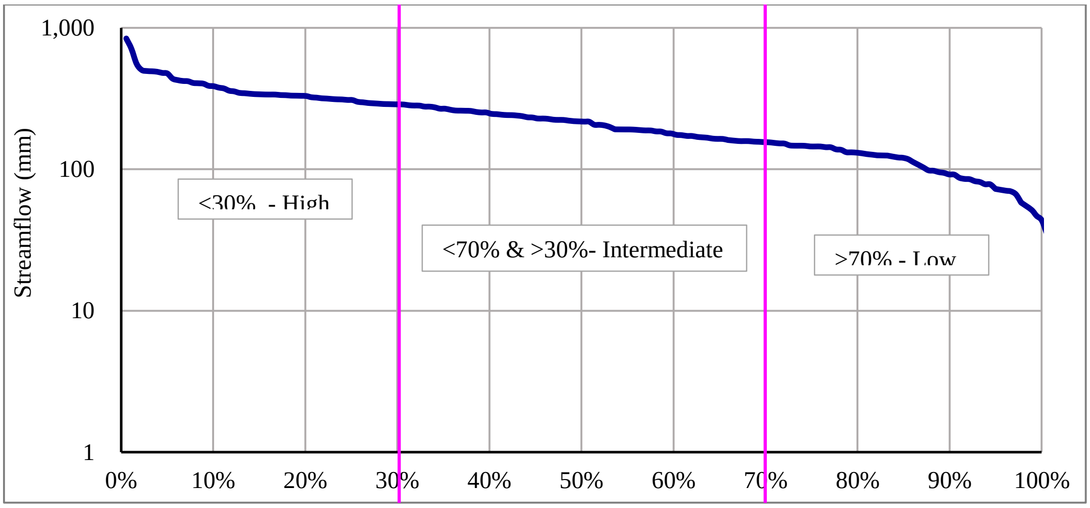

Figure D-2: Flow Duration Curve – Monthly Scale - Tawalama Watershed (Log Scale)

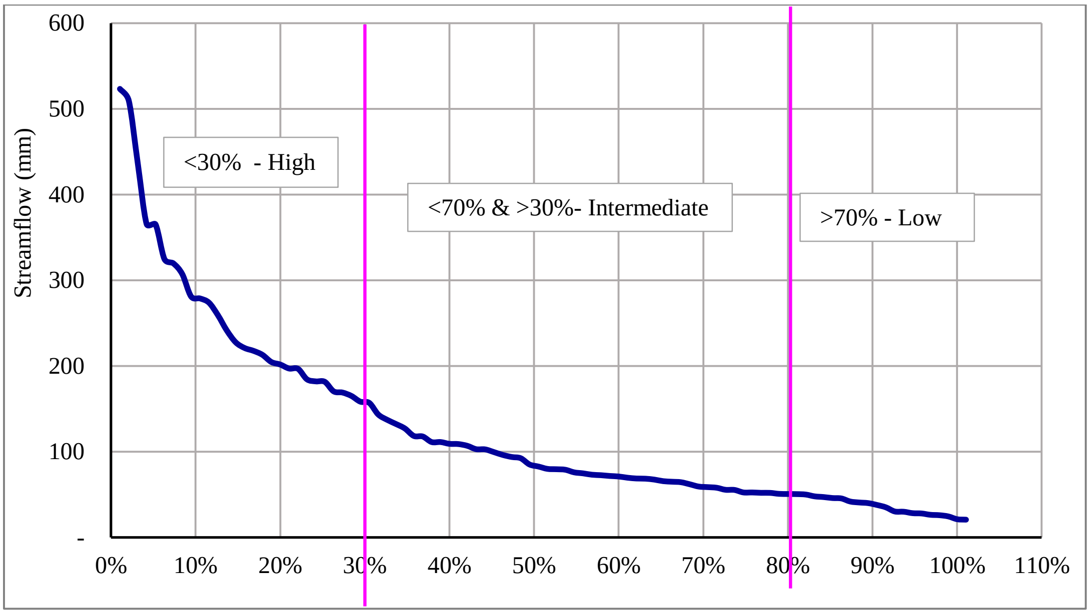

Figure D-3: Flow Duration Curve – Monthly Scale - Ellagawa Watershed (Normal Scale)

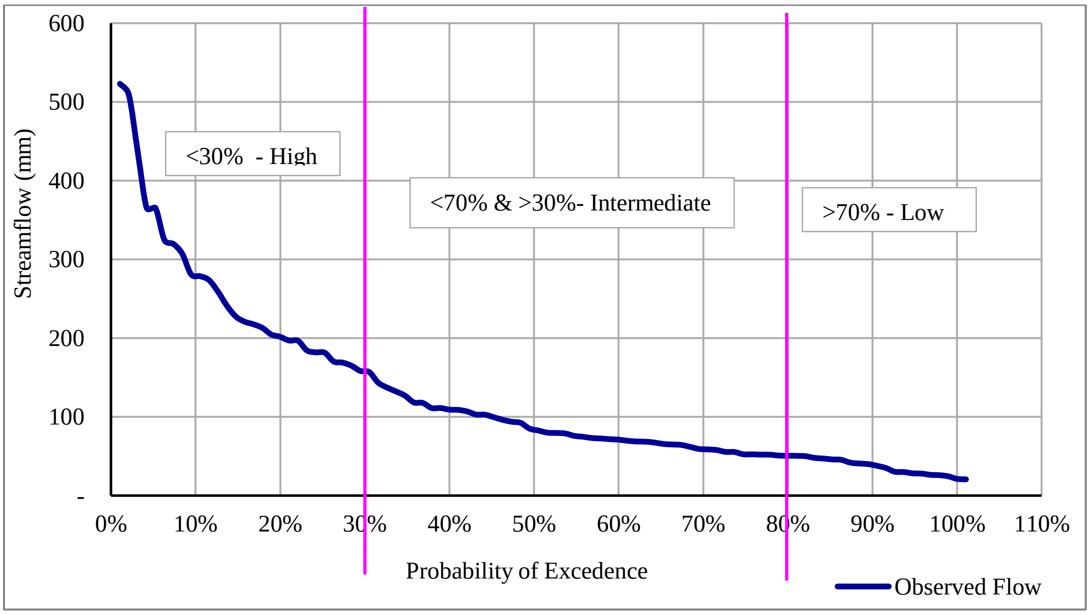

Figure D-4: Flow Duration Curve – Monthly Scale - Ellagawa Watershed (Log Scale)

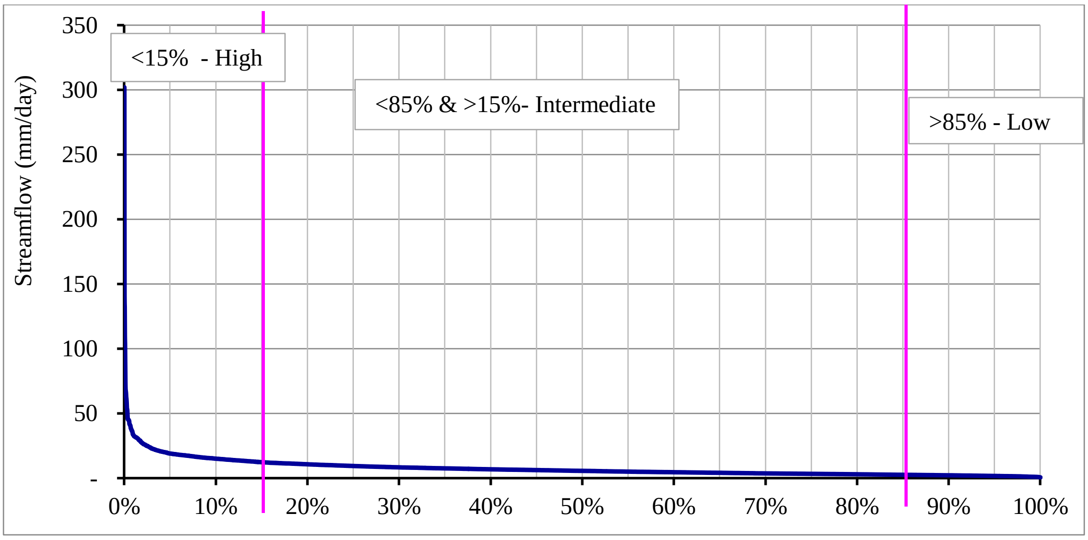

Figure D-5: Flow Duration Curve – Daily Scale - Tawalama Watershed (Normal Scale)

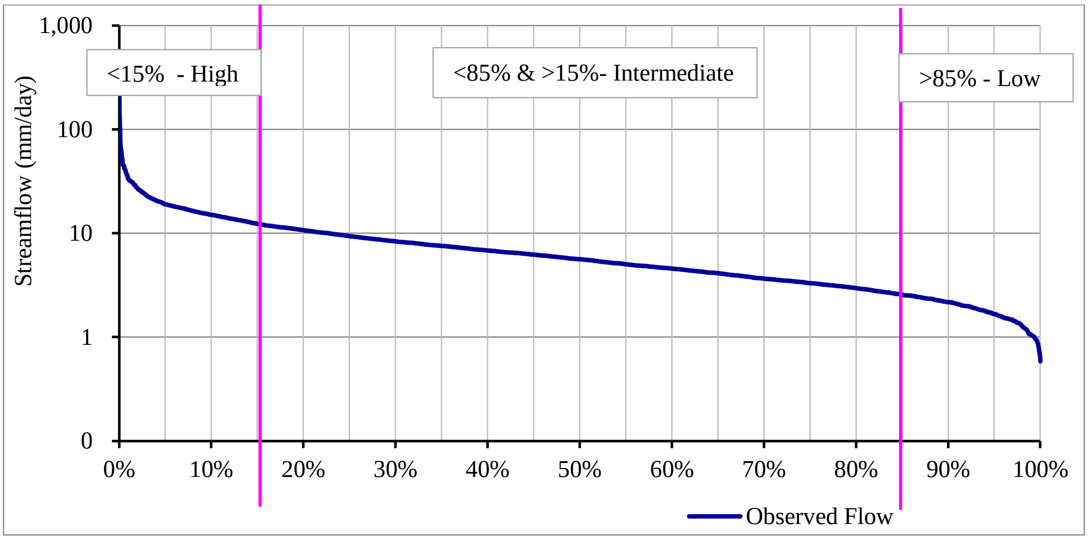

Figure D-6: Flow Duration Curve – Daily Scale - Tawalama Watershed (Log Scale)

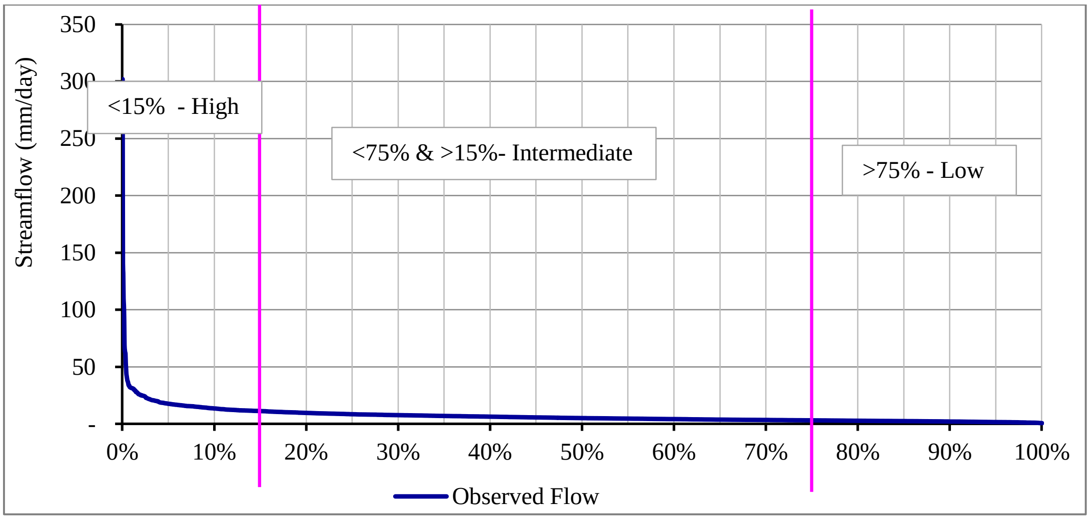

Figure D-7: Flow Duration Curve – Daily Scale - Ellagawa Watershed (Normal Scale)

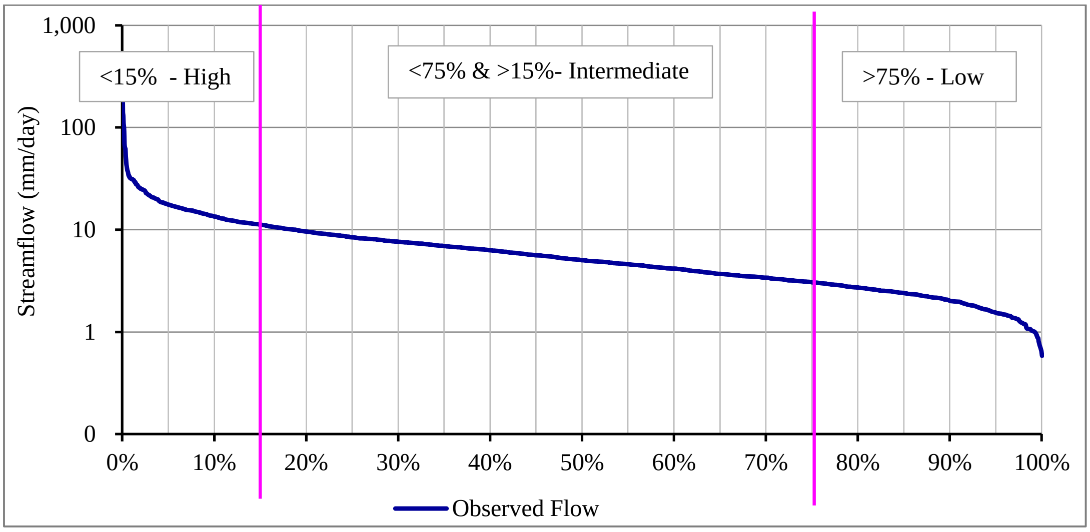

Figure D-8: Flow Duration Curve – Daily Scale - Ellagawa Watershed (Log Scale)

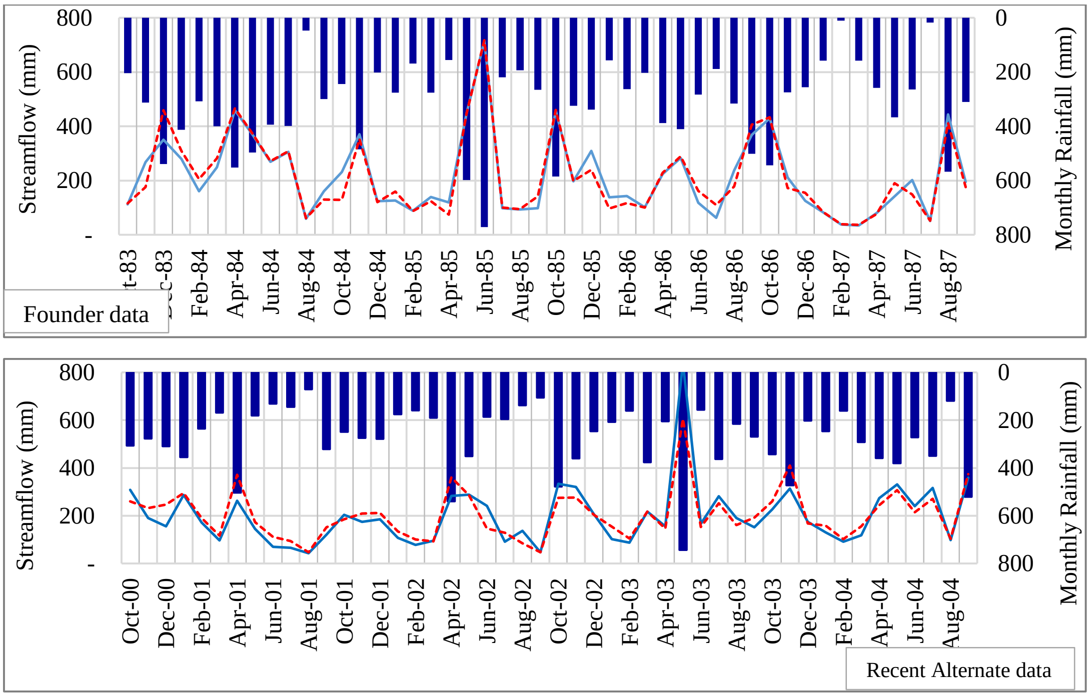

Figure D-9: Streamflow Comparison with Kandu.D.,(2016,unpuble) Model– Tawalama watershed – Founder and Alternate Data (Normal Scale)

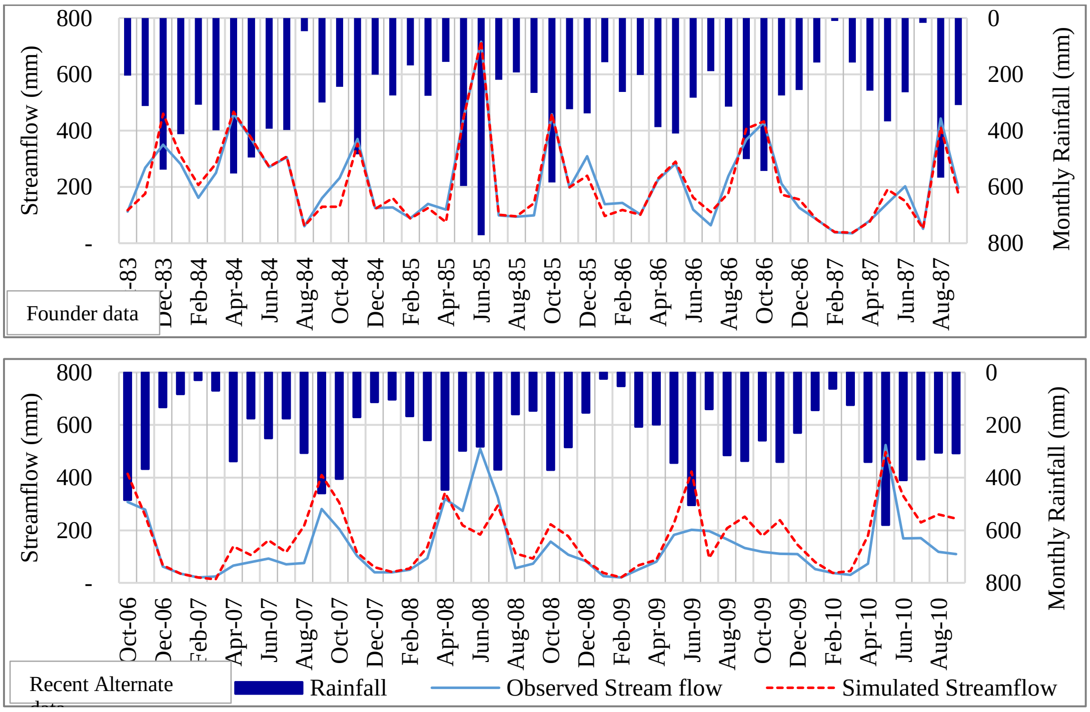

Figure D-10: Streamflow Comparison with Sariffi.M.B.,(2016,unpuble) Model– Ellagawa watershed – Founder and Alternate Data (Normal Scale)

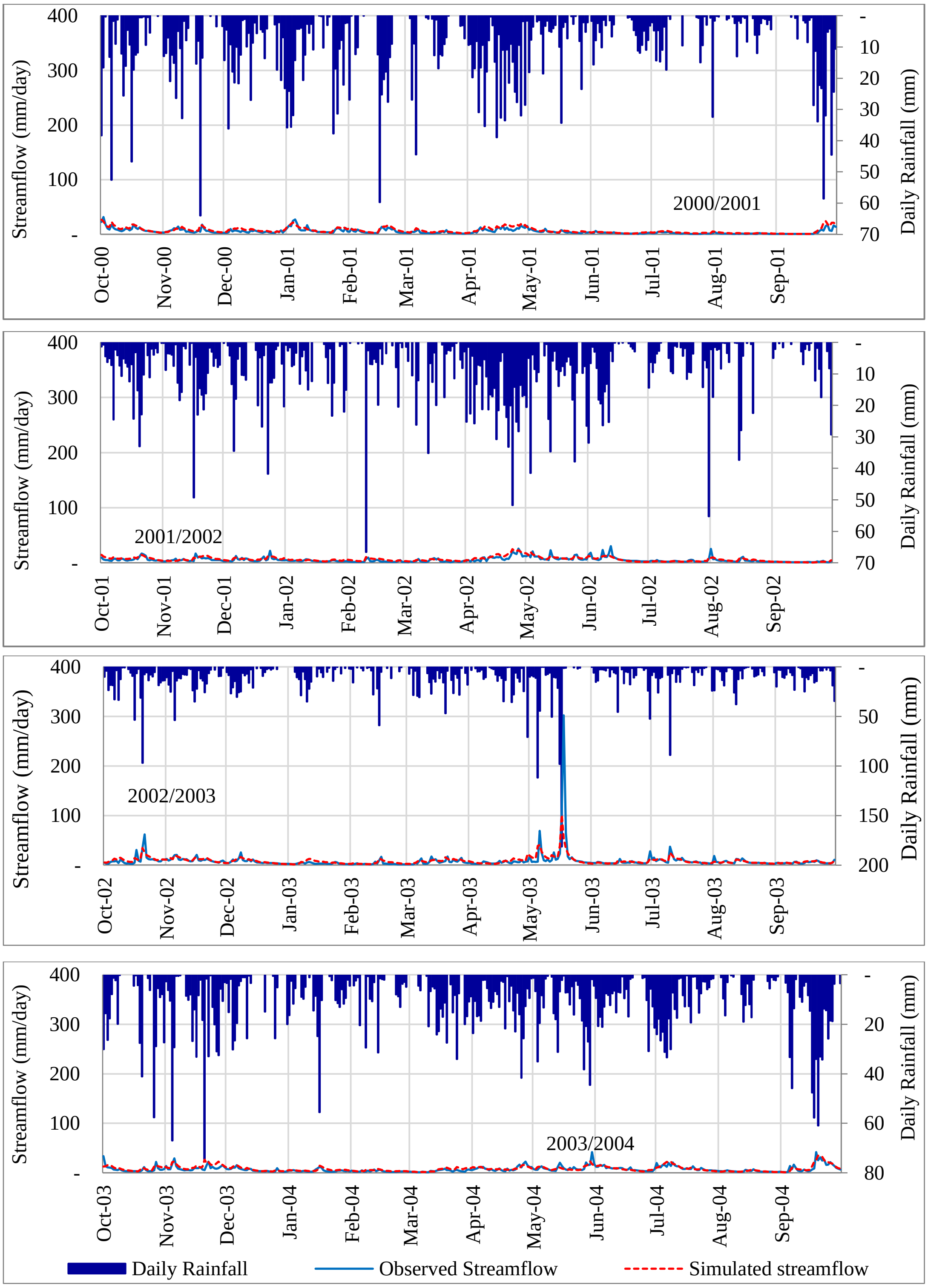

Figure D-11: Output hydrographs from 2PM (Daily) – with calibrated parameters – Calibration - Tawalama watershed (Normal Scale Plot)

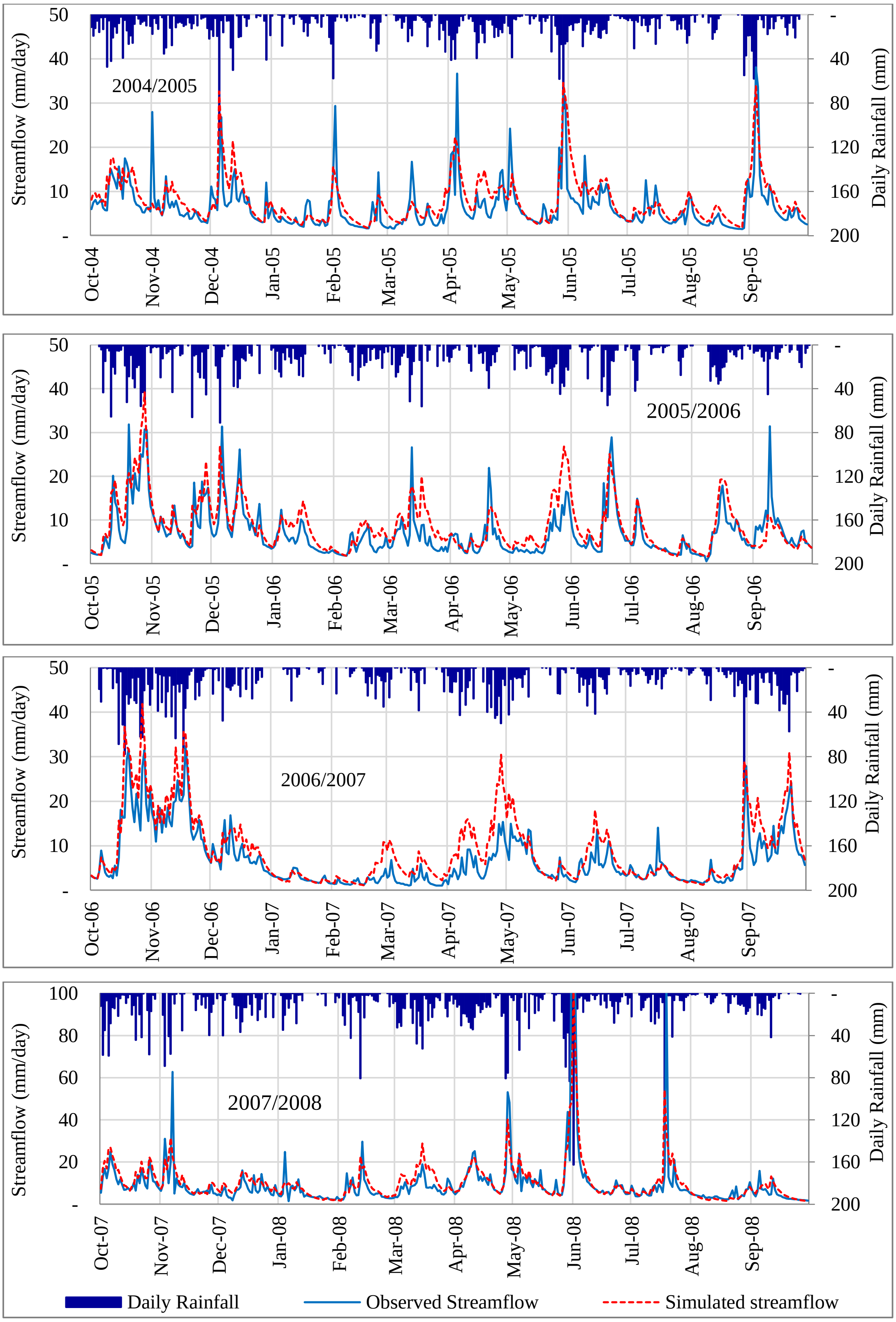

Figure D-12: Output hydrographs from 2PM (Daily) – with calibrated parameters – Calibration - Tawalama watershed (Normal Scale Plot)

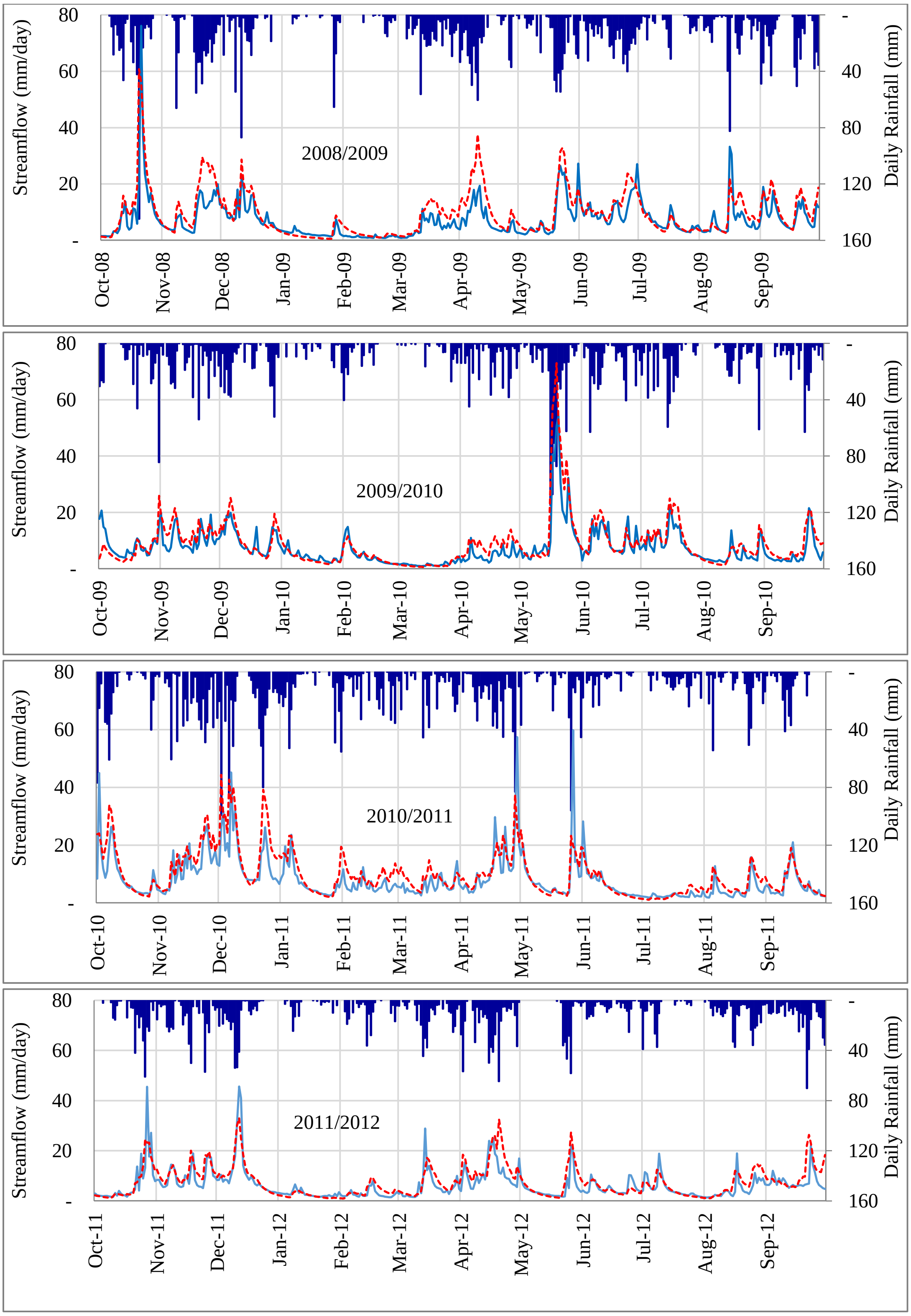

Figure D-13: Output hydrographs from 2PM (Daily) –Verification - Tawalama watershed (Normal Scale Plot)

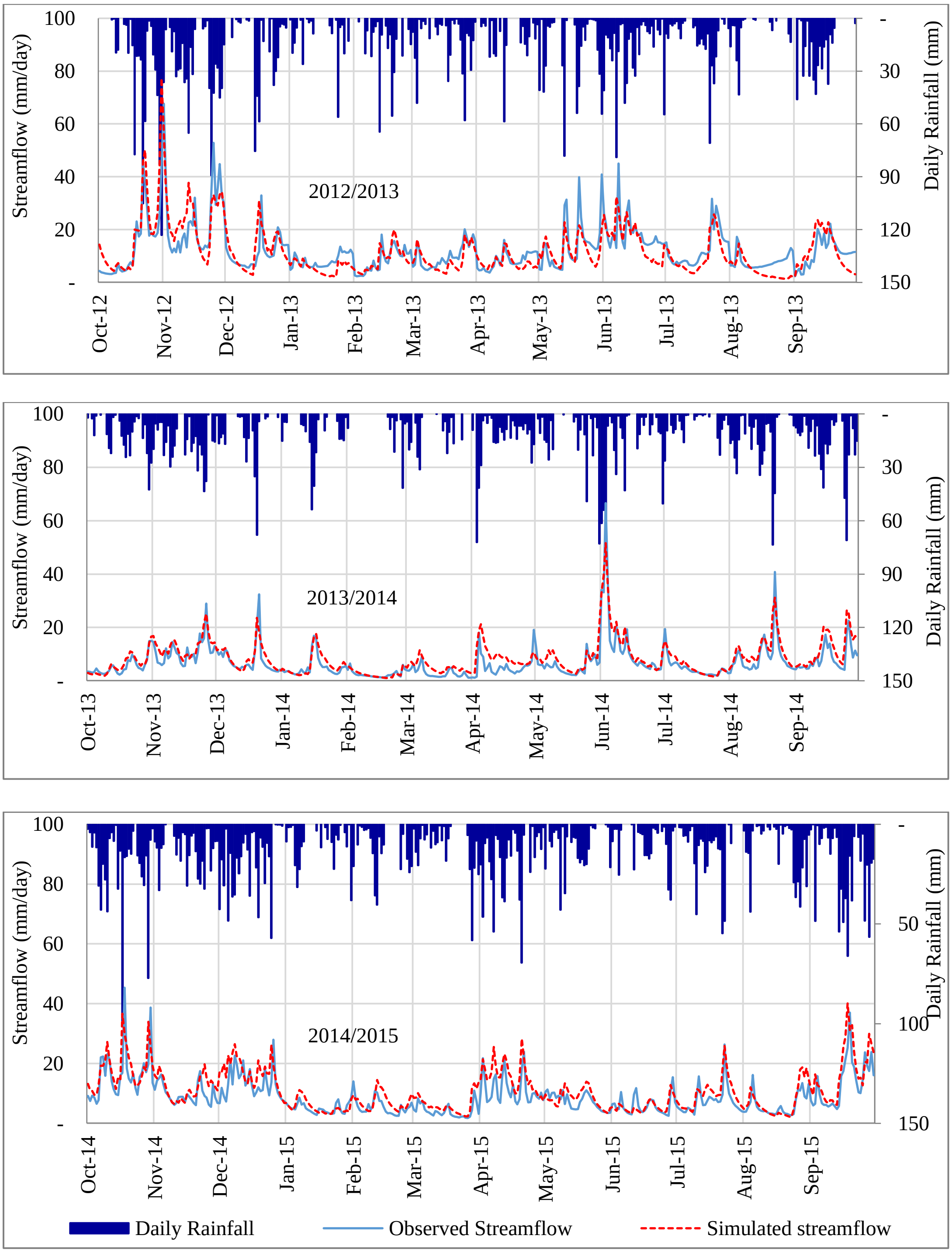

Figure D-14: Output hydrographs from 2PM (Daily) –Verification - Tawalama watershed (Normal Scale Plot)

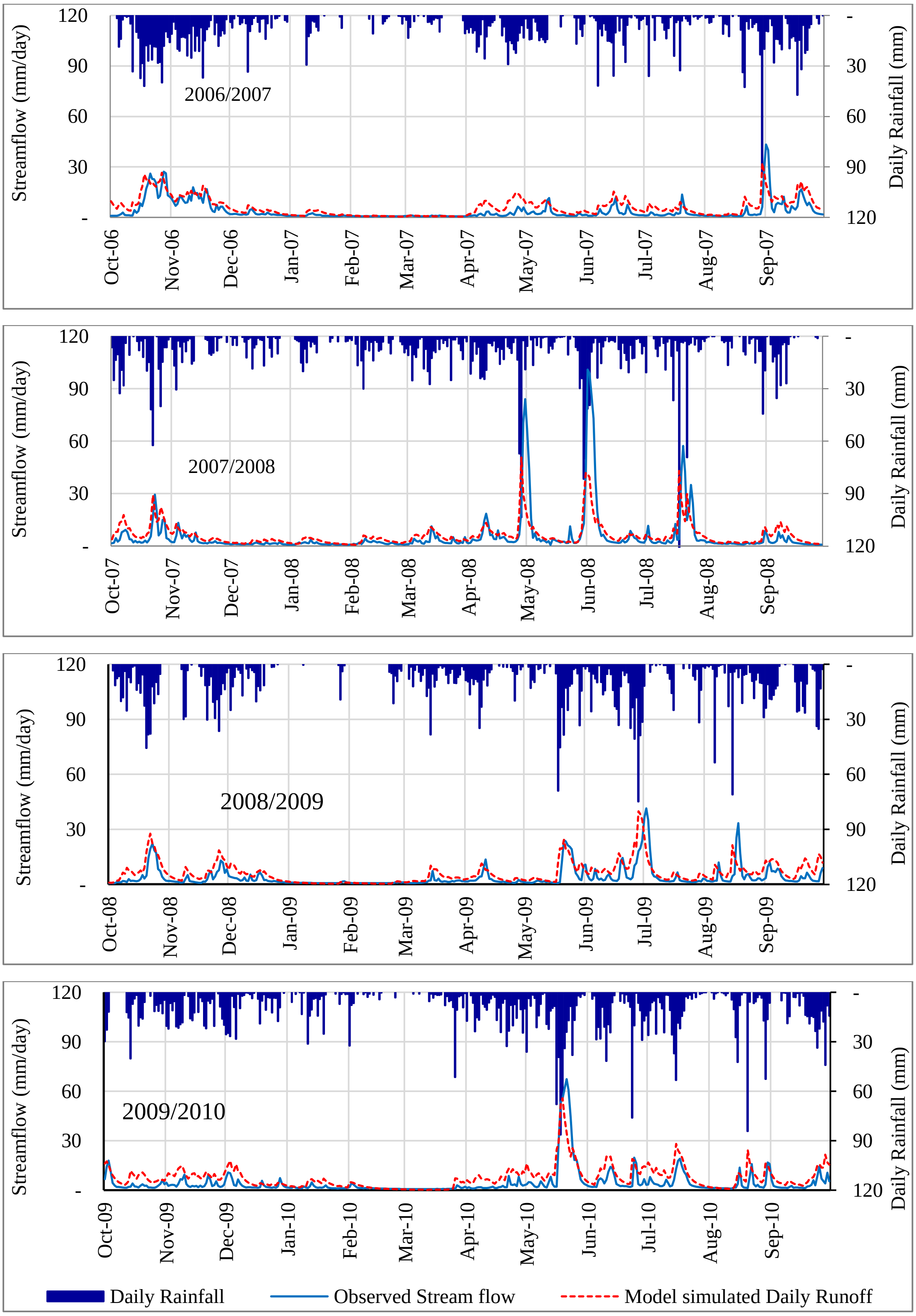

Figure D-15: Output hydrographs from 2PM (Daily) – with calibrated parameters – Calibration - Ellagawa watershed (Normal Scale Plot)

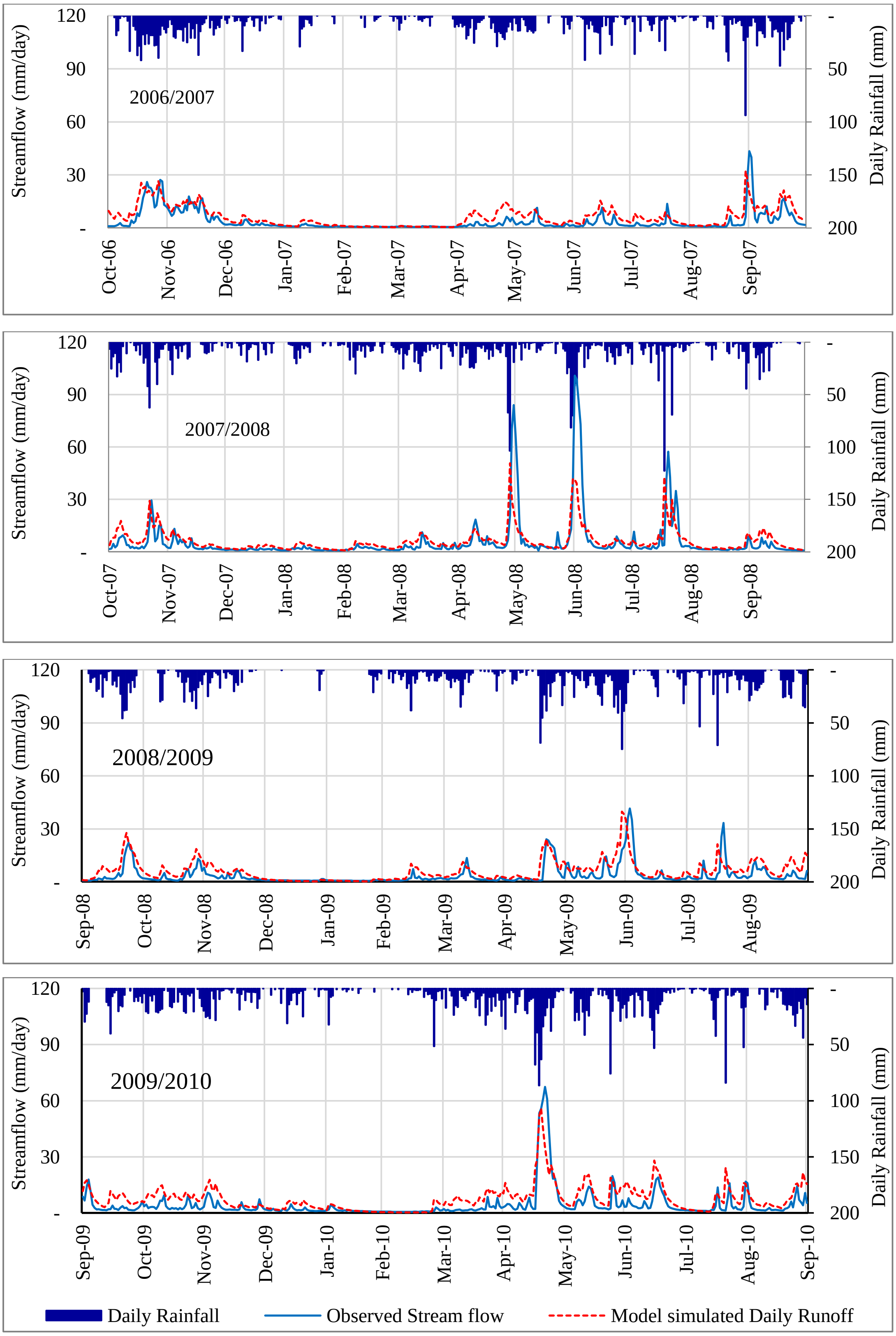

Figure D-16: Output hydrographs from 2PM (Daily) – Calibration - Ellagawa watershed (Normal Scale Plot)

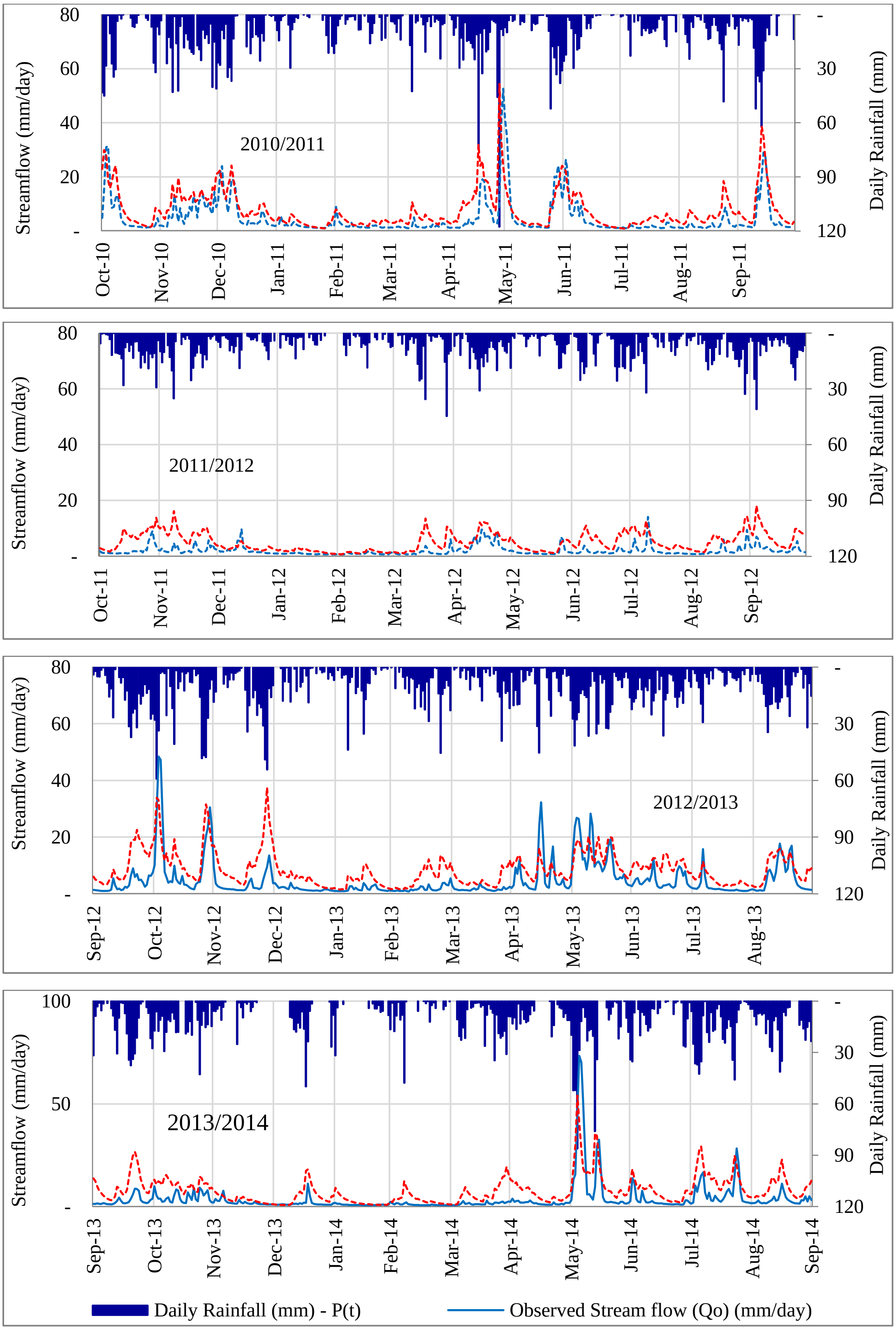

Figure D-17: Output hydrographs from 2PM (Daily) – with calibrated parameters – Validation - Ellagawa watershed (Normal Scale Plot)

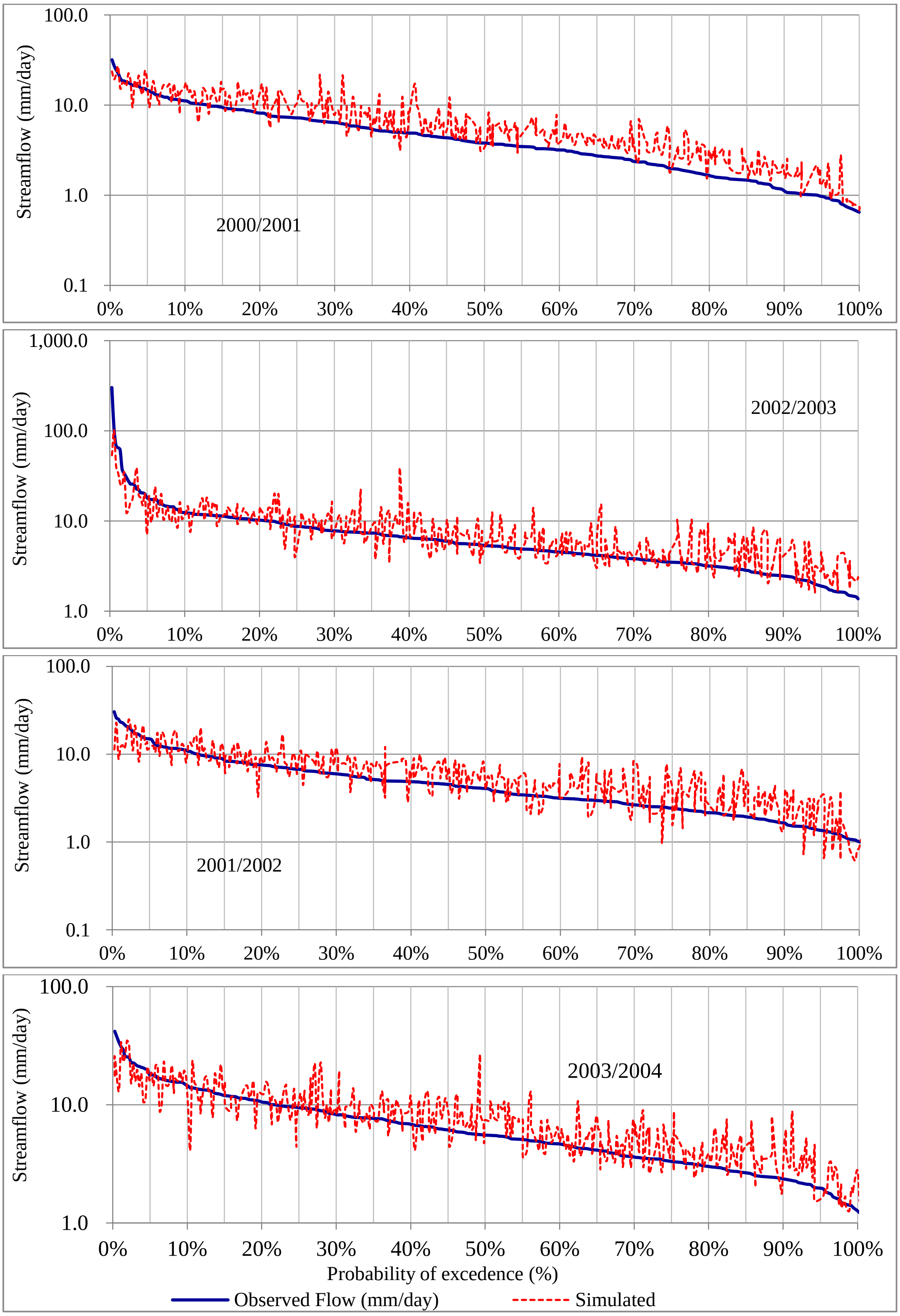

Figure D-18: Flow duration curves for 2PM (Daily) – with calibrated parameters – Calibration - Tawalama watershed (Log Scale Plot)

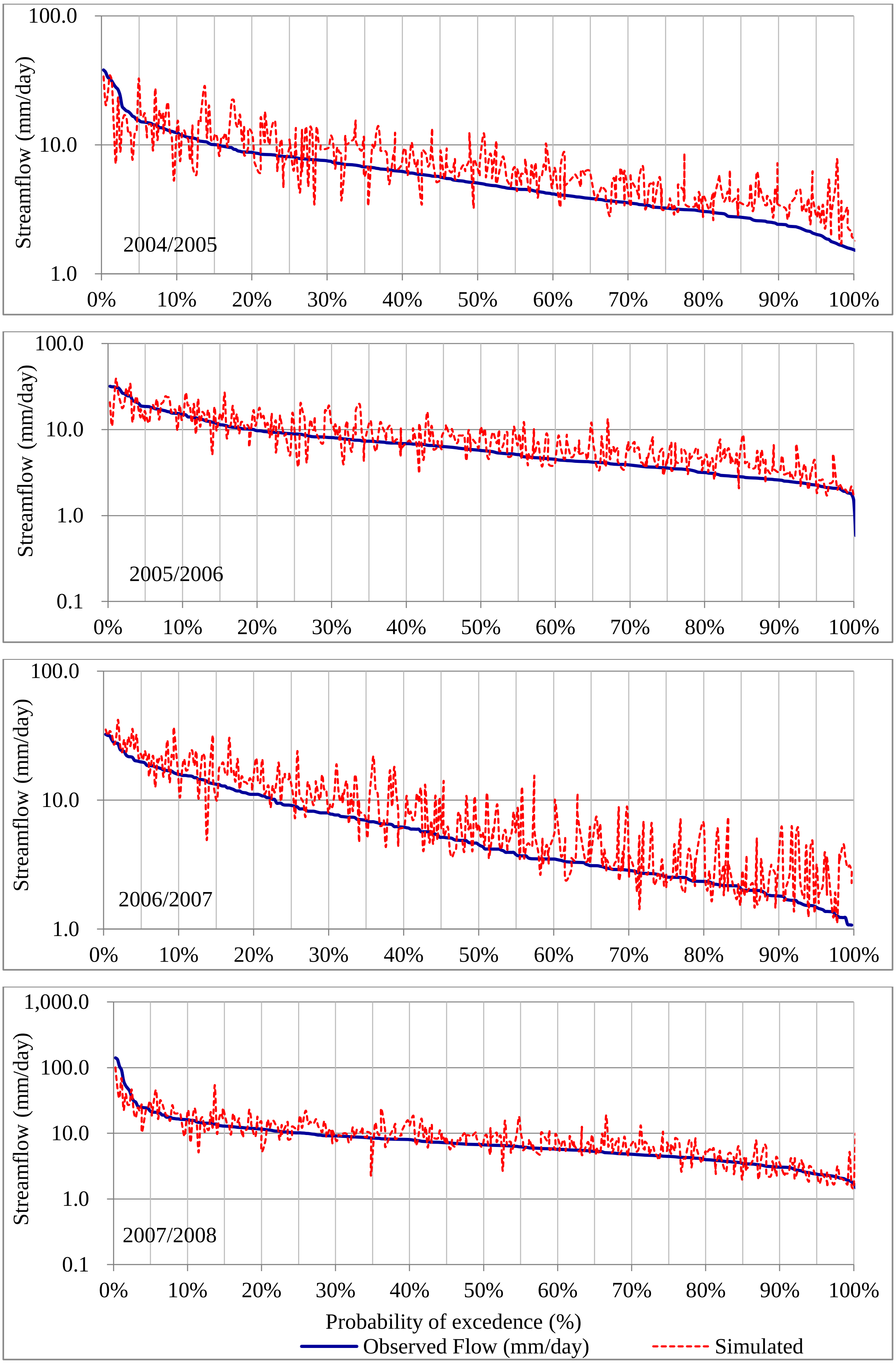

Figure D-19: Flow Duration Curves for 2PM (Daily) – with calibrated parameters – Calibration - Tawalama watershed (Log Scale Plot)

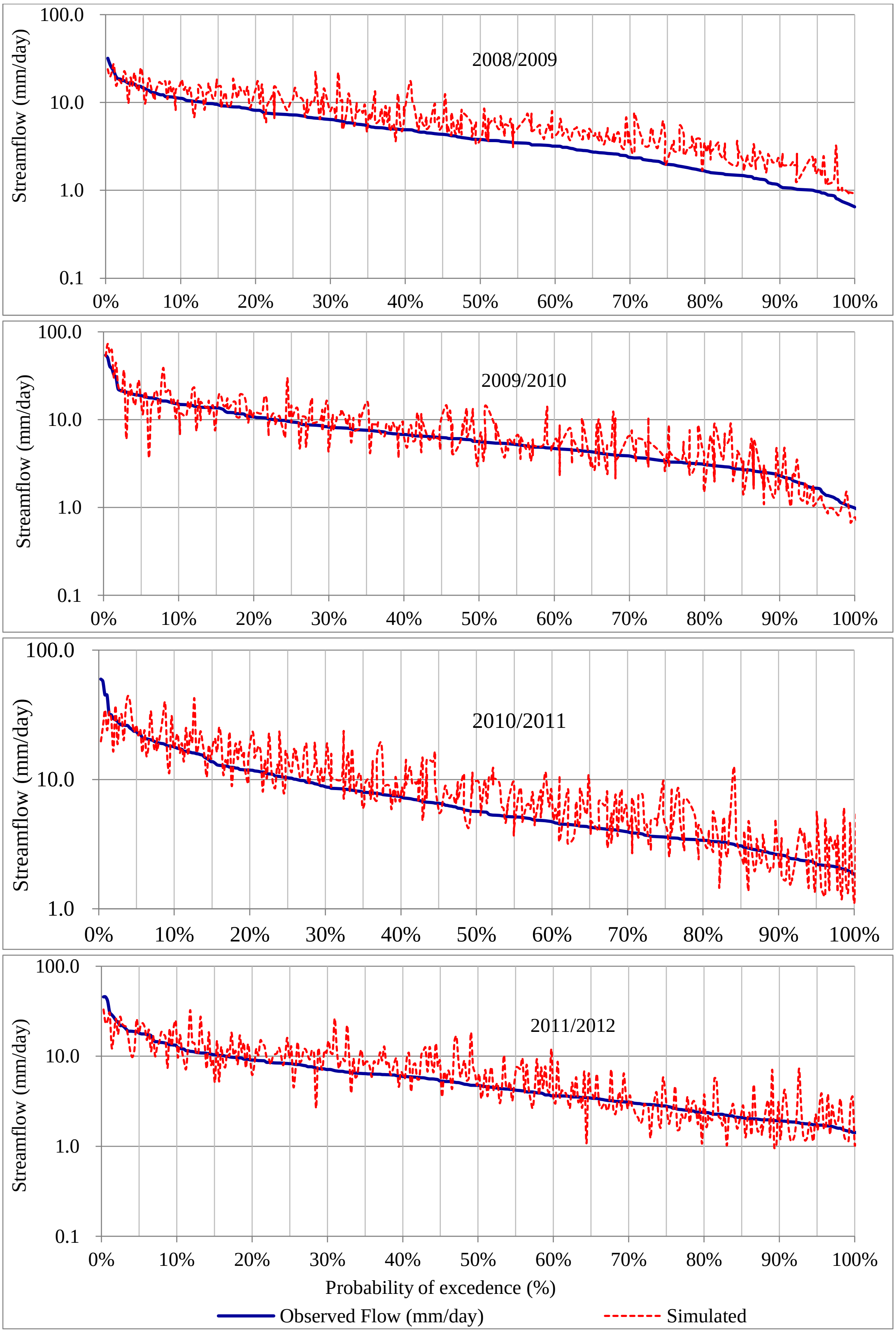

Figure D-20: Flow Duration Curves for 2PM (Daily) – with calibrated parameters – Validation - Tawalama watershed (Log Scale Plot)

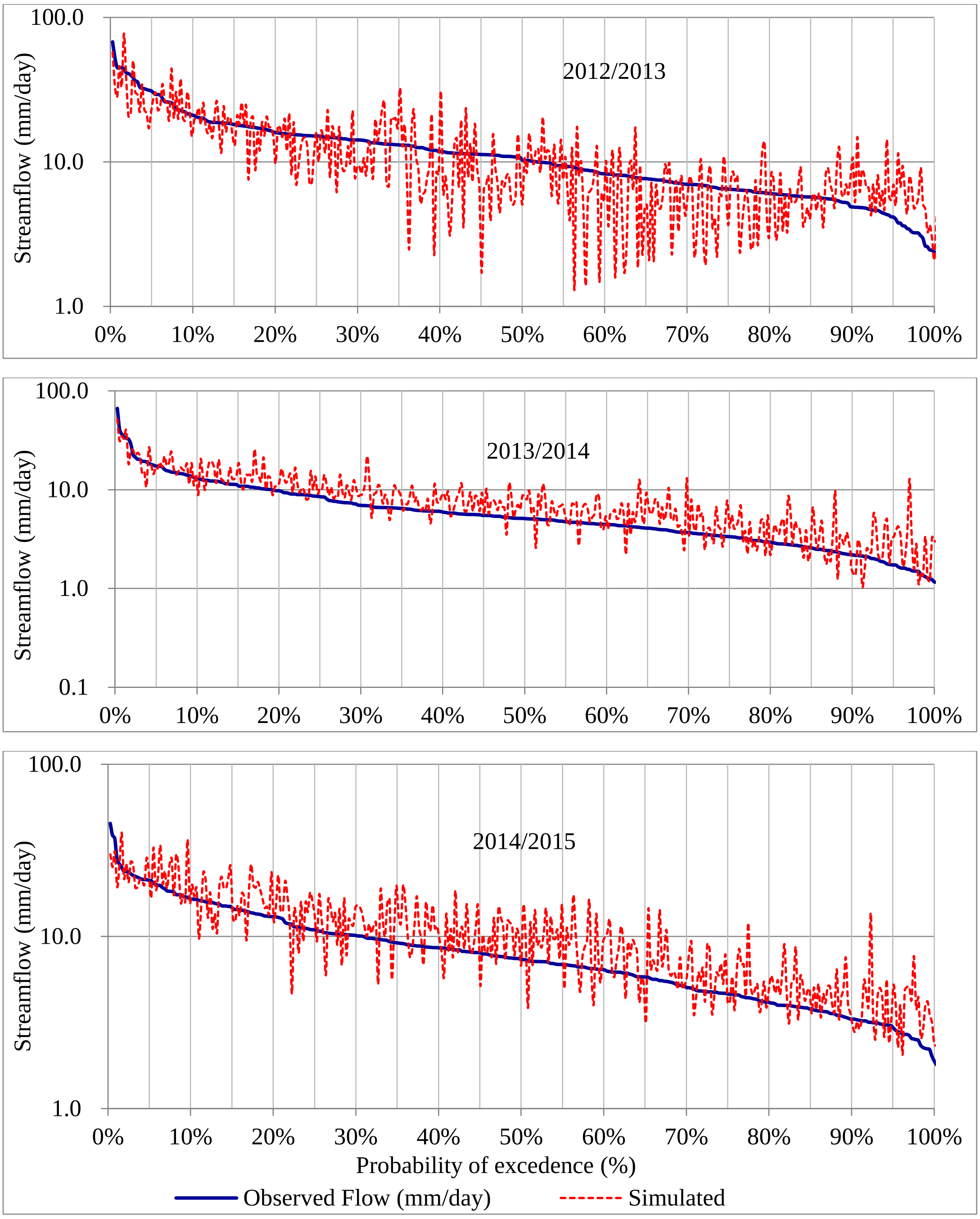

Figure D-21: Flow Duration Curves for 2PM (Daily) – with calibrated parameters – Validation - Tawalama watershed (Log Scale Plot)

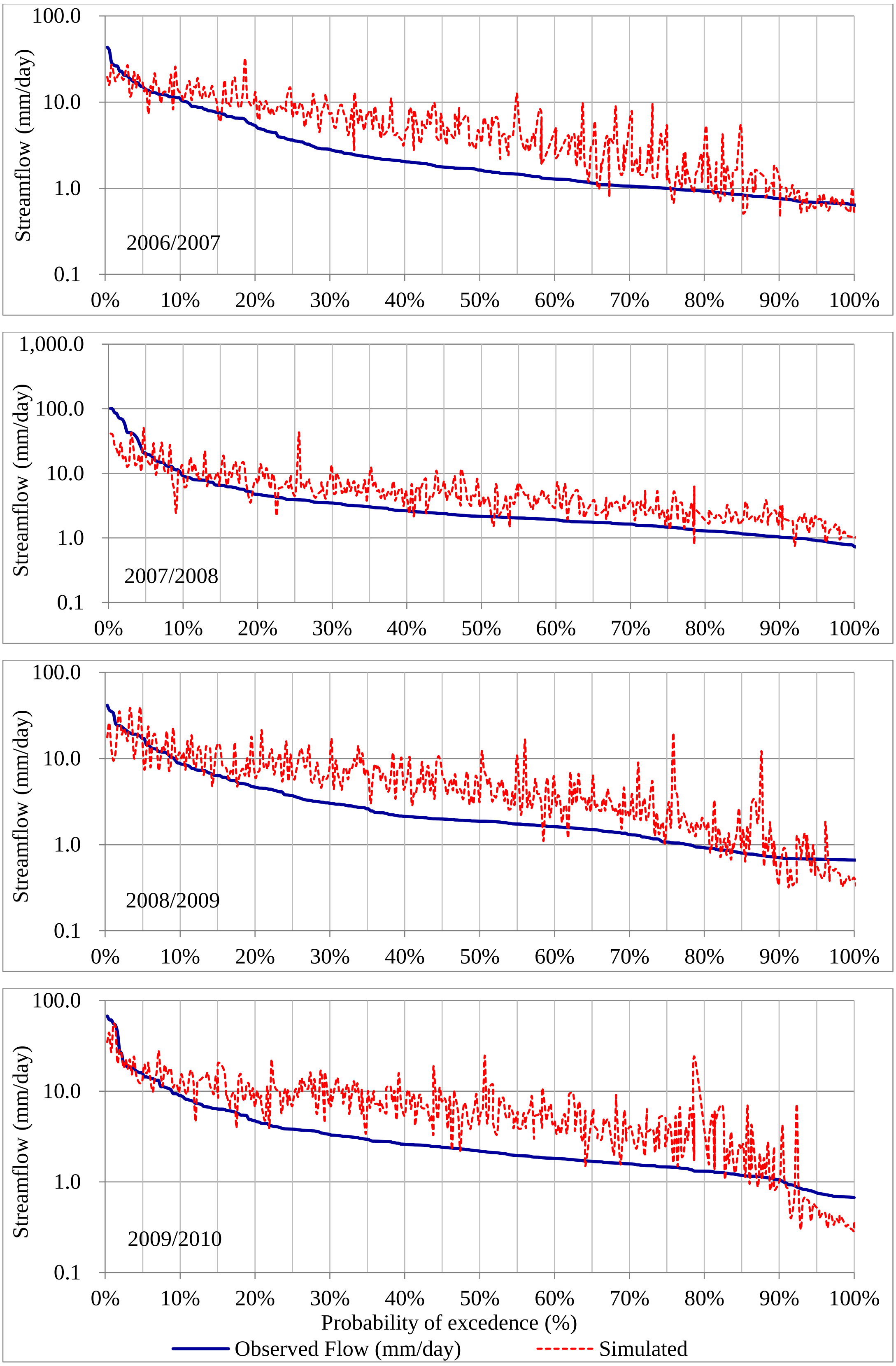

Figure D-22: Flow Duration Curves for 2PM (Daily) – with calibrated parameters – Calibration - Ellagawa watershed (Log Scale Plot)

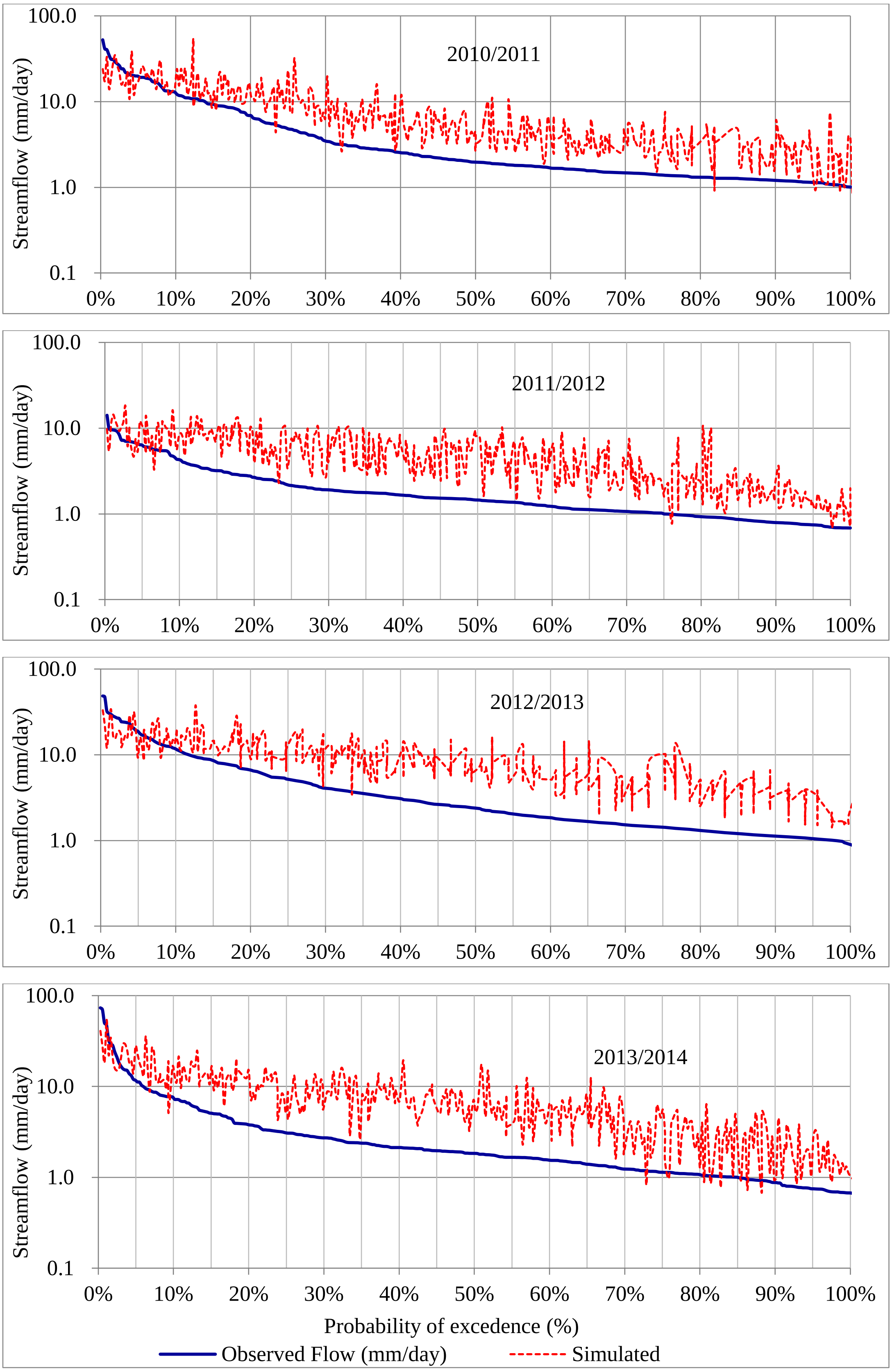

Figure D-23: Flow Duration Curves for 2PM (Daily) – with calibrated parameters – Validation - Ellagawa watershed (Log Scale Plot)

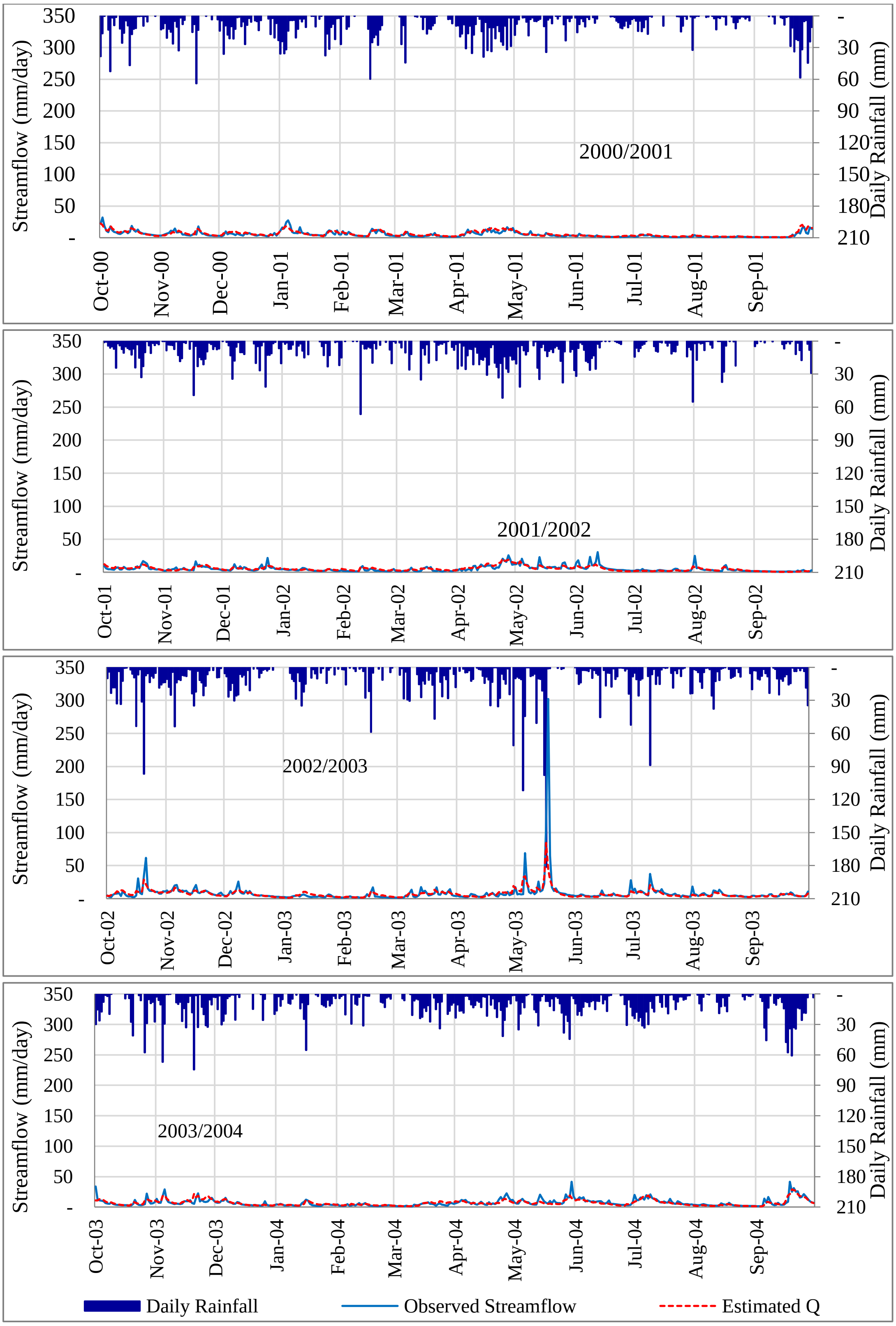

Figure D-24: Output hydrographs for 3PM (Daily) – Calibration - Tawalama watershed (Log Scale Plot)

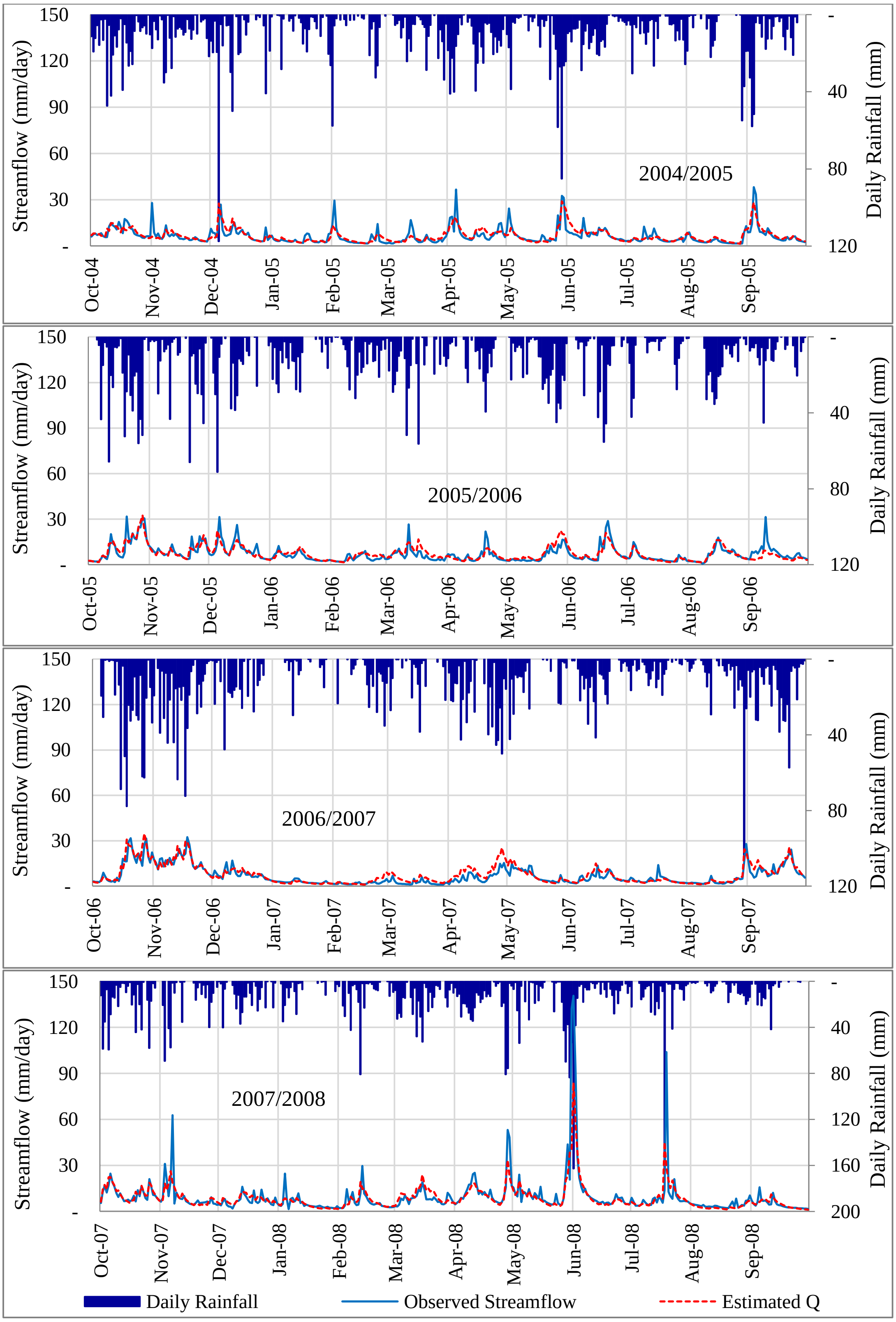

Figure D-25: Output hydrographs for 3PM (Daily) – Calibration - Tawalama watershed (Log Scale Plot)

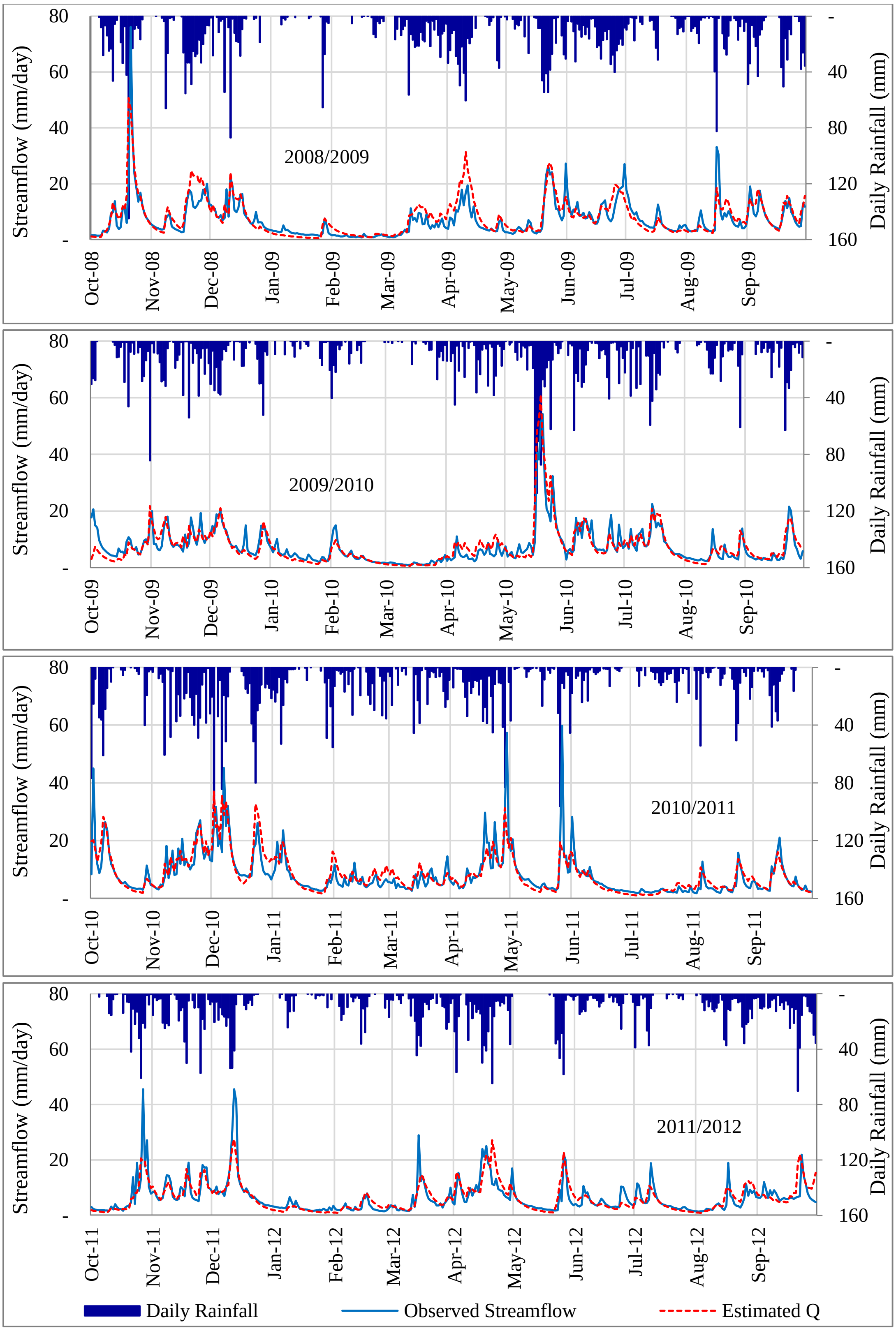

Figure D-26: Output hydrographs for 3PM (Daily) – Verification - Tawalama watershed (Normal Scale Plot)

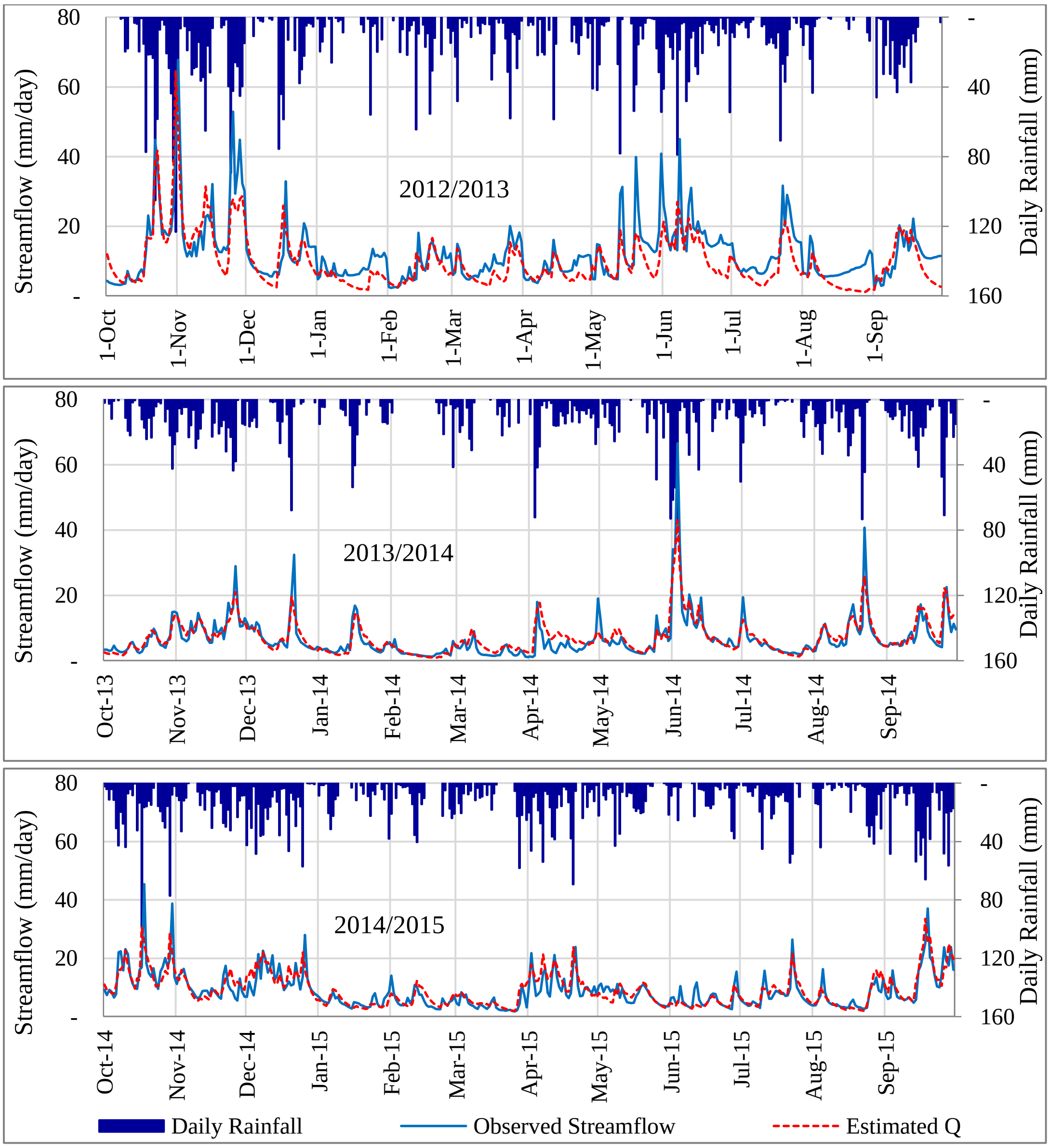

Figure D-27: Output hydrographs for 3PM (Daily) – Verification - Tawalama watershed (Normal Scale Plot)

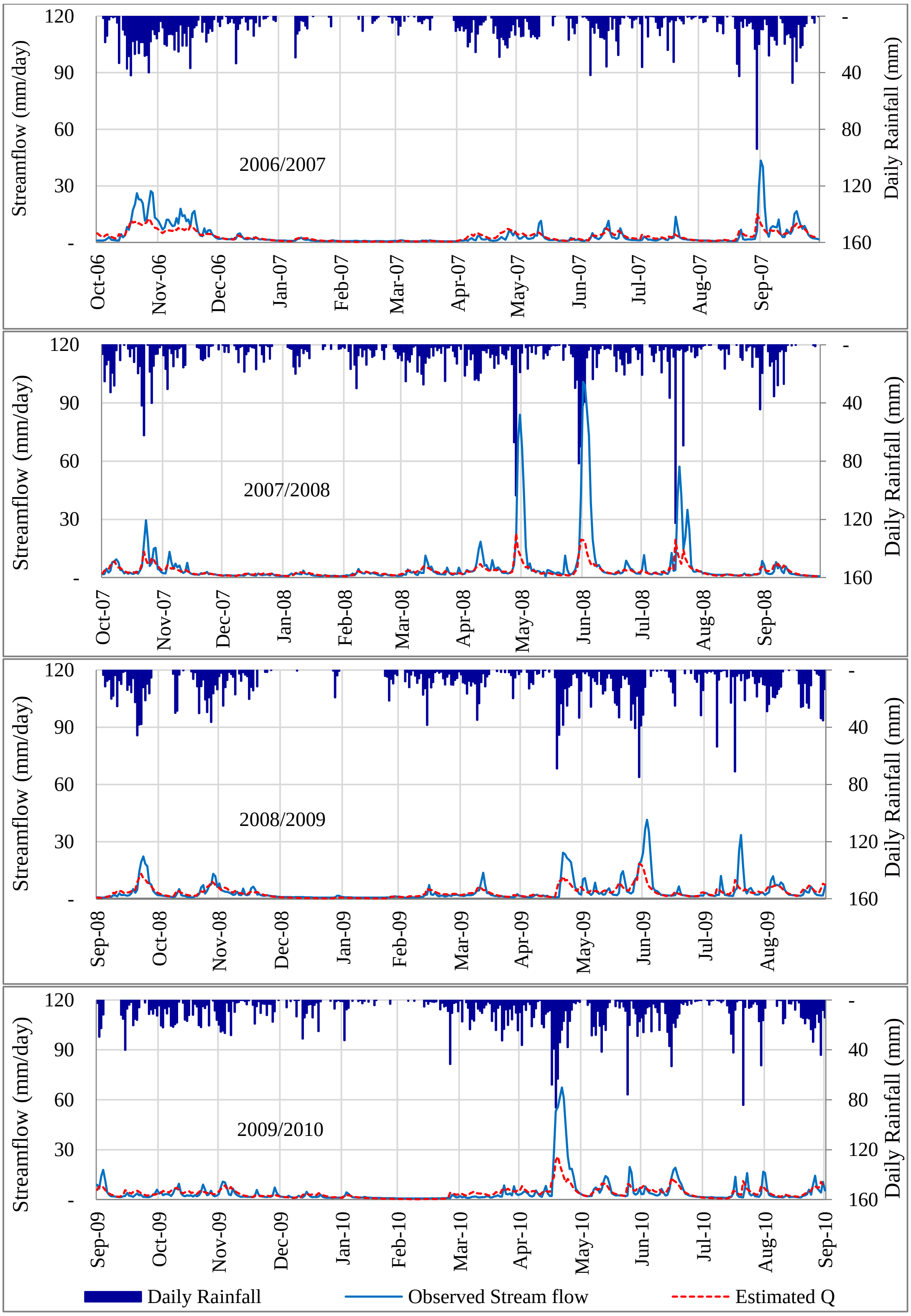

Figure D-28: Output hydrographs for 3PM (Daily) – Calibration - Ellagawa watershed (Normal Scale Plot)

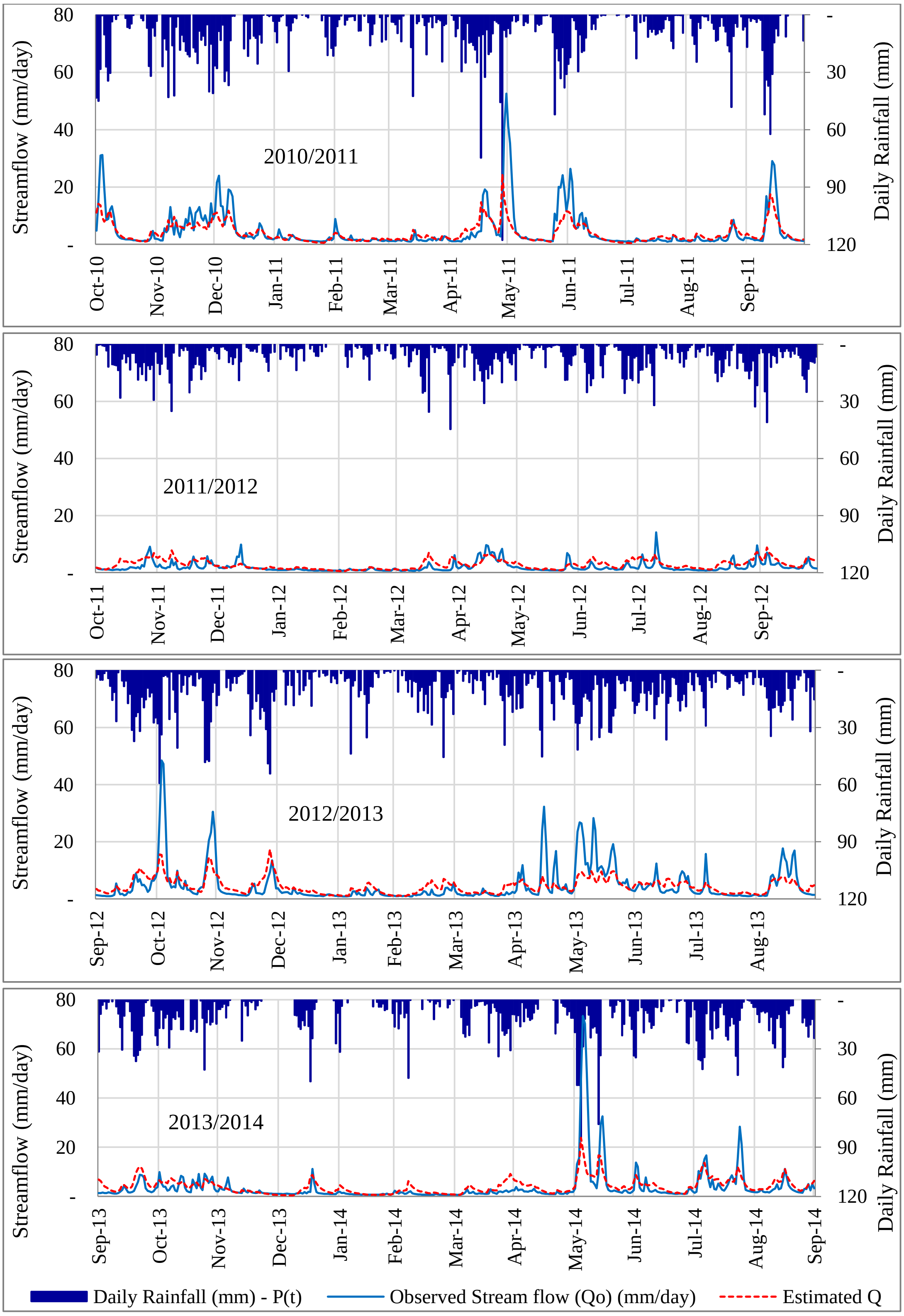

Figure D-29: Output hydrographs for 3PM (Daily) – Verification - Ellagawa watershed (Normal Scale Plot)

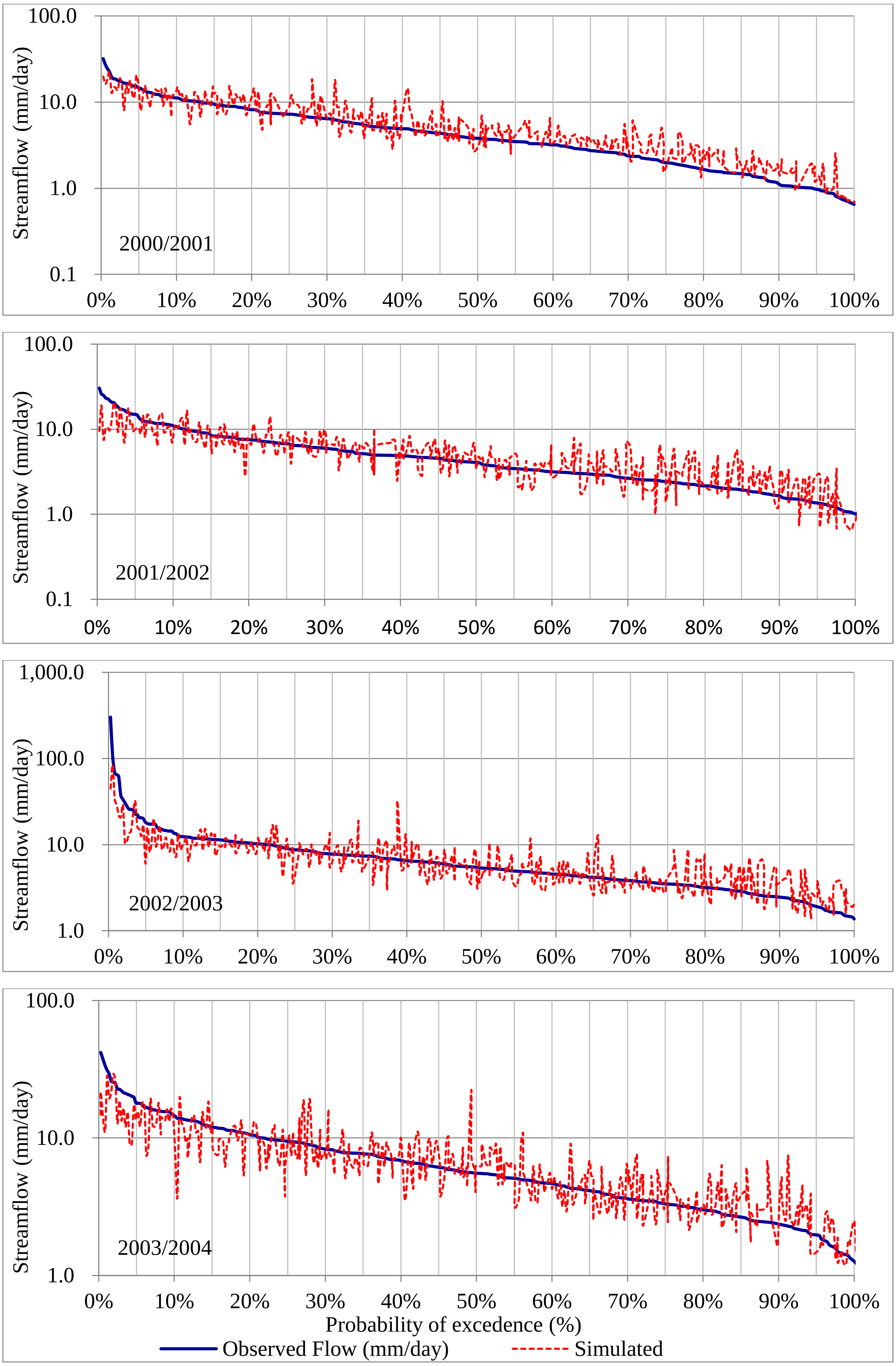

Figure D-30: Flow duration curves for 3PM (Daily) – Calibration - Tawalama watershed (Log Scale Plot)

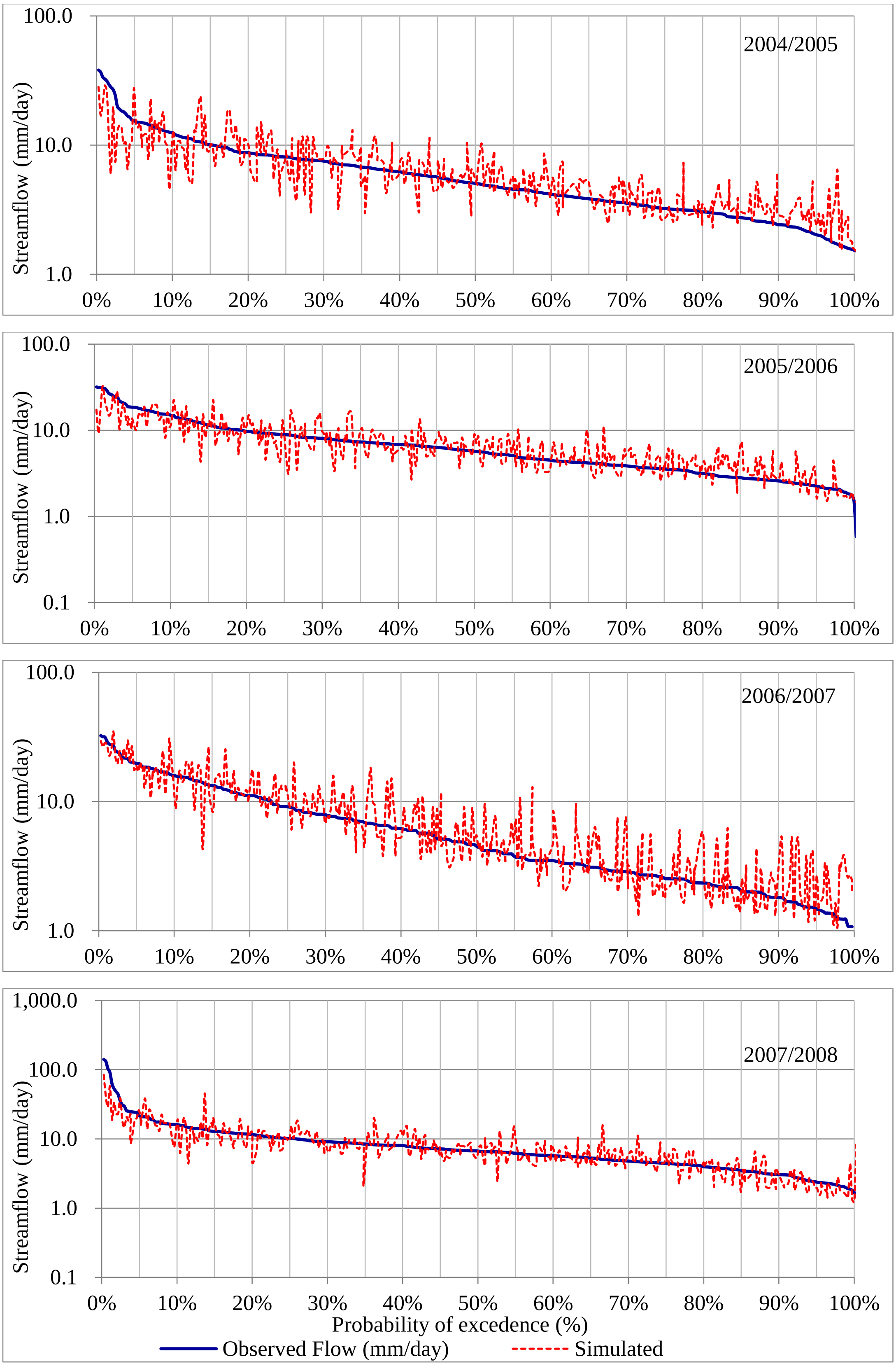

Figure D-31: Flow duration curves for 3PM (Daily) – Calibration - Tawalama watershed (Log Scale Plot)

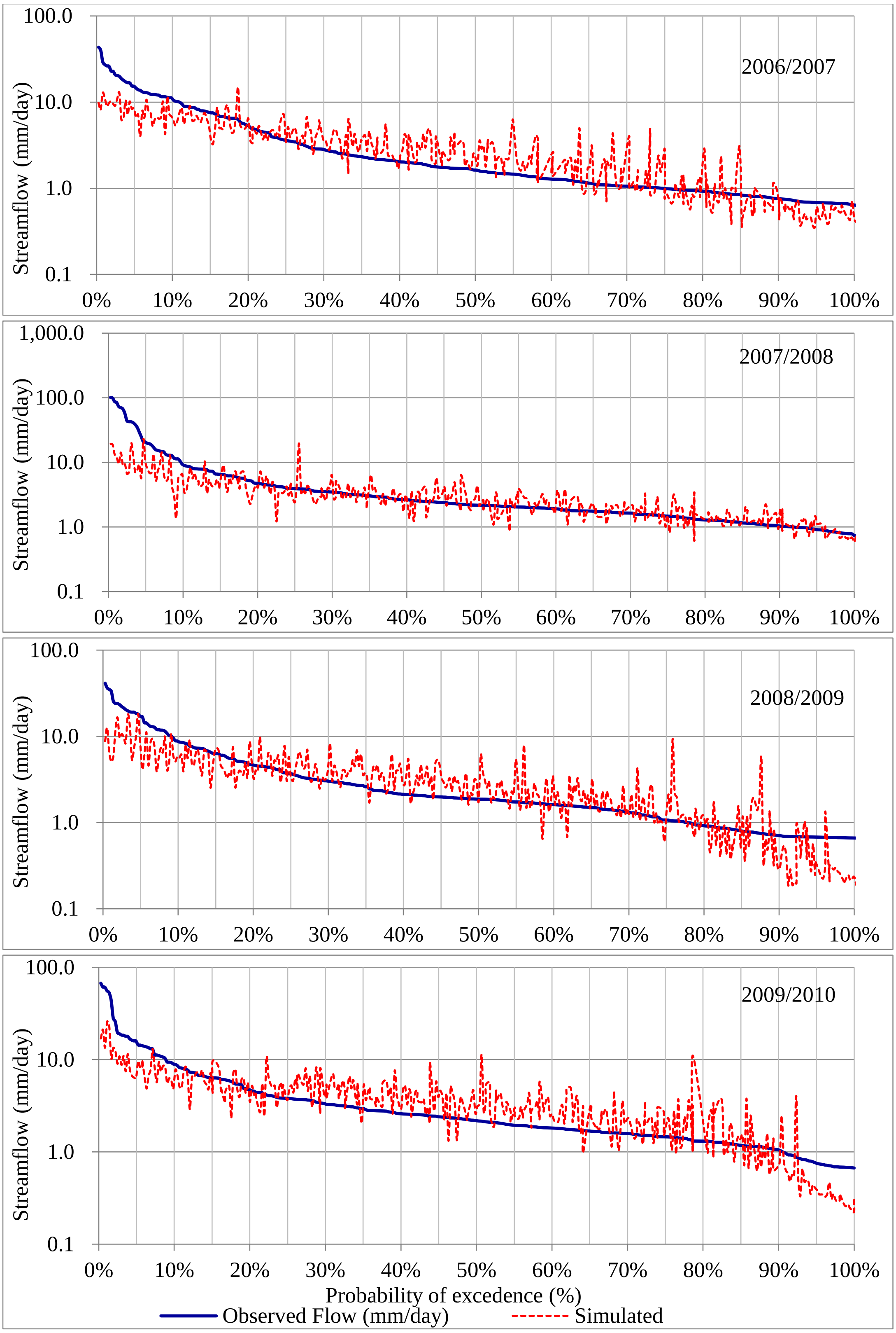

Figure D-32: Flow duration curves for 3PM (Daily) – Calibration – Ellagawa watershed (Log Scale Plot)

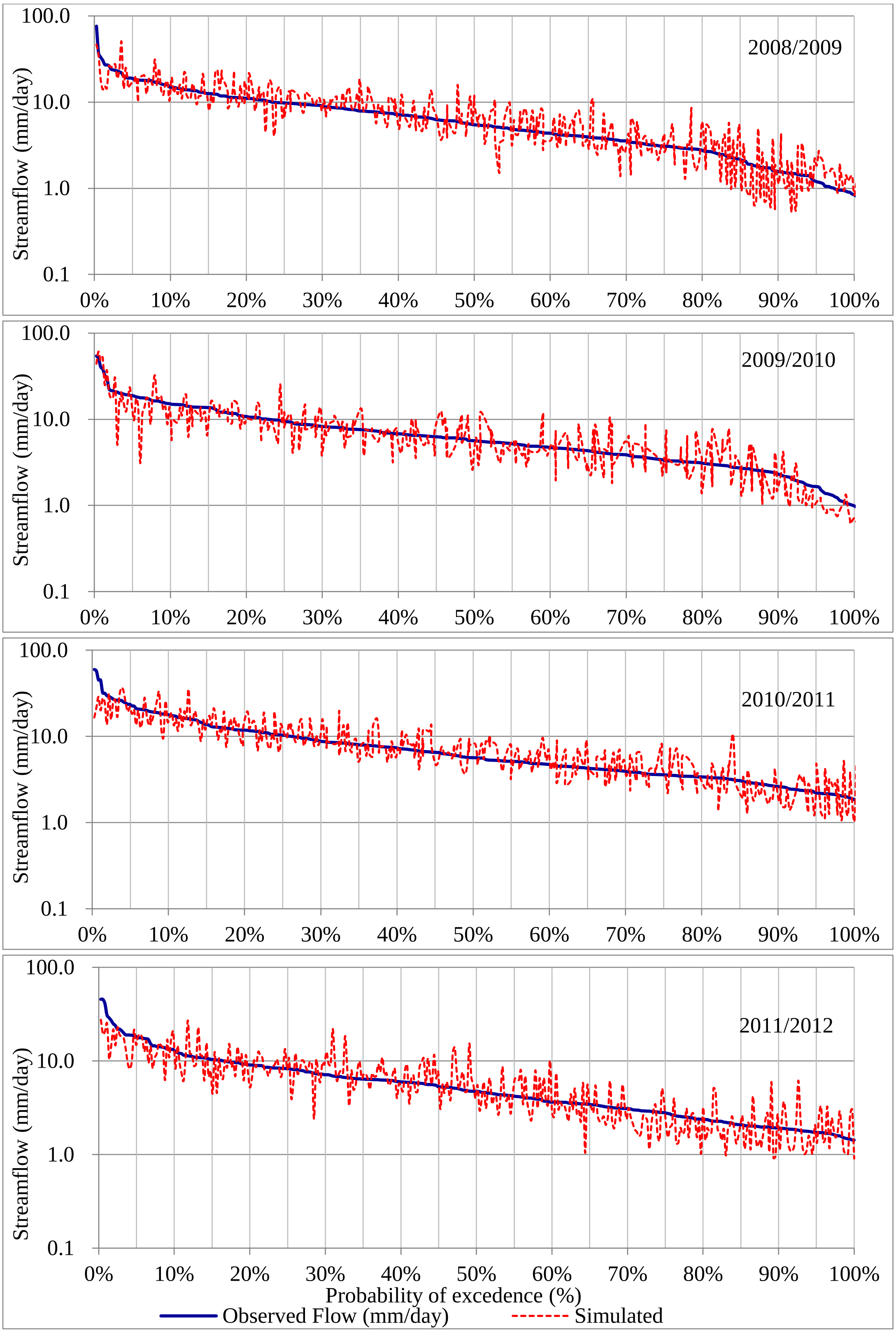

Figure D-33: Flow duration curves for 3PM (Daily) – Validation – Tawalama watershed (Log Scale Plot)

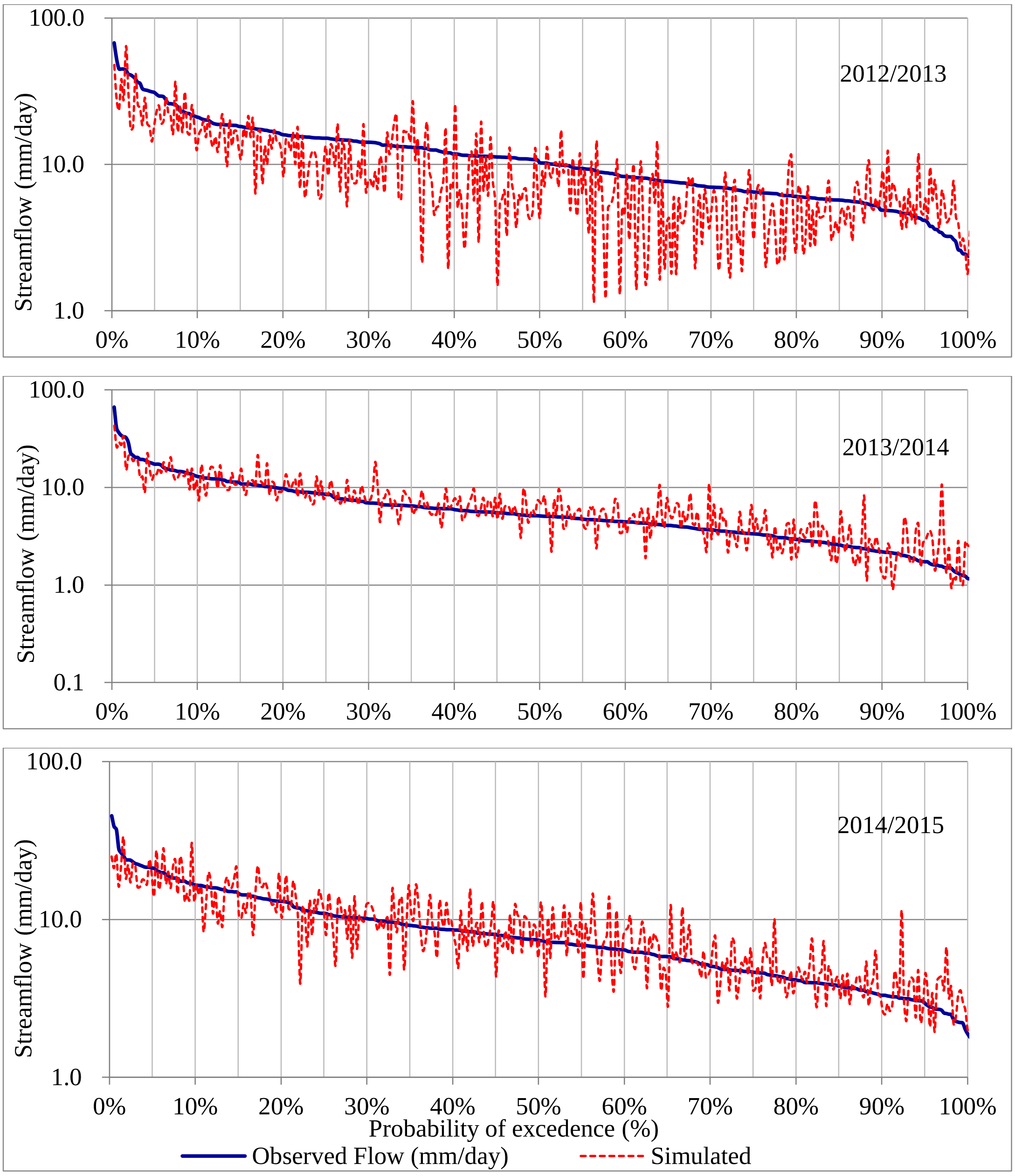

Figure D-34: Flow duration curves for 3PM (Daily) – Validation – Tawalama watershed (Log Scale Plot)

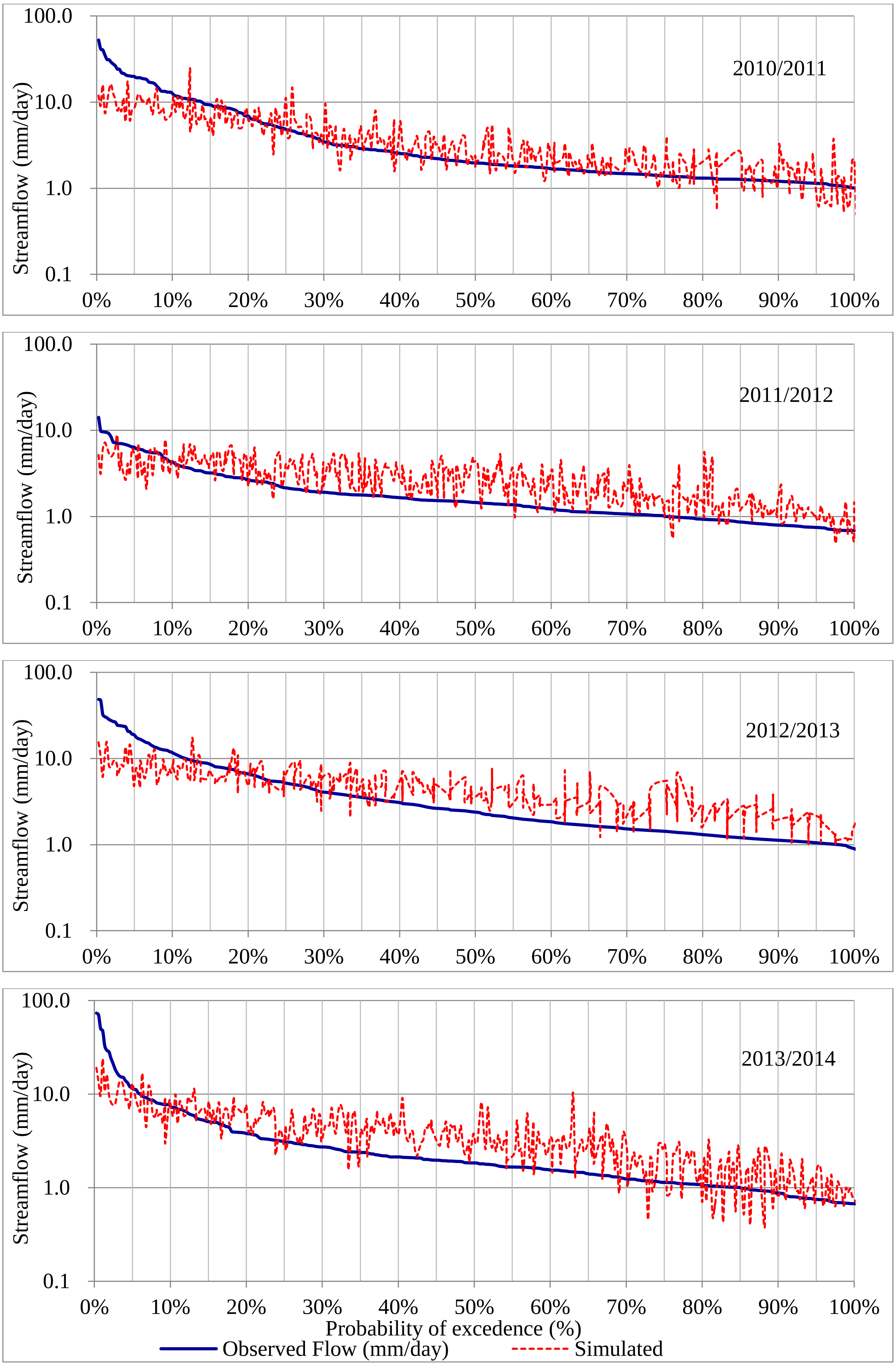

Figure D-35: Flow duration curves for 3PM (Daily) – Validation – Ellagawa watershed (Log Scale Plot)

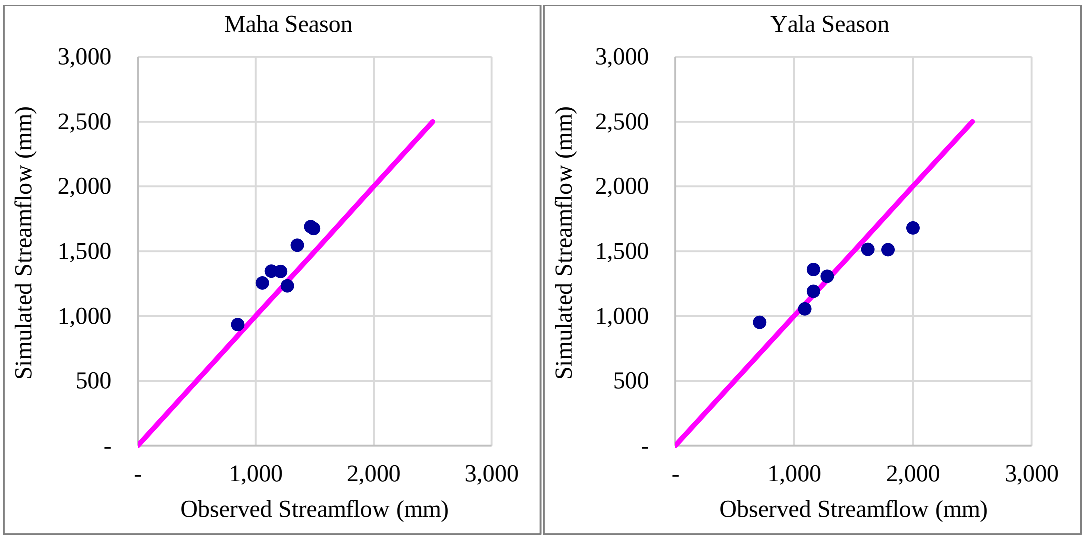

Figure D-36: 2PM (Monthly) – Seasonal Comparison (Calibration) - Tawalama

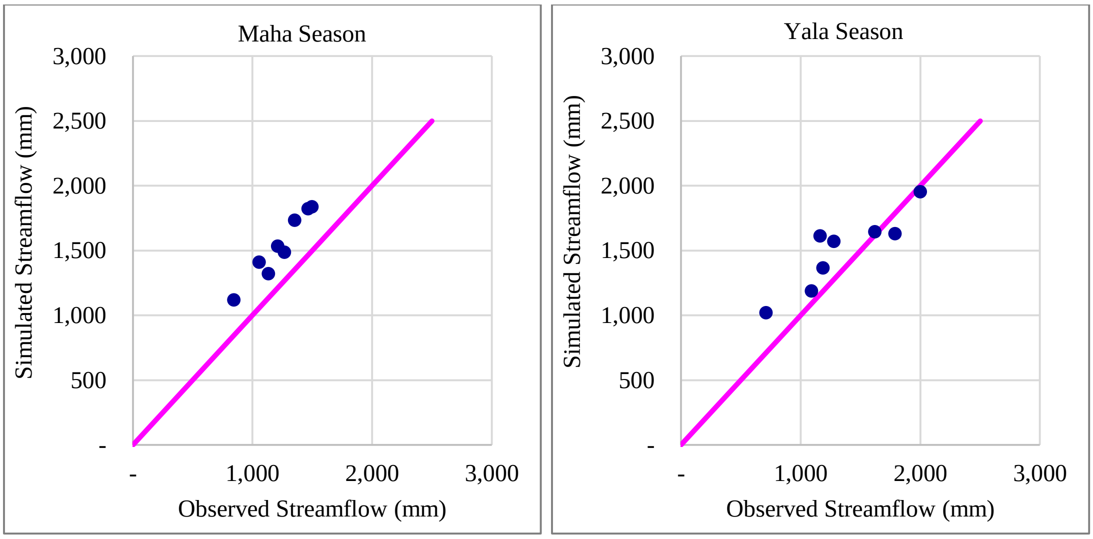

Figure C-37: 2PM (Daily) – Seasonal Comparison (Calibration) – Tawalama

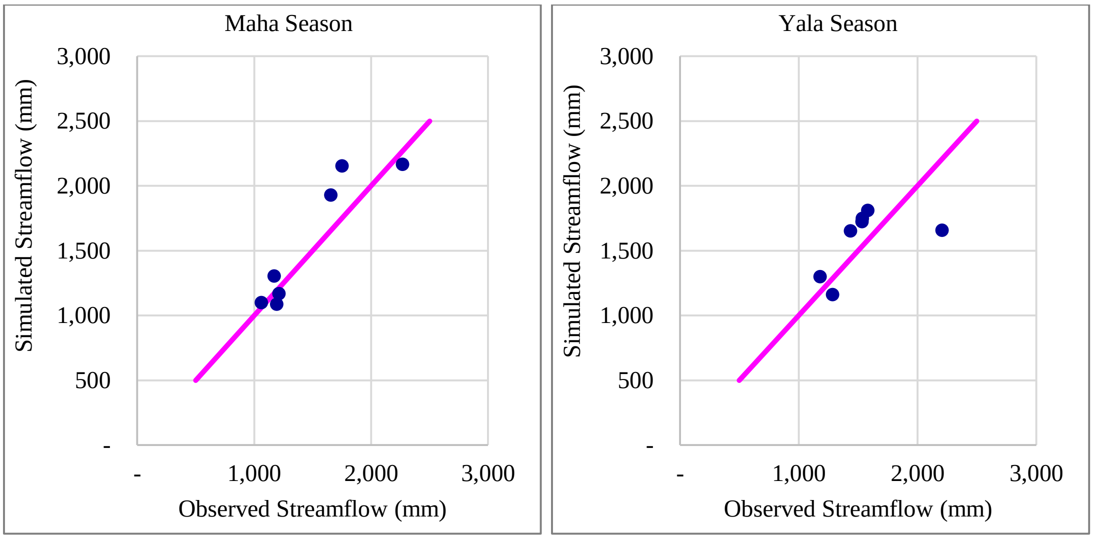

Figure D-38: 2PM (Monthly) – Seasonal Comparison (Validation) - Tawalama

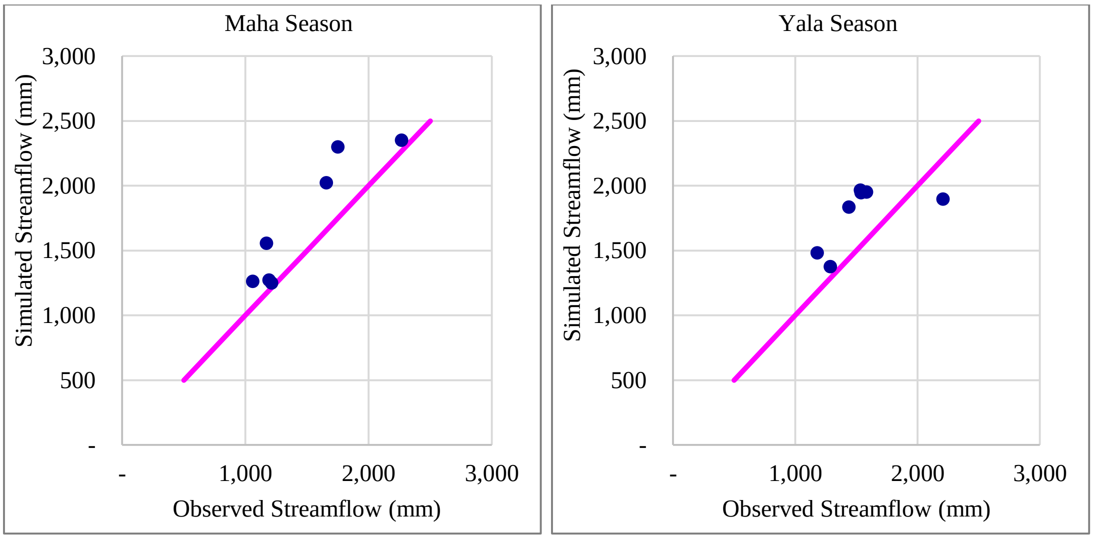

Figure D-39: 2PM (Daily) – Seasonal Comparison (Validation) - Tawalama

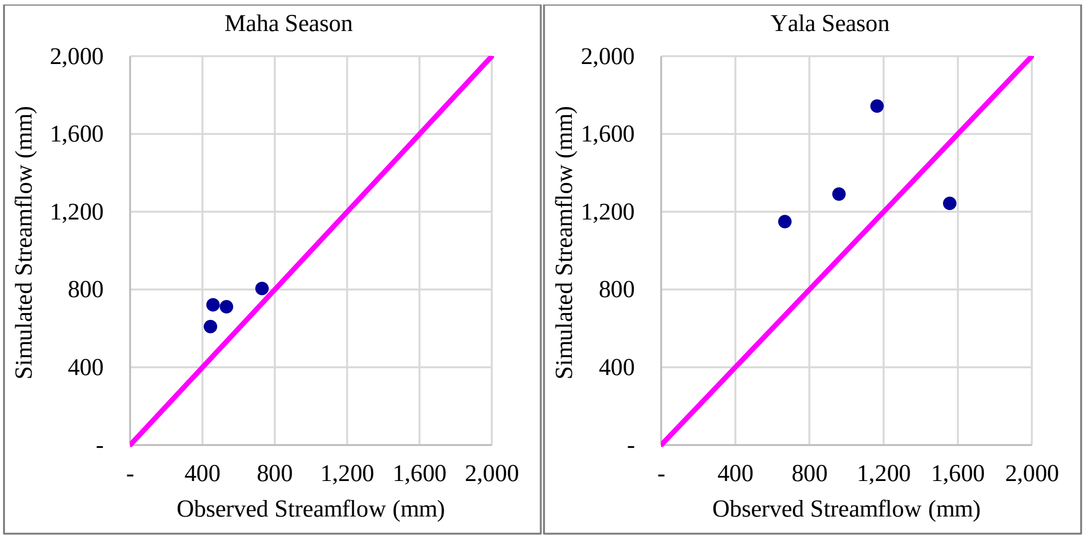

Figure D-40: 2PM (Monthly) – Seasonal Comparison (Calibration) – Ellagawa

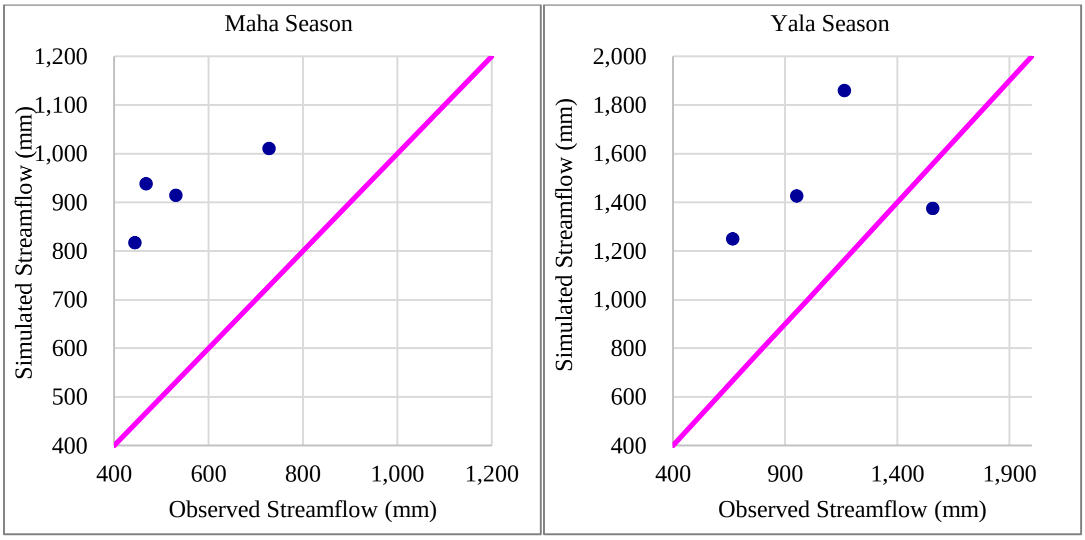

Figure D-41: 2PM (Daily) – Seasonal Comparison (Calibration) – Ellagawa

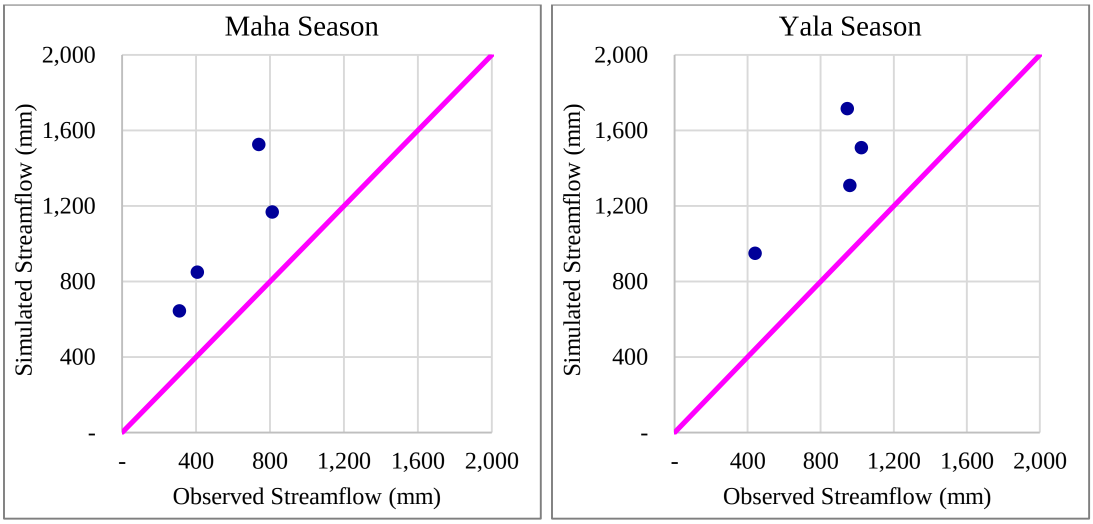

Figure D-42: 2PM (Monthly) – Seasonal Comparison (Validation) – Ellagawa

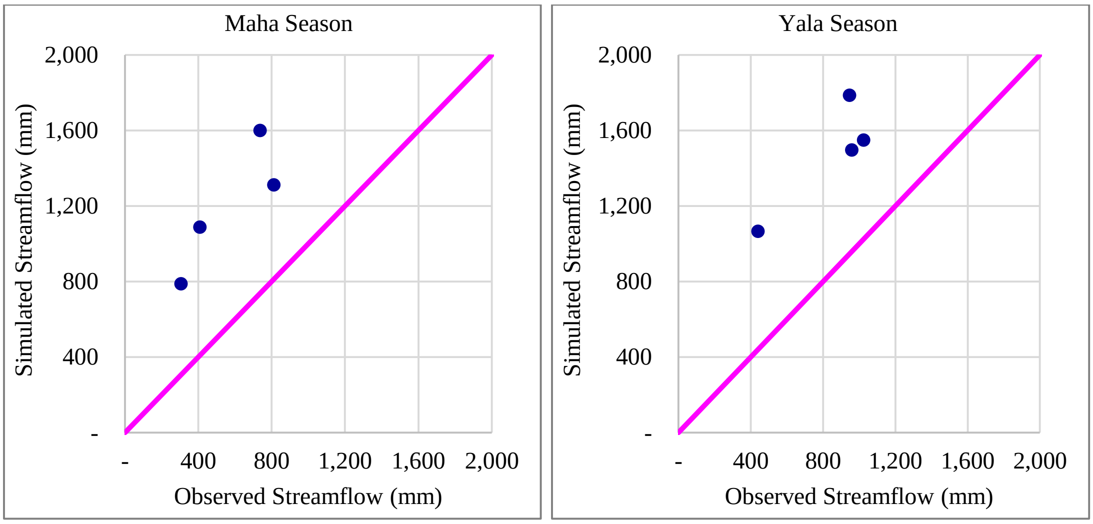

Figure D-43: 2PM (Daily) – Seasonal Comparison (Validation) – Ellagawa

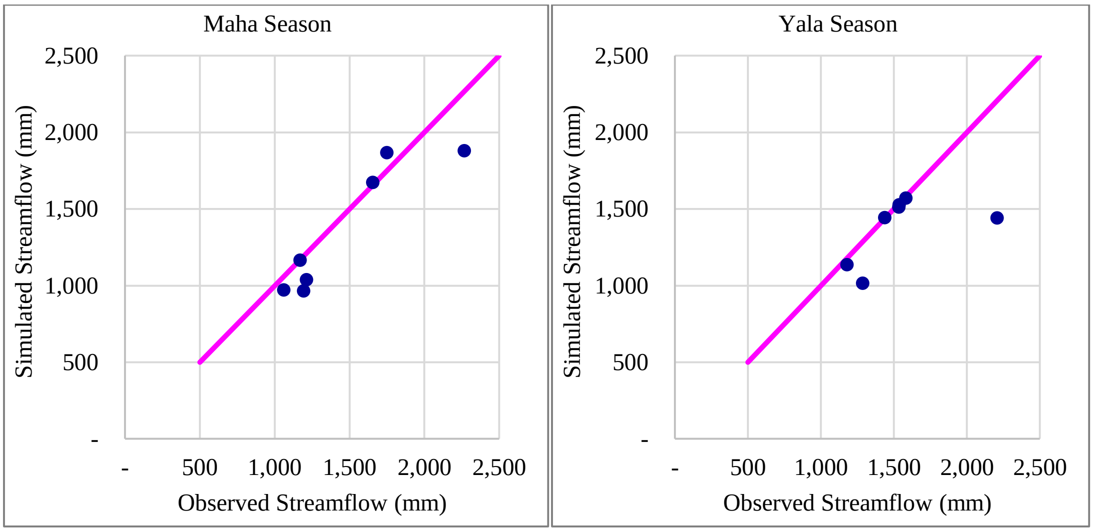

Figure D-44: Seasonal comparison – 3PM (Monthly) – Validation – Tawalama

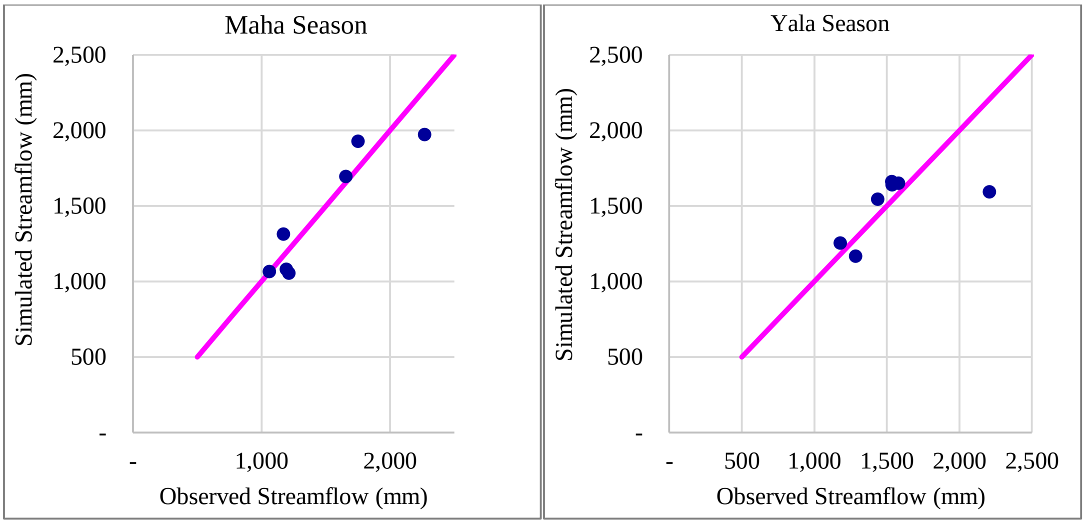

Figure D-45: Seasonal comparison – 3PM (Daily) – Validation – Tawalama

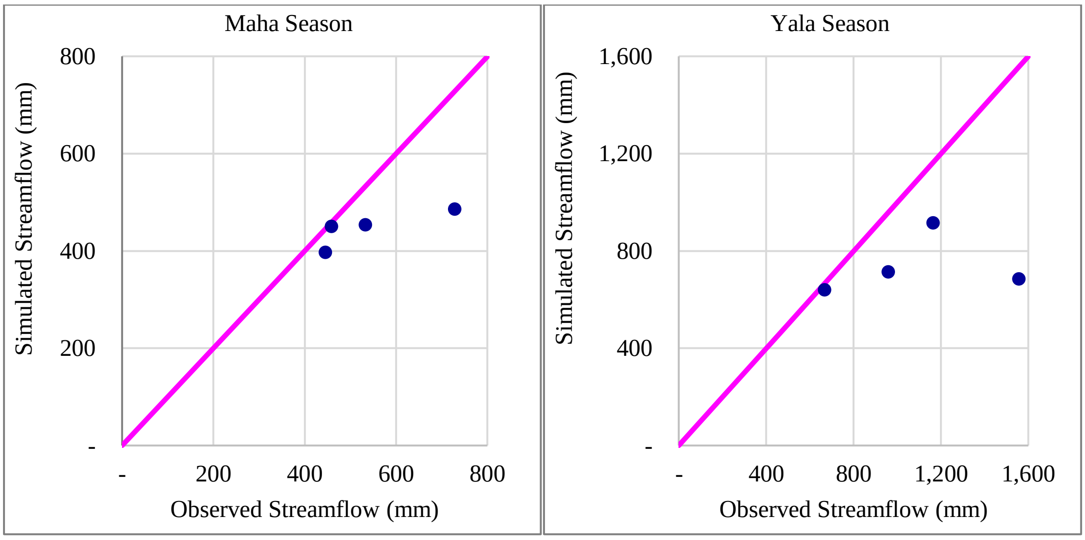

Figure D-46: Seasonal comparison – 3PM (Monthly) – Calibration – Ellagawa

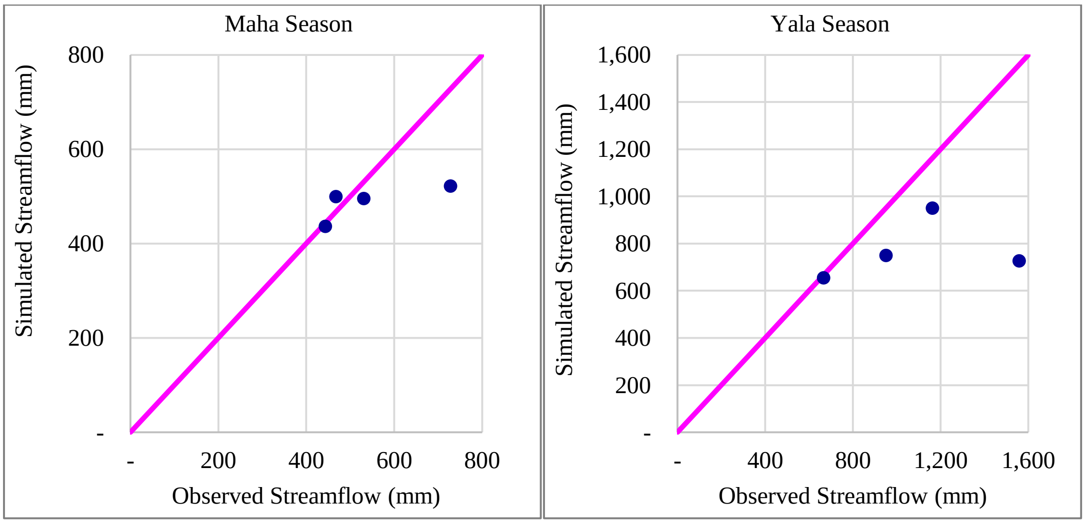

Figure D-47: Seasonal comparison – 3PM (Daily) – Calibration – Ellagawa

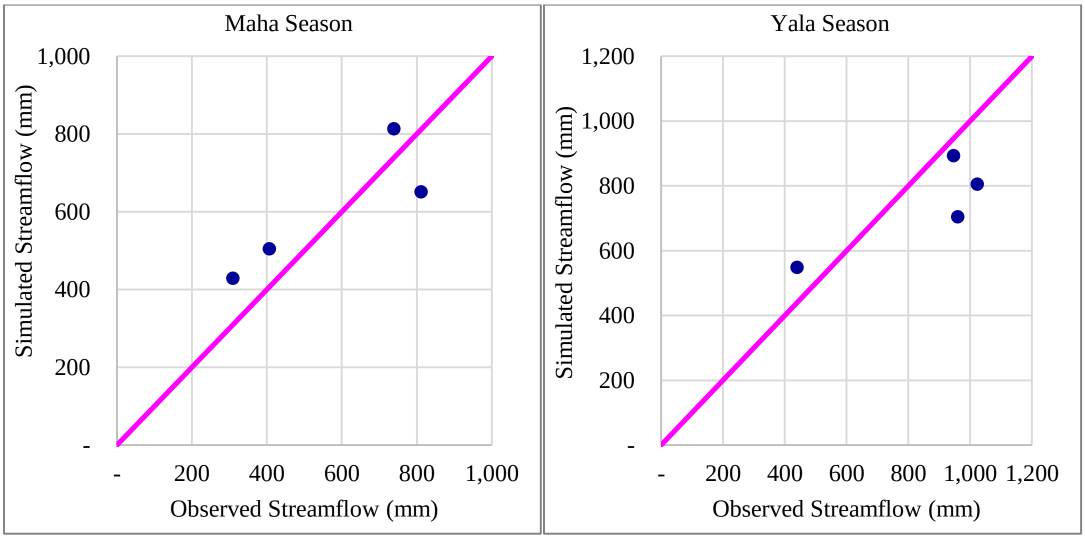

Figure D-48: Seasonal comparison – 3PM (Monthly) – Validation – Ellagawa

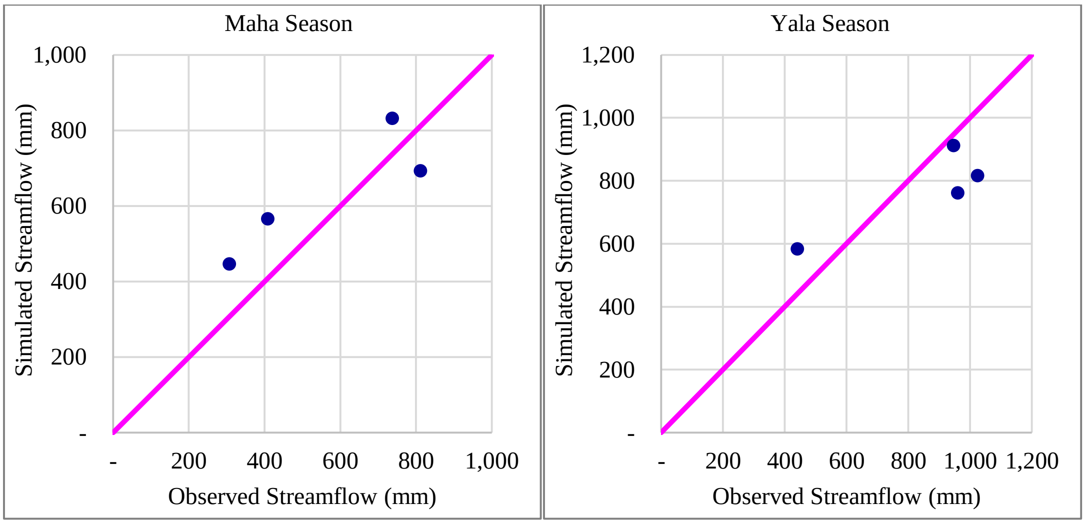

Figure D-49: Seasonal comparison – 3PM (Daily) – Validation – Ellagawa

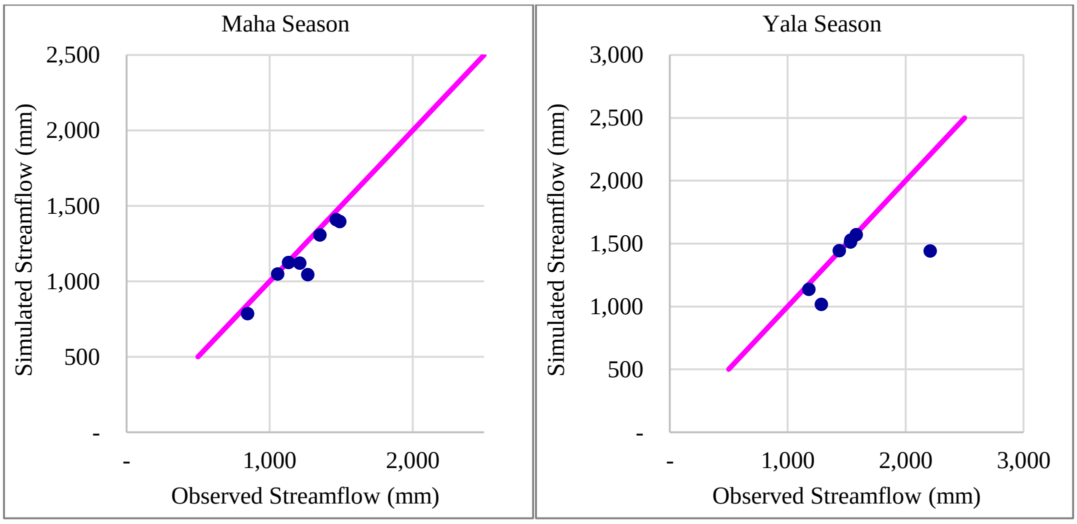

Figure D-50: Seasonal comparison – 3PM (Monthly) – Calibration – Tawalama

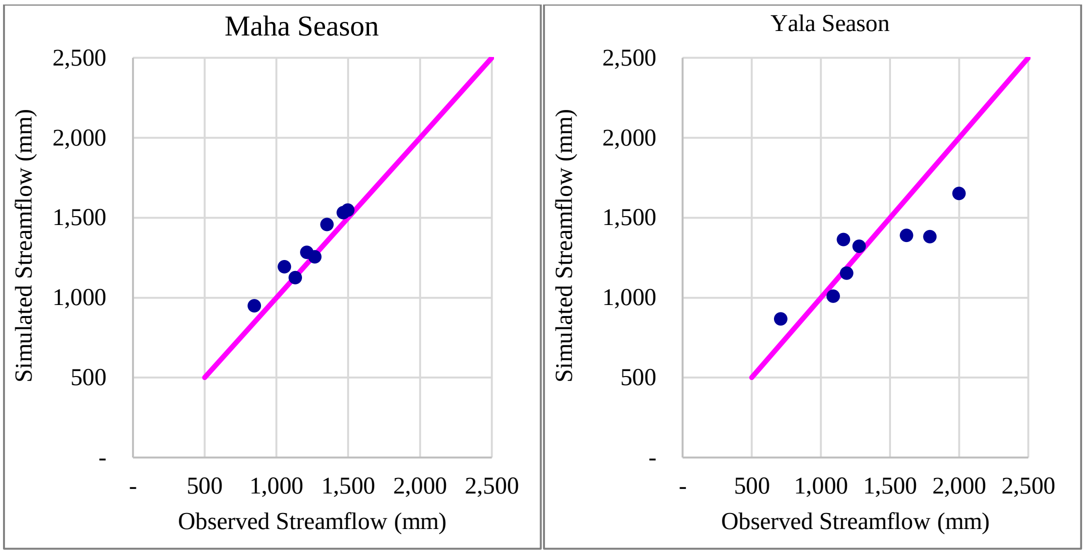

Figure D-51: Seasonal comparison – 3PM (Daily) – Calibration – Tawalama

Table D-1: Data points with Disparities – Ellagawa Watershed

Date	Rainfall	Observed Streamflow
Apr-07	338.33	65.67
Aug-07	306.65	75.94
Jun-08	281.69	40.79
Aug-08	159.26	55.44
Jun-09	504.15	201.72
Sep-09	337.15	132.34
Nov-09	340.57	111.29
Apr-10	341.14	73.19
Jun-10	410.17	169.00
Jul-10	330.32	170.40
Aug-10	305.84	117.76
Sep-10	308.38	109.21
Nov-10	486.36	217.66
Apr-11	562.23	241.49
Jul-11	168.29	45.50
Aug-11	249.16	69.67
Oct-11	303.01	67.49
Nov-11	272.41	74.77
Mar-12	251.25	41.92
Jun-12	256.62	50.67
Aug-12	282.97	65.01
Sep-12	273.96	79.01
Oct-12	442.50	111.29
Dec-12	394.84	102.75
Feb-13	189.56	47.93
Mar-13	332.97	59.34
Apr-13	214.45	50.06
Jul-13	382.71	143.51
Oct-13	368.23	96.22
Nov-13	361.83	137.25
Jan-14	253.36	52.52
Feb-14	60.22	26.42
Mar-14	130.76	30.31
Apr-14	331.34	47.14
May-14	214.76	55.57
Sep-14	388.64	99.54

Table D-2: Data points with Disparities – Ellagawa Watershed

Month	Monthly Rainfall	Observed Streamflow
Dec-00	309.97	155.45
Apr-01	503.77	263.34
Jun-01	131.45	69.75
Jul-01	144.98	66.37
Aug-01	71.13	43.62
Sep-01	321.48	120.50
Feb-02	159.20	78.16
Jul-02	195.11	91.61
Sep-02	105.37	46.84
Jan-03	207.62	102.86
Mar-04	291.60	117.89
Feb-06	241.85	117.63
May-06	429.07	185.79
Feb-07	205.79	58.08
Apr-07	530.95	191.34
Aug-07	310.12	124.91
Mar-08	471.04	259.43
Nov-08	479.42	267.76
Feb-09	50.50	35.16
Apr-09	458.71	224.09
May-09	447.86	267.79
Aug-10	243.94	147.38
Feb-11	289.07	169.29
Jun-11	131.77	198.98
Jul-11	163.16	78.32
Feb-12	190.63	81.22
Aug-12	339.87	146.67
Sep-12	410.72	232.94
Oct-12	702.48	420.51
Aug-13	132.70	245.12
Oct-13	297.36	164.65
Apr-14	385.04	163.83
May-14	300.37	171.92
Sep-14	467.89	258.18
Mar-15	270.70	126.78

Table D-3: Behaviour of MRAE with c & Sc – Tawalama Watershed

Initial Parameters		Optimized Parameters		Optimized MRAE
c	Sc	c	Sc	
0.0001	0.10	5,368.71	0.10	0.31453
0.10	1.00	5,368,709.22	1.00	0.31456
0.0001	200.00	-	-	No value
0.0001	2,500.00	-	-	No value
0.0001	10,000.00	-	-	No value
0.20	200.00	0.60	-	No value
0.20	2,500.00	0.37	-	No value
0.20	10,000.00	0.36	-	No value
0.30	0.10	0.95	0.10	0.29750
0.30	200.00	1.25	-	No value
0.30	2,500.00	0.68	-	No value
0.80	1,500.00	1.42	1,288.71	0.206687562518
0.80	0.10	0.95	0.10	0.29750
0.80	10,000.00	2.56	-	No value
2.50	200.00	2.50	1,288.71	0.206687563469
2.50	2,500.00	2.50	1,288.71	0.206687564383
2.50	10,000.00	2.50	-	No value
100.00	0.10	100.00	0.10	0.31453
100.00	1,500.00	100.00	1,288.71	0.206687562608
100.00	10,000.00	100.00	-	No value
1,000.00	0.20	1,000.00	0.20	0.31453
1,000.00	1,500.00	1,000.00	1,288.71	0.206687562608
1,000.00	10,000.00	1,000.00	-	No value
10,000.00	0.10	10,000.00	0.10	0.31453
10,000.00	1,500.00	10,000.00	1,288.71	0.206687562608
10,000.00	10,000.00	10,000.00	-	No value
0.00	10.00	6.81	1,288.58	0.206687658
0.00	10.00	0.96	-	No value
0.01	10.00	0.96	-	No value
0.01	100.00	0.02	-	No value
0.10	10.00	2.66	-	No value
0.00	1,000.00	0.001	577.83	0.559781457
0.00	10,000.00	0.00	-	No value
0.01	1,000.00	0.52	-	No value
0.01	10,000.00	0.01	-	No value
1.00	1.00	0.95	1.00	0.297504552
0.00	100.00	0.00	-	No value
10.00	10.00	10.00	-	No value
100.00	10.00	100.00	-	No value
1,000.00	10.00	1,000.00	-	No value
10,000.00	10.00	10,000.00	-	No value
1,000,000.00	10.00	1,000,000.00	-	No value
1,000,000.00	10,000.00	1,000,000.00	-	No value
1,000.00	100.00	1,000.00	-	No value
10,000.00	100.00	10,000.00	-	No value
1,000,000.00	1,000.00	1,000,000.00	1,288.71	0.206687565
100,000.00	100.00	100,000.00	-	No value

Table D-4: Behaviour of MRAE with c & Sc – Ellagawa Watershed – 2PM

Initial Parameters		**Optimized Parameters**		**Optimized MRAE**
c	**Sc**	**c**	**Sc**	
0.0001	0.10	1.77	0.10	0.6689
0.10	1.00	1.77	1.00	0.6689
0.0001	200.00	0.00	188.20	1.3566
0.0001	2,500.00	-	-	No Value
0.0001	10,000.00	0.00	-	No Value
0.20	200.00	7.43	959.01	0.5056
0.20	2,500.00	0.32	-	No Value
0.20	10,000.00	0.32	-	No Value
0.30	0.10	1.77	0.10	0.6689
0.30	200.00	16.46	959.01	0.5056
0.30	2,500.00	0.58	-	No Value
0.80	1,500.00	1.75	853.02	0.48576
0.80	0.10	1.00	0.10	0.6791
0.80	10,000.00	2.82	-	No Value
2.50	200.00	1.27	827.88	0.48478
2.50	2,500.00	1.33	853.02	0.4850
2.50	10,000.00	3.02	-	No Value
100.00	0.10	100.00	0.10	0.7450
100.00	1,500.00	100.00	959.01	0.5056
100.00	10,000.00	100.00	-	No Value
1,000.00	0.20	1,000.00	0.20	0.7450
1,000.00	1,500.00	1,000.00	959.01	0.5056
1,000.00	10,000.00	1,000.00	-	No Value
10,000.00	0.10	10,000.00	0.10	0.7450
10,000.00	1,500.00	10,000.00	959.01	0.5056
10,000.00	10,000.00	10,000.00	-	No Value
0.00	10.00	0.00	-	No Value
0.00	10.00	0.00	-	No Value
0.01	10.00	0.04	-	No Value
0.01	100.00	0.81	-	No Value
0.10	10.00	2.48	-	No Value
0.00	1,000.00	0.00	-	No Value
0.00	10,000.00	0.00	-	No Value
0.01	1,000.00	0.01	-	No Value
0.01	10,000.00	0.01	-	No Value
1.00	1.00	1.00	1.00	0.679114956
0.00	100.00	1.07	1,165.89	0.568388273
10.00	10.00	10.00	-	No Value
100.00	10.00	100.00	-	No Value
1,000.00	10.00	1,000.00	-	No Value
10,000.00	10.00	10,000.00	-	No Value
1,000,000.00	10.00	1,000,000.00	-	No Value
1,000,000.00	10,000.00	1,000,000.00	-	No Value
1,000.00	100.00	1,000.00	97.59	0.68787592
10,000.00	100.00	10,000.00	97.59	0.68787592
1,000,000.00	1,000.00	1,000,000.00	959.01	0.505634092
100,000.00	100.00	100,000.00	97.59	0.68787592

Table D-5: Annual Water Balance 2PM (Monthly Input - Calibration) - Tawalama Watershed

Year	Thiessen Averaged Rainfall (mm)	Simulated Streamflow (mm)	Observed Streamflow (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2000/2001	3006	2293	1920	1085	713	372
2001/2002	2842	1988	1935	908	854	53
2002/2003	3783	2745	3055	727	1038	-311
2003/2004	3719	2768	2674	1044	951	93
2004/2005	3560	2652	2410	1151	908	242
2005/2006	3763	2879	2628	1136	884	252
2006/2007	3924	2905	2513	1410	1018	392
2007/2008	4176	3352	3489	688	824	-137
Average				1019	899	120

Table D-6: Annual Water Balance 2PM (Monthly Input - Validation) - Tawalama Watershed

Year	Thiessen Averaged Rainfall	Simulated Streamflow	Observed Streamflow	Observed Water Balance	Simulated Water Balance	Annual Water Balance Error
2008/2009	4167	3053	2705	1461	1114	348
2009/2010	3807	2892	2743	1063	914	149
2010/2011	4149	3315	3034	1115	834	281
2011/2012	3437	2386	2370	1067	1050	16
2012/2013	4684	3823	4473	210	860	-650
2013/2014	3666	2750	2496	1171	916	254
2014/2015	4639	3740	3236	1403	899	504
Average				1070	941	129

Table D-7: Annual Water Balance 2PM (Monthly Input - Calibration) - Ellagawa Watershed

Year	Thiessen Averaged Rainfall (mm)	Simulated Streamflow (mm)	Observed Streamflow (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2006/2007	2873	1955	1394	1479	917	561
2007/2008	2920	1955	2089	831	965	-134
2008/2009	2932	1899	1403	1529	1034	496
2009/2010	3436	2466	1621	1814	970	845
Average	3040	2069	1627	1413	971	442

Table D-8: Annual Water Balance 2PM (Monthly Input - Validation) - Ellagawa Watershed

Year	Thiessen Averaged Rainfall (mm)	Simulated Streamflow (mm)	Observed Streamflow (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2010/2011	3387	2475	1770	1617	912	705
2011/2012	2597	1594	748	1849	1004	845
2012/2013	3976	3033	1761	2214	942	1272
2013/2014	3460	2564	1352	2108	896	1212
Average	3355	2416	1408	1947	939	1008

Table D-9 : Annual Water Balance - 2PM (Daily Input) – Calibration Period – Tawalama Watershed

Year	Thiessen Averaged Rainfall (mm)	Simulated Streamflow (mm)	Observed Streamflow (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2000/2001	3006	2554	1919	1086	451	635
2001/2002	2842	2307	1934	909	536	373
2002/2003	3794	3117	3054	740	677	63
2003/2004	3719	3056	2673	1046	663	383
2004/2005	3565	2894	2408	1157	672	485
2005/2006	3763	3188	2650	1114	576	538
2006/2007	3924	3347	2512	1411	576	835
2007/2008	4339	3790	3494	845	549	296
Average				1038	587	451

Table D-10 : Annual Water Balance - 2PM (Daily Input) – Validation Period – Tawalama Watershed

Year	Thiessen Average d Rainfall (mm)	Simulated Streamflo w (mm)	Observed Streamflo w (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2008/2009	4167	3502	2705	1461	665	796
2009/2010	3807	3214	2743	1063	592	471
2010/2011	4149	3674	3034	1115	475	640
2011/2012	3437	2757	2370	1067	680	387
2012/2013	4684	4248	4473	210	435	-225
2013/2014	3666	3097	2496	1171	569	602
2014/2015	4639	3975	3236	1403	663	739
Average				1070	583	487

Table D-11 : Annual Water Balance - 2PM (Daily Input) – Calibration Period – Tawalama Watershed

Year	Thiessen Averaged Rainfall (mm)	Simulated Streamflow (mm)	Observed Streamflow (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2006/2007	2760	2261	1394	1366	500	867
2007/2008	2920	2289	2088	832	631	201
2008/2009	2929	2242	1395	1535	687	848
2009/2010	3438	2798	1630	1808	641	1167
Average				1385	615	771

Table D-12 : Annual Water Balance - 2PM (Daily Input) – Validation Period – Ellagawa Watershed

Year	Thiessen Averaged Rainfall (mm)	Simulated Streamflow (mm)	Observed Streamflow (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2010/2011	3388	2808	1770	1618	580	1038
2011/2012	2593	1855	747	1846	738	1108
2012/2013	3948	3148	1761	2187	800	1387
2013/2014	3493	2874	1354	2139	619	1521
Average	3355	2671	1408	1947	684	1263

Table D-13: Behaviour of MRAE with c & Sc – Tawalama Watershed – 2PM

Initial Parameters			Optimized Parameters			Optimized MRAE
c	Sc	Rc	c	Sc	AF	
0.0001	0.10	0.00	0.4010	0.10	0.72	0.22538
0.10	1.00	0.10	0.40	1.00	0.72	0.22538
0.0001	200.00	0.20	(0.03)	200.00	0.64	0.27626
0.0001	2,500.00	10.00	25.4969	2,500.00	0.81	0.19848
0.0001	10,000.00	100.00	2,670.1528	9,999.95	0.71	0.30552
0.20	200.00	100.00	3,282.05	200.25	0.83	0.33147
0.20	2,500.00	1,000.00	284,415.67	2,475.57	0.81	0.19753
0.20	10,000.00	10,000.00	26,843,608.17	9,545.64	0.71	0.30291
0.30	0.10	100.00	3,285.40	0.10	0.85	0.28099
0.30	200.00	10,000.00	33,922,806.53	2,377.46	0.82	0.19357
0.30	2,500.00	10.00	26.53	2,500.00	0.81	0.19848
0.80	0.10	10.00	38.61	0.10	0.85	0.28099
0.80	10,000.00	100,000.00	53,687,092.00	9,129.99	98,315.06	125,630.53315
2.50	200.00	0.10	2.50	200.29	0.82	0.331485946057
2.50	2,500.00	1,000.00	2.50	2,465.86	0.81	0.197142926238
2.50	10,000.00	100.00	2.50	9,999.94	0.71	0.30552
100.00	0.10	1.00	100.00	0.10	0.85	0.28099
100.00	10,000.00	10,000.00	100.00	9,444.11	0.71	0.30230
1,000.00	0.20	10.00	1,000.00	0.20	0.85	0.28099
1,000.00	10,000.00	10,000.00	1,000.00	9,444.11	0.71	0.30230
10,000.00	0.10	0.01	10,000.00	0.10	0.85	0.28099
10,000.00	10,000.00	10,000.00	10,000.00	9,444.11	0.71	0.30230
1.00	1,500.00	0.8	1.02	1,292.00	0.83	0.173326027
0.00	10.00	10.00	29.56	10.00	0.85	0.282298351
0.00	10.00	100.00	3,266.22	1.27	0.84	0.281586649
0.01	10.00	1,000.00	314,026.72	10.01	0.85	0.282299825
0.01	100.00	100.00	3,270.65	100.94	0.83	0.318225764
0.10	10.00	0.10	0.40	10.00	0.72	0.225384207

Initial Parameters			Optimized Parameters			Optimized MRAE
c	Sc	Rc	c	Sc	AF	
0.00	1,000.00	0.10	(0.01)	1,000.00	0.64	0.223035331
0.00	10,000.00	100.00	2,671.48	9,999.95	0.71	0.305521864
0.01	1,000.00	10.00	26.13	1,000.00	0.89	0.189740959
0.01	10,000.00	100.00	2,684.67	9,999.95	0.71	0.305521863
1.00	1.00	1.00	0.40	1.00	0.72	0.225383439
0.00	100.00	10.00	29.90	100.01	0.83	0.317894135
10.00	10.00	10.00	10.00	10.01	0.85	0.282299131
100.00	10.00	100.00	100.00	10.76	0.85	0.282383628
1,000.00	10.00	1,000.00	1,000.00	116.71	0.84	0.323216999
10,000.00	10.00	10,000.00	10,000.00	10.00	10,000.00	10279.18348
1,000,000.00	10,000.00	10,000.00	1,000,000.00	9,444.11	0.71	0.302295429
1,000.00	100.00	1,000.00	1,000.00	169.94	0.83	0.3318077
10,000.00	100.00	10,000.00	10,000.00	7,098.92	0.73	0.284566407
100,000.00	100.00	1,000.00	100,000.00	169.94	0.83	0.3318077

Table D-14: Behaviour of MRAE with c & Sc – Ellagawa Watershed – 2PM

Initial Parameters			Optimized Parameters			Optimized MRAE
c	**Sc**	**AF**	**c**	**Sc**	**AF**	
0.0001	0.1000	0.1000	0.0001	0.10	0.3925	0.2895
0.1000	1.0000	0.0001	0.0017	0.80	0.3927	0.2895
0.0001	200.0000	0.5000	0.0001	823.80	0.3802	0.2402
0.0001	2,500.0000	10.0000	0.0001	823.28	0.3802	0.2402
0.0001	10,000.0000	100.0000	0.0001	6,125.80	0.2326	0.4336
0.2000	200.0000	100.0000	0.2176	199.94	0.44	0.3385
0.2000	2,500.0000	1,000.0000	0.2149	2,216.33	0.38	0.2881
0.2000	10,000.0000	10,000.0000	0.2135	9,025.00	0.34	0.4544
0.2000	200.0000	0.0001	0.1088	908.77	0.39	0.2364
0.2000	2,500.0000	100,000.0000	0.2149	2,217.52	0.37659	0.2881
0.2000	10,000.0000	0.0000	-	1,312,837,369,303	3,176.19	0.5753
0.0001	0.1000	10,000.0000	0.0001	0.10	0.39253	0.2895
0.1000	1.0000	1,000.0000	0.1042	1.00	0.40	0.2923
0.0001	200.0000	100.0000	0.0001	200.03	0.39	0.3240
0.3000	0.1000	100,000.0000	0.3418	0.10	0.46	0.3080
0.3000	200.0000	10.0000	0.3316	205.43	0.45	0.3494
0.3000	2,500.0000	0.0100	-	-	0.19	No value
0.8000	1,500.0000	0.0100	-	-	0.24	No value
0.8000	0.1000	100.0000	1.1864	0.10	0.60	0.4483
0.8000	10,000.0000	0.8000	0.9735	-	0.52	No value
2.5000	200.0000	0.0010	3.2933	-	0.03	No value
2.5000	2,500.0000	0.0000	0.1384	25,386,706.76	0.24	0.5710
2.5000	10,000.0000	1,000.0000	2.5794	8,732.21	0.45	0.4259
100.0000	0.1000	100.0000	100.0000	0.10	0.52	0.4115
100.0000	1,500.0000	0.5000	100.0000	1,991.07	0.62	0.2576
100.0000	10,000.0000	0.8000	100.0000	-	0.46	No value
1,000.0000	0.2000	0.4000	1,000.0000	0.20	0.52	0.4115
1,000.0000	1,500.0000	1,000.0000	1,000.0000	1,260.20	0.65	0.2816
1,000.0000	10,000.0000	10,000.0000	1,000.0000	8,702.49	0.46	0.4215
10,000.0000	0.1000	0.5000	10,000.0000	0.10	0.52	0.4115
10,000.0000	1,500.0000	0.1000	10,000.0000	1,991.42	0.62	0.2576

Initial Parameters			Optimized Parameters			Optimized MRAE
c	**Sc**	**AF**	**c**	**Sc**	**AF**	
10,000.0000	10,000.0000	10,000.0000	10,000.0000	8,702.49	0.46	0.4215
0.0001	10.0000	0.8000	0.0001	-	0.39	No value
0.0010	10.0000	10.0000	0.0010	10.00	0.39	0.2896
0.0100	10.0000	0.5000	0.0053	-	0.39	No value
0.0100	100.0000	100,000.0000	0.0100	100.27	0.39	0.3170
0.1000	10.0000	0.5000	-	6.93	0.39	0.2895
0.0010	1,000.0000	0.0000	-	7,724,606.97	0.20	0.5723
0.0010	10,000.0000	0.5000	0.0010	-	0.30	No value
0.8000	1,000.0000	0.8000	0.5234	975.20	0.4637	0.22538
0.8000	1,000.0000	10,000.0000	1.1362	899.52	0.66	0.2595
0.8000	1,000.0000	100.0000	0.8995	1,202.03	0.56	0.2338
0.5234	975.2002	0.0001	0.0018	591,927.69	0.21	0.5681
0.5234	975.2002	0.0100	0.4310	932.91	0.45	0.2264
0.5234	975.2002	1,000.0000	0.6507	893.84	0.50	0.2302
0.5234	975.2002	0.8000	0.5234	975.29	0.46	0.2253758
0.0100	10,000.0000	0.5000	0.0100	-	0.30	No value
1.0000	1.0000	0.1000	-	1.00	0.39	0.2894595
0.0010	100.0000	10.0000	0.0010	-	0.43	No value
10.0000	10.0000	10.0000	10.0000	10.05	0.52	0.4140
100.0000	10.0000	100.0000	100.0000	10.08	0.52	0.4140
1,000.0000	10.0000	0.1000	1,000.0000	-	0.52	No value
10,000.0000	10.0000	100.0000	10,000.0000	10.08	0.52	0.4140

Table D-15: Annual Water balance (Calibration) - 3PM (Monthly Input) – Tawalama

Year	Thiessen Averaged Rainfall (mm)	Simulated Streamflow (mm)	Observed Streamflow (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2000/2001	3006	1928	1920	1085	1078	8
2001/2002	2842	1678	1935	908	1165	-257
2002/2003	3783	2304	3055	727	1479	-752
2003/2004	3719	2319	2674	1044	1400	-355
2004/2005	3560	2219	2410	1151	1342	-191
2005/2006	3763	2401	2628	1136	1363	-227
2006/2007	3924	2448	2513	1410	1475	-65
2007/2008	4176	2799	3489	688	1377	-690
Average				1019	1335	-316

Table D-16: Annual Water balance (Validation) - 3PM (Monthly) – Tawalama

Year	Thiessen Averaged Rainfall (mm)	Simulated Streamflow (mm)	Observed Streamflow (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2008/2009	4167	2694	2705	1461	1473	-11
2009/2010	3807	2551	2743	1063	1255	-192
2010/2011	4149	2884	3034	1115	1265	-150
2011/2012	3437	2103	2370	1067	1334	-267
2012/2013	4684	3323	4473	210	1361	-1150
2013/2014	3666	2415	2496	1171	1252	-81
2014/2015	4639	3245	3236	1403	1394	9
Average				1070	1333	-263

Table D-17: Annual Water balance (Calibration) - 3PM (Monthly Input) – Ellagawa

Year	Thiessen Averaged Rainfall (mm)	Simulated Streamflo w (mm)	Observed Streamflow (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2006/2007	2873	1127	1394	1479	1746	-267
2007/2008	2920	1138	2089	831	1781	-950
2008/2009	2932	1111	1403	1529	1821	-292
2009/2010	3436	1366	1621	1814	2070	-256
Average	3040	1186	1627	1413	1854	-441

Table D-18: Annual Water balance (Calibration) - 3PM (Monthly Input) – Ellagawa

Year	Thiessen Averaged Rainfall (mm)	Simulated Streamflo w (mm)	Observed Streamflow (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2006/2007	2873	1127	1394	1479	1746	-267
2007/2008	2920	1138	2089	831	1781	-950
2008/2009	2932	1111	1403	1529	1821	-292
2009/2010	3436	1366	1621	1814	2070	-256
Average	3040	1186	1627	1413	1854	-441

Table D-19: Annual Water balance (Calibration Period) - 3PM (Daily Input) – Tawalama

Year	Thiessen Averaged Rainfall (mm)	Simulated Streamflow (mm)	Observed Streamflow (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2000/2001	3006	1928	1920	1085	1078	8
2001/2002	2842	1678	1935	908	1165	-257
2002/2003	3783	2304	3055	727	1479	-752
2003/2004	3719	2319	2674	1044	1400	-355
2004/2005	3560	2219	2410	1151	1342	-191
2005/2006	3763	2401	2628	1136	1363	-227
2006/2007	3924	2448	2513	1410	1475	-65
2007/2008	4176	2799	3489	688	1377	-690
Average	3,596.65	2,261.90	2,578.09	1,018.56	1,334.75	(316.18)

Table D-20: Annual Water balance (Validation Period) - 3PM (Daily Input) – Tawalama

Year	Thiessen Averaged Rainfall (mm)	Simulated Streamflow (mm)	Observed Streamflow (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2008/2009	4167	2694	2705	1461	1473	-11
2009/2010	3807	2551	2743	1063	1255	-192
2010/2011	4149	2884	3034	1115	1265	-150
2011/2012	3437	2103	2370	1067	1334	-267
2012/2013	4684	3323	4473	210	1361	-1150
2013/2014	3666	2415	2496	1171	1252	-81
2014/2015	4639	3245	3236	1403	1394	9
Average	4,078.18	2,744.96	3,008.14	1,070.04	1,333.23	(263.19)

Table D-21: Annual Water balance (Calibration Period) - 3PM (Daily Input) – Ellagawa

Year	Thiessen Averaged Rainfall (mm)	Simulated Streamflow (mm)	Observed Streamflow (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2000/2001	2760	1178	1394	1366	1583	-216
2001/2002	2920	1222	2088	832	1698	-866
2002/2003	2929	1186	1395	1535	1744	-209
2003/2004	3438	1450	1630	1808	1988	-180
Average	3012	1259	1627	1385	1753	-368

Table D-22: Annual Water balance (Validation Period) - 3PM (Daily Input) – Ellagawa

Year	Thiessen Averaged Rainfall (mm)	Simulated Streamflow (mm)	Observed Streamflow (mm)	Observed Water Balance (mm)	Simulated Water Balance (mm)	Annual Water Balance Error (mm)
2004/2005	3388	1455	1770	1618	1933	-315
2005/2006	2593	1030	747	1846	1563	283
2006/2007	3948	1648	1761	2187	2300	-113
2007/2008	3493	1478	1354	2139	2015	124
Average	3355	1403	1408	1947	1953	-5