ESTIMATION OF SCS CURVE NUMBER FOR STREAMFLOW MODELLING - A CASE STUDY OF BADALGAMA WATERSHED IN MAHA OYA BASIN, SRI LANKA

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DECLARATION

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ABSTRACT

Estimation of SCS Curve Number for Streamflow Modelling - A case study of Badalgama Watershed in Maha Oya Basin, Sri Lanka

Accurate runoff estimation is a prerequisite for effective management and development of water resources. Many methods are being used to estimate runoff in literature. However, the SCS-CN method still remains a popular, fruitful and frequently used method in Sri Lanka and elsewhere around the world. The attractive feature of the SCS-CN method is that it integrates the complexity of runoff generation into a single parameter, i.e. curve number (CN). In Sri Lanka, the CN is usually selected from available standard tables in the National Engineering Handbook, Section-4 (NEH-4). However, such an estimation could yield erroneous results in the absence of a research on different CN estimation methods. The present study carried out an event based runoff estimation in Badalgama watershed of the Maha Oya basin using CN values from two different CN determination methods; i) weighted CN value using NEH-4 and, ii) rainfall-runoff data. The SCS unit hydrograph was developed to make the study more usable for other ungauged watersheds with similar characteristics. Concave method was used for baseflow separation and the constant loss method was incorporated for the determination of effective rainfall. Twenty events each for calibration and verification were used which formed a representative data from both perspective of quantity of flows and the seasons.

Model evaluation was carried out by first developing CN_{II} for both the cases. Then, since the event separation was required rendering rainless period before the start of the event, CN_{I} values were also computed and evaluated. Finally, the selected CN was manually optimized for individual calibration events and the average was used for model verification. Parameter optimizations were done with the Mean Ratio of Absolute Error (MRAE) as the objective function while the Ratio of Absolute Error to Mean (RAEM), Ratio of Absolute Errors (RAE) corresponding to Q_p, T_p, T_b of the hydrographs were computed to reflect the goodness of fit. Based on the modelling results, it could be identified that 3 out of 4 SCS-CN models developed for the Badalgama watershed were not representative of the watershed response reflected in the observed hydrographs. The average MRAE and RAEM among the four methods was between 0.36 ~ 2.18 and 0.54 ~ 2.08, respectively.

The present work revealed that the use of CN_{I} values from weighted CN method was the nearest to model reality followed by the CN_{II} determination from rainfall runoff model. Use of CN_{I} from rainfall-runoff data yields the most inaccurate result followed by the CN_{II} from the weighted CN method. The SCS-CN model developed using individual parameter optimized CN value for the Badalgama watershed produced average MRAE of 0.22 and average RAEM of 0.30 in calibration and an average of 0.37 and 0.49 in verification, respectively. The average RAE value corresponding to Q_p, T_p, T_b and streamflow volume were 0.78, 0.37, 0.43 and 0.42, respectively, in model verification. The SCS-CN method is the best reasonably suitable method for quick and fairly accurate runoff estimation in the regions such as the wet zone of Sri Lanka where hydrologic gauging stations are not widely available.

Keywords: runoff generation, event based modelling, baseflow separation, wet zone

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1. INTRODUCTION

1.1 General

A considerable area of the world falls under arid and semi-arid regions. Such regions face the twin situation of droughts and water shortage issues in some periods while in other periods there is inconsistent rainfall, flash floods, erosion due to high rainfall intensity and high runoff velocity. Modelling techniques and reliable runoff estimation plays a pivotal role in watershed management, mitigation of flood and design of various infrastructure in these regions.

In general, rainfall–runoff modelling is the basic tool to design a wide variety of hydraulic structures, environmental impact assessment, evaluation of the impact of climate change, irrigation scheduling, flood forecasting, planning of tactical military operations, augmentation of runoff records, pollution abatement, watershed management and so on (Mishra & Singh, 2003, p. 513).

The need for a robust rainfall runoff model is intensified due to the lack of flow measuring devices in these places. According to Linsley (1982), models are classified as deterministic, stochastic, conceptual, theoretical, black box, continuous, event, routing and simplified models among others. In general, models are classified under the categories of empirical, conceptual and physical. The choice of the model depends upon data requirements including spatial and temporal variation of model input and output, accuracy and validity of the model including underlying assumptions, components of the model, etc. (Merritt, Letcher, & Jakeman, 2003).

The research on finding the most suitable models for different geographic conditions continue to be of focus to engineers. Among them, ‘the Natural Resource Conservation Service - Curve Number (NRCS-CN) model formerly named, as Soil Conservation Service - Curve Number (SCS-CN) model is simpler in nature’ (Bales & Betson, 1981). It is one of the most popular models for computing the volume of surface runoff for a given rainfall event from small to medium sized agricultural watersheds. The model has been the focus of much discussion in agricultural hydrologic literature and is also widely used in continuous modelling schemes (Mishra & Singh, 1999).

According to Garen and Moore (2005), though the SCS-CN model originated as an empirical, event-based procedure for flood hydrology, the method has been adapted and used in the earlier said models for simulating the runoff behaviour of ordinary as well as large rainfalls and daily time series as well as events. The use of SCS-CN model in this manner, however, is beset with a number of problems, issues, and misinterpretations that undermine its utility in providing a realistic and accurate representation of the water quantity in the flow paths, and source area upon which erosion and water quality predictions depend.

Some of the major limitations of the SCS-CN model are:

1. The rainfall intensity which is an important source of variability is not accounted for by the SCS-CN methodology.
2. A lack of clear guidance on how to vary antecedent condition.
3. The discrete relation between CN and soil moisture content.
4. The fixing of initial abstraction ratio (λ) at 0.2.

Especially, the procedure adopted in the SCS-CN model to consider Antecedent Moisture Condition (AMC) in runoff estimation lacks continuous relationship and uses 5 day antecedent rainfall based on subjective judgement.

Techniques of streamflow determination in ungauged basin is crucial for Sri Lanka and South Asian in general. Most of the countries in the region have data scarcity and uncertainty. Conversely, these countries are plagued with floods every year and issues of water scarcity is becoming more pertinent. Therefore, use of SCS-CN model with the most reliable curve number can help water resource engineers' transfer calibrated model parameters from donor gauged catchments to manage resources more efficiently.

The SCS-CN method is widely being used in Sri Lanka and in Asia. Researchers such as Bandara, DeSilva, and Singh (2003), Wijesekera and Ghanapala (2003), Ranjan, Kazama, and Masaki (2006), Halwatura and Najim (2012) are some of users of this method in the region and have produced quality research papers. Its use is also prominent in South Asia mostly for rainfall-runoff simulation. Its inclusion in open software such as HEC-HMS among others has further extended its use. Mishra and Singh (1999, 2003) have produced considerable research on the method including the modified version of the method termed as MS Model.

However, despite its widespread use and age, the method is empirical and still has grey area to fill in. There is a significant body of literature published on SCS-CN model and several recent articles have reviewed the model at length. Yet a number of facts about the CN procedure, however, are apparently not well known and have led either to a misinterpretation of its results or its usage well beyond its realm of applicability (Garen & Moore, 2005).

The findings from this research will be useful to water resource managers to plan and prepare for water related issues ranging from flood estimation, infrastructure design to quantity estimation. Sri Lanka and likewise other South Asian countries suffer greatly due to floods and are far behind with technological advancements for data related with water sector such as rainfall and streamflow. Thus, a robust method such as SCS-CN coupled with the correct understanding on the usage of a realistic curve number suitable for the watershed under observation can prove a useful tool for water resource engineers to fill in the incapacities related to design and projection due to lack of measured data in a particular catchment.

1.2 Problem statement

Researchers have introduced different methods to estimate the most crucial parameter, the CN value in the SCS unit hydrograph runoff estimation method used for ungauged basins. In the absence of past studies to suggest the most appropriate method for use, there is a risk of adopting inappropriate CN value leading to inaccurate streamflow series. This study was to compare the two popular methods of estimating CN, i.e. i) using the weighted CN value from NEH-4 handbook using land use and soil cover and ii) using measured rainfall-runoff field data of a known catchment of similar characteristics. Results from this research would shed light to future streamflow estimation in ungauged watersheds with the use of SCS unit hydrograph.

1.3 Objective of the study

1.3.1 Overall objective

The main objective of this study was to evaluate the most suitable CN determination method for its application in an event based streamflow modelling using the SCS unit hydrograph method for a Sri Lankan watershed.

1.3.2 Specific objective

The present study was to carry out event based rainfall modelling of Maha Oya watershed at the Badalgama stream gauging station and had the following specific objectives;

i. State of the art review to comprehend the present state of research in the area of SCS-CN method and related applications.
ii. To compute streamflow using the curve number obtained through NEH-4 handbook procedure.
iii. To compute streamflow using the curve number obtained through the rainfall-runoff field data procedure.
iv. To develop streamflow based on selected CN value and further optimization using model calibration and verification.
v. To derive suitable recommendations for its application in ungauged watersheds.

2 LITERATURE REVIEW

2.1 Introduction

The SCS model was developed in 1954 by the U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS), and is described in The National Engineering Handbook (NEH-4) Soil Conservation Service-Curve Number (SCS-CN) method (Soil Conservation Service, 1956, 1964, 1971, 1985, 1993). In 1994, the SCS became Natural Resources Conservation Service (NRCS). For simplicity and consistency, it is referred as SCS-CN throughout this document. The SCS-CN model is the product of more than 20 years of studies of rainfall–runoff relationships from small rural watersheds (Rallison & Miller, 1981). Based on annual flood data collected at a number of study watersheds with drainage areas of 1 sq. miles (2.6 km^2) or less and with a uniform basin hydrologic soil–cover complex, the SCS developed the CN tables (Bales & Betson, 1981). It is a simple procedure for estimating streamflow volume (exclusive of baseflow) generated by large rainstorms. Further, the SCS-CN model is basically empirical, and provided a consistent basis for estimating the amount of runoff under varying land use and soil types.

Sherman (1932, 1949) was the first to propose the plotting of direct runoff against storm rainfall and is considered the origin of SCS-CN methodology. Mockus (1949) proposed that the estimates of surface runoff for ungauged watersheds could be based on soil, land use, antecedent rainfall, storm duration, and average annual temperature. He combined the above factors in a parameter 'b' which characterized the relationship between rainfall depth (P) and runoff depth (Q) as:

$$Q = P(1 - 10^{-bP}) \qquad (2\text{-}1)$$

According to Mishra and Singh (1999, 2003), Equation (2-1) forms the basis of the development of the SCS-CN concept. In a separate attempt, Andrews (unpublished report, 1954) developed a graphical procedure for estimating runoff from rainfall utilizing infiltrometer data, and consequently, graphs were developed for several combinations of soil texture, type and amount of cover, and conservation practices, combined together referred as 'soil–cover complex'. Mockus's empirical rainfall–

runoff (P–Q) relationship and Andrew's soil–cover complex formed the basis of the conceptual rainfall–runoff relationship incorporated in NEH-4 (Ponce & Hawkins, 1996).

Essentially the SCS-CN method is formulated by applying the water balance equation and two hypothesis as below;

i. Water Balance Equation

$$P = I_a + F + Q \tag{2-2}$$

ii. The Proportionality Hypothesis

$$\frac{Q}{P-I_a} = \frac{F}{S} \tag{2-3}$$

iii. The I_a-S Hypothesis

$$I_a = \lambda S \tag{2-4}$$

Where;

Q= Direct surface runoff

P= Total rainfall

F= Cumulative infiltration

S= Potential maximum retention

I_a= Initial abstraction

λ = Initial abstraction ratio

Mockus (1949) suggested that the model produced rainfall–runoff curves of the type found on natural watersheds. The Handbook of Hydrology (Maidment, 1993) states that the assumption of proportionality (Equation 2-3) seems to be quite arbitrary and has no theoretical or empirical justification. Based on this proportionality, Mishra and Singh (2003) described it in terms of C = S_r concept, where C is the runoff coefficient and S_r is the degree of saturation, and presented several SCS-CN-inspired models.

2.2 Development of curve number

The basic parameter, curve number (CN) of the SCS-CN model requires the watershed characteristics such as land use and treatment classes such as agricultural, range, forest, and more recently urban, Antecedent Moisture Condition (AMC), Hydrologic Soil

Group (HSG) information (A, B, C, and D), and hydrologic surface condition (Poor, Fair, and Good) of a watershed. From the error analysis, Hawkins (1975) pointed out that the errors in CN may have much more serious consequences than errors of similar magnitude in P, but for a considerable precipitation range (up to about 9 inches). Chen (1981) pointed out that smaller the values of CN, the larger are the effects of the variation of initial abstraction and rainfall on runoff. Further, Bales and Betson (1981) emphasized that CN is significantly related to storm hydrograph model parameters, such as the peak flow. Especially, in low runoff and low rainfall situations, errors in runoff calculation near its threshold are severe. According to Knisel and Davis (2000), CN is a sensitive parameter in the simulation of runoff volume in Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) software and found that the runoff estimates for small changes in high CN are more sensitive than equivalent small changes in low CN. Therefore, it is clearly understood that the accurate CN estimation is very important for storm runoff calculation.

Mishra, Babu and Singh (2007) categorized the CN based on their estimation procedure and as follows;

1. Hydrologic soil-cover complex number procedure.
    a. Weighted CN method
    b. Weighted Q method
2. CN's from field data
    a. Asymptotic approach
    b. Least square approach
    c. NEH-4 procedure
        i. Graphical approach
        ii. Median CN approach

2.3 Curve number and antecedent moisture condition relation

For runoff estimation, the curve number is adjusted according to AMC of the watershed, which can be defined as the initial moisture condition of the watershed prior to the storm event of interest. The SCS-CN methodology expresses this parameter as an index based on seasonal limits for the total 5 day antecedent rainfall as follows:

- AMC_I represents dry soil with a dormant season rainfall (5 day) of less than 12.7 mm and a growing season rainfall (5 day) of less than 35.56 mm,
- AMC_{II} represents average soil moisture conditions with dormant season rainfall averaging from 12.7 to 27.94 mm and growing season rainfall from 35.56 to 53.34 mm, and
- AMC_{III} conditions represent saturated soil with dormant season rainfall of over 27.94 mm and growing season rainfall over 53.34 mm.

Later, depending on the 5 day precipitation amount, AMC_{II} (represented as CN_{II}) is convertible to AMC_I (CN_I) or AMC_{III} (CN_{III}) using any of the relations in Table 2-1 given by different researchers. Table 2-1 shows the respective formulae from different authors used for AMC conversation.

Table 2-1: Different formulae to convert AMC_{II} to AMC_I and AMC_{III}

Method	**AMC_I**	**AMC_{II}**
Sobhani (1975)	$CN_I = \frac{CN_{II}}{2.334 - 0.01334CN_{II}}$	$CN_I = \frac{CN_{II}}{0.4036 + 0.005964CN_{II}}$
Hawkins et al. (1985)	$CN_I = \frac{CN_{II}}{2.281 - 0.01281CN_{II}}$	$CN_I = \frac{CN_{II}}{0.427 + 0.00573CN_{II}}$
Chow et al. (1988)	$CN_I = \frac{4.2CN_{II}}{10 - 0.058CN_{II}}$	$CN_I = \frac{23CN_{II}}{10 + 0.13CN_{II}}$
Neitsch et al. (2002)	$CN_I = CN_{II} - \frac{20(100 - CN_{II})}{\{100 - CN_{II} + exp[2.533 - 0.0636(100 - CN_{II})]\}}$	$CN_I = \frac{CN_{II}}{0.4036 + 0.005964CN_{II}}$

Mishra, Jain, Babu, Venugopal, and Kaliappan (2008) evaluated these AMC conversion formulae and concluded that the Sobhani formula was found to perform the best in CN_I conversion, and the Hawkins et al. (1985) formula in CN_{III} conversion.

Sobhani (1975) formulae; The Sobhani (1975) formulae for CN conversion from AMC_{II} (CN_{II}) to AMC_I (CN_I) and AMC_{III} (CN_{III}) are given in Table 2-1. In an analysis of the SCS (1972) table for CN, Sobhani (1975) found the existence of linear relationships between the potential retention (S) for AMC_{II} and that for AMC_{I} or AMC_{III}. These equations are reportedly applicable in the CN-range (55, 95), which encompasses the most estimated or experienced range of CN variation.

2.4 Streamflow modelling using SCS curve number

Bales and Betson (1981) noticed that if SCS-CN tables were used for determining a hydrologic soil–cover complex number and if the wettest antecedent moisture condition was assumed, the runoff volumes would be regularly under-predicted in the regions represented by these data. The runoff volumes will apparently be under-predicted even for the higher yield events, for which the SCS-CN methodology best applies. According to Chen (1981), a drastic (discrete) change of AMC over a short period of time may cause a serious error in CN value and hence the estimated runoff. Further, Hjelmfelt, Kramer, and Burwell (1981) found that the AMC conversion table described the 90% (AMC_{I}), 50% (AMC_{II}), and 10% (AMC_{III}) cumulative probabilities of exceedance of runoff depth for a given rainfall. Again, Hjelmfelt (1982) tested the association of CN variation with antecedent precipitation and with peak discharge. He found good correlation with antecedent precipitation while it is poor with peak discharge. Gray, Katz, DeMonsabert, and Cogo (1982) assumed four AMC classes with respect to initial infiltration capacities for each soil type, instead of three AMC classes defined by SCS, and performed a regression analysis using average annual precipitation.

According to Ponce and Hawkins (1996), the AMC table does not account for regional differences or scale effects and, therefore, an antecedent period longer than 5 days might be required for large watersheds.

Soulis and Valiantzas (2012) introduced a simplified concept of a two-system heterogeneous system to model the CN versus rainfall depth variation. A two-system approach would take into account the soil-cover complex spatial variation in the estimation of CN values from measured rainfall-runoff data. They mentioned that all previously developed methodologies for estimating CN from measured data focus mainly on the determination of a single asymptotic CN value characterizing the watershed hydrologic response for high rainfall depths. The observed deviations from the asymptotic behaviour for lower rainfall depths are not essentially taken into consideration and are rather attributed to various sources of temporal variability. For this reason, the resulting CN values fail to describe the watershed response in small and medium rainfall events, limiting the applicability of the method to its original scope, namely the estimation of peak runoff values. Furthermore, the above methods fail to determine a final CN value in "complacent" watersheds. According to Hawkins (1993), an asymptotic CN cannot be safely determined from data for this behaviour.

The validity of their analysis was investigated on two watersheds; The Little River, Georgia, and Lykorrema, Greece. These watersheds were selected because they have been presented in the (other) literature as examples of the "standard" and the "complacent" behaviour respectively. They concluded that the results of the synthetic data analysis and the results of the real watersheds examples indicate that the SCS-CN method using the CN values obtained by the proposed CN determination methodology provides superior runoff predictions in most cases and extends the applicability of the original SCS-CN method for a wider range of rainfall depths in heterogeneous watersheds. Furthermore, the proposed methodology allows the CN determination in complacent watersheds.

Stewart, Canfield, and Hawkins (2012) evaluated four CN determination methods on 16 watersheds in the south western U.S. using 1,284 events that satisfy rainfall and runoff criteria. The methods compared in this study are as follows:

- Method I, partial duration series, ordered pairs, CN_∞,
- Method II, annual series (based on flood peak), ordered pairs, CN_∞,
- Method III, annual series (based on flood peak), natural pairs, CN_∞, and
- Method IV, annual series (based on flood peak), natural pairs, median CN as suggested by the Soil Conservation Service (1986).

The analysis was limited to events with $P=S > 0.46$, as recommended by Hawkins, Hjelmfelt, and Zevenbergen (1985) for natural paired data as the threshold when 90% of rainstorms produce runoff. They concluded that all methods except the NRCS median annual peak method gave similar results, while the later resulted in in distinctly higher CNs which was contradictory since in most studies data-defined CNs result to be higher than the handbook determined CN values.

Sahu, Mishra, and Eldho (2010) presented a revised version of the SCS-CN model is by incorporating a hydrologically more sound procedure for accounting antecedent moisture in the MS model and evaluated the model performance is evaluated on the dataset from 82 small US watersheds. The SME equation was developed as;

$$Q = \frac{(P-I_a)(P-I_a+M)}{P-I_a+S_0}, if\ P > I_{a,} 0\ otherwise \quad (2\text{-}5)$$

$$I_a = \lambda(S_0 - M) \quad (2\text{-}6)$$

$$M = \beta\left[\frac{(P_5-\lambda S_0)S_0}{P_5+(1-\lambda)S_0}\right], for\ P_5 > \lambda S_0\ and\ M = 0, for\ P_5 \leq \lambda S_0 \quad (2\text{-}7)$$

The performance evaluation indicates that both SME and MS models performed equally well with equal mean standard error (SE) of 4.4 mm, but better than the existing SCS-CN method yielding mean SE of 5.3 mm in calibration. They concluded that the SME model results are closer to the observed ones than those due to MS model for most of the high rainfall–runoff events, and therefore, the former model generally performs better than the latter for high-runoff events. However, the performance of both the models is very close to each other.

Geetha, Mishra, Eldho, Rastogi, and Pandey (2008) presented a rain duration-dependent procedure based on the SCS-CN methodology for computation of direct surface runoff from long duration rains. Their research had the idea to link AMC with the antecedent duration. They studied the Hemavati, Narmada, and Kalu catchments of India. Here, the CN values were computed from rainfall-runoff data of varying duration. They concluded that curve numbers derived from the   from long-term daily rainfall runoff data yielded better results than those selected from a few storm events.

Jain, Mishra, and Singh (2006) evaluated quantitatively the performance of the SCS-CN model, its variants, and the modified MS model for different physical characteristics of watersheds, viz., land use or soil type or a combination thereof; and evaluated the suitability of these models for both high and low runoff producing watersheds, but with mixed land use. They concluded that usual NEH-4 procedure with varying value of initial abstraction performed as good as the MS model for a land use of pasture/range type of land use. This is relevant to our context since large area falls under pasture such as agriculture or forests.

Banasik and Woodward (2010) used over sixty rainfall-runoff events, collected during 29 years (1980-2008) in a small ($A=23.4\ km^2$), lowland and agricultural watershed in the centre of Poland, to determine runoff curve number and to check change tendency. The aim of the paper was to check applicability of the method for prediction purposes in small watersheds in Poland. The curve number for investigated area has been estimated by three means:

a) Based on land use and soil types i.e. as for ungauged watershed from NEH-4 handbook (SCS, 1972)
b) Based on rainfall-runoff records with the use of largest storms (Hawkins et al., 1985)
c) Based on all rainfall-runoff events with the use of "asymptotic approach" (Hawkins, 1993).

Here the use of 'asymptotic approach' has been considered as the confirmation. The main objective was to evaluate the use of NEH-4 table on the catchment and confirm it by the asymptotic method. This research revealed that the precipitation value for an event had huge implication on the result variability. If the precipitation was larger than 20 mm, then the CN determined from the handbook and from the empirical methods had very small variation and concluded that the values in NEH-4 could be used in other locations in Poland and that the values developed for the US catchments were representative of the catchments in Poland.

Kowalik and Walega (2015) also brought similar results when attempting to describe P-CN_{obs} relationships by means of asymptotic functions in four watershed in southern Poland. They used the standard function described by Hawkins (1993), kinetics equation and complementary error function peak. The research also compares the field data calculated CN with its values provided in the NEH-4 handbook and Technical

Release 20 (TR-20). The analysis showed that empirical CN values presented in the NEH-4 tables with AMC_{II} condition corresponded to the observed CN values. Calculations revealed a strong correlation between the observed CN and precipitation (P). In three of the analysed watersheds, a typical pattern of the observed CN stabilization during abundant precipitation was perceived. It was found that model based on a kinetics equation, most effectively described the P-CN relationship. In most cases, the observed CN in the investigated watersheds was similar to the empirical CN, corresponding to average moisture conditions set out by NEH-4.

Guru (2015) compared the simulation performance of the runoff for both the original SCS-CN and MS model over the Mahanadi basin lying in Odisha, India and its total five sub-basins. Here, he found out that the result of the MS model was better than the original SCS-CN method. While the R-squared using the original SCS-CN method had an average of 0.591 the MS model performed better with 0.951. The reasoning for this is because in the method instead of the AMC I, II & III it takes the M value and instead of the daily rainfall here P_5 is taken into consideration. So, for the P_5 and the M value there was a better result in the MS model.

However, MS model is still being tested and not familiar to a large community of water resource engineers. Hence, this study is limited to investigate the determination of most appropriate CN determination method among the NEH-4 handbook method and from rainfall-runoff data observed in the field. However, since this is an event based analysis, two levels of calculation will be done; one with AMC_{II} condition and one with AMC_{I} condition to take into account the rainless period considered for event separation.

2.5 SCS dimensionless unit hydrograph

The dimensionless unit hydrograph used by the SCS was developed by Victor Mockus (SCS, 1985) and was derived based on a large number of unit hydrographs from basins which varied in characteristics such as size and geographic location. The unit hydrographs were averaged and the final product was made dimensionless by considering the ratios of q/q_p (flow/ peak flow) on the ordinate axis and t/t_p (time/ time to peak) on the abscissa, where the units of q and q_p are flow/inch of runoff/unit area. This final, dimensionless unit hydrograph has a time-to-peak located at approximately 20% of its time base and an inflection point at 1.7 times the time-to-peak. The dimensionless unit hydrograph is illustrated in Figure 2-1. Figure 2-1 also illustrates the cumulative mass curve for the dimensionless unit hydrograph.

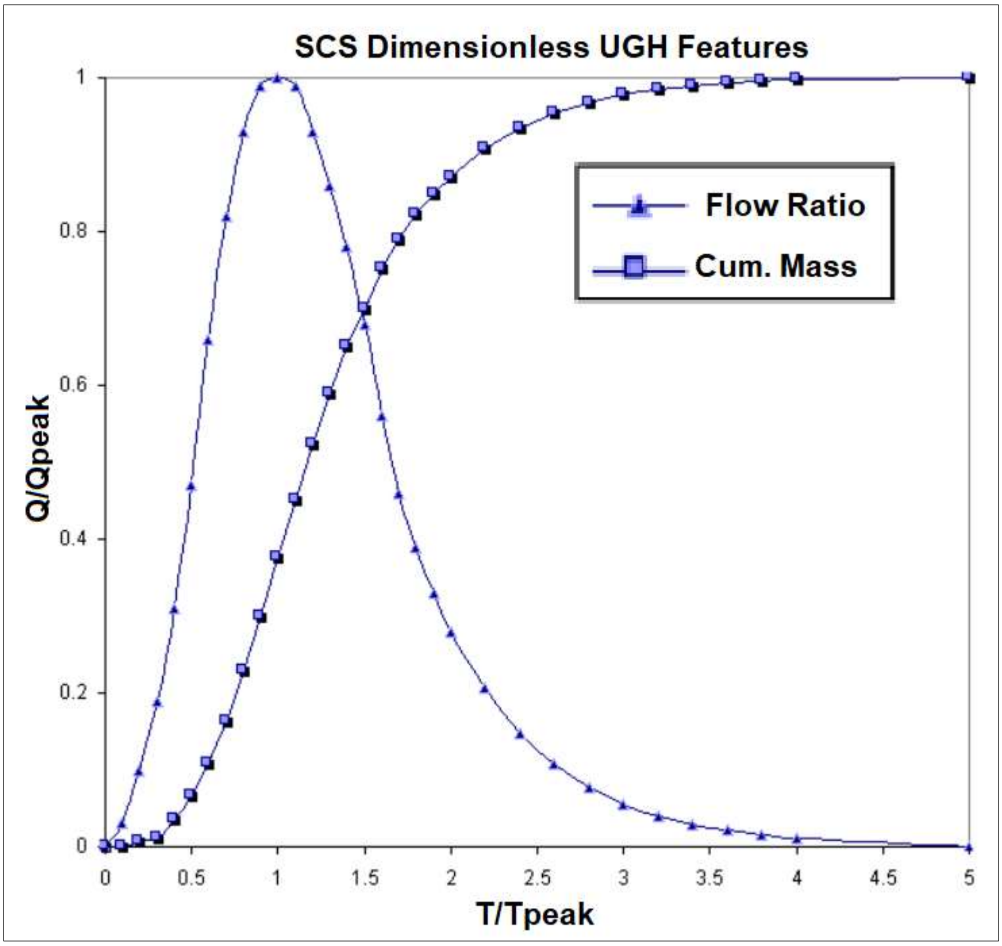


Figure 2-1: SCS dimensionless unit hydrograph and mass curve

Source: (National Operational Hydrologic Remote Sensing Centre website)

2.6 Event based streamflow modelling

Hydrological models can also be classified as event based and continuous models (Moradkhani & Sorooshian, 2008). Event based models deal with single hydrologic events like estimation of surface runoff generated from a rainfall event, whereas continuous models consider multiple events.

Knighton and Nanson (2001) noted that event based models describe the hydrologic processes better than the continuous models, since distinctiveness of runoff periods implies that an event based approach provides the most appropriate means to analyse the hydrology of semi-arid regions.

In the simplest form, the event-based approach consists out of a single design storm with a fixed duration. This design storm duration is a very significant determinant of the computed peak discharge, and often chosen equal to the concentration time of a water system (Hoes & Nelen, 2005).

Azmat, Qamar, Ahmed, Hussain and Umair (2017) used HEC-HMS for the event and continuous simulation in high altitude scarcely-gauged catchment under changing climate and resulted in better performance of the model under event based condition with least NS coefficient of 0.76 and 0.68 for continuous simulation.

2.7 Rainfall loss

Effective rainfall sometimes called excess rainfall is the component of the storm hyetograph which is neither retained on the land surface nor infiltrates into the soil. The effective rainfall produces overland flow that results in the direct runoff hydrograph from a sub-area of a catchment. The difference between the storm and the effective rainfall hyetographs is termed the abstractions or rainfall losses.

There are many noted methods in the literature to separate the effective component from the total rainfall. Viessman, Lewis, and Knapp (1989) had noted,

i. Horton method
ii. Green-Ampt method
iii. Phi-Index method
iv. NRCS (SCS) curve number method
v. Mass curve method

Chow, Maidment and Mays (2010, 1988) mentioned that the use of SCS method for rainfall loss depends on the initial abstraction, which in turn depends upon the curve number value of the catchment.

2.8 Separation of events and minimum inter-event time

The spatio-temporal distribution of rainfall and the corresponding inter-event dry period separating two rainfalls play a major role in the planning and management of water resources of a country. Knowledge of the distribution of inter-event dry period is necessary in storm water management related to designs of best management practices such detention and retention ponds (Dan’azumi & Shamsudin, 2011).

Many notable authors (such as Over & Gupta, 1996) recognize that special care has to be taken with the concept of any rain event used in the analysis of data because the scaling regimes are influenced by the rainfall intermittency and its’ inside event gaps. Different approaches exist to define a rain event (Dunkerley, 2008), so caution is required when comparing them (Molini, Parodi, Rebora, & Craig, 2011).

For defining a rain event, it is usually needed a fixed rainless period, the minimum inter-event time (MIT), which is required to be reached or exceeded before and after each event (Dunkerley, 2008). There is a wide range of MIT that can be used usually related with the resolution of the available data sets.

The available literature has prescribed the MIT of more than 24 hours and as per the Linsley, Kohler, & Paulhus (1975) unit hydrograph method the MIT must be minimum of three days. All most all studies that used the event based approach do not report how the events were identified (Dunkerley, 2008). Most of the methods used were based on empirical relationships that deriving direct runoff duration as the MIT.

From a catchment response standpoint, the independence threshold may be chosen to be the critical duration of rainfall to which the catchment responds; small urbanized catchments would require a short dry period threshold, whilst a larger catchment underlain by chalk would be more suited to a long threshold (Arceman, 1990).

Event direct runoff duration is based on many factors such as catchment area, slope, width, land use and the soil imperviousness. The Time to base (T_b) derived from the unit hydrograph for this study is 2.12 days while using Linsley et al. (1975) empirical method $N=A^{0.2}$, N equals to 3 days. Therefore considering the two empirical methods the MIT is considered as 3 days minimum and the event duration shall be more than 3 days.

2.9 Separation of flows

The U.S. Environmental Protection Agency (EPA, 2007) in the development of guidelines for total maximum daily loads (TMDL) for practitioners who are familiar with relevant technical approaches and legal requirements had incorporated a five zone categorisation for streamflow. This categorisation divides the streamflow in to five zones:

i) High flows (0-10%),
ii) Moist conditions (10-40%),
iii) Mid-range flows (40-60%),
iv) Dry conditions (60-90%), and
v) Low flows (90-100%).

2.10 Baseflow separation

The separation of surface runoff from baseflow is a time honoured exercise in hydrology and has been described variously as one of the most desperate analysis techniques in use in hydrology (Hewlett & Hibbert, 1967) and fascinating arena of fancy and speculation (Appleby, 1970).

Traditionally groundwater and surface water have been managed as separate water resources. However, in many regions, they are hydraulically connected and the abstraction from one can influence the other.

The total runoff hydrograph is composed of the direct runoff and baseflow. Separation of the baseflow will result in the production of direct runoff hydrograph. There are many techniques available in the literature for the separation and thus selection of the most relevant technique is essential for an accurate analysis. The techniques are largely grouped under graphical and automated.

Based on the literature review, it is clear that hydrograph analysis is a well-established strategy in understanding the magnitude and dynamics of groundwater discharge, and there is a strong consensus among practicing hydrologists that baseflow analysis provides a very useful tool for understanding groundwater discharge to streams (Evans

& Neal, 2005, Brodie & Hostetler, 2005, Ivkovic, Letcher, Croke, Evans & Stauffacher, 2005). Specifically, Evans and Neal (2005) state these underused techniques provide valuable insights to groundwater processes, especially the relative and absolute magnitude of surface water and groundwater interaction.

The graphical way of separation has three methods suggested by Chow et al. (2010, 1998) i.e. Constant discharge, Constant slope and Concave method which are shown in Figure 2-2.

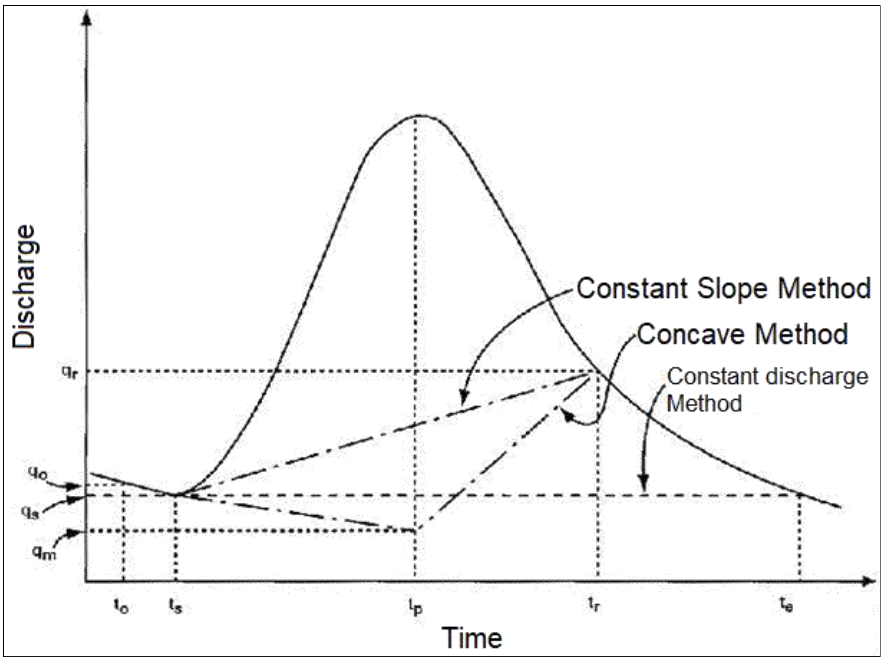


Figure 2-2: Baseflow separation methods.

Source: McCuen (1998)

2.11 Time of concentration

Time of concentration is a fundamental watershed parameter. It is used to compute the peak discharge for a watershed. The peak discharge is a function of the rainfall intensity, which is based on the time of concentration. Time of concentration is the longest time required for a particle to travel from the watershed divide to the watershed outlet.

The following equations are used for the calculation. The equations can be found in Chin (2000), Chow et al. (2010, 1988), Corbitt (1999), and Singh (1992).

i. FAA equation: $t = G\,(1.1 - c)\,L^{0.5} / (100\,S)^{1/3}$ (2-8)

ii. Kirpich equation: $t = G\,k\,(L / S^{0.5})^{0.77}$ (2-9)

iii. Kerby equation: $t = G\,(L\,r / S^{0.5})^{0.467}$ (2-10)

Where;

t = Time of concentration, minutes.

G = Constant. FAA: G=1.8, Kirpich: G=0.0078, Kerby: G=0.8268

c = Rational Method runoff coefficient.

k = Kirpich adjustment factor. See table below.

L = Longest watercourse length in the watershed, ft.

r = Kerby retardance roughness coefficient.

S = Average slope of the watercourse, ft/ft or m/m.

The Federal Aviation Administration Method (FAA) method was developed using data obtained from airport runoff but has been successfully applied to overland flow in urban areas. The Kirpich equation was developed from data obtained in seven rural watersheds in Tennessee, USA. The watersheds had well-defined channels and steep slopes of 0.03 to 0.1 ft/ft (3 to 10%) and areas of 1 to 112 acres. It is used widely in urban areas for both overland flow and channel flow; and it is used for agricultural watersheds up to 200 acres (80 hectares). The Kerby equation was developed from data obtained in watersheds having watercourses less than 1200 ft. (365 m), slopes less than 0.01 ft/ft (1%), and areas less than 10 acres (4 hectares).

2.12 Optimization of parameter

Traditionally, calibration has been performed manually using a trial-and-error parameter adjustment procedure. The process of manual calibration, however, may be a very tedious and time-consuming task, depending on the number of free model parameters and the degree of parameter interaction (Madsen, Wilson, & Ammentorp, 2002). Methods of automatic calibration can overcome these shortcomings.

Deterministic rainfall-runoff models require parameter calibration with the aim of matching the modelled streamflow record to an observed record as closely as possible (Cohen, Ollington, & Linga, 2013).

In the present study the Mean Ratio of Absolute Error (MRAE), which is suggested by World Meteorological Organization (WMO, 1975) have been computed to evaluate the model efficiency and to match each and every point of the two hydrographs relative to the observed value at that particular time point (Perera & Wijesekera, 2011).

$$MRAE = \frac{1}{n}\sum\frac{|Q_c - Q_o|}{Q_o} \qquad (2\text{-}11)$$

In equation 2-11, Q_o is the observed streamflow and Q_c is the calculated streamflow and n is the number of observations used for comparison. Wannirachchi (2013) and Wijesekera and Rajapaske (2013) used MRAE to determine model performance.

For similar works on runoff estimation, researchers such as Thapa and Wijesekera (2017) took the MRAE as the primary objective function while Ratio of Absolute Error to Mean (RAEM) was also applied during optimization and verification.

$$RAEM = \frac{\sum|Q_o - Q_c|}{n\overline{Q_o}} \qquad (2\text{-}12)$$

Goodness of fit: Researchers dealing on similar subject such as Thapa (2014) have used the RAEM for the purpose of calibration and verification. Tobgay (2012) used MRAE as the optimization criteria. They have mentioned the need to average the parameters in case of event based modelling. This practice is the same as that reported in the studies carried out by Rallison and Miller (1981).

The different indicators used for evaluation in this study along with its formulae are presented in Table 2-2.

Table 2-2: Different indicators used for evaluation

Sl. No.	Indicator	Function
1	MRAE of event	$\text{MRAE} = \frac{1}{n}\sum\frac{\lvert Q_c - Q_o\rvert}{Q_o}$
2	RAEM of event	$\text{RAEM} = \frac{\sum\lvert Q_o - Q_c\rvert}{n\overline{Q_o}}$
3	Ratio of Absolute Error in Q_p	Abs($Q_p$cal - $Q_p$obs)/ $Q_p$obs
4	Ratio of Absolute Error in T_p	($T_p$cal - $T_p$obs)/ T_p obs
5	Ratio of Absolute Error in T_b	($T_b$cal – $T_b$obs)/ $T_b$obs

Where;

Q_o is the observed streamflow

Q_c is the calculated streamflow

n is the number of observations used for comparison

$\overline{Q_o}$ is the mean of the observed streamflow

$Q_p$obs is the observed peak streamflow

$Q_p$cal is the calculated peak streamflow

$T_p$obs is the time to peak from the observed data

$T_p$cal is the time to peak from the calculated data

$T_b$obs is the time base from the observed data

$T_b$cal is the time base from the calculated data

3 MATERIALS AND METHODS

This chapter gives the required information on the materials used such as the study area, the methodology flow chart and description of methodology, the data, its resolution and sources. It will also discuss on data checking using visual methods and filling of the missing data.

3.1 Study area

The Maha Oya is a major river in the Sabaragamuwa Province of Sri Lanka. It measures approximately 134 kilometres in length. It runs across four provinces and five districts. Maha Oya has 14 water supply networks to serve the water needs and more than one million people live by the river. Its catchment area receives approximately 3644 million cubic meters of rain per year, and approximately 34 percent of the water reaches the sea. It has a catchment area of 1,510 square kilometres. For the present study purpose, area up to Badalgama stream gauging station is selected. Badalgama watershed as shown in Figure 3-1 is a sub watershed of Maha Oya Basin and drainage area 1337.13 km^2.

3.2 Data and data checking

The main data used for the study are rainfall and streamflow, land use and soil maps.

3.2.1 Data sources and data resolution

Irrigation Department is the sole agency responsible for the maintenance of most streamflow gauging stations in Sri Lanka. The Department of Meteorology has the maximum number of rain gauging stations islandwide. The land use map and soil map were acquired from theDepartment of Survey. The data resolution and sources are indicated in the Table 3-1;

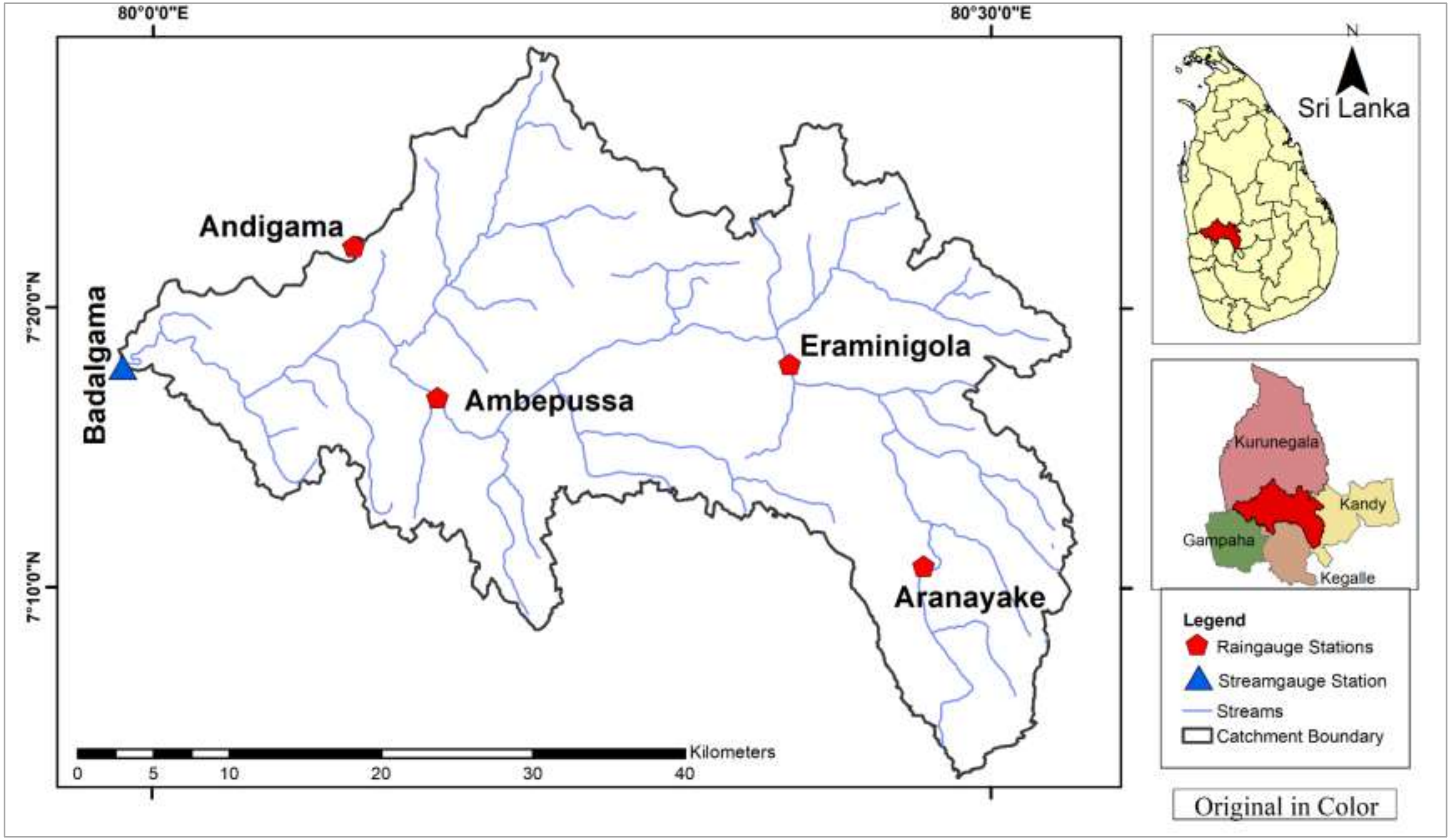


Figure 3-1: Study area of Badalgama watershed

Table 3-1: Data resolution and sources

Serial Number	Data Type	Resolution	Source
1	Streamflow	Daily (2005-2017)	Department of Irrigation
2	Rainfall	Daily (2005-2017)	Department of Meteorology
3	Land use map	1:50,000 (2003)	Department of Survey
4	Soil map	1:250,000 (2003)	Department of Survey

3.2.2 Rainfall and streamflow data

Rainfall is the most important factor in the modelling of a streamflow. Four rain gauging stations were used to compute the Thiessen polygons and determine a Thiessen rainfall value. The stream gauging station at Badalgama was used as the outlet measurement point. Rain gauging stations and streamflow gauging station along with coordinates are shown in Table 3-2 and Table 3-3.

Table 3-2: Rain gauging station details

Serial Number	Rain gauge name	Coordinates
1	Ambepussa Govt. Farm	7° 16' 48" N, 80° 10' 12" E
2	Andigama Farm	7° 22' 12" N, 80° 07' 12" E
3	Aranayake Govt. Hospital	7° 10' 48" N, 80° 27' 36" E
4	Eraminigolla	7° 17' 60" N, 80° 22' 48" E

Table 3-3: Stream gauging station details

Serial Number	Streamflow gauge name	Coordinates
1	Badalgama Station	7° 18' 54" N, 80° 00' 14.4" E

3.2.3 Data checking

Available data requires satisfactory checking before it is used in modelling. Inconsistencies and non-homogeneities in the hydrological and meteorological time series could be identified by incorporating statistical tests that detect trends and change points (Wijesekera & Perera, 2012).

3.2.4 Missing data

When the rainfall data was missing for a station it was on a monthly scale i.e., data of an entire month was missing. In case of streamflow data only a few days were missing consecutively, except for the month of March 2014 where only 3 days of data was available. These details are presented in Table 3-4 for rainfall and Table 3-5 for streamflow.

Figure 3-2 shows the total missing days of each station in the entire data set. In the years from 2006-2008 and in 2016 no data is missing from any station. Overall, Eraminigolla station has the maximum missing data particularly in 2009.

Table 3-4: Details of missing rainfall data

Rainfall Station Name	Missing Data (Monthly data)
Ambepussa	2005 November, 2009 January, 2011 July, 2011 October, 2011 November, 2012 January, 2013 January
Andigama	2010 November, 2014 March, 2014 September, 2014 August, 2015 March, 2015 October, 2017 September
Aranayake	2014 December
Eraminigolla	2009 January, 2009 April - December 2009, 2010 December, 2011 February, 2011 December, 2012 December, 2015 January, 2015 September, 2015 December

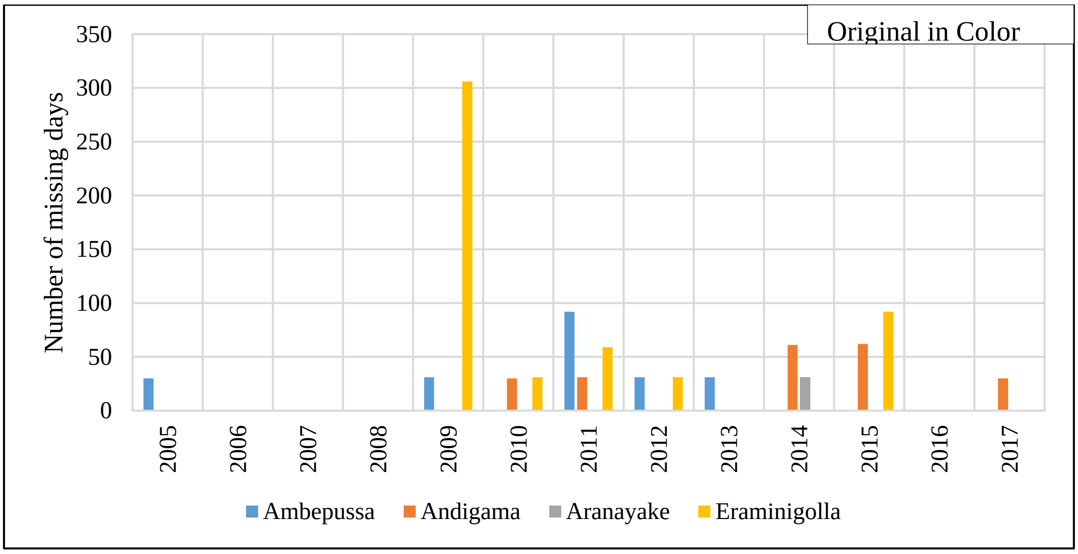


Figure 3-2: Missing days in each rain gauging station

Table 3-5: Details of missing streamflow data

Streamflow missing dates	Streamflow missing dates
2004 January- 18th	2012 February- 5th – 9th
2004 May- 8th, 22nd, 23rd 29th, 30th	2014 January- 20th – 31st
2004 June- 20th	2014 February- 1st – 24th
2004 July- 31st	2014 March- 18th – 22nd and 26th- 31st
2005 March-12th	2014 April- 1st to 7th

Musiake and Wijesekera (1990) carried a study to model streamflow at Peradeniya gauging station. They had used data from 1969 to 1973 for calibration and from 1976 to 1980 for verification. They mentioned that data from 1974 to 1975 appeared to be erroneous and hence were not used in the calculations.

Since 9 months (April to December 2009) of continuous data was missing from the Eraminigolla rain gauging station, it was decided that the dataset of 2009 would be excluded from both calibration and validation data set for all the stations.

Figure 3-4 to 3-6 show an example of missing data of some months and stations identified during the visual inspection of missing data. The green coloured box shows the missing rainfall data.

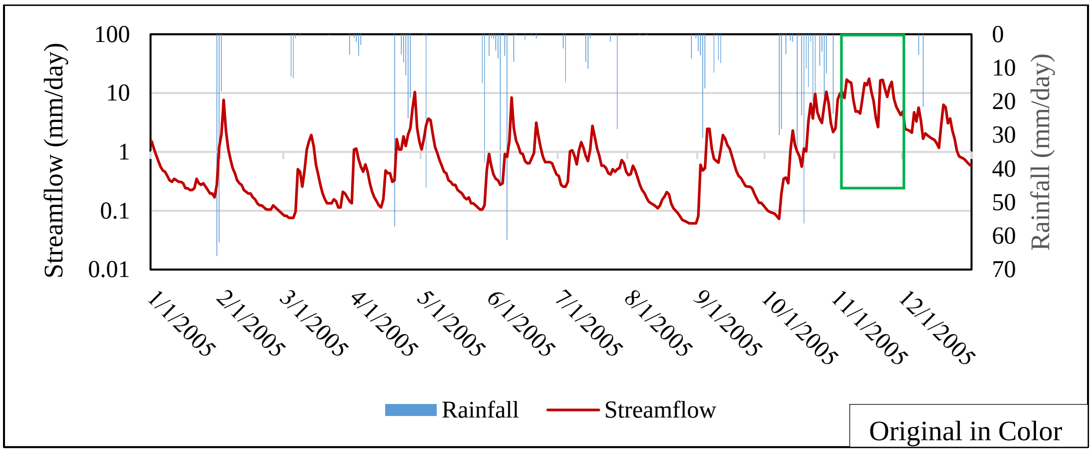


Figure 3-3: Missing data of Ambepussa station

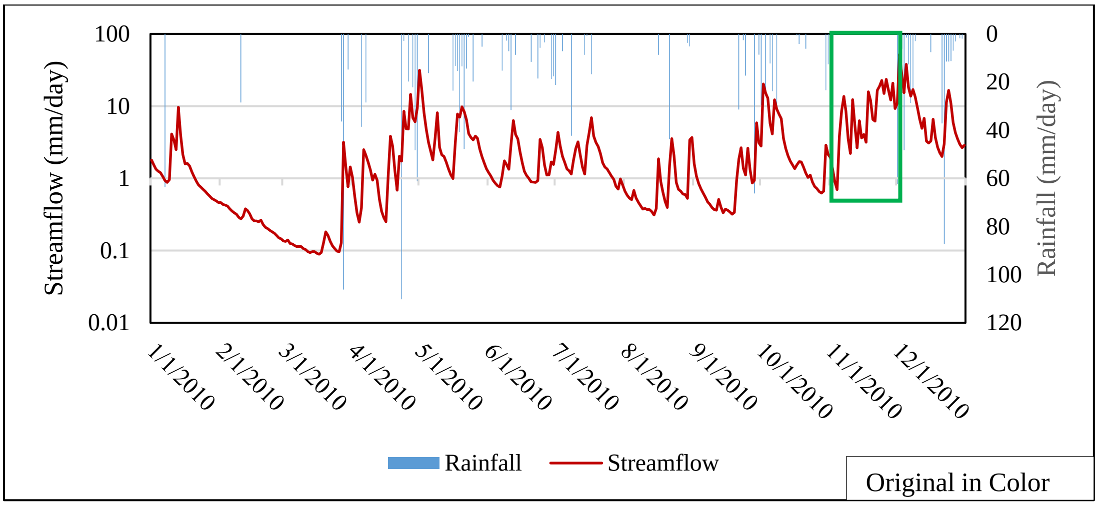


Figure 3-4: Missing data of Andigama station

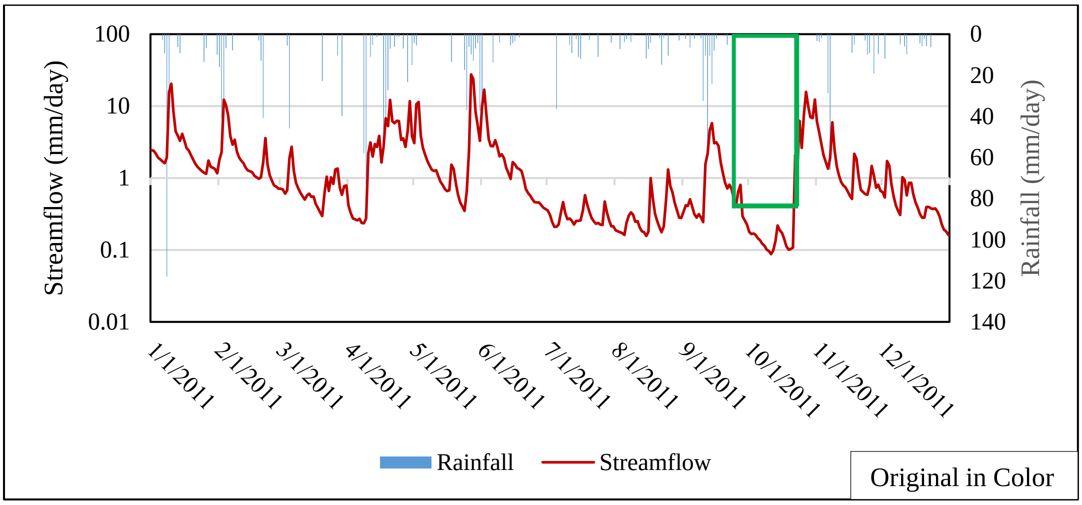


Figure 3-5: Missing data of Aranayake station

3.2.5 Missing rainfall data

In the present work, rainfall data were verified by comparing daily values at each station. Since the research deals in event based streamflow modelling, missing data was not filled for each station. Instead, the Thiessen average value for each day was calculated based on the Thiessen weights generated from the available stations. At any point, data from only one station was missing making a minimum of three stations available for Thiessen weight determination. The rain gauge density when all four are available is 334.4 km^2 and when only three stations are available is 445.86 km^2 both of which is greater than the WMO (2008) recommended value of 575 km^2 per station.

The details of the Thiessen weights of the five different combinations of rain gauge availability is in Table 3-6 followed by the Thiessen weights using all four stations in Table 3-7. Details of the Thiessen weights based on the different combinations of the available stations is given in Appendix A.

Table 3-6: Thiessen weights of different combination of rain gauge stations:

Station	All stations present	Ambepussa missing	Andigama missing	Aranayake missing	Eraminigolla missing
Ambepussa	0.262	-	0.453	0.264	0.371
Andigama	0.189	0.390	-	0.192	0.197
Aranayake	0.198	0.196	0.196	-	0.432
Eraminigolla	0.351	0.414	0.351	0.545	-
Total	1.000	1.000	1.000	1.000	1.000

Table 3-7: Thiessen weights of each station (when all stations are present)

Rain gauge	**Area of Influence (km^2)**	**Thiessen Weight**
Ambepussa Govt. Farm	350.39	0.262
Andigama Farm	253.55	0.189
Aranayake Govt. Hospital	264.36	0.198
Eraminigolla	468.97	0.351
Total	1337.27	1.000

3.2.6 Thiessen rainfall

The Thiessen polygon is a commonly used methodology for computing the mean areal precipitation for a catchment from rain gauge observations which was presented by Thiessen (1911). The area of each polygon is used to weight the rainfall amount of the station in the centre of the polygon. If the amount for any station is missing, the polygon must be changed. The Thiessen method is unable to consider orographic differences in rainfall distributions.

The total area of the watershed is 1337.27 km^2 and the spatial contribution of each station using Thiessen method is shown in Figure 3-6. An example of the Thiessen rainfall value from Ambepussa station in 2005 is given in Figure 3-7 followed by the overall Thiessen rainfall and streamflow comparison for 2005-2017 from Figure 3-8 to Figure 3-19.

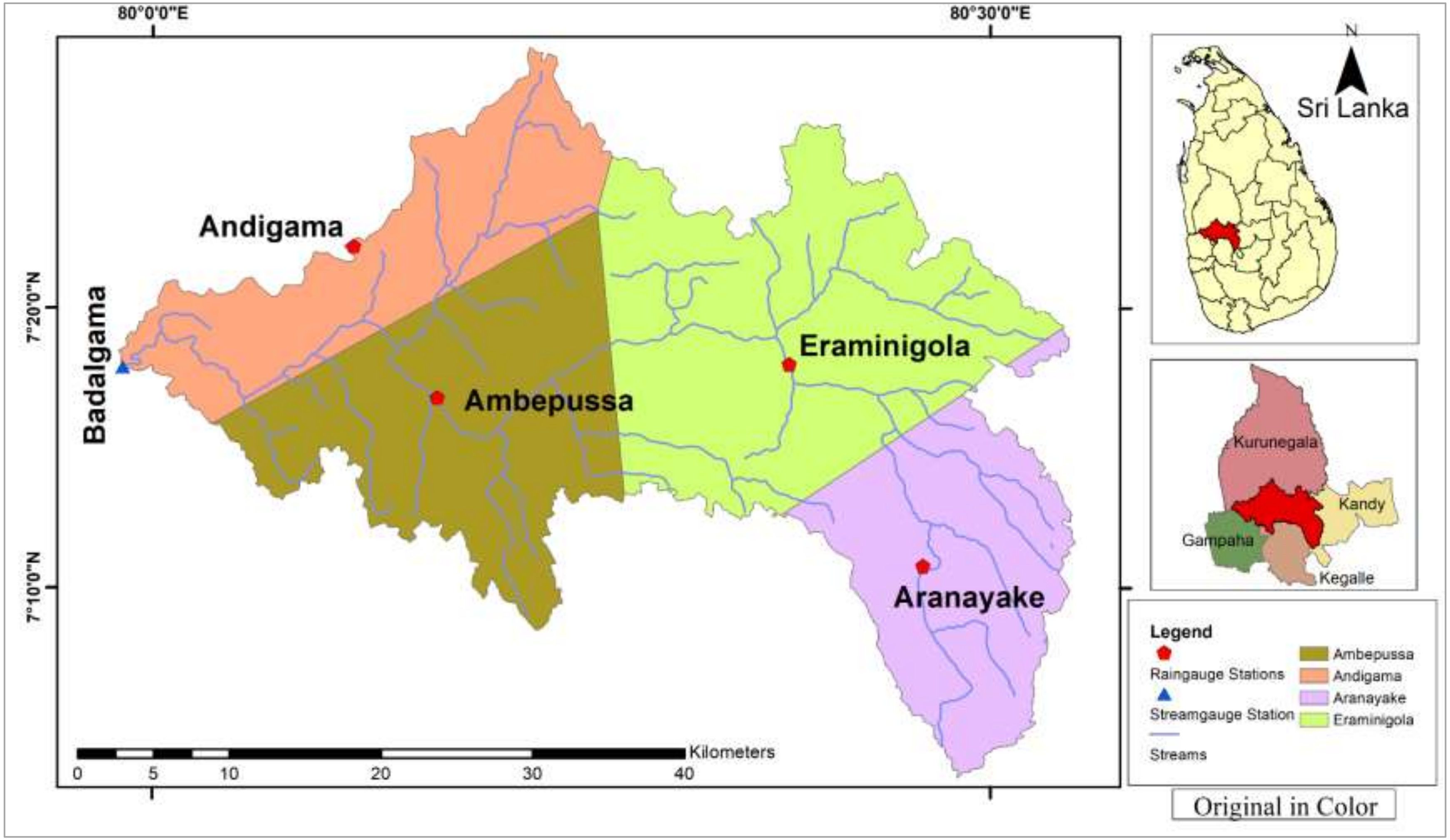


Figure 3-6: Thiessen weights of the watershed

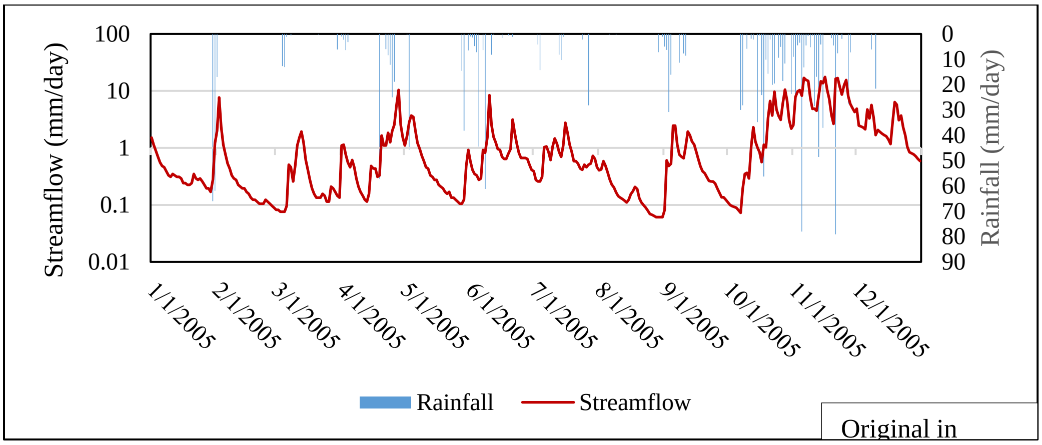


Figure 3-7: Streamflow vs. Thiessen rainfall for Ambepussa station for 2005

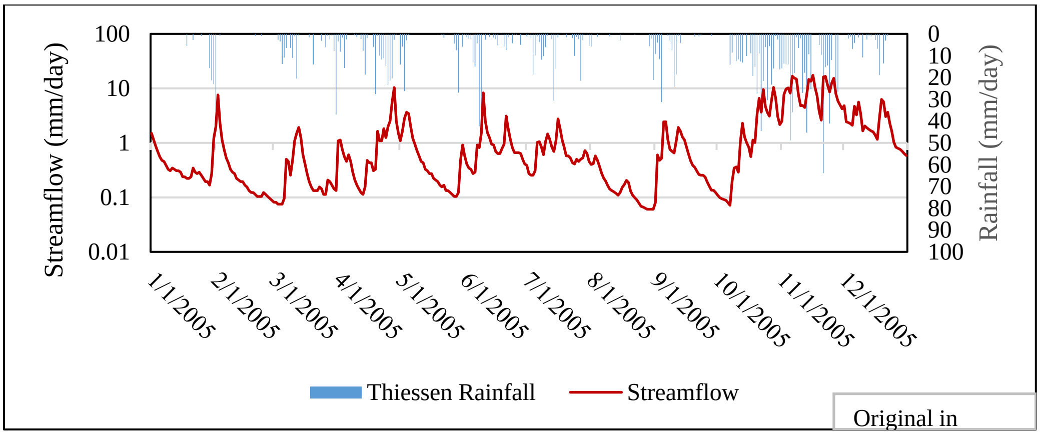


Figure 3-8: Streamflow vs. Thiessen rainfall for Badalgama watershed for 2005

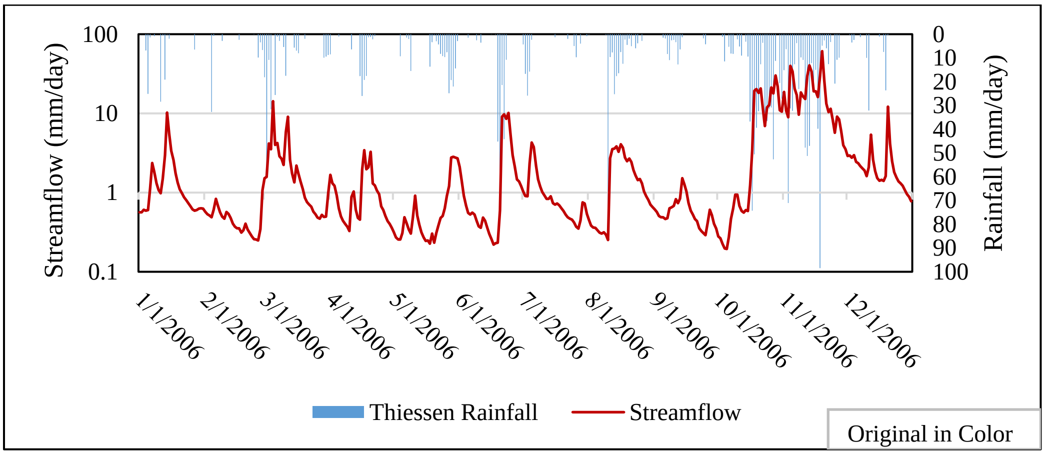


Figure 3-9: Streamflow vs. Thiessen rainfall for Badalgama watershed for 2006

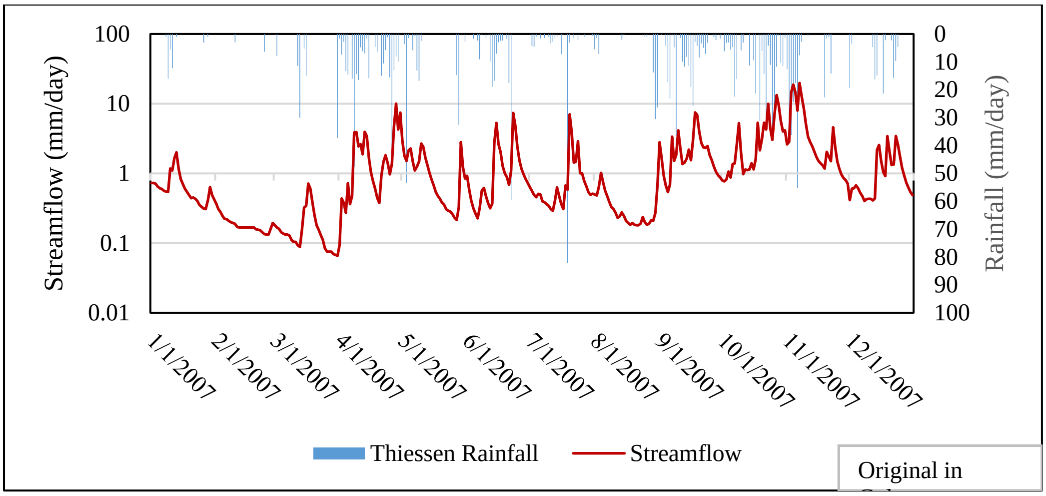


Figure 3-10: Streamflow vs. Thiessen rainfall for Badalgama watershed for 2007

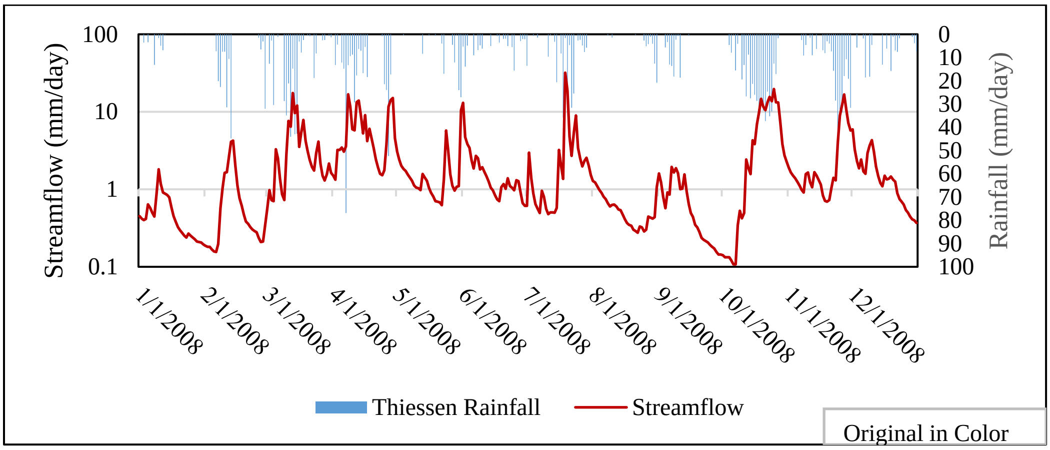


Figure 3-11: Streamflow vs. Thiessen rainfall for Badalgama watershed for 2008

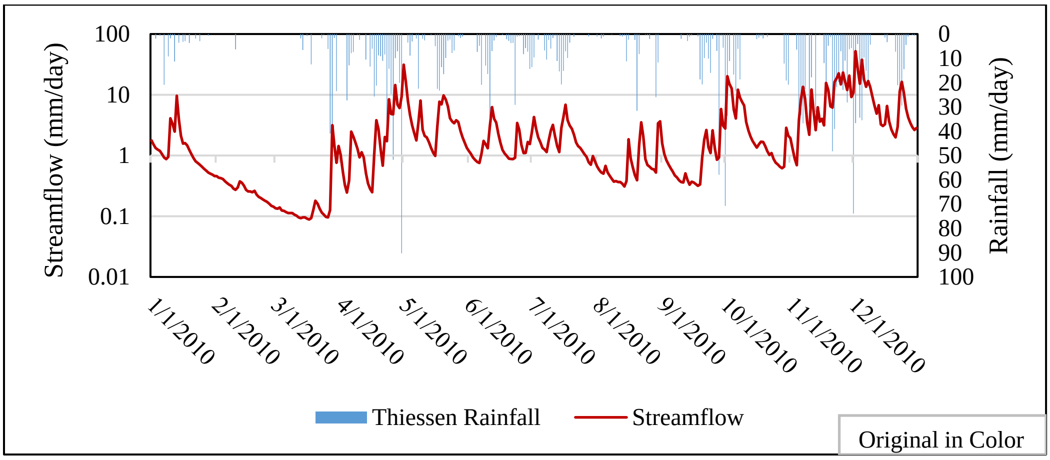


Figure 3-12: Streamflow vs. Thiessen rainfall for Badalgama watershed for 2010

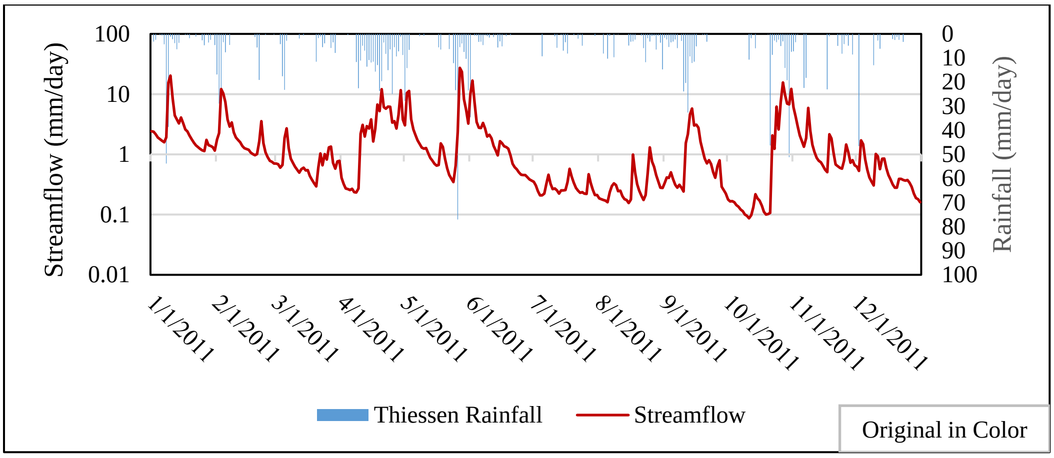


Figure 3-13: Streamflow vs. Thiessen rainfall for Badalgama watershed for 2011

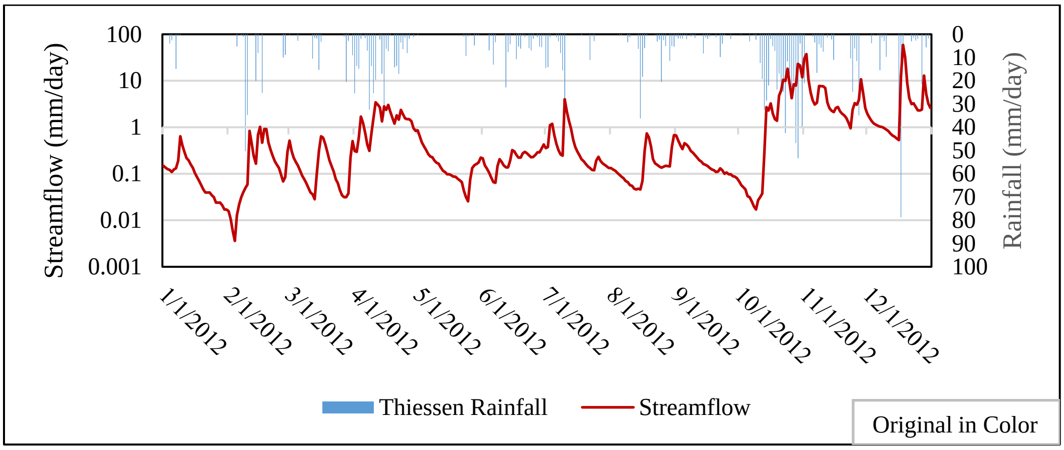


Figure 3-14: Streamflow vs. Thiessen rainfall for Badalgama watershed for 2012

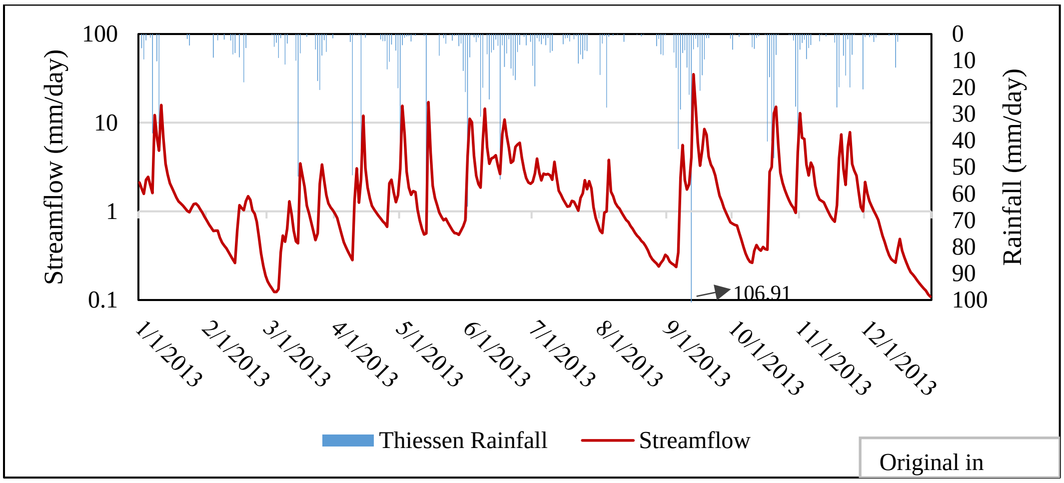


Figure 3-15: Streamflow vs. Thiessen rainfall for Badalgama watershed for 2013

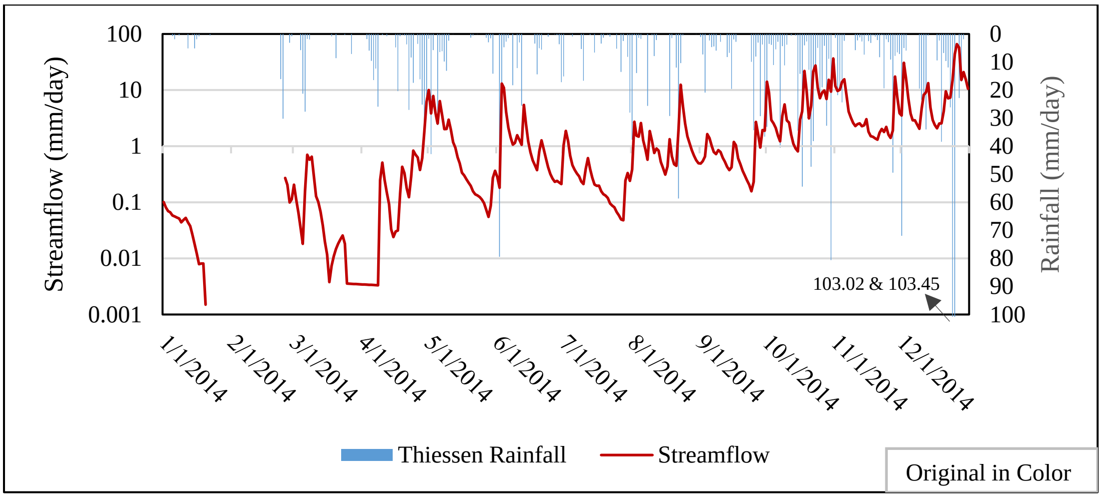


Figure 3-16: Streamflow vs. Thiessen rainfall for Badalgama watershed for 2014

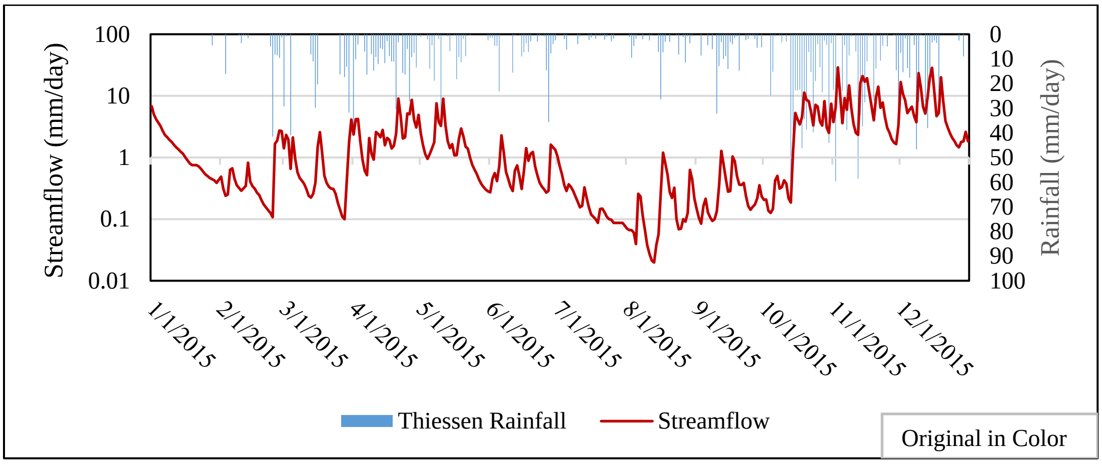


Figure 3-17: Streamflow vs. Thiessen rainfall for Badalgama watershed for 2015

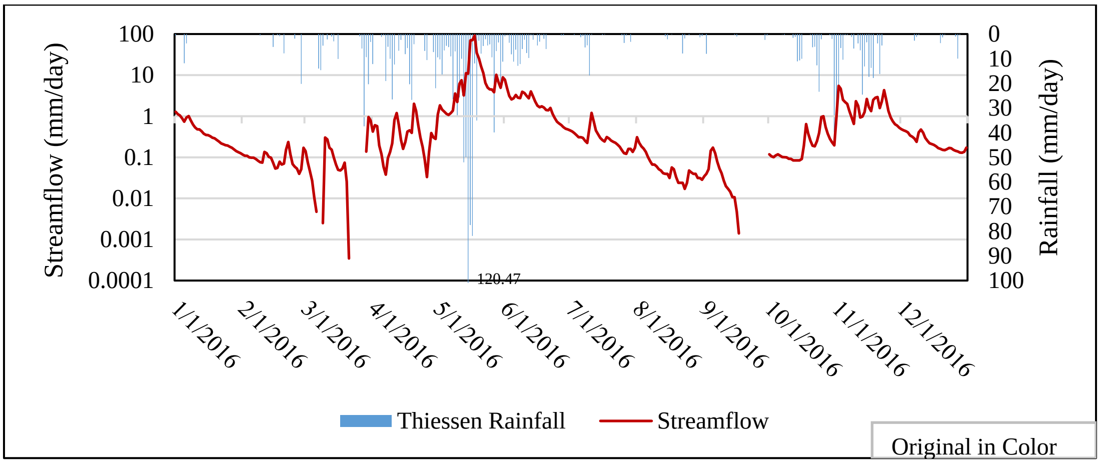


Figure 3-18: Streamflow vs. Thiessen rainfall for Badalgama watershed for 2016

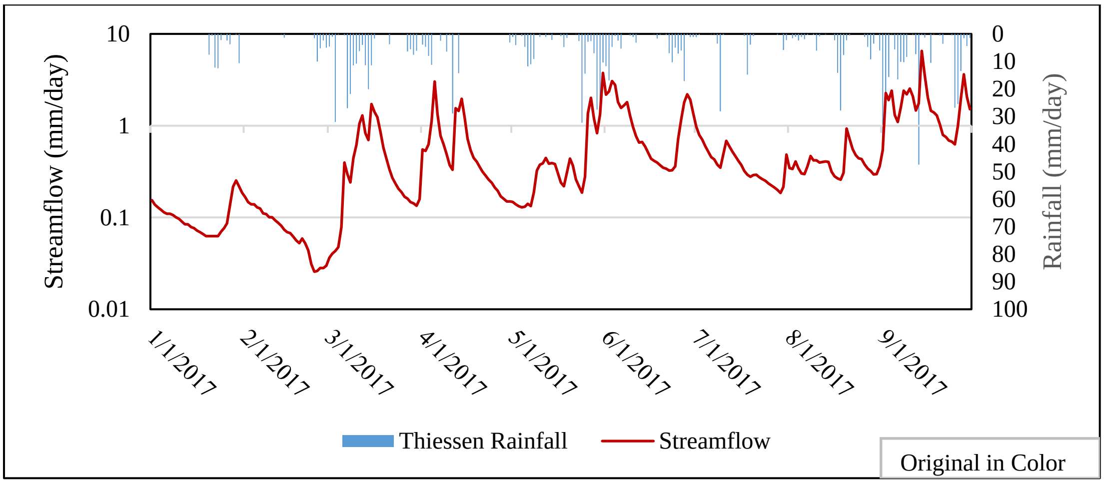


Figure 3-19: Streamflow vs. Thiessen rainfall for Badalgama watershed for 2017

3.2.7 Annual water balance

Water balance can be used to describe the flow of water in and out of a system. Annual water balance was carried out for Badalgama watershed from 2005 to 2017 in order to compare the annual rainfall and streamflow data and is shown in Table 3-8. It can be observed that overall the ratios are similar in all the years. A cyclic pattern can be observed which relates to an increases rainfall for about two years followed by a decreased rainfall which could be due to complex weather patterns resulting from variations in ocean temperatures in the Equatorial Pacific. Graphical representation of annual water balance is in Figure 3-20.

Table 3-8: Annual water balance for the watershed

Year	Avg. Thiessen Rainfall (mm)	Stream-flow (mm)	Runoff Coeffici-ent	Pan Evaporat-ion	Pan Coeffici-ent	Actual Evapor-ation	Water Balance
2005	1926.3	634.9	0.33	1142.5	0.7	799.7	1268.4
2006	2453.0	1251.2	0.43	1416.7	0.7	991.7	1118.4
2007	1837.8	573.1	0.50	1425.7	0.7	998.0	1215.4
2008	2330.0	934.9	0.44	1265.5	0.7	885.9	1168.9
2010	2437.9	1226.3	0.51	1503.9	0.7	1052.7	915.6
2011	1565.9	692.3	0.74	1421.0	0.7	994.7	472.6
2012	1808.3	614.0	0.22	1559.3	0.7	1091.5	919.7
2013	1954.5	795.9	0.52	1354.0	0.7	947.8	1106.8
2014	2566.6	1004.6	0.25	1517.3	0.7	1062.1	1241.8
2015	2422.2	882.7	0.48	1208.0	0.7	845.6	1164.1
2016	1623.1	619.6	0.50	1336.0	0.7	935.2	1131.6
2017	1071.0	172.5	0.18	1213.5	0.7	849.5	1119.0

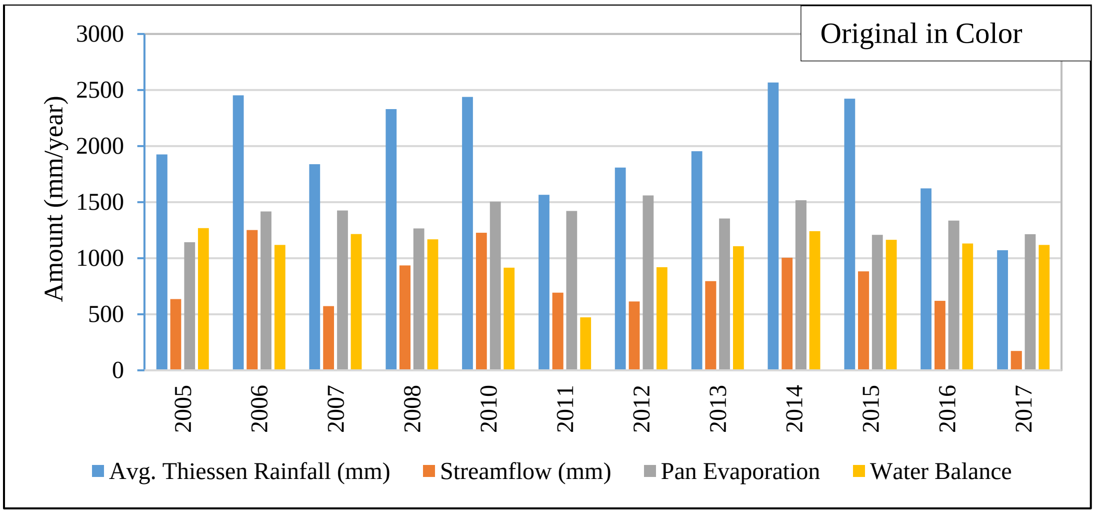


Figure 3-20: Annual water balance of watershed

3.2.8 Land use pattern

The land use of the watershed is dominated by 56.34% of plantations (coconut, rubber and tea), 20% as home steads followed by 15.17% of agricultural land (chena, paddy and other cultivations). The other areas include built-up areas, forest, garden, marsh and waterbodies. Details of the land use are shown in in Table 3-9 followed by the land use map presented in Figure 3-21.

Table 3-9: Land use details of Badalgama watershed

Land use type	Area (km^2)	Area (%)	Reclassification
Built-up Area	0.337	0.025	Built-up Area
Cemetery	0.036	0.003	Built-up Area
Chena	0.021	0.002	Agriculture
Coconut	495.716	37.090	Plantation
Forest	34.726	2.598	Forest
Grassland	0.029	0.002	Grass land
Homesteads	267.285	19.998	Homesteads
Marsh	0.067	0.005	Marsh
Other cultivation	17.772	1.330	Agriculture
Paddy	184.925	13.836	Agriculture
Rock	17.258	1.291	Built-up Area
Rubber	203.295	15.211	Plantation
Scrub land	50.562	3.783	Grass land
Stream	9.502	0.711	Waterbodies
Swamp	0.779	0.058	Marsh
Tea	54.031	4.043	Plantation
Waterholes	0.196	0.015	Waterbodies

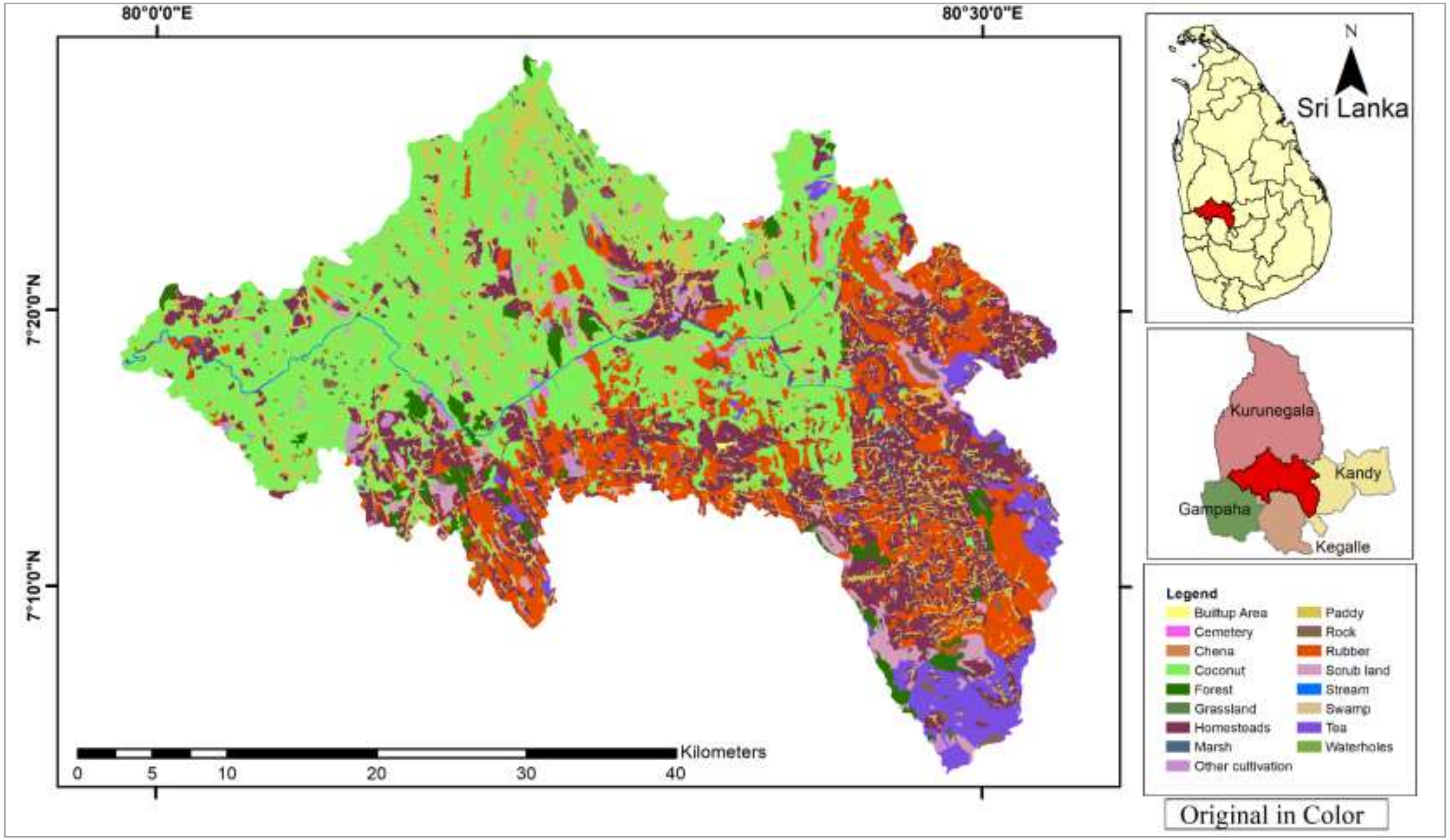


Figure 3-21: Land use pattern of Badalgama watershed
Source: Department of Survey, Sri Lanka

For study purpose land use was re-classified into 8 classes as given in Table 3-10. The reclassification was necessary as to make the land use details consistent with the classification in NEH-4 handbook. However, adequate care was taken to ensure that the classification is grouped in the most realistic manner possible considering the landuse properties of each type. The reclassified land use is shown in Figure 3-22.

Table 3-10: Reclassified land use details

Landuse Type	**Area (km^2)**	**Area (%)**
Agriculture	202.72	15.17
Builtup Area	17.63	1.32
Forest	34.73	2.60
Grassland	50.59	3.79
Homesteads	267.29	20.00
Marsh	0.85	0.06
Plantations	753.04	56.34
Waterbodies	9.70	0.73

3.2.9 Soil type

The predominant soil type in the study area is red-yellow podzolic soil which suits in the Group C classification of the NRCS classification (SCS, 1986). 64.6% of the area is dominated with red podzolic soil as shown in Figure in 3-23. The details of the area occupied by the five different soil types available in the study are is in Table 3-11.

Table 3-11: Different soil type coverage in Badalgama watershed

Sl. No	**Soil Type**	**% of Area**
1	Alluvial Soil	3.5
2	Brown Loams	8.8
3	Erosional Lithosols	1.2
4	Letosolic Soils	21.9
5	Red Podzolic	64.6

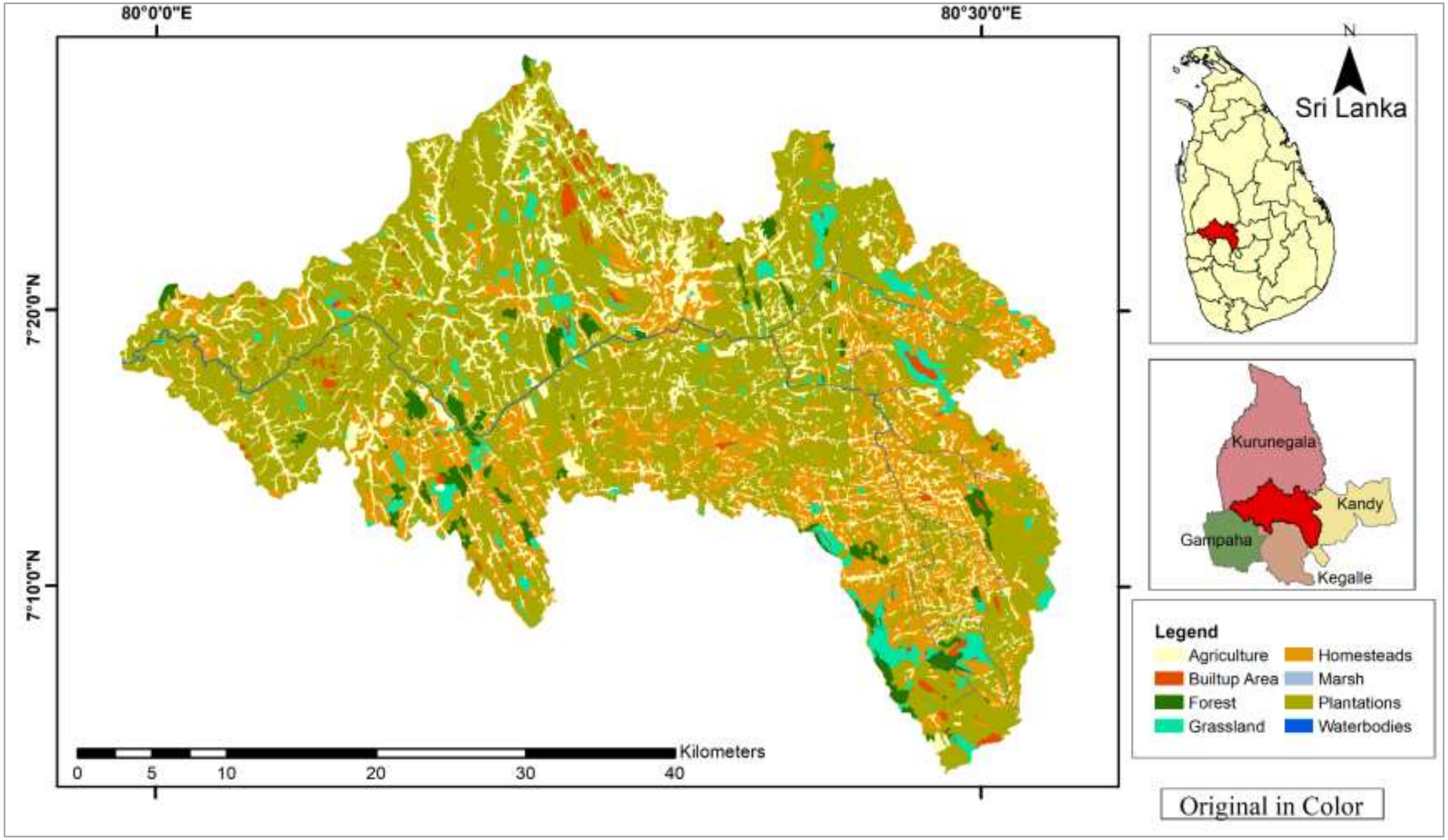


Figure 3-22: Reclassified land use for Badalgama watershed

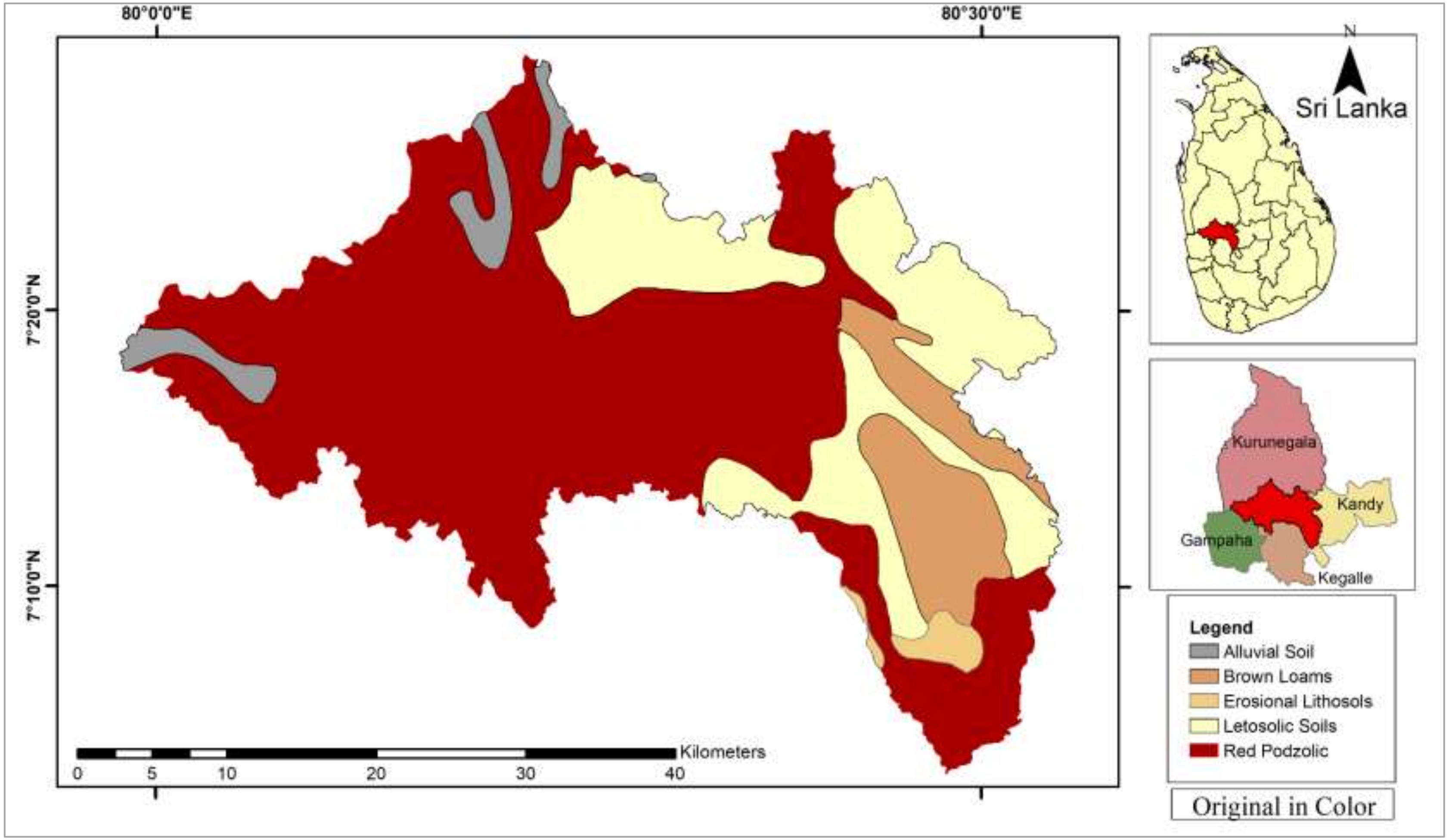


Figure 3-23: Soil classification of Badalgama watershed
Source: Department of Survey, Sri Lanka

3.3 Methodology

The methodology flow chart shown in Figure 3-24 was prepared to be consistent with research objectives and in tandem with the previous works of other researchers covering similar subject. After the identification of objectives and detailed literature review, the following methods have been chosen for carrying out this research.

3.4 Model development

3.4.1 Minimum inter-event time

The literature review gave a perspective on the different types of MIT concepts and based on the frequency of use by researchers, the N-Day concept of Linsley et al. (1975) recession method was used. The event separation was done considering a 3 days rainless period.

3.4.2 Rainfall event selection

Rainfall data on a daily resolution was available from 2005 to 2017 from four rain gauging stations. As discussed above, the MIT taken was 3 days before the start of the rainfall event.

For selection of streamflow, observation was made to the rainfall pulses. The starting point was the response with rise in hydrograph and during the recession the inflection point was the end of the streamflow event. In cases where the infliction point was not clear, the N days’ concept of Linsley et al. (1975) was used to conclude an event.

3.4.3 Event selection

Events were selected using the daily rainfall records maintained with the four rain gauging stations namely, Ambepussa, Andigama, Aranayake and Eraminigolla. Details of these stations are presented under subheading 3.2.2.

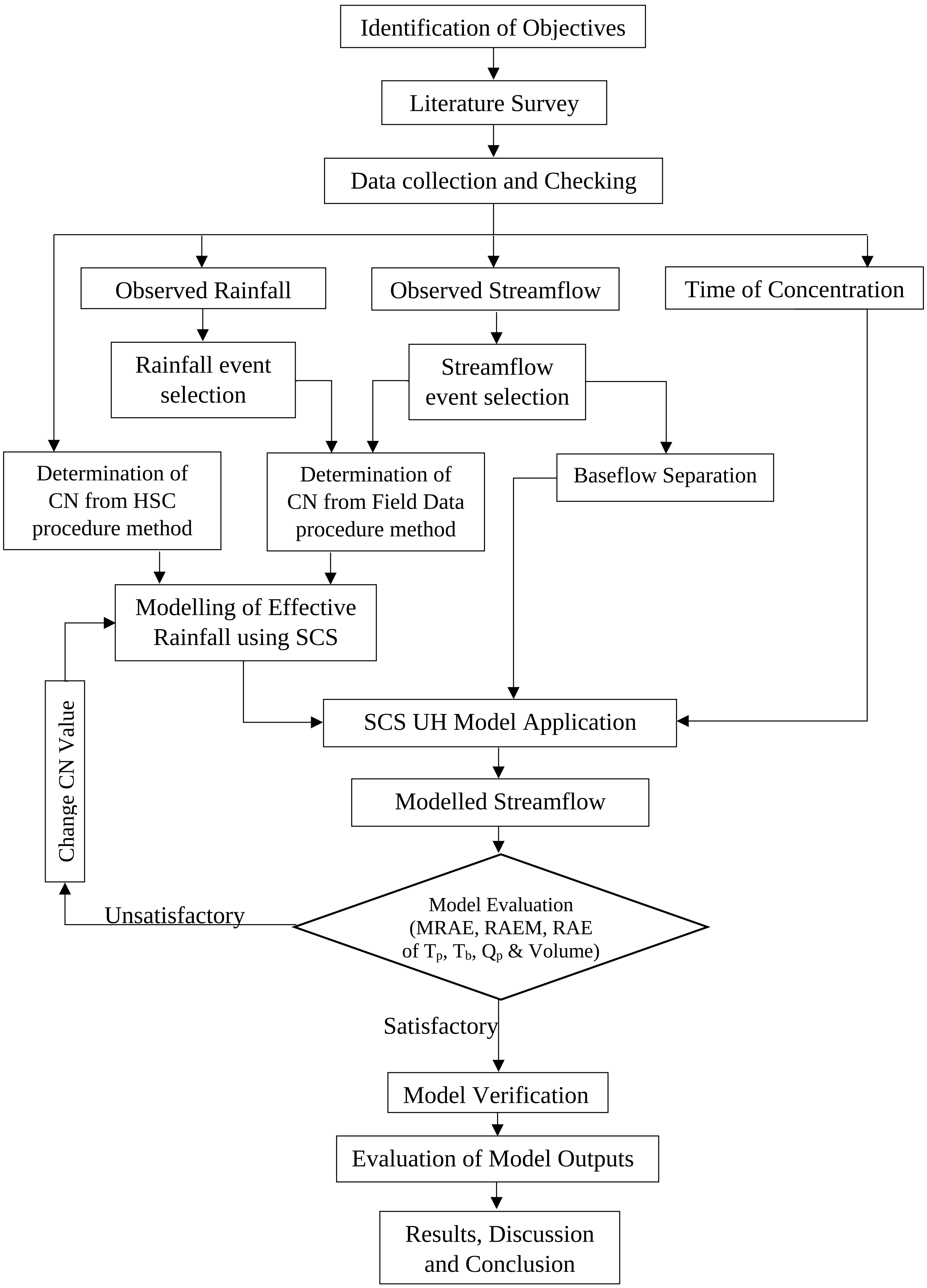


Figure 3-24: Methodology flow chart

3.4.4 Baseflow separation

Hydrograph separation traditionally has been done manually. Two commonly used methods are base-flow-recession methods (Olmsted & Hely, 1962; Riggs, 1963; Rorabaugh, 1963) and curve-fitting methods (Pettyjohn & Henning, 1979; Linsley, Kohler, & Paulhus, 1982).

As discussed in the literature review, the Concave method for baseflow separation is the most realistic. Duration of surface runoff was calculated using empirical relation, N= $A^{0.2}$, where N is the number of days after which surface runoff ceases, and A is the drainage area in square miles (Linsley et al., 1975). The interval 2N used for hydrograph separation is the odd integer between 3 and 11 nearest to 2N (Pettyjohn & Henning, 1979). For the study area with a catchment of 1336.2 km^2, the N was 2 days while the odd integer 2N* was 3.

3.4.5 Curve number from watershed properties

In order to develop SCS-CN model for Badalgama watershed, it is necessary to compute a curve number for the catchment. Weighted CN method was used to compute the CN considering land use, antecedent moisture content, and hydrological soil group.

3.4.6 Curve number from field data

Curve number was determined for the watershed, using the recorded rainfall-runoff (P-Q) episodes. To this end, S, the retention volume for each P-Q pair was calculated using the equation

$$S = 5\left[(P + 2Q) - \sqrt{Q(4Q + 5P)}\right] \qquad (3\text{-}1)$$

Where S is in mm and P and Q are cumulative values of that event both in mm. S was transformed to CN scale using the following empirical relation;

$$CN = \frac{25{,}400}{S + 254} \qquad (3\text{-}2)$$

By using this procedure the CN was derived for individual events and the corresponding runoff was derived using the unit hydrograph.

3.4.7 Antecedent moisture condition conversion

AMC conversion was done based on Sobhani (1975) fromula. Since in the present case a rainless period of 3 days was selected based on MIT, all events would result to be either in AMC_{II} or AMC_{I} condition.

3.4.8 Time of concentration

Time on concentration is required to calculate the Time of Peak (T_p) that will be used in the calculation of SCS unit hydrograph. Based on the literature review the Kirpich's equation was used. Although there exist a method to calculate the T_c based on SCS lag method as;

$$T_{lag} = L^{0.8} \frac{(S+1)^{0.7}}{1900\sqrt{Y}} \tag{3-3}$$

Where:

T_{lag} = Lag time in hours.

L= Hydraulic length of watershed in feet.

Y = watershed slope in percent.

S = maximum retention in the watershed in inches as defined by (1000/CN)-10

However, this method results in the use of CN value and therefore the unit hydrograph ordinates would vary for each event making the computation extremely complex.

3.5 Model development

3.5.1 Spreadsheet model for computation

There is no use of software package in the current work. Instead spreadsheets were developed using the Microsoft Excel program to compute the following;

i. Effective rainfall

ii. SCS unit hydrograph

iii. Direct runoff hydrograph

3.5.2 Effective rainfall computation

Among the various methods discussed in Chapter 2, the most relevant for this study was the SCS infiltration model. Simulation of water infiltration through a loamy sandy soil, e.g. a sandy material is bounded above by the soil surface and below by the groundwater table. It is important to note that initial soil moisture content, rainfall rate and duration and surface runoffs are factors that affect the rate of water infiltration into the soil. The purpose is to calculate the daily infiltration amount into the soil profile. Whenever there is a lack of soil moisture data or insufficient definition of the boundary conditions, the SCS model is a suitable semi-empirical model.

$$R = (P - 0.2S_w)^2/(P + 0.8S_w) \qquad (3\text{-}4)$$

-for $P>0.2S_w$, R=0

-for $P<0.2S_w$, and Q=P-R

Where;

R=Runoff, millimetres

P= Daily rainfall, millimetres

S_w= (25400/CN)-254

3.5.3 SCS unit hydrograph computation

The unit hydrograph for every watershed is different. In the SCS-UH computations, the runoff hydrograph for one unit of excess rainfall on the selected catchment is determined. Peak discharge and the corresponding time to peak of standard SCS-UH are computed using catchment parameters. Since the rainfall data are of daily resolution, a one day SCS-UH was developed. Once the time to peak and the peak discharge were computed then the co-ordinates of Curvilinear UH can be determined (Chow et al., 2010). The developed UH was checked for input output balance prior to using for modelling. Direct Runoff Hydrographs (DRH) for selected events were computed by applying effective rainfall on the SCS-UH model and using superposition.

3.5.4 Direct runoff hydrograph computation

The UH model computes the DRH for a corresponding unit depth of effective rainfall. Effective rainfall was calculated from rainfall events using SCS-CN method and applied for UH model to compute the DRH. In this model it is assumed that effective rainfall fraction is contributed to the direct runoff while the rest is infiltrated into the ground and contributes to the sub-surface storage. The total runoff hydrograph is then computed by adding baseflow and direct runoff hydrographs. Spreadsheet model computations were checked to ensure fulfilling of input-output balance when generating the hydrographs.

3.5.5 Hydrograph for catchment curve number value

Event hydrographs generated using the catchment averaged CN value were compared using the MRAE as the objective function. MRAE for the entire hydrograph, for the peak flow and the time to peak were evaluated to identify the degree of matching.

3.5.6 Optimizing event curve number values

Evaluations carried out using catchment CN value computed using literature guidance reflected the need to modify the CN value for best matching. Therefore, CN values were considered as parameters and optimized to study the model performance.

3.5.7 Model calibration and validation

Calculated streamflow of each event using SCS model were matched by optimizing the CN value for that event. As such optimized CN values were determined for each calibration event. Model calibration was done using 20 events while another 20 events were used for verification.

The MRAE values of the event, the RAE (Ratio of Absolute Error) values of peak flow, time to peak, time base and streamflow volume were computed and compared during model parameter optimization. Model verification was carried out with the average CN from the calibrated events. Performance of model was compared by considering various possible scenario.

4 RESULTS AND ANALYSIS

4.1 Event Selection

4.1.1 Minimum inter-event time (MIT)

Based on the literature as specified by Linsley, Kohler & Paulhus (1975) on the N value concept for event separation, a duration of 72 hours of rainless period was taken as the minimum inter-event time gap between the two consecutive rainfalls.

4.1.2 Rainfall and streamflow selection

Primarily after specifying the criteria of 72 hours MIT for event selection, the streamflow events were selected based on the hydrograph profile. The starting of the event was selected when the streamflow starts to respond to the rainfall and the end was taken as the point of recession or the duration N as recommended by Pettyjohn and Henning (1979).

Special consideration was made that no event selected would fall in the data missing period, i.e. for the event to be selected there would have to be rainfall data available from all the four rain gauging stations.

Based on the MIT value, a total of 96 events were selected from 2005-2017. The total period was broken in terms of calibration and validation as shown in Table 4-1.

Table 4-1: Data period distribution for calibration and verification events

Purpose	Data Period
Calibration	01/01/2005 to 31/12/2011
Verification	01/01/2012 to 30/09/2017

However, in order to make a representative sample of data based on flow categories, EPA (2007) was used as the reference since it had five classifications of flow enabling the research to focus on a finer classification as shown in Figure 4-1 for calibration events and Figure 4-2 for verification events.

Key features of the 40 events are summarized in Table 1 (Appendix - B). Variation of peak flow, rainfall duration and maximum rainfall are given in the table.

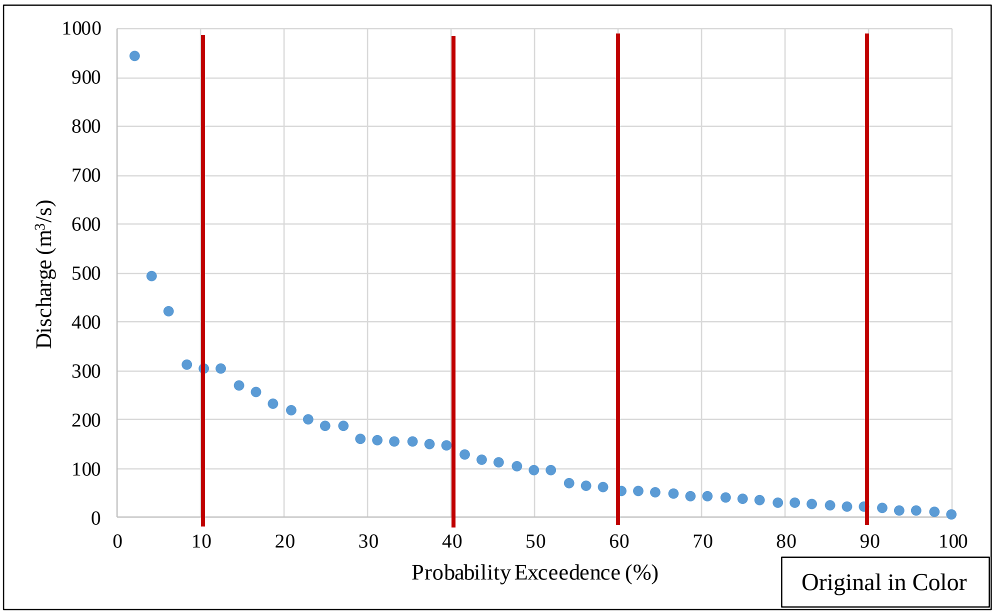


Figure 4-1: Flow classification for calibration events

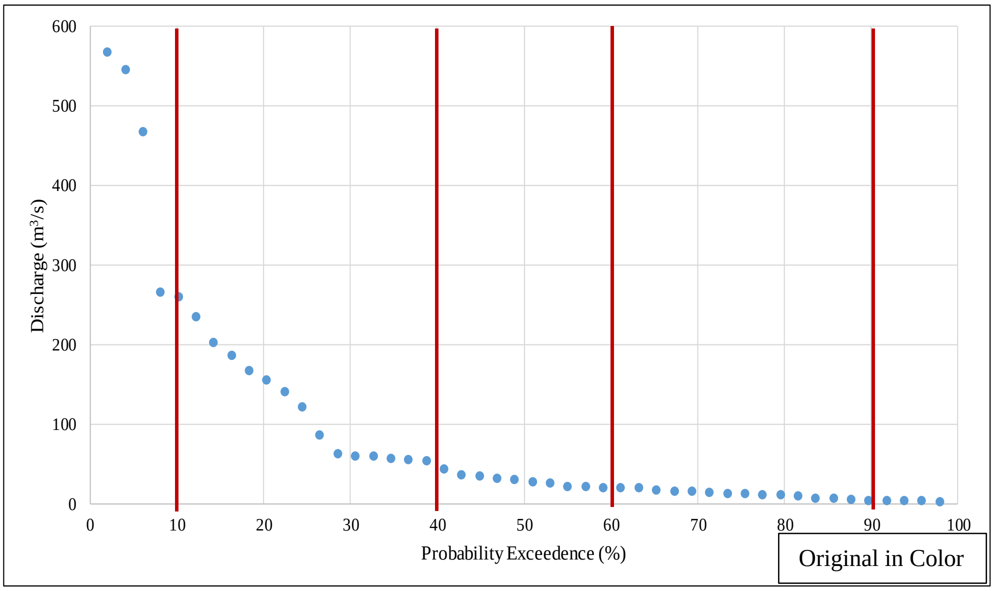


Figure 4-2: Flow classification for verification events

Based on the classification a total of four events comprising of two from Yala season and two from Maha season were selected from each classification resulting in 20 events for calibration and 20 events for verification. The events that had a shorter duration were chosen first followed by any other event with representative peak value.

As seen in the Figure 4-1, the distribution is representative except event E1 which has a very high peak discharge of 944.6 m^3/s. Figure 4-3 shows the correlation between peak flow and cumulative discharge of each event while Figure 4-4 shows the different peak flow for all the events of calibration and verification. The details of the total discharge over the entire individual rainfall event is shown in Figure 4-5. Is was found that where there is a high peak discharge, the overall event rainfall is also high inferring that most contribution to an event occurs from a peak rainfall event.

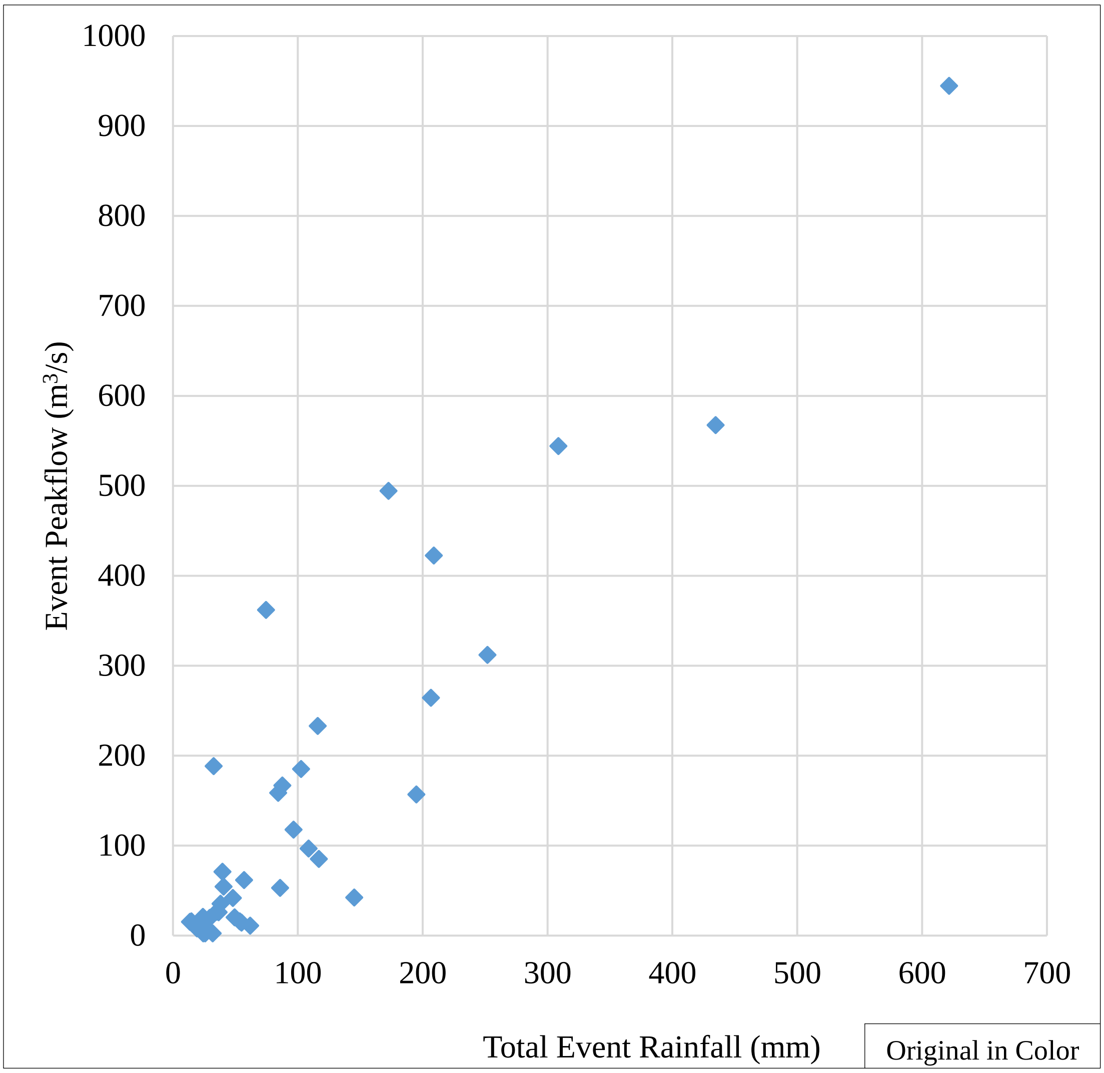


Figure 4-3: Correlation between event peak flow and total event rainfall

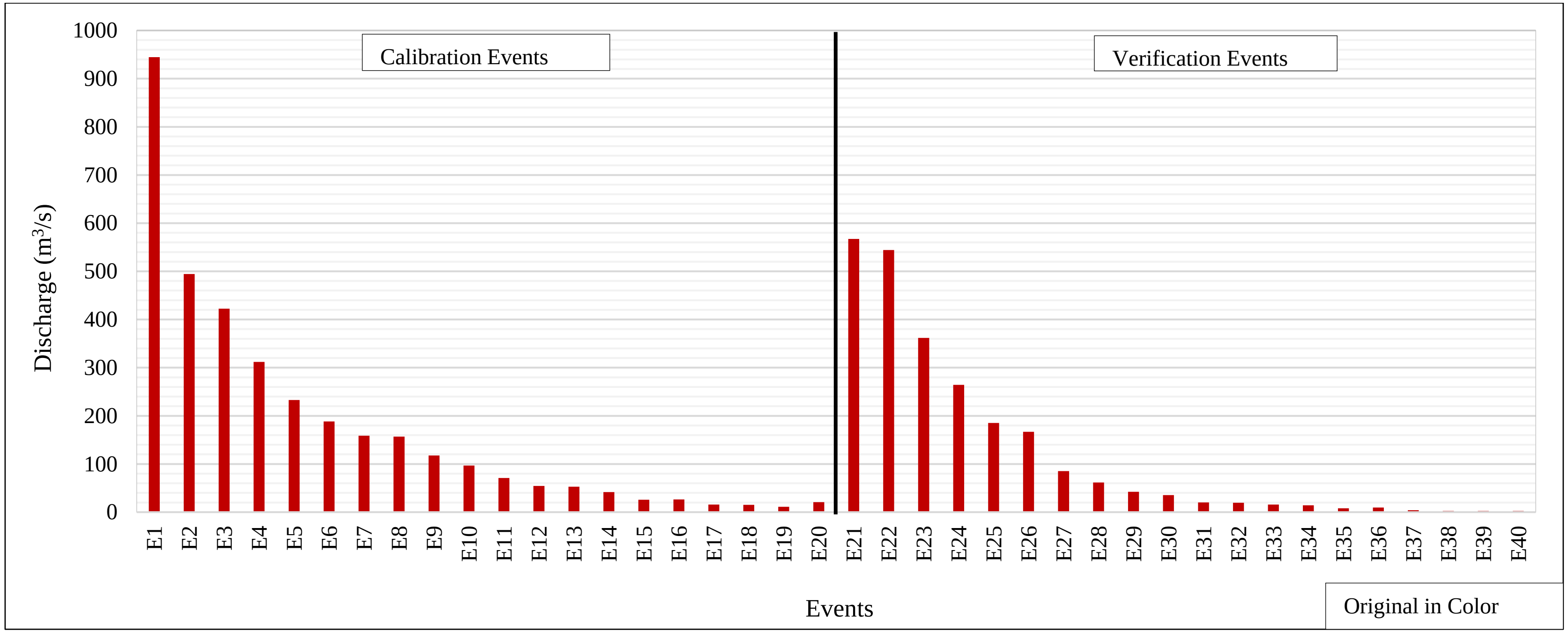


Figure 4-4: Peak flow of each event

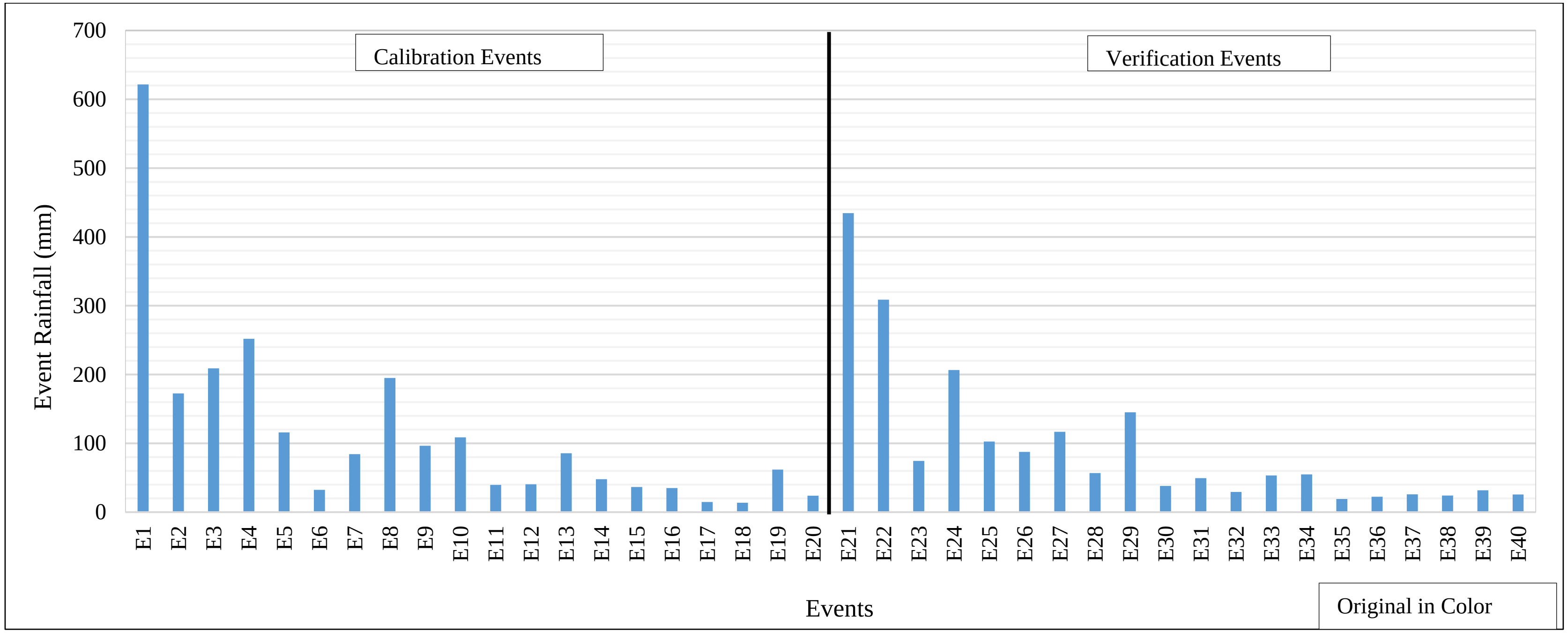
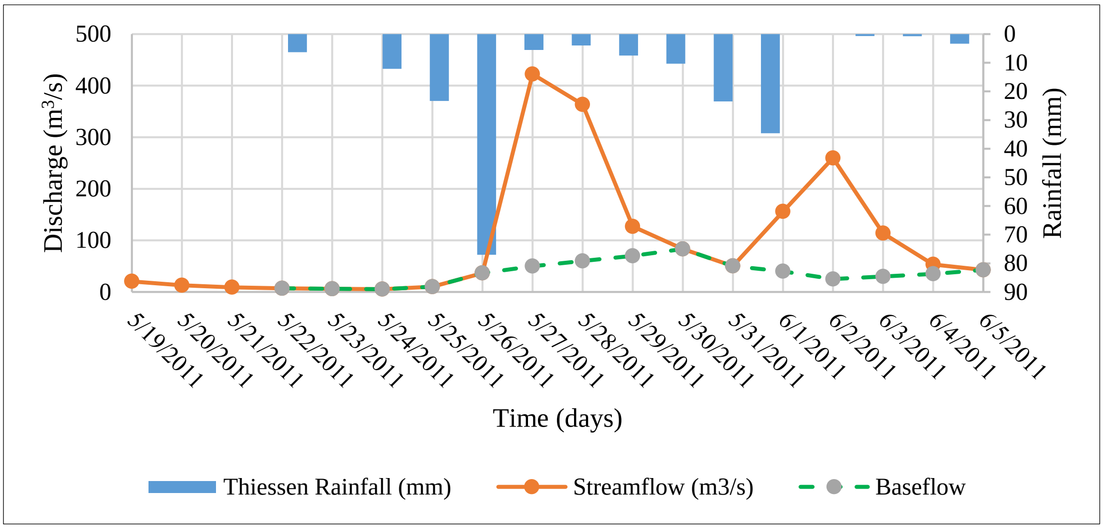


Figure 4-5: Cumulative event rainfall for all events

4.13 Baseflow separation

Baseflow separation of all the 40 events was carried out as per the procedure prescribed by Pettyjohn et al. (1979). This was achieved as per the concave method which was discussed under Section 3.4.4. Figure 4-6 (a) and (b) show the baseflow separation carried out for Event E3 and Table 4-2 shows the details of the rainfall, streamflow, direct runoff and baseflow volume of all the 40 events. The details of the computed values and graphs of each event is given in Appendix C.



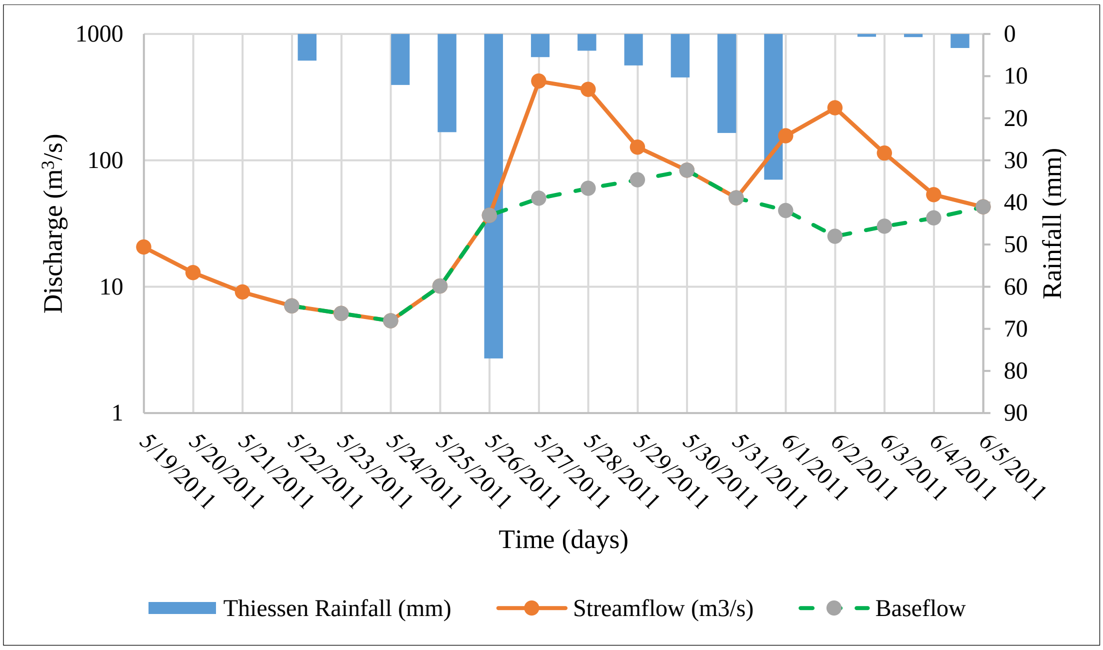


Figure 4-6: Streamflow hydrograph and baseflow separation of event number E3
(a) Normal Graph (b) Log graph

Table 4-2: Baseflow separation and streamflow details for all events

Event ID	Rainfall duration (days)	Rainfall (MMC)	Streamflow (MMC)	Total DRO (MMC)	Total baseflow (MMC)
E1	24	831.13	717.75	356.28	361.47
E2	17	230.77	119.84	98.40	21.44
E3	15	279.39	150.09	102.43	47.66
E4	14	336.77	142.81	90.56	52.25
E5	9	154.93	77.60	47.33	30.27
E6	8	43.47	35.47	17.41	18.06
E7	14	112.74	48.29	28.70	19.59
E8	9	260.70	65.34	44.43	20.92
E9	8	129.09	20.59	13.66	6.92
E10	11	145.28	35.08	19.25	15.83
E11	8	52.99	21.50	8.42	13.08
E12	6	54.23	12.06	8.10	3.96
E13	9	114.63	22.43	15.65	6.78
E14	7	64.15	11.59	4.78	6.81
E15	7	48.91	9.50	3.93	5.57
E16	5	46.77	9.58	2.12	7.46
E17	8	19.71	6.61	1.50	5.10
E18	6	18.21	3.21	1.51	1.69
E19	9	82.71	3.96	2.40	1.56
E20	7	32.13	7.93	4.68	3.24
E21	20	581.10	312.28	226.71	85.57
E22	18	412.78	142.48	123.55	18.94
E23	6	276.31	155.49	82.95	72.54
E24	14	99.70	34.91	28.42	6.49
E25	10	137.11	35.83	29.28	6.55
E26	9	117.09	45.76	34.63	11.13
E27	8	156.13	22.07	15.52	6.55
E28	8	76.13	12.94	8.54	4.40
E29	14	194.17	26.30	22.26	4.04
E30	10	50.92	9.70	6.29	3.41
E31	9	66.10	8.66	5.14	3.52
E32	7	39.38	6.44	3.50	2.93
E33	9	71.43	6.95	4.85	2.11
E34	8	73.44	5.07	1.26	3.81
E35	7	25.67	2.24	1.14	1.10
E36	7	30.04	3.11	1.22	1.89
E37	5	34.73	0.70	0.22	0.49

Event ID	Rainfall duration (days)	Rainfall (MMC)	Streamflow (MMC)	Total DRO (MMC)	Total baseflow (MMC)
E38	6	32.41	0.93	0.06	0.87
E39	5	42.54	0.70	0.08	0.62
E40	6	34.39	0.94	0.16	0.78

4.2 Direct runoff hydrograph

Since the data resolution was of daily time step, the DRH was also prepared for the same resolution. The effective rainfall computed based on the SCS-CN method was used to produce the DRH using the convolution theorem.

A unit hydrograph (UH) based on the catchment properties was prepared. The SCS-UH was selected in the present case. However, in order to make the analysis solely dependent on the CN variability change, the time of concentration was not derived using the SCS method but with the Kirpich method.

The catchment properties are tabulated in the Table 4-3. The longest stream from the furthest part of the catchment was 100.51 kilometres long. The slope calculated based on the elevation at the outlet and the lowest point at the catchment was found to be 1.45%. Following this, the T_c was 705.94 minutes. As discussed, the standard duration t_r was taken as 1440 minutes and the basin lag time t_p was found to be 423.56 minutes resulting in the time to peak (T_p) to be 1143.57 minutes. The corresponding peak discharge (Q_p) was 145.91 m^3/s.

Table 4-3: Badalgama watershed characteristics

Sl. No.	Description			Units	Result
	Notation	Meaning	Formula		
1	L	Length of stream	-	meters	100,551.45
2	S	Slope of catchment	-	%	1.45
3	T_c	Time of concentration	$0.0078\left(\frac{L^{0.77}}{S^{0.385}}\right)$	minutes	705.94
4	A	Catchment area	-	km^2	1337.03
5	t_r	Standard duration	-	minutes	1440.00
6	t_p	Basin lag time	$0.6 * T_c$	minutes	423.56

Sl. No.	Description			Units	Result
	Notation	Meaning	Formula		
7	T_p	Time to peak	$\frac{t_r}{2} + t_p$	minutes	1143.57
8	Q_p	Peak Discharge	$2.08\frac{A}{T_p}$	m^3/s-cm	145.91

Computation of the UH was done at a time resolution of 1.905 hours. The curvilinear UH for the watershed is as shown in Figure 4-7 and the details of the ratios of t/t_p and q/q_p is shown in Table D-1 under Appendix D. Chow et al. (2010) was referred for the ratio computation.

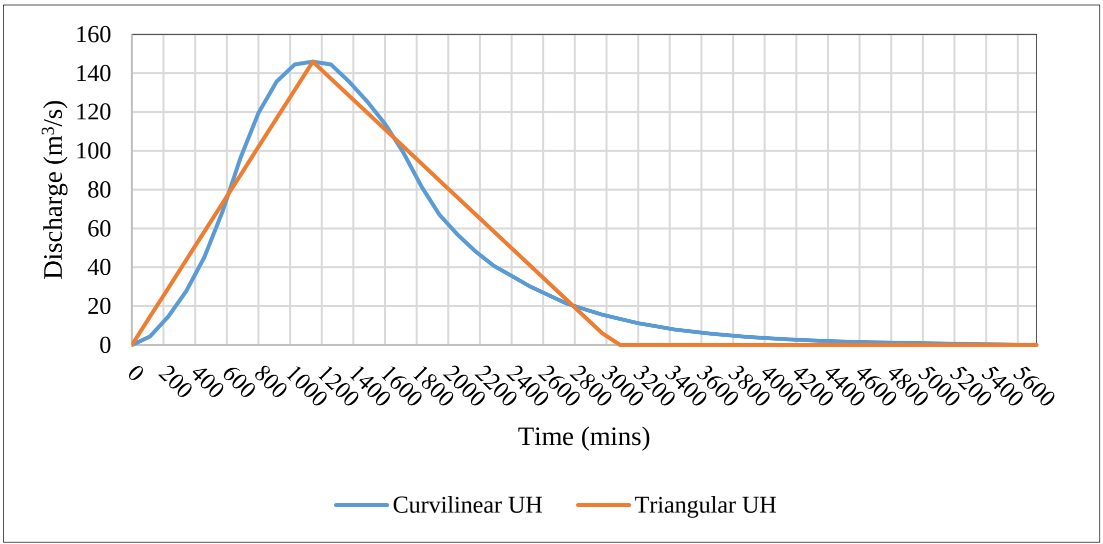


Figure 4-7: Unit hydrograph of the watershed

4.3 Estimation CN_{II} from NEH-4 handbook

The present work consisted of two methods of deriving the curve number. The first method is to compute as per the NEH-4 handbook recommended method from land use, soil class and normal moisture condition (AMC_{II}). The first step in the procedure was to compute the effective rainfall based on the rainfall amount from each day in the event. The direct runoff from observed data was calculated by subtracting the baseflow from the observed streamflow. To get the simulated streamflow, the effective rainfall was used in the SCS-UH model.

As discussed in methodology chapter, the curve number to be computed from the handbook was based on land use, soil type and AMC. A normal condition of soil moisture was selected (AMC_{II}) with the standard initial abstraction value of 0.2 to compute the curve number for each land use under the soil Type C since 64.6% of the area fell under red pudzolic soil type classified under Type C. The weighted value of the curve number was 83.45 and was taken for the study area. The highest CN was for waterbodies and marsh at 98 and the lowest was for grassland which was 74. The details of each of the CN value as per the land use and its weighted CN is shown in Table 4-4.

Table 4-4: Weighted curve number of the watershed

Land use Type	**Area (km^2)**	**Soil Group C**		
		Area (%)	**CN**	**Weighted CN**
Agriculture	202.72	15.17	88	1334.96
Built-up Area	17.63	1.32	78	102.96
Forest	34.73	2.6	77	200.20
Grassland	50.59	3.79	74	280.46
Homesteads	267.29	20.00	78	1560.00
Marsh	0.85	0.06	98	5.88
Plantations	753.04	56.34	85	4788.90
Waterbodies	9.70	0.73	98	71.54
Weight CN value for the watershed				**83.45**

The average MRAE of the 40 events was 2.18 while the RMAE was 2.08. The RAE of Q_p, T_p, T_b and the volume under hydrograph was 2.90, 0.32, 0.24 and 1.97, respectively.

Comparison of the observed and calculated hydrographs with event rainfall are in Table E1 (Appendix E). Key values of the streamflow estimation using the weighted CN_{II} for the watershed are shown in Appendix F.

Evaluated results were plotted with both volume and MRAE values of each event in Figure 4-8. The hydrographs estimated using the weighted CN method showed a significant mismatch.

4.4 Estimation of CN_{II} from rainfall-runoff data

In this method, firstly the parameter S (potential maximum retention) was calculated based on the cumulative rainfall and runoff of individual events. The S value was converted to CN using the empirical relation in Equation 3-1. The rest of the procedure of computing the effective rainfall and deriving the direct runoff values of the simulated streamflow were the same as both methods used UH method for uniformity in comparison.

The average MRAE, with a value of 0.46 was 475% better than that with the CN_{II} from handbook method. While considering the standards of a hydrological modelling results it is however, still not very good. Evaluated results were plotted with both volume and MRAE values of each event in Figure 4-9.

The RMAE was 0.56 and RAE of Q_p, T_p, T_b and the volume under hydrograph was 1.39, 0.31, 0.41 and 0.37, respectively.

Comparison of the observed and calculated hydrographs with event rainfall are in table G1 (Appendix G). Key values of the streamflow estimation using the rainfall-runoff derived CN_{II} for the watershed are shown in Appendix H.

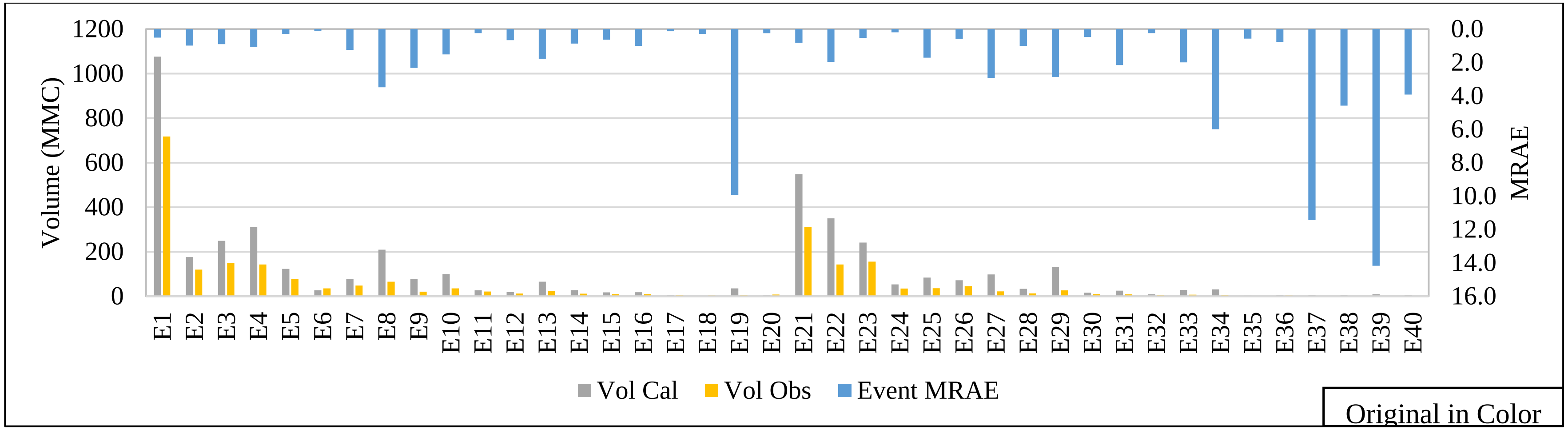


Figure 4-8: Comparison between observed and simulated volume using CN_{II} values from handbook and its MRAE values

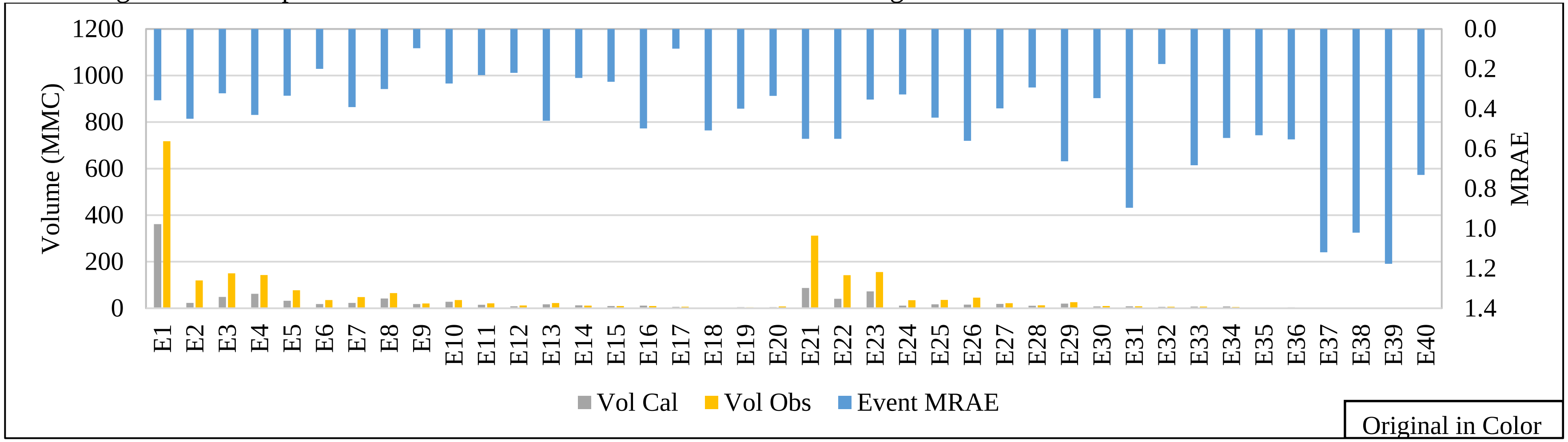


Figure 4-9: Comparison between observed and simulated volume using CN_{II} values from field data and its MRAE values

4.5 Estimation with CN_I values from NEH-4 handbook

In this method, the CN_I was computed for each event using conversion formula of Shobani (1975) and the resulting CN value was used to derive the S value. The CN_I value that resulted from this was 68.38 which was less by 15.09 (or 18%) than the CN_{II} value from the same method. This resulted in the S value increasing by 133% from 50.4 mm to 117.6 mm.

The rest of the procedure of computing the effective rainfall and deriving the direct runoff values of the simulated streamflow were the same as all methods used UH method for uniformity in comparison.

The average MRAE of the 40 events was much better than method using CN_{II} values from handbook. The value of MRAE was 0.60 and 0.72 for RAEM. The RAE of Q_p, T_p, T_b and the volume under hydrograph was 1.08, 0.39, 0.31 and 0.55, respectively.

Evaluated results are plotted with both volume and MRAE values of each event in Figure 4-10. Comparison of the observed and calculated hydrographs with event rainfall are in table I1 (Appendix I). Key values of the streamflow estimation using the CN_I from this method are shown in Appendix J.

4.6 Estimation with CN_I from rainfall-runoff data

The CN_{II} computed from the general process of determining the S value from the cumulative rainfall and runoff was converted to CN_I for individual events. The remaining procedure of computing the effective rainfall and deriving the direct runoff value was the same as above.

The MRAE and RMAE was 0.36 and 0.54, respectively while RAE of Q_p, T_p, T_b and the volume under hydrograph was 1.95, 0.60, 1.29 and 0.55, respectively.

However, the most crucial finding here is that the low value of MRAE and RAEM does not correctly represent the real watershed condition. Due to the excessive low value of CN, resulting in high initial abstraction value, 39 out of 40 events did not yield effective rainfall resulting in no production of direct runoff hydrographs.

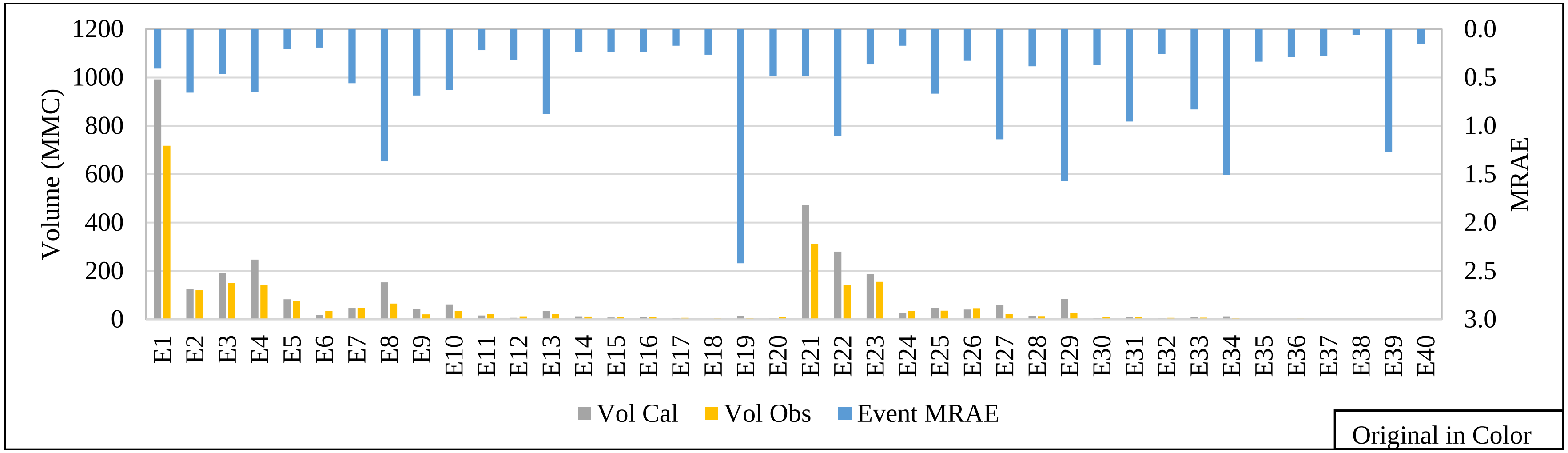


Figure 4-10: Comparison between observed and simulated volume using CN_I values from handbook and its MRAE values

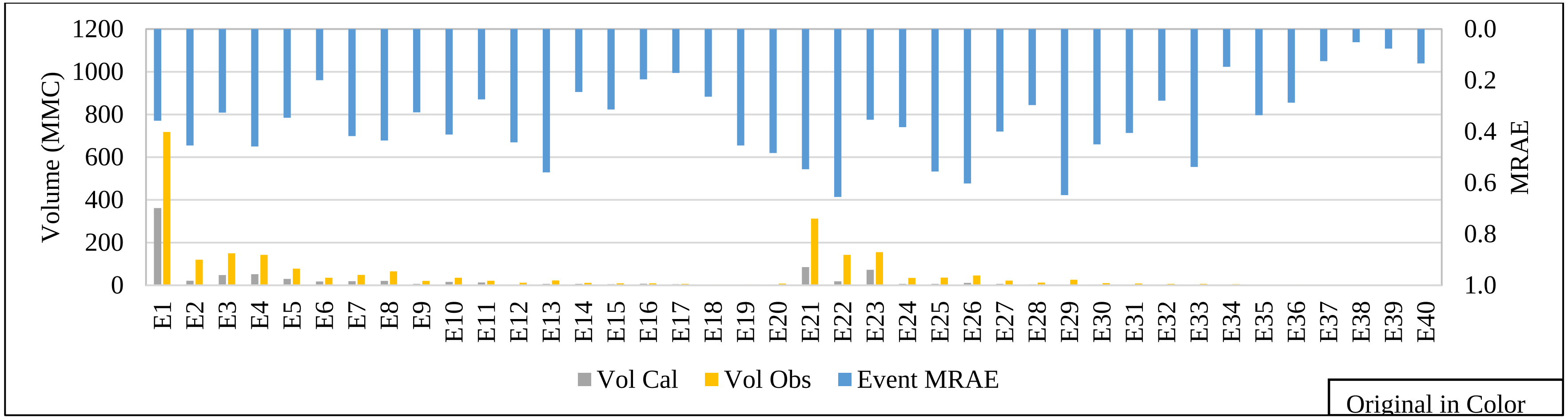


Figure 4-11: Comparison between observed and simulated volume using CN_I values from field data and its MRAE values

Evaluated results were plotted with both volume and MRAE values of each event in Figure 4-11. Comparison of the observed and calculated hydrographs with event rainfall are in table K1 (Appendix K). Key values of the streamflow estimation using the rainfall-runoff derived CN_I for the watershed are shown in Appendix L.

Overall, the results made it clear that there is a need to check the effect of changing curve number for individual event, hence the events were manually calibrated. The average value of the calibration events were taken as the optimum CN value of the watershed and was used to verify the model.

4.7 Model calibration

The selected 40 events were divided in two parts of calibration and verification. Event E1 to E20 were used for calibration and E21 to E40 for verification. The results of the calibration events are shown in Table 4-5 and plotted in Appendix O. Model parameter CN was optimized for each event by trial and error method for best fit of observed and simulated hydrographs. The MRAE was considered as the objective function for hydrograph matching.

Table O2 (Appendix O) shows the optimized CN, MRAE and other parameters for each event in sorted order. Average CN of 60.04 was computed yielding average MRAE and RAEM of 0.22 and 0.30, respectively. The other parameters, RAE of Q_p, T_p, T_b and the volume under hydrograph was 0.53, 0.21, 0.31 and 0.24, respectively. Key values of the streamflow estimation of calibration events using optimized CN values are shown in Appendix P.

Overall matching of the hydrographs and peak flows was very good. Variation of simulated and observed streamflow volume of each event is shown in Figure 4-12 and 4-13 and shows the goodness of fit during calibration events.

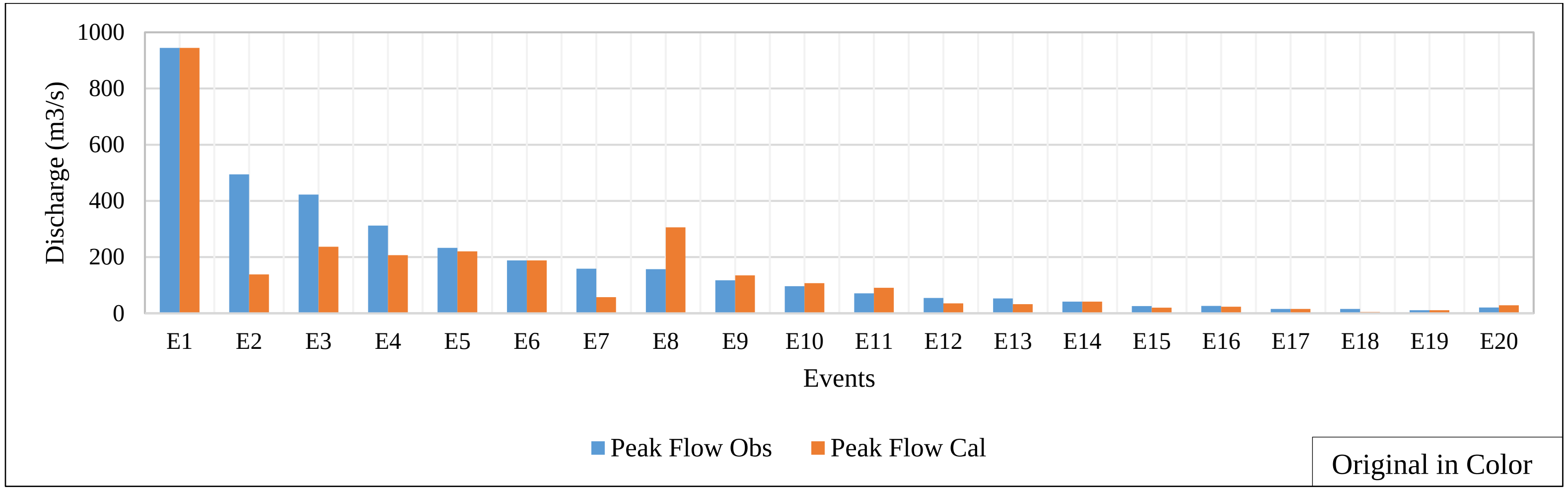


Figure 4-12: Comparison of simulated and observed peak flow during calibration

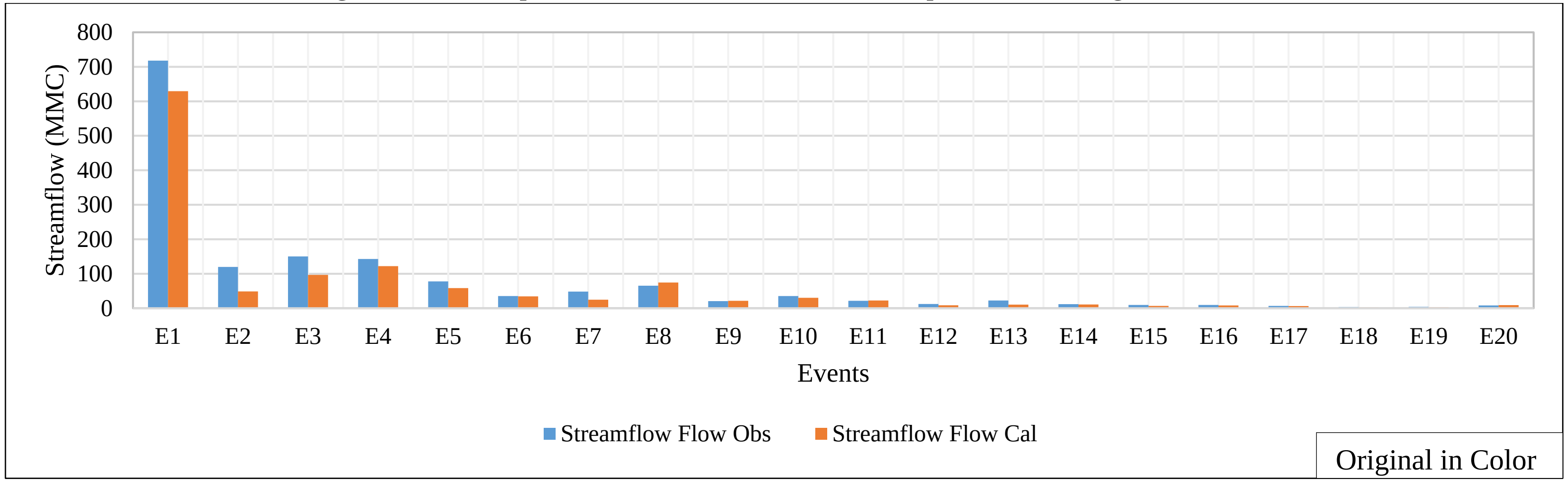


Figure 4-13: Comparison of simulated and observed streamflow during calibration

Table 4-5: Calibrated CN values, other key features and indicators

Event ID	From	To	Total RF (mm)	CN	Qp (m3/s)		Tp (day)		Tb (day)		Vol (MMC)		Error (RAE)				Event MRAE	Event RAEM
					Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Qp	Tp	Tb	Vol		
E1	10/30/2006	11/22/2006	621.6	28.50	944.6	944.6	20	20	5	5	629.3	717.8	0.00	0.00	0.00	0.12	0.22	0.23
E2	7/11/2008	7/27/2008	172.6	41.84	138.5	494.3	12	8	6	10	48.4	119.8	2.57	0.50	0.40	0.60	0.32	0.67
E3	5/22/2011	6/5/2011	209.0	42.03	236.8	422.4	11	5	5	11	96.6	150.1	0.78	0.55	1.20	0.36	0.26	0.45
E4	9/27/2010	10/10/2010	251.9	39.55	206.8	312.0	12	5	3	10	122.0	142.8	0.51	0.58	2.33	0.15	0.42	0.40
E5	4/24/2008	5/2/2008	115.9	56.52	220.3	233.0	4	5	6	5	58.3	77.6	0.06	0.20	0.20	0.25	0.17	0.25
E6	12/16/2006	12/23/2006	32.5	89.61	188.3	188.3	4	4	5	5	34.4	35.5	0.00	0.00	0.00	0.03	0.05	0.04
E7	1/4/2006	1/17/2006	84.3	50.20	57.5	158.7	10	10	5	5	24.8	48.3	1.76	0.00	0.00	0.49	0.36	0.49
E8	6/19/2006	6/27/2006	195.0	45.63	305.8	156.9	4	5	6	5	74.5	65.3	0.49	0.25	0.17	0.14	0.23	0.32
E9	1/29/2005	2/5/2005	96.5	54.74	135.2	117.7	4	4	5	5	21.5	20.6	0.13	0.00	0.00	0.04	0.06	0.11
E10	6/5/2010	6/15/2010	108.7	50.42	107.2	96.7	7	7	5	5	30.2	35.1	0.10	0.00	0.00	0.14	0.26	0.23
E11	11/19/2007	11/26/2007	39.6	79.01	91.0	70.9	4	4	5	5	22.5	21.5	0.22	0.00	0.00	0.05	0.11	0.15
E12	8/20/2010	8/25/2010	40.6	72.48	35.3	54.5	2	2	5	5	8.7	12.1	0.54	0.00	0.00	0.28	0.20	0.29
E13	4/15/2006	4/23/2006	85.7	47.26	32.3	53.0	4	2	6	8	10.2	22.4	0.64	0.50	0.33	0.54	0.43	0.56
E14	3/3/2011	3/9/2011	48.0	65.74	41.8	41.8	3	3	5	5	10.7	11.6	0.00	0.00	0.00	0.08	0.15	0.19
E15	3/29/2006	4/4/2006	36.6	66.75	20.3	25.9	4	3	4	5	6.8	9.5	0.27	0.25	0.25	0.29	0.22	0.29
E16	12/15/2008	12/19/2008	35.0	65.15	23.5	26.5	3	1	3	4	8.0	9.6	0.13	0.67	0.33	0.16	0.16	0.18
E17	7/31/2007	8/7/2007	14.7	85.16	15.8	15.8	4	4	5	5	6.0	6.6	0.00	0.00	0.00	0.09	0.08	0.09
E18	8/15/2011	8/20/2011	13.6	81.87	4.9	15.3	4	2	3	5	1.8	3.2	2.10	0.50	0.67	0.43	0.23	0.44
E19	3/12/2007	3/20/2007	61.9	50.99	11.1	11.1	5	5	5	5	2.4	4.0	0.00	0.00	0.00	0.39	0.35	0.39
E20	3/20/2011	3/26/2011	24.0	87.29	28.7	20.8	4	3	4	5	8.9	7.9	0.28	0.25	0.25	0.13	0.14	0.19
												Max	***2.57***	***0.67***	***2.33***	***0.60***	***0.43***	***0.67***
												Min	***0.00***	***0.00***	***0.00***	***0.03***	***0.05***	***0.04***
												Average	***0.53***	***0.21***	***0.31***	***0.24***	***0.22***	***0.30***

The following three graphs (Figure 4-14 to 4-16) show the MRAE values of the 20 calibrated events, the variation of the curve number, and the variation of MRAE. Figure 4-14 gives the visual representation of different events based on its MRAE value. Here, event E6 has the best MRAE and the E13 has the worst, however, all values are below 0.5.

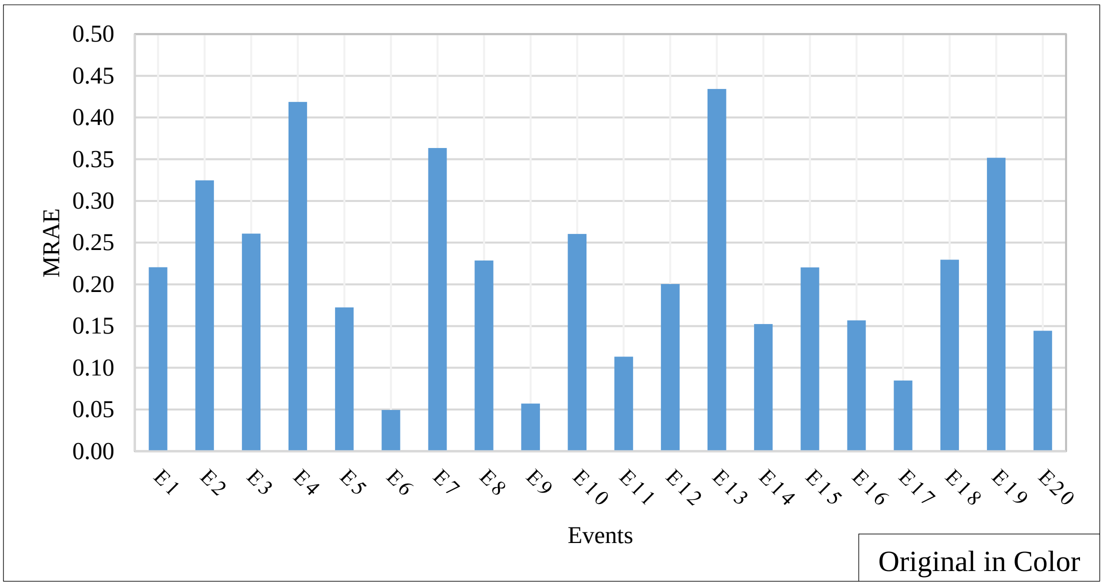


Figure 4-14: Variation of MRAE vs events for calibration data

Figure 4-15 shows the variation of the curve number for the different events that were sorted based on their MRAE values while Figure 4-16 shows the variation of MRAE and the CN values of calibrated events. Here it is seen that events whose CN value is greater than 50 has lower MRAE compared to the ones with lower CN values.

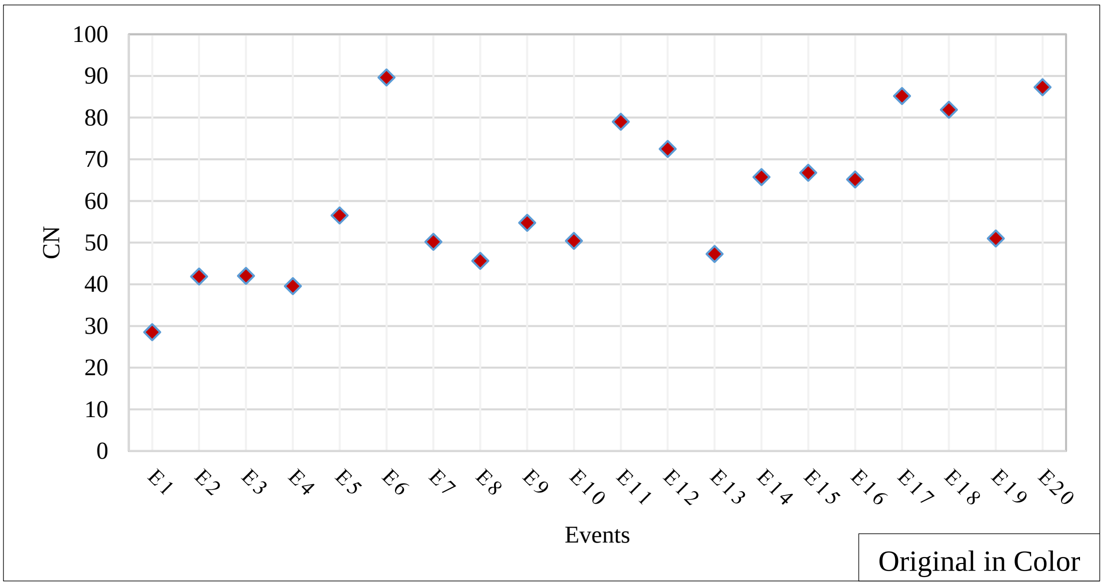


Figure 4-15: Variation of optimized CN during calibration

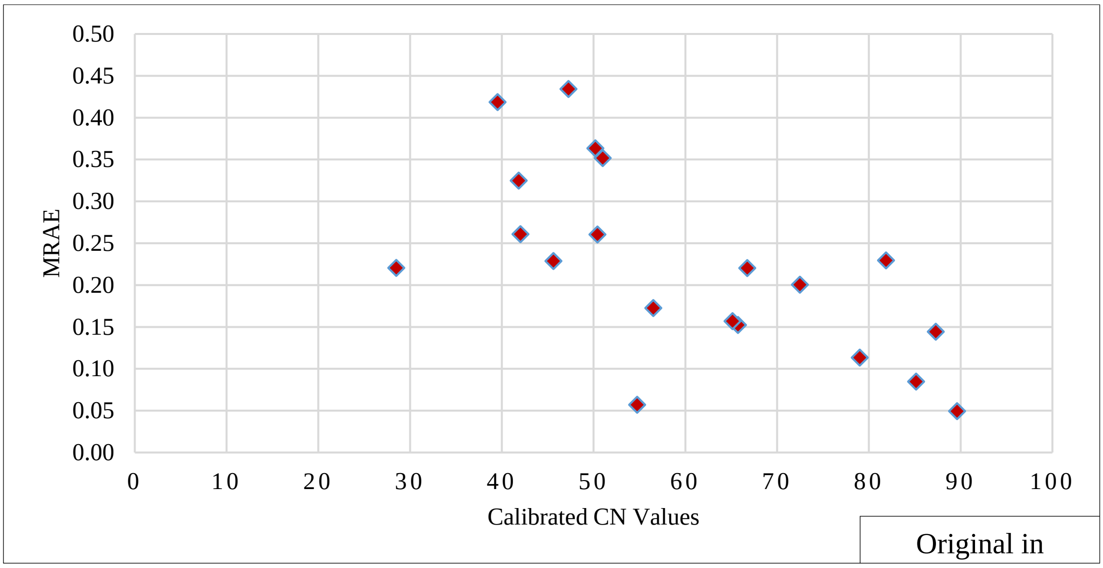


Figure 4-16: Variation of MRAE with CN for calibration events

4.8 Model verification

During the calibration of individual events it was observed that minimum and maximum CN values were 89.61 and 28.50. Figure 4-17 shows the frequency of the CN values, showing majority of the events to fall below 60. The average CN value of 60.04 was used to in verification data.

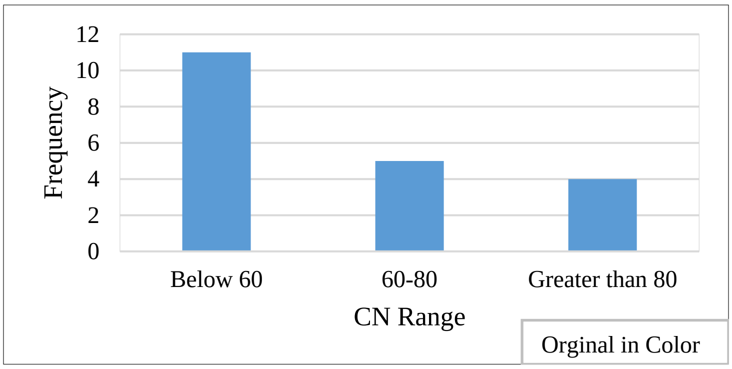


Figure 4-17: CN frequency in calibration

The average MRAE of the verification events was 0.37 while the RMAE was 0.49. The RAE of Q_p, T_p, T_b and the volume under hydrograph was 0.78, 0.43, 0.42 and 0.37, respectively. Verification results show a fairly good match between computed and observed streamflow but not as good as the calibration data.

Comparison of the observed and calculated hydrographs with event rainfall are in table M1 (Appendix M). Key values of the streamflow estimation for the verification dataset in shown in Appendix N. Comparison of the streamflow volume and MRAE values is shown in Figure 4-18.

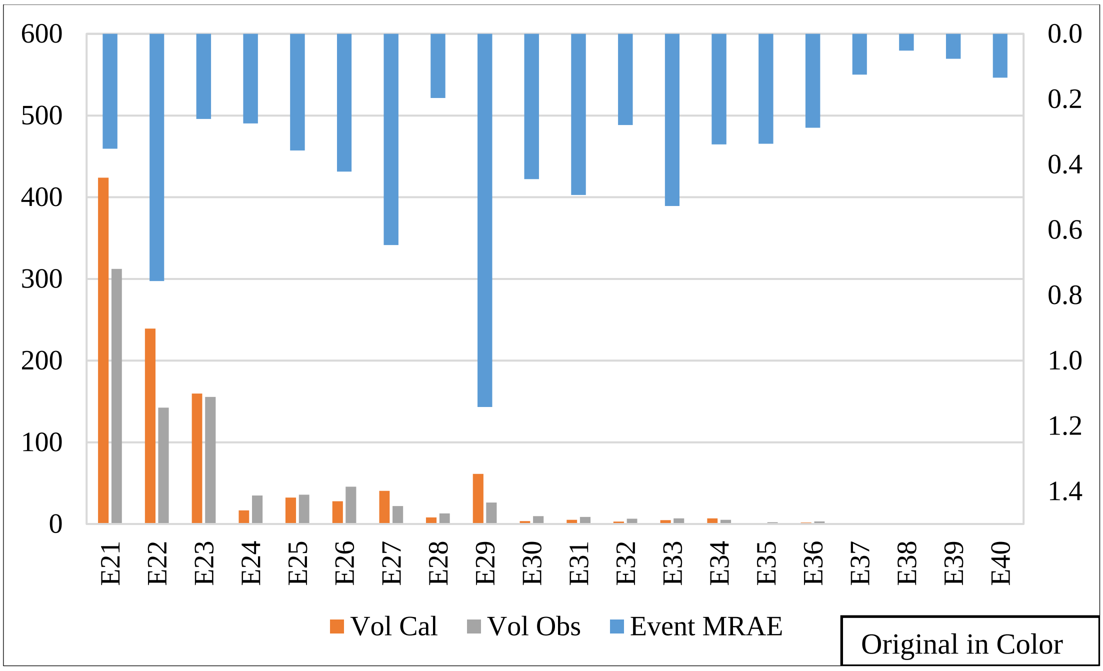


Figure 4-18: CN frequency in verification events

4.9 Summary of events

Along with the calibration events, the verification events were also finally individually optimized to capture the best fit CN value. However, even in this case the average CN value of E21 to E40 was 60.55 which is the same as derived from the average of the optimized calibration events.

The average MRAE and RAEM of 0.26 and 0.34 respectively was observed. The other parameters, RAE of Q_p, T_p, T_b and the volume under hydrograph was 0.26, 0.22, 0.38 and 0.26, respectively. All these values are almost the same as that for calibration events.

Comparison of the observed and calculated hydrographs with event rainfall are in table Q1 (Appendix Q). Key values of the streamflow estimation for the verification dataset in shown in Appendix R.

5 DISCUSSION

5.1 Event selection

This present research used daily runoff (stream flow) and rainfall data from the Badalgama stream gauging station and four rain gauging stations (Ambepussa, Andigama, Aranayake and Eraminigolla) for a period from January 2005 to September 2017. The data for the year 2009 was not considered due to excessive missing data (9 consecutive months of missing data in Eraminigolla gauging station).

The events selected for the study were from those periods where the rainfall data was available from all the stations. Based on the literature recommended MIT values, a total of 97 events were selected for analysis. Among these, the data was broken in two parts for calibration (2005-2011) and verification (2012-2017) and a probability exceedance graph was plotted to classify the events based on high, moist, mid-range, dry and low flow regimes. This was carried out to ensure that a representative sample of data was selected. Among the data set, 4 events (2 from Maha season and 2 from Yala season) for each flow classification were chosen, totalling 20 events for calibration and 20 for verification. This also resulted in 20 events from Maha and 20 from Yala season to be selected, respectively. This was expected to make the model predict reasonable results for application throughout a year, covering both seasons.

While selecting the events from this lot, considering the ease of computation, the events that were shorter were selected first followed by the longer events. The duration of all 40 events were analysed to evaluate the event distribution. It was found that 35.0% of the events were between 1 ~ 6 days, 52.5% were between 7 ~ 13 days and 12.5% were greater than 13 days. The longest event was found to expand over 23 days while the shortest was mere 4 days. The average length of the events was 8.6 days.

The MIT value for the watershed was 3 days. The starting point at which the observed streamflow hydrograph responds to rainfall event was considered as starting point of the event and the infliction point of the hydrograph was considered as the end point. However, in some events, when it was not possible to clearly identify the inflection point, and for such cases, the N value suggested by Linsley et al., (1975) was taken to determine the end point of the direct runoff which was 3 days.

5.2 Data resolution

Typically, unit hydrographs yield good results on hourly or finer data resolution. In the present case, the data resolution was daily and was perceived to be a challenge in computing good results.

The SCS method of determination of time of concentration was avoided to make the CN determination a sole parameter for optimization, and thus the Kirpich equation was used. It resulted in the T_c of 705.9 minutes. The other watershed details, longest stream length and the slope were 10.05 kilometres and 1.45%, respectively.

The daily data resolution resulted in a mismatch in some of the observed and computed hydrographs. A major concern was the shift of peak flow which could not be improved because of the resolution. Of the total of 20 events in calibration, 10 events did not match the peak and the situation was same for verification as well where 10 events did not match reasonably.

5.3 Effective rainfall

Computation of effective rainfall (ERF) is required to estimate streamflow using UH model. In this work, ERF was calculated using SCS abstraction method.

During UH model calibration, the CN value for each event was varied manually by trial and error method until optimized value was obtained using MRAE as objective function. In this computation the corresponding ERF value was changed accordingly and adjusted for initial abstractions of that event. When the CN value decreases, it leads to an increase in the initial abstraction value. The condition for the effective rainfall being, if $P_{cumm}>I_a$, then ER is $P_{cumm}-I_a-F_a$, otherwise 0.

Based on this condition, the effective rainfall could not be correctly derived which consecutively did not yield any direct runoff making the procedure inefficient in many events. This was especially the case while deriving CN_I values from the field data where only one (1) event yielded effective rainfall.

5.4 CN_{II} from NEH-4 handbook

The weighted CN_{II} for the watershed was developed in accordance to the literature using the catchment land use and soil condition taking the moisture condition to be AMC_{II}. The soil group fell into Group C as the majority of the soil was red podzolic soil. The land use was dominated by plantations with 56.34% being covered under it and 20% as homesteads followed by 15.17% of agricultural land. The other areas included built-up areas, forest, garden, marsh and waterbodies. The highest CN_{II} was for waterbodies and marshes at 98.0 and the lowest was for grassland which was 74.0. The weighted CN_{II} was 83.45.

When streamflow was computed using this CN_{II} value, it was observed that majority of the peaks did not match by a huge margin; 36 out of 40 events had predicted greater peak than the observed.

The overall MRAE with this CN_{II} value was 2.18 which was 85.6% higher than the MRAE computed from the calibrated CN value. The RAEM was 2.08. The average RAE value, error values corresponding to Q_p, T_p and T_b were 2.90, 0.32, 0.24 and 1.97, respectively. The error in model prediction could be attributed to similar initial soil moisture conditions assumed for all events. A comparison of peak flow simulated using CN_{II} values derived based on handbook and observed peak value is plotted in Figure 5-1.

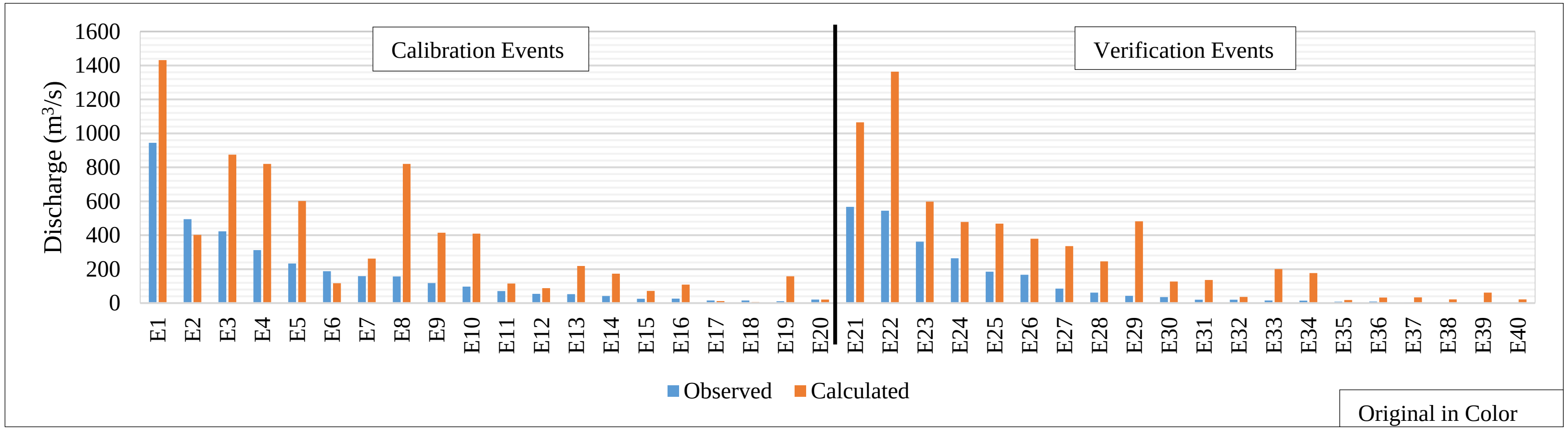


Figure 5-1: Comparison of peak flows with the use of CN_{II} values from handbook

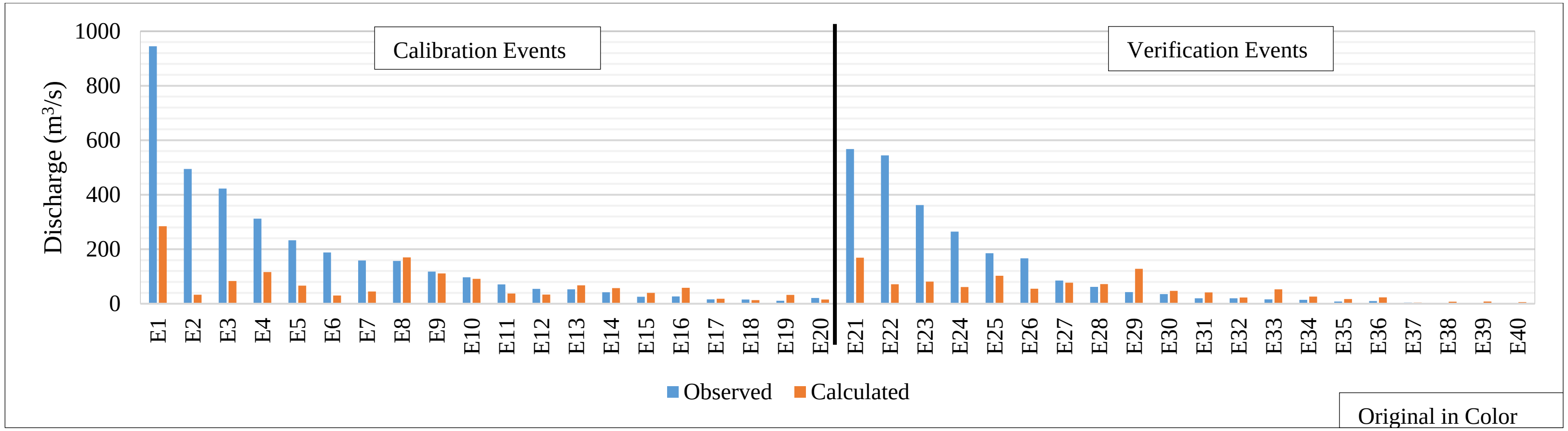


Figure 5-2: Comparison of peak flows with the use of CN_{II} values from field data

5.5 CN_{II} from rainfall-runoff data

In this method, the CN_{II} was computed from the parameter S. Firstly the parameter S was calculated based on the cumulative rainfall and runoff of individual events. The S value was converted to CN_{II} using the empirical relation.

The average MRAE of the 40 events, with a value of 0.46 was much better than that of CN_{II} using handbook. The RAEM was 0.56 and RAE of Q_p, T_p, T_b and the volume under hydrograph was 1.39, 0.31, 0.41 and 0.37, respectively.

Here, CN value varied from 5.08 to 88.55 with an average of 55.79. The lower CN values were observed for longer events with smaller P to Q ratio. 21 out of 40 events predicted lower event peak than the observed. However, others, mostly in the medium flows, predicted very close to observed values as reflected in Figure 5-2.

5.6 CN_I from NEH-4 handbook

Since this study was an event based modelling and required setting a MIT, it resulted in rainless period of at least three days at least between the events. Hence, the need to compare the results using the CN_I condition was felt. The CN_I was computed for each event using conversion formula of Shobani (1975) and the resulting CN value was used to derive the S value.

Of the 40 events, 23 events had the peak greater than the observed peak value as shown in Figure 5-3. The MRAE was 0.60 and RAEM was 0.72. The average RAE value, error values corresponding to Q_p, T_p, T_b and streamflow volume were 1.08, 0.39, 0.31, and 0.55, respectively.

Emphasis must be made that the values of T_p is almost equal to that from model verification and T_b is much better. The most crucial analysis here is that only 6 out 40 events did not produce a direct runoff hydrograph. These events were E17, E18, E20, E35, E36 and E40 which are all low flow events and are not much of consideration for water resources planning purposes.

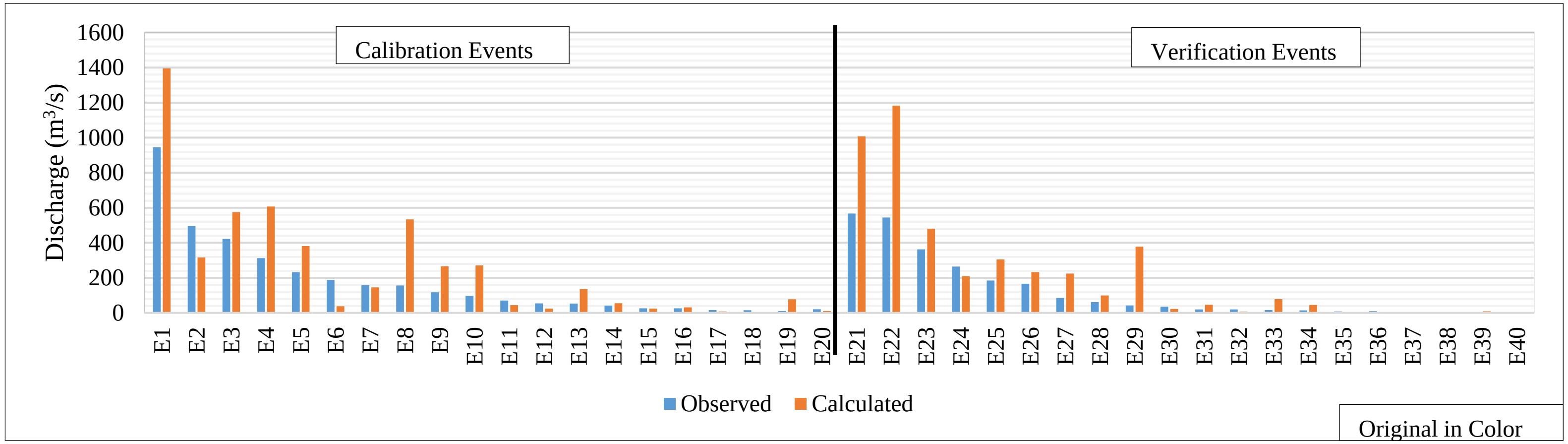


Figure 5-3: Comparison of peak flow with the use of CN_I values converted from handbook

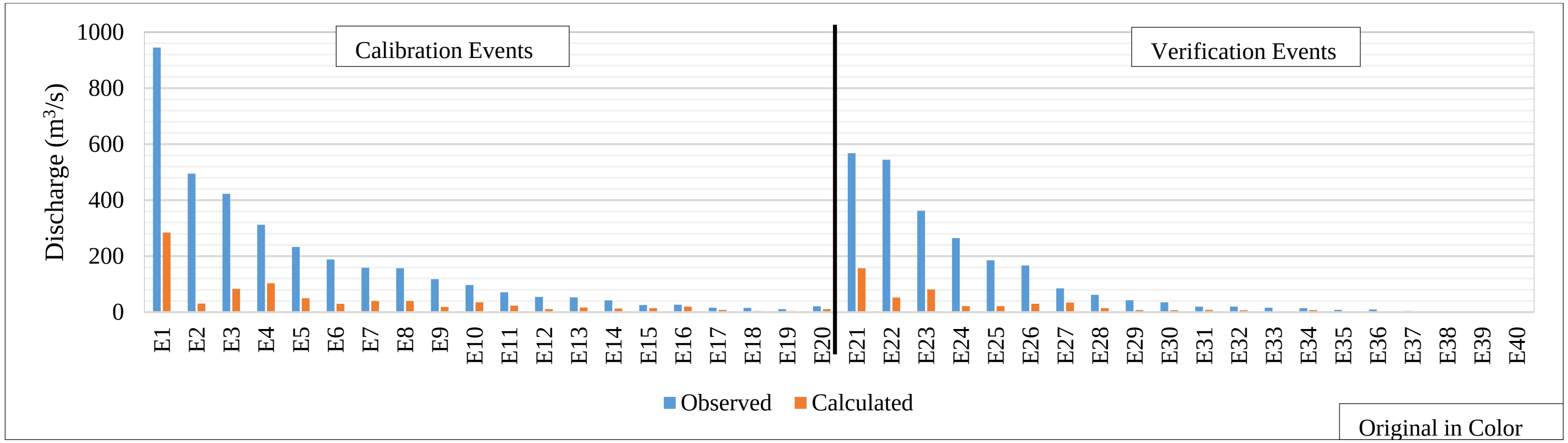


Figure 5-4: Comparison of peak flow with the use of CN_I values converted from field data

5.7 CN_I from rainfall-runoff model

As shown in Figure 5-4, all 40 events predicted lower peak flow than the observed value. This was anticipated as the values of the CN_{II} from this method had already predicted lower peak value for 21 out of 40 events and further lowering the CN value would result in this condition. The lower CN values resulted in excessive high initial abstraction value yielding no effective rainfall and thus no direct runoff production for some events.

The MRAE was 0.36 and RAEM was 0.54. The average RAE value, error values corresponding to Q_p, T_p, T_b and streamflow volume were 1.95, 0.60, 1.29, and 0.55, respectively.

The low values of the MRAE are very misleading because the model has not produced direct runoff hydrographs for 39 out of 40 events.

5.8 Model calibration

The calibration of the model was done by manually optimizing of the parameter CN for individual events. The results were relatively good with the average MRAE value of 0.22 and RAEM of 0.30. The average RAE value, error values corresponding to Q_p, T_p, T_b and streamflow volume were 0.53, 0.21, 0.31 and 0.24, respectively.

About half of the events had CN values below 60, 5 events had between 60 to 80 and 4 values had greater than 80. While the highest value was 89.61, the lowest was 28.50 and an average value of 60.04.

Figure 5-5 (a) and (b) shows the overall comparison of simulated and observed peak flow calibration events. When compared, the peak flows for some events matched better against all the four methods tested. This is because unlike in the case of weighted CN from handbook or from rainfall-runoff data, the calibration procedure was to optimize the individual event to match the entire hydrograph. However, 6 out of 40 events overestimated the peak flow.

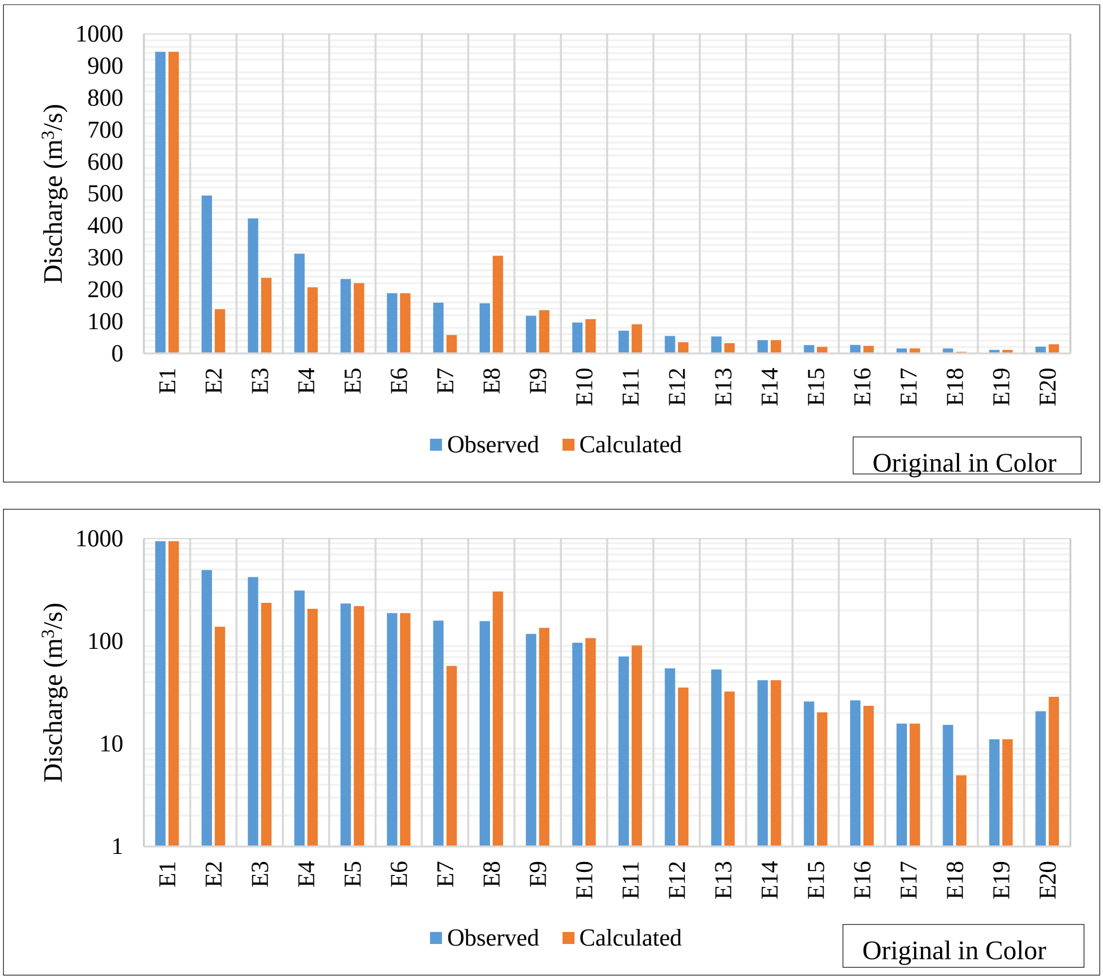


Figure 5-5: Comparison of peak flows during calibration (a) Normal graph and (b) Log graph

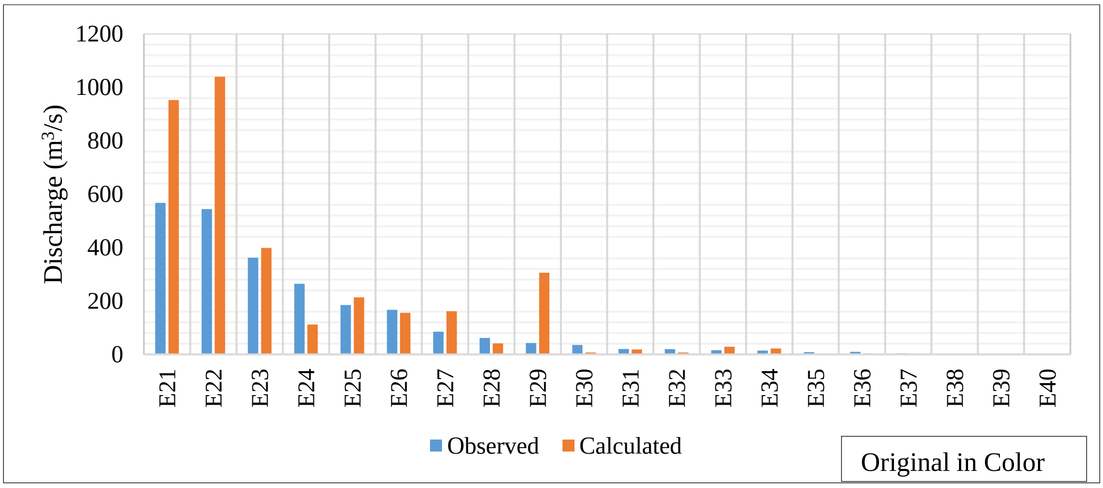
5.9 Model verification

The verification data was from the data period 2012 to 2017. Similar to the representative event selection for calibration events, 20 events were selected representing the different flow categories and comprised of equal number of Maha and Yala events from each category.

The average optimized CN value of 60.04 was used into the verification data. This resulted in the average MRAE of 0.37 and RAEM of 0.49. The average RAE value, error values corresponding to Q_p, T_p, T_b and streamflow volume were 0.78, 0.37, 0.43 and 0.42, respectively.

However, it was noted that due to CN value of 60.04, 8 out of 40 events did not yield direct runoff hydrograph. Due to the low CN value which resulted in high initial abstraction, the effective rainfall was not produced yielding no direct runoff hydrograph. Figure 5-6 (a) and (b) shows the overall comparison of simulated and observed peak flow calibration events. In verification, 8 events predicted higher peak flow than the observed streamflow.

It was observed that in the validation events errors were higher slightly than those obtained for calibration events. Hydrograph plots revealed that though the error indicators reflected acceptable values, the matching of shape was not promising. The hydrograph shape response reflected the need for significant improvement.



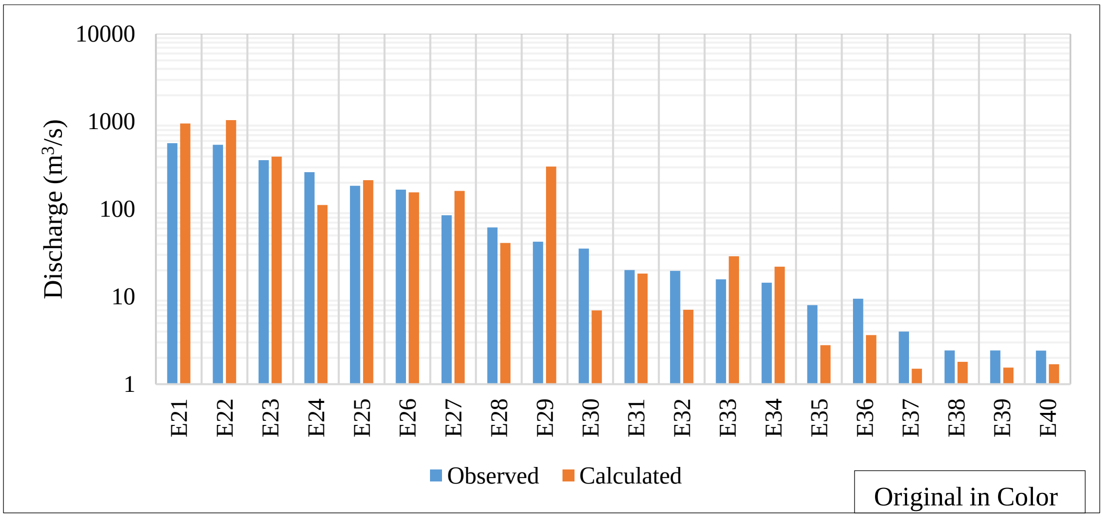


Figure 5-6: Comparison of peak flows during verification (a) Normal graph and (b) Log graph

5.10 Comparison of average and individual calibration

In order to understand the best optimization values of the data, CN values of the verification data were also optimized in addition to the calibration data. This revealed that 20 events had CN below 60, 16 events had CN between 60 and 80, and 4 events had CN above 80.

Several events yielded good results with average MRAE of 0.24 and RAEM of 0.34. In addition to that the average RAE value, error values corresponding to Q_p, T_p, T_b and streamflow volume were 0.39, 0.22, 0.34 and 0.25, respectively.

In comparison, the average CN value of 60.04 from the calibrated events of did not yield very good results. While the indicators showed fairly acceptable results, the modelling showed the inability to plot direct runoff hydrographs using this value.

5.11 Summary discussion

1. The present work deals with event based rainfall-runoff model development using the SCS unit hydrograph. The work attempted to find the most suitable CN determination method for runoff prediction in ungauged catchments similar to Badalgama watershed in Sri Lanka. Four methods were used for the determination of CN;
    i) CN_{II} based on NEH-4 Handbook
    ii) CN_{II} based on observed rainfall-runoff data
    iii) CN_{I} based on NEH-4 Handbook
    iv) CN_{II} based on observed rainfall-runoff data

    The need to calculate the CN_{I} values was felt since this was an event based modelling resulting in rainless periods for event separation. This meant that the initial soil moisture could be dry.

2. There were 20 events each for calibration (2005-2011) and verification (2012-2017) purposes selected based on a careful analysis of both flows (high, moist, mid-range, dry and low flows) and season (Maha and Yala).

3. The CN_{II} value of 83.45 obtained from NEH-4 handbook did not yield good results. Results showed that the NEH-4 handbok based CN_{II} value resulted in a poor runoff hydrograph and that some event hydrographs did not match suitably and had a significant error in estimation.

4. The CN_{II} values developed from the rainfall-runoff data resulted in better MRAE of 0.46 which was better than using CN_{II} values from handbook. Here CN values varied from 5.08 to 88.55 with an average of 55.79. The lower CN values were observed for longer events with smaller P to Q ratio. 21 out of 40 events predicted lower event peak than the observed especially in the case of the higher flows, it predicted well for moist, mid-range and dry conditions. The RAE for the streamflow volume was the best among all the methods.

5. The CN_{I} value converted using Shobani (1975) formula from CN_{II} obtained from the handbook resulted in MRAE and RAEM of 0.60 and 0.72, respectively. Emphasis must be made that the values of T_p is almost equal to that from model verification and T_b is much better. The most crucial analysis here is that only 6 out 40 events did not produce a direct runoff hydrograph. These events were E17, E18, E20, E35, E36 and E40 which are all low flow events and may not be of much consideration for planning purposes. In comparison to the CN_{II} values from handbook, all indicators yielded better result except a slight change in T_p and T_b.

6. The CN_{I} value from the rainfall runoff data resulted in the MRAE of 0.36 and RAEM of 0.54. The better MRAE in this method is misleading because the model did not produce direct runoff hydrographs for 39 out of 40 events. This is because, the CN_{II} values obtained from rainfall runoff data were too small and the values further reduced when converted to CN_{I}.

7. The model developed through calibration had MRAE and RAEM value of 0.22 and 0.30, respectively. Average CN value from the calibration was 60.04. Despite the use of an optimized value for individual events, the peak flows of only some events matched better than the other models tested. However, the

time of occurrence of peak runoff was the major concern during these estimations and this was evident from the absolute error in the T_b computations. Individual event modelling results are plotted in the Appendix P.

8. Model verification was carried out using the average CN value of 60.04 and this produced an average MRAE of 0.37 and RAEM of 0.49. The model verification showed deviation of the modelled hydrograph shapes in many events. This was expected because the verification enabled only the application of an average CN value. However, considering overall results, the obtained MRAE values are considerable acceptable. When individual verification events were individually optimized it resulted in an average CN 60.55 which was almost the same as the value obtained from calibration results. Verification results of individual events are plotted in the Appendix F.

6 CONCLUSION

1. The SCS-CN model using the CN_{II} value from NEH-4 handbook produced streamflow hydrographs of a lesser accuracy or quality than those computed with individual event based CN values. This led to a considerable research coverage in the present study with the attempt to find a better model for the determination of CN which earlier contended the direct use of the NEH-4 handbook recommendations. Hence, the computation of watershed CN values using NEH-4 handbook under AMC_{II} condition should be carried out with caution. However, even though it predicted lower peak values than observed data, it reasonably predicted the streamflow volume nearest to the observed data making it suitable for use in water resource planning and management where only the overall volume of an event is required.

2. The SCS CN model with the CN_{I} values converted from CN_{II} value obtained from the handbook method was the best model in comparison with the three other models based on the error values. The error in the indicators of this model were the nearest to that of model verification. This is because the CN_{I} of 68.36 derived from this model was the nearest to the model calibration average value of 60.04.

   This is an important finding in the area of event based modelling. Event based model as explained in this research has to take into consideration the rainless period resulting in a dry soil moisture condition which is accounted for in AMC_{I} condition. Hence, the use of CN_{I} against the use of CN_{II} results in a more accurate result when using values from NEH-4 handbook.

3. The SCS-CN model with CN_{I} values from the rainfall-runoff data should be used with caution. This method results in very low CN value rendering null values of effective rainfall and thus no production of direct runoff. In fact, 39 out of 40 events did not produce a direct runoff hydrograph while using this method. This could be because the rainfall-runoff data is an observed data and

the CN_{II} resulting from this approach has already considered the soil conditions.

4. The optimization function, MRAE should not be referenced as the single parameter to determine good result match. This is because even though the MRAE values are good, evaluation of other indicators showed clearly that the model did not give good predictions for T_p and T_b among others.

5. The SCS CN model showed very good potential to estimate streamflow in case of individually calibrated storm events. When carrying out calibration, the results were satisfactory with the average MRAE value of 0.22 and RAEM of 0.30. The average RAE value, error values corresponding to Qp, Tp, Tb and streamflow volume were 0.53, 0.21, 0.31 and 0.24, respectively.

6. Considering all aspects of the results from all models including calibration and verification results, it is suggested that in the absence of rainfall-runoff data for an ungauged similar watershed, CN_I values converted using Shobani (1975) formula from CN_{II} values obtained from NEH-4 handbook be used since it leaves fewer events without computation for direct runoff.

7. In the presence of rainfall-runoff data of a similar watershed, individual events shall be manually calibrated to yield a representative CN_{II} value to be used in in an ungauged watershed.

7 RECOMMENDATIONS

1. It is advisable and recommended to use average, optimized CN (60.04) for runoff estimation in an ungauged watershed having similar watershed parameters.

2. In the approach of deriving a curve number for an event based runoff modelling using the NEH-4 handbook, it is suggested to use CN_I condition instead of CN_{II} condition for similar ungauged watersheds.

3. The method of CN_I values derived from rainfall-runoff field data not being able to yield good runoff model is an area for possible exploration since several researchers have claimed otherwise.

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Appendix A: Thiessen weights computation

The Thiessen weights used when each of the station was missing is given below.

1. Ambepussa missing

Rain gauge	Area of Influence (km^2)	Thiessen Weight
Andigama Farm	521.74	0.390
Aranayake Govt. Hospital	262.56	0.196
Eraminigolla	552.97	0.414
Total	1337.27	1

2. Andigama missing

Rain gauge	Area of Influence (km^2)	Thiessen Weight
Ambepussa	605.92	0.453
Aranayake Govt. Hospital	262.55	0.196
Eraminigolla	468.79	0.351
Total	1337.27	1

3. Aranayake missing

Rain gauge	Area of Influence (km^2)	Thiessen Weight
Ambepussa	352.47	0.264
Andigama Farm	256.66	0.192
Eraminigolla	728.14	0.545
Total	1337.27	1

4. Eraminigolla missing

Rain gauge	Area of Influence (km^2)	Thiessen Weight
Ambepussa	496.49	0.371
Andigama Farm	262.96	0.197
Aranayake Govt. Hospital	577.81	0.432
Total	1337.27	1

Appendix B: Rainfall and streamflow details of 40 events

Event ID	Rainfall (mm)	Rainfall Duration (days)	Total Streamflow (MMC)	Peakflow (m^3/s)
E1	621.6	24	717.75	944.6
E2	172.6	17	119.84	494.3
E3	209.0	15	150.09	422.4
E4	251.9	14	142.81	312.0
E5	115.9	9	77.60	233.0
E6	32.5	8	35.47	188.3
E7	84.3	14	48.29	158.7
E8	195.0	9	65.34	156.9
E9	96.5	8	20.59	117.7
E10	108.7	11	35.08	96.7
E11	39.6	8	21.50	70.9
E12	40.6	6	12.06	54.5
E13	85.7	9	22.43	53.0
E14	48.0	7	11.59	41.8
E15	36.6	7	9.50	25.9
E16	35.0	5	9.58	26.5
E17	14.7	8	6.61	15.8
E18	13.6	6	3.21	15.3
E19	61.9	9	3.96	11.1
E20	24.0	7	7.93	20.8
E21	434.6	20	312.28	567.4
E22	308.7	18	142.48	544.2
E23	74.6	6	155.49	264.4
E24	206.7	14	34.91	361.9
E25	102.5	10	35.83	185.1
E26	87.6	9	45.76	166.8
E27	116.8	8	22.07	85.2
E28	56.9	8	12.94	61.7
E29	145.2	14	26.30	42.4

Event ID	Rainfall (mm)	Rainfall Duration (days)	Total Streamflow (MMC)	Peakflow (m^3/s)
E30	38.1	10	9.70	35.4
E31	49.4	9	8.66	20.2
E32	29.5	7	6.44	19.7
E33	53.4	9	6.95	15.8
E34	54.9	8	5.07	14.4
E35	19.2	7	2.24	8.0
E36	22.5	7	3.11	9.5
E37	26.0	5	0.70	4.0
E38	24.2	6	0.93	2.4
E39	31.8	5	0.70	2.4
E40	25.7	6	0.94	2.4
Minimum	**13.6**	**5**	0.70	**2.4**
Maximum	**621.6**	**24**	717.75	**944.6**
Average	**104.9**	**9.7**	58.87	**146.8**

Appendix C: Baseflow separation of 40 events.

Table C-1: Observed rainfall, streamflow and baseflow separation for event no. E1

Event No 1	*Cumulative Rainfall (mm)*	*Hyetograph Rainfall (mm)*	*Cumulative Abstractions (mm)*		*Cumulative Excess Rainfall (mm)*	*Excess Rainfall Hyetograph*		*Runoff (Qobs) (m^3/s)*		
Date	P_{cum}	*P*	*Ia*	*Fa*	*Pe*	*mm*	*cm*	*Q*	*Baseflow*	*DRO*
10/30/2006	20.63	20.63	10.08	8.72	1.83	1.83	0.18	169.55	169.55	0.00
10/31/2006	47.80	27.17	10.08	21.57	16.15	14.32	1.43	162.75	162.75	0.00
11/1/2006	62.96	15.17	10.08	25.80	27.09	10.93	1.09	288.07	150.00	138.07
11/2/2006	69.26	6.29	10.08	27.21	31.97	4.88	0.49	167.74	130.00	37.74
11/3/2006	140.30	71.04	10.08	36.32	93.90	61.93	6.19	138.50	100.00	38.50
11/4/2006	171.55	31.25	10.08	38.40	123.08	29.18	2.92	615.47	80.00	535.47
11/5/2006	203.84	32.29	10.08	39.98	153.78	30.70	3.07	522.90	130.00	392.90
11/6/2006	216.49	12.65	10.08	40.49	165.92	12.14	1.21	317.96	200.00	117.96
11/7/2006	220.24	3.75	10.08	40.64	169.53	3.61	0.36	263.92	263.92	0.00
11/8/2006	243.36	23.11	10.08	41.43	191.85	22.32	2.23	265.00	265.00	0.00
11/9/2006	253.15	9.79	10.08	41.73	201.34	9.49	0.95	284.67	284.67	0.00
11/10/2006	264.00	10.85	10.08	42.04	211.88	10.54	1.05	252.44	252.44	0.00
11/11/2006	311.73	47.73	10.08	43.17	258.48	46.60	4.66	234.88	234.88	0.00
11/12/2006	362.95	51.23	10.08	44.08	308.79	50.31	5.03	459.09	200.00	259.09
11/13/2006	409.97	47.02	10.08	44.74	355.16	46.36	4.64	625.09	195.00	430.09
11/14/2006	422.18	12.20	10.08	44.89	367.21	12.05	1.21	520.19	190.00	330.19
11/15/2006	442.30	20.12	10.08	45.12	387.11	19.90	1.99	293.91	195.00	98.91
11/16/2006	457.32	15.02	10.08	45.28	401.96	14.86	1.49	293.91	210.00	83.91
11/17/2006	497.14	39.82	10.08	45.66	441.41	39.45	3.94	248.63	160.00	88.63
11/18/2006	595.59	98.45	10.08	46.39	539.13	97.72	9.77	464.38	120.00	344.38
11/19/2006	600.47	4.88	10.08	46.42	543.98	4.85	0.48	944.58	90.00	854.58
11/20/2006	603.11	2.64	10.08	46.43	546.61	2.63	0.26	407.36	110.00	297.36
11/21/2006	609.03	5.91	10.08	46.47	552.48	5.88	0.59	205.84	130.00	75.84
11/22/2006	621.63	12.60	10.08	46.54	565.01	12.53	1.25	160.49	160.49	0.00
						Total	56.50	8307.33	4183.69	4123.64

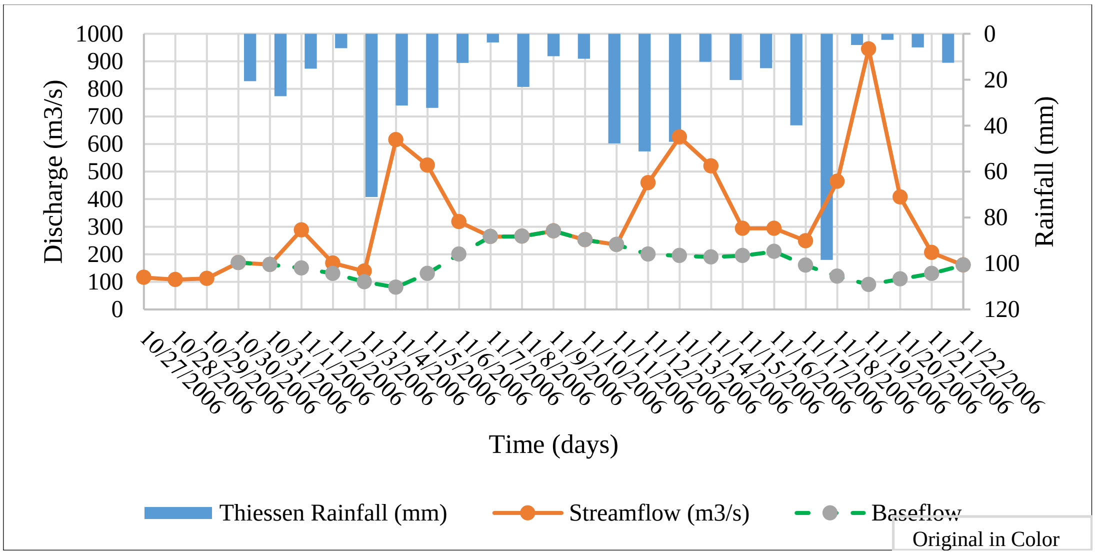


Figure C-1: Observed streamflow and baseflow for event no. E1

Table C-2: Observed rainfall, streamflow and baseflow separation for event no. E2

Event No 2	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m³/s)***		
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
7/11/2008	9.63	9.63	9.63	0.00	0.00	0.00	0.00	7.40	7.40	0.00
7/12/2008	9.95	0.31	9.95	0.00	0.00	0.00	0.00	7.78	7.78	0.00
7/13/2008	9.95	0.00	9.95	0.00	0.00	0.00	0.00	7.78	7.78	0.00
7/14/2008	13.14	3.20	10.08	2.89	0.18	0.18	0.02	7.70	7.70	0.00
7/15/2008	33.80	20.65	10.08	16.13	7.59	7.42	0.74	8.89	8.89	0.00
7/16/2008	33.80	0.00	10.08	16.13	7.59	0.00	0.00	49.93	10.00	39.93
7/17/2008	42.06	8.26	10.08	19.56	12.42	4.83	0.48	31.33	12.00	19.33
7/18/2008	77.90	35.85	10.08	28.91	38.92	26.50	2.65	21.07	14.00	7.07
7/19/2008	79.47	1.57	10.08	29.19	40.21	1.29	0.13	494.26	15.00	479.26
7/20/2008	100.93	21.45	10.08	32.41	58.45	18.24	1.82	290.99	16.00	274.99
7/21/2008	105.62	4.69	10.08	32.99	62.56	4.12	0.41	73.92	17.00	56.92
7/22/2008	137.22	31.60	10.08	36.08	91.07	28.51	2.85	41.81	19.00	22.81
7/23/2008	162.71	25.49	10.08	37.88	114.76	23.69	2.37	83.77	21.07	62.70
7/24/2008	162.71	0.00	10.08	37.88	114.76	0.00	0.00	138.50	15.00	123.50
7/25/2008	165.39	2.68	10.08	38.04	117.28	2.52	0.25	53.00	17.00	36.00
7/26/2008	167.77	2.38	10.08	38.18	119.51	2.24	0.22	38.38	22.00	16.38
7/27/2008	172.60	4.83	10.08	38.46	124.07	4.55	0.46	30.54	30.54	0.00
						Total	12.41	1387.06	248.17	1138.89

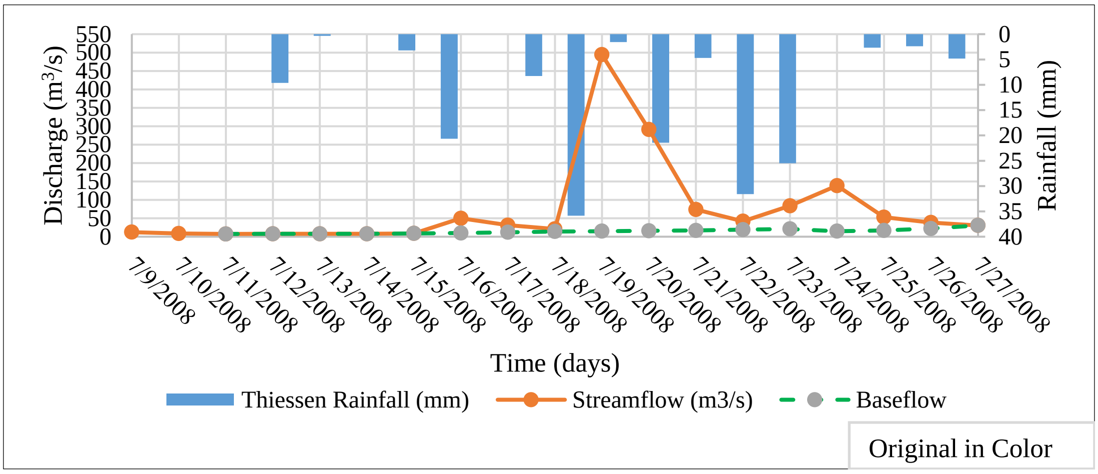


Figure C-2: Observed streamflow and baseflow for event no. E2

Table C-3: Observed rainfall, streamflow and baseflow separation for event no. E3

Event No	Cumulative Rainfall (mm)	Hyetograph Rainfall (mm)	Cumulative Abstractions (mm)		Cumulative Excess Rainfall (mm)	Excess Rainfall Hyetograph		Runoff (Qobs) (m^3/s)		
3										
Date	P_{cum}	*P*	*Ia*	*Fa*	*Pe*	*mm*	*cm*	*Q*	*Baseflow*	*DRO*
5/22/2011	6.32	6.32	6.32	0.00	0.00	0.00	0.00	7.04	7.04	0.00
5/23/2011	6.32	0.00	6.32	0.00	0.00	0.00	0.00	6.14	6.14	0.00
5/24/2011	18.44	12.12	10.08	7.17	1.19	1.19	0.12	5.36	5.36	0.00
5/25/2011	41.76	23.32	10.08	19.45	12.23	11.04	1.10	10.08	10.08	0.00
5/26/2011	118.78	77.02	10.08	34.42	74.28	62.05	6.20	36.64	36.64	0.00
5/27/2011	124.29	5.51	10.08	34.96	79.26	4.97	0.50	422.39	50.00	372.39
5/28/2011	128.28	3.99	10.08	35.32	82.88	3.63	0.36	363.43	60.00	303.43
5/29/2011	135.76	7.48	10.08	35.96	89.72	6.84	0.68	126.95	70.00	56.95
5/30/2011	146.10	10.34	10.08	36.76	99.26	9.54	0.95	83.34	83.34	0.00
5/31/2011	169.61	23.51	10.08	38.29	121.25	21.99	2.20	50.33	50.33	0.00
6/1/2011	204.19	34.58	10.08	40.00	154.12	32.87	3.29	155.98	40.00	115.98
6/2/2011	204.19	0.00	10.08	40.00	154.12	0.00	0.00	259.60	25.00	234.60
6/3/2011	204.87	0.68	10.08	40.03	154.77	0.65	0.07	113.74	30.00	83.74
6/4/2011	205.63	0.76	10.08	40.06	155.49	0.72	0.07	53.42	35.00	18.42
6/5/2011	208.97	3.34	10.08	40.20	158.69	3.20	0.32	42.74	42.74	0.00
						Total	15.87	1737.17	551.67	1185.51

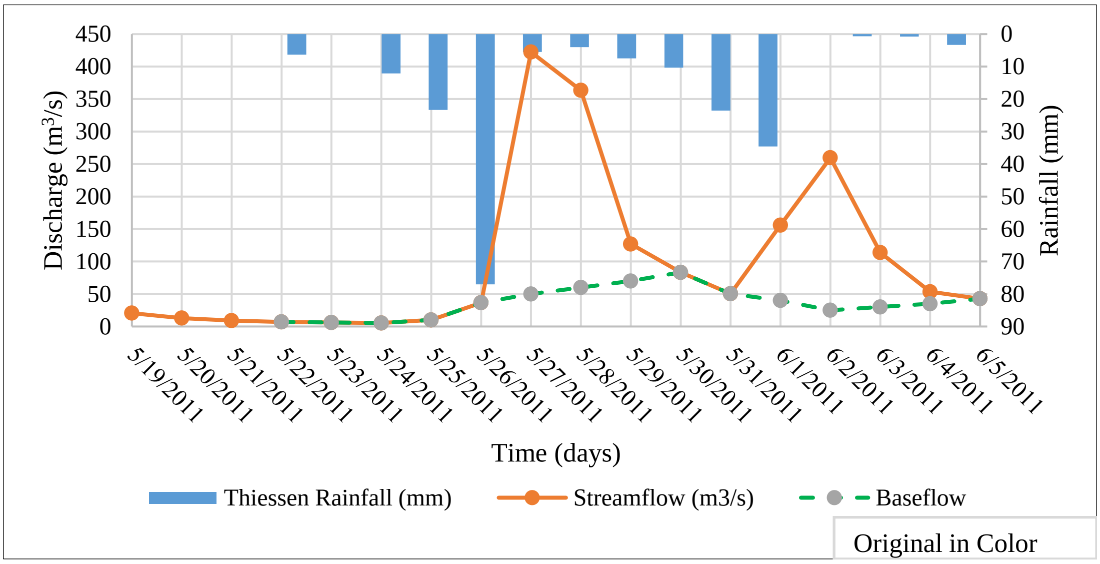


Figure C-3: Observed streamflow and baseflow for event no. E3

Table C-4: Observed rainfall, streamflow and baseflow separation for event no. E4

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
4										
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
9/27/2010	6.98	6.98	6.98	0.00	0.00	0.00	0.00	13.21	13.21	0.00
9/28/2010	64.92	57.93	10.08	26.26	28.58	28.58	2.86	14.35	14.35	0.00
9/29/2010	65.59	0.67	10.08	26.41	29.10	0.52	0.05	90.23	23.00	67.23
9/30/2010	71.25	5.66	10.08	27.63	33.55	4.45	0.44	47.73	17.00	30.73
10/1/2010	141.97	70.71	10.08	36.45	95.44	61.89	6.19	42.93	12.00	30.93
10/2/2010	175.63	33.66	10.08	38.62	126.93	31.49	3.15	312.05	10.00	302.05
10/3/2010	186.73	11.10	10.08	39.20	137.45	10.53	1.05	233.46	35.00	198.46
10/4/2010	186.78	0.05	10.08	39.20	137.50	0.05	0.00	197.51	60.00	137.51
10/5/2010	203.47	16.69	10.08	39.97	153.43	15.93	1.59	88.94	88.94	0.00
10/6/2010	227.05	23.58	10.08	40.88	176.09	22.66	2.27	63.01	63.01	0.00
10/7/2010	233.17	6.12	10.08	41.10	182.00	5.91	0.59	188.29	37.00	151.29
10/8/2010	251.88	18.71	10.08	41.69	200.11	18.11	1.81	139.39	52.00	87.39
10/9/2010	251.88	0.00	10.08	41.69	200.11	0.00	0.00	118.57	76.00	42.57
10/10/2010	251.88	0.00	10.08	41.69	200.11	0.00	0.00	103.25	103.25	0.00
						Total	20.01	1652.91	604.75	1048.15

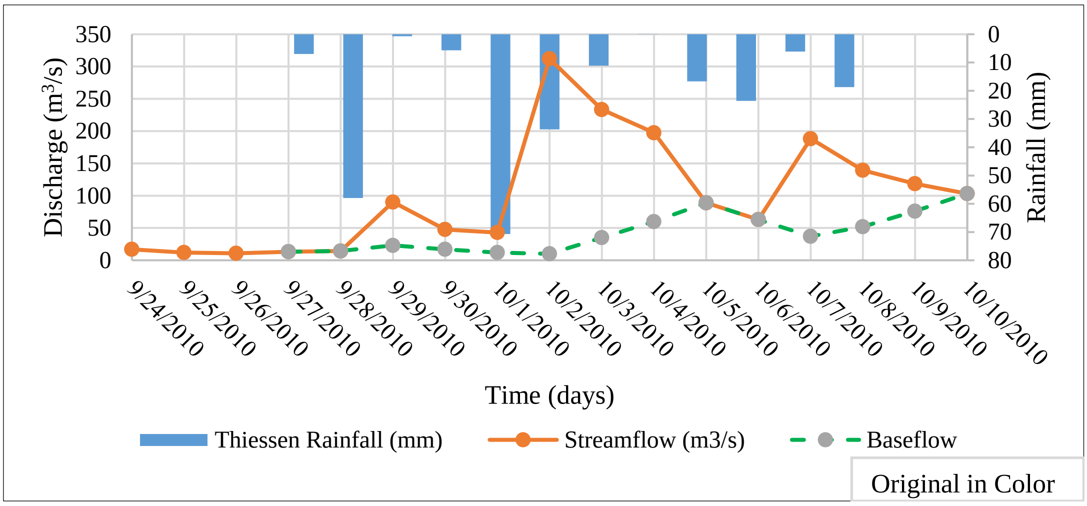


Figure C-4: Observed streamflow and baseflow for event no. E4

Table C-5: Observed rainfall, streamflow and baseflow separation for event no. E5

Event No 5	*Cumulative Rainfall (mm)*	*Hyetograph Rainfall (mm)*	*Cumulative Abstractions (mm)*		*Cumulative Excess Rainfall (mm)*	*Excess Rainfall Hyetograph*		*Runoff (Qobs) (m^3/s)*		
Date	P_{cum}	*P*	*Ia*	*Fa*	*Pe*	*mm*	*cm*	*Q*	*Baseflow*	*DRO*
4/24/2008	0.81	0.81	0.81	0.00	0.00	0.00	0.00	23.47	23.47	0.00
4/25/2008	22.32	21.50	10.08	9.85	2.39	2.39	0.24	27.18	27.18	0.00
4/26/2008	46.26	23.94	10.08	21.06	15.12	12.73	1.27	58.55	32.00	26.55
4/27/2008	98.60	52.34	10.08	32.11	56.42	41.30	4.13	180.04	40.00	140.04
4/28/2008	115.87	17.27	10.08	34.13	71.67	15.25	1.53	220.30	43.00	177.30
4/29/2008	115.87	0.00	10.08	34.13	71.67	0.00	0.00	232.99	50.00	182.99
4/30/2008	115.87	0.00	10.08	34.13	71.67	0.00	0.00	70.93	50.00	20.93
5/1/2008	115.87	0.00	10.08	34.13	71.67	0.00	0.00	47.34	47.34	0.00
5/2/2008	115.87	0.00	10.08	34.13	71.67	0.00	0.00	37.33	37.33	0.00
						Total	7.17	898.13	350.32	547.81

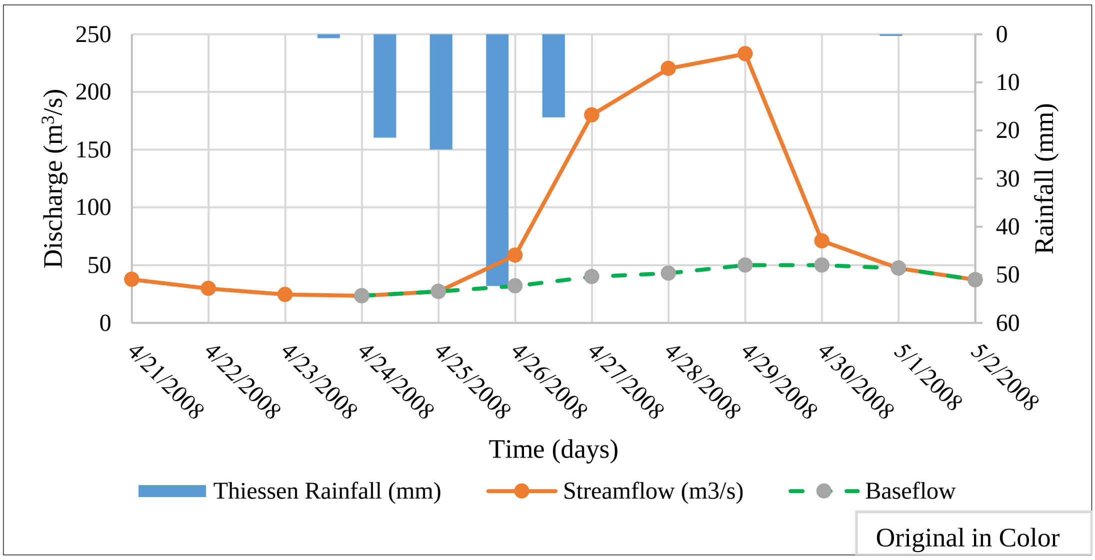
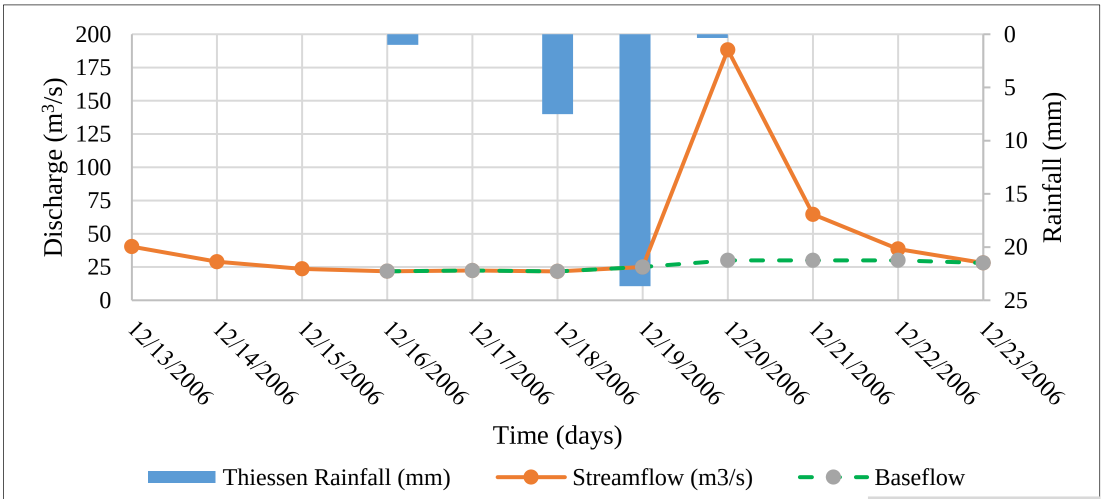


Figure C-5: Observed streamflow and baseflow for event no. E5

TableC0-6: Observed rainfall, streamflow and baseflow separation for event no. E6

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
6										
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
12/16/2006	0.99	0.99	0.99	0.00	0.00	0.00	0.00	21.86	21.86	0.00
12/17/2006	0.99	0.00	0.99	0.00	0.00	0.00	0.00	22.39	22.39	0.00
12/18/2006	8.50	7.51	8.50	0.00	0.00	0.00	0.00	21.72	21.72	0.00
12/19/2006	32.16	23.67	10.08	15.35	6.73	6.73	0.67	25.01	25.01	0.00
12/20/2006	32.51	0.35	10.08	15.52	6.91	0.18	0.02	188.29	30.00	158.29
12/21/2006	32.51	0.00	10.08	15.52	6.91	0.00	0.00	64.61	30.00	34.61
12/22/2006	32.51	0.00	10.08	15.52	6.91	0.00	0.00	38.56	30.00	8.56
12/23/2006	32.51	0.00	10.08	15.52	6.91	0.00	0.00	28.08	28.08	0.00
						Total	0.69	410.52	209.06	201.46



Original in Color

Figure C-6: Observed streamflow and baseflow for event no. E6

Table C-7: Observed rainfall, streamflow and baseflow separation for event no. E7

Event No / **7**	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m³/s)***		
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
1/4/2006	6.87	6.87	6.87	0.00	0.00	0.00	0.00	9.14	9.14	0.00
1/5/2006	32.02	25.15	10.08	15.29	6.66	6.66	0.67	9.30	9.30	0.00
1/6/2006	33.34	1.32	10.08	15.92	7.35	0.69	0.07	17.48	9.30	8.18
1/7/2006	33.34	0.00	10.08	15.92	7.35	0.00	0.00	36.64	10.00	26.64
1/8/2006	34.12	0.77	10.08	16.28	7.77	0.42	0.04	28.23	10.00	18.23
1/9/2006	34.12	0.00	10.08	16.28	7.77	0.00	0.00	20.30	10.00	10.30
1/10/2006	34.12	0.00	10.08	16.28	7.77	0.00	0.00	16.67	10.00	6.67
1/11/2006	62.51	28.39	10.08	25.69	26.74	18.97	1.90	15.21	13.00	2.21
1/12/2006	63.04	0.53	10.08	25.82	27.14	0.40	0.04	23.20	16.00	7.20
1/13/2006	82.17	19.13	10.08	29.66	42.44	15.29	1.53	45.97	17.00	28.97
1/14/2006	82.43	0.26	10.08	29.70	42.66	0.22	0.02	158.68	19.00	139.68
1/15/2006	84.32	1.89	10.08	30.01	44.23	1.58	0.16	85.92	22.00	63.92
1/16/2006	84.32	0.00	10.08	30.01	44.23	0.00	0.00	52.17	32.00	20.17
1/17/2006	84.32	0.00	10.08	30.01	44.23	0.00	0.00	39.99	39.99	0.00
						Total	4.42	558.90	226.73	332.17

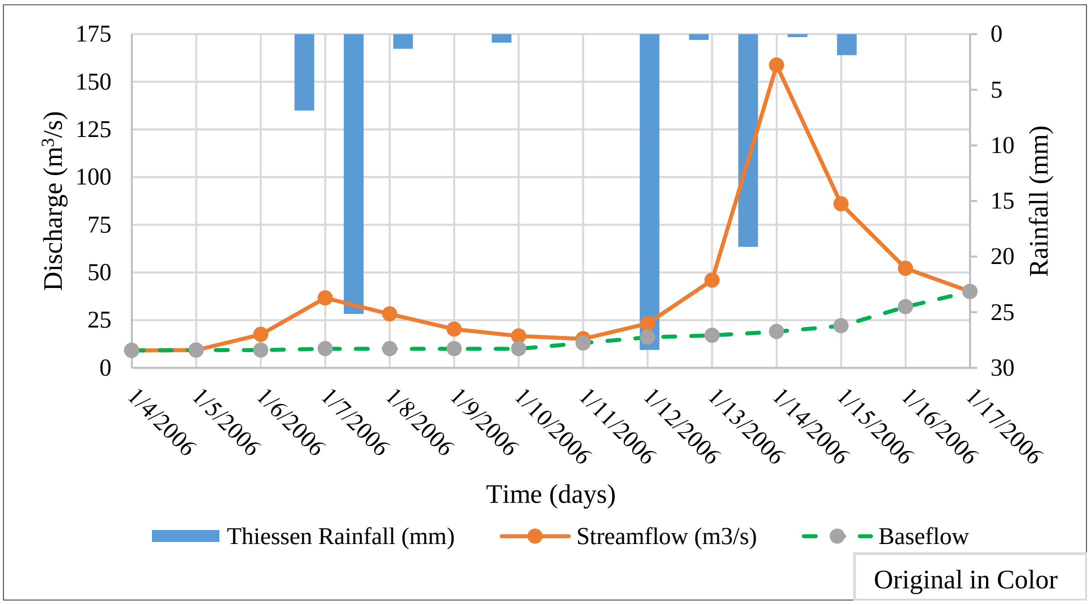


Figure C-7: Observed streamflow and baseflow for event no. E7

Table C-8: Observed rainfall, streamflow and baseflow separation for event no. E8

Event No	*Cumulative Rainfall (mm)*	*Hyetograph Rainfall (mm)*	*Cumulative Abstractions (mm)*		*Cumulative Excess Rainfall (mm)*	*Excess Rainfall Hyetograph*		*Runoff (Qobs) (m³/s)*		
8										
Date	***P_{cum}***	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
6/19/2006	45.19	45.19	10.08	20.69	14.43	14.43	1.44	3.60	3.60	0.00
6/20/2006	118.61	73.41	10.08	34.41	74.12	59.70	5.97	9.22	9.22	0.00
6/21/2006	140.01	21.40	10.08	36.30	93.63	19.51	1.95	141.17	20.00	121.17
6/22/2006	184.20	44.19	10.08	39.07	135.05	41.42	4.14	150.58	22.00	128.58
6/23/2006	194.98	10.79	10.08	39.59	145.32	10.27	1.03	132.27	40.00	92.27
6/24/2006	194.98	0.00	10.08	39.59	145.32	0.00	0.00	156.88	40.00	116.88
6/25/2006	194.98	0.00	10.08	39.59	145.32	0.00	0.00	83.34	38.00	45.34
6/26/2006	194.98	0.00	10.08	39.59	145.32	0.00	0.00	45.97	36.00	9.97
6/27/2006	194.98	0.00	10.08	39.59	145.32	0.00	0.00	33.27	33.27	0.00
						Total	14.53	756.31	242.09	514.21

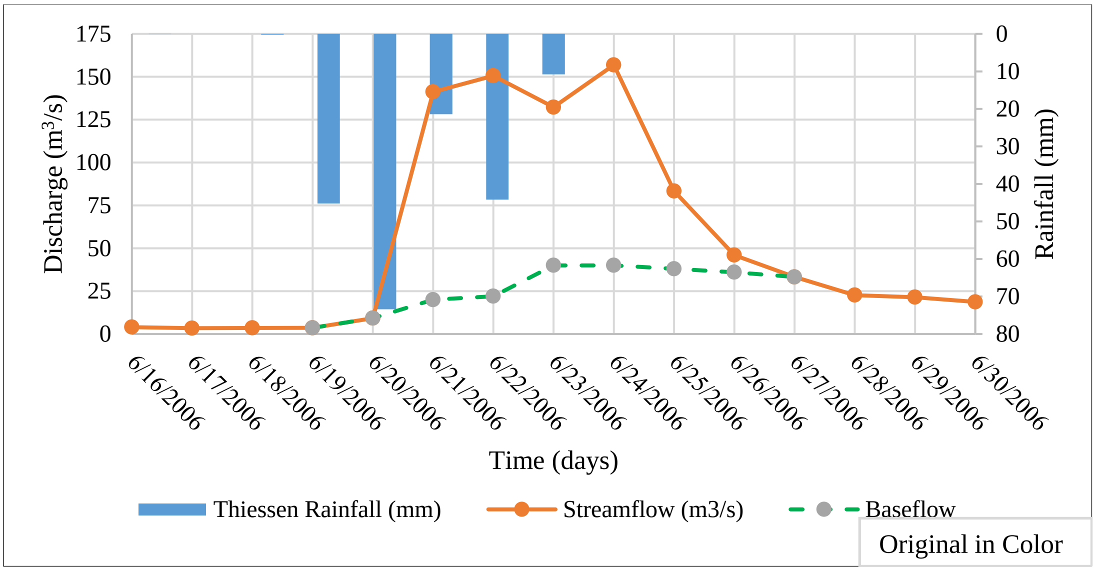


Figure C-8: Observed streamflow and baseflow for event no. E8

Table C-9: Observed rainfall, streamflow and baseflow separation for event no. E9

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m³/s)***		
9										
Date	P_{cum}	*P*	*Ia*	*Fa*	*Pe*	*mm*	*cm*	*Q*	*Baseflow*	*DRO*
1/29/2005	15.71	15.71	10.08	5.06	0.57	0.57	0.06	2.59	2.59	0.00
1/30/2005	37.00	21.30	10.08	17.55	9.38	8.81	0.88	4.21	4.21	0.00
1/31/2005	60.05	23.05	10.08	25.09	24.89	15.51	1.55	18.68	18.68	0.00
2/1/2005	95.56	35.50	10.08	31.70	53.78	28.90	2.89	30.54	12.00	18.54
2/2/2005	95.56	0.00	10.08	31.70	53.78	0.00	0.00	117.69	10.00	107.69
2/3/2005	96.55	0.99	10.08	31.83	54.64	0.85	0.09	35.44	10.00	25.44
2/4/2005	96.55	0.00	10.08	31.83	54.64	0.00	0.00	17.48	11.00	6.48
2/5/2005	96.55	0.00	10.08	31.83	54.64	0.00	0.00	11.63	11.63	0.00
						Total	5.46	238.27	80.12	158.15

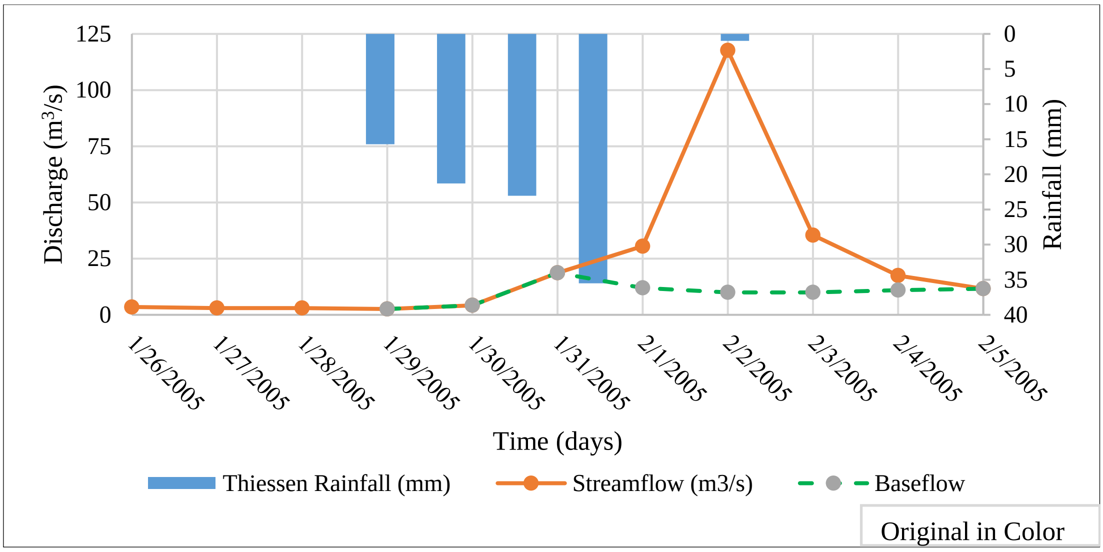


Figure C-9: Observed streamflow and baseflow for event no. E9

Table C-10: Observed rainfall, streamflow and baseflow separation for event no. E10

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
10										
Date	P_{cum}	*P*	*Ia*	*Fa*	*Pe*	*mm*	*cm*	*Q*	*Baseflow*	*DRO*
6/5/2010	7.33	7.33	7.33	0.00	0.00	0.00	0.00	12.11	12.11	0.00
6/6/2010	12.16	4.83	10.08	2.00	0.08	0.08	0.01	11.63	11.63	0.00
6/7/2010	33.09	20.92	10.08	15.80	7.21	7.13	0.71	16.55	10.00	6.55
6/8/2010	33.32	0.24	10.08	15.91	7.34	0.13	0.01	26.89	11.00	15.89
6/9/2010	46.34	13.01	10.08	21.08	15.18	7.83	0.78	23.75	12.00	11.75
6/10/2010	62.76	16.43	10.08	25.75	26.93	11.76	1.18	20.43	13.00	7.43
6/11/2010	97.66	34.89	10.08	31.98	55.60	28.67	2.87	46.55	14.00	32.55
6/12/2010	104.68	7.02	10.08	32.87	61.73	6.13	0.61	96.73	15.00	81.73
6/13/2010	107.35	2.67	10.08	33.19	64.08	2.36	0.24	62.11	21.00	41.11
6/14/2010	108.66	1.31	10.08	33.34	65.24	1.16	0.12	53.84	28.00	25.84
6/15/2010	108.66	0.00	10.08	33.34	65.24	0.00	0.00	35.44	35.44	0.00
						Total	6.52	406.03	183.18	222.84

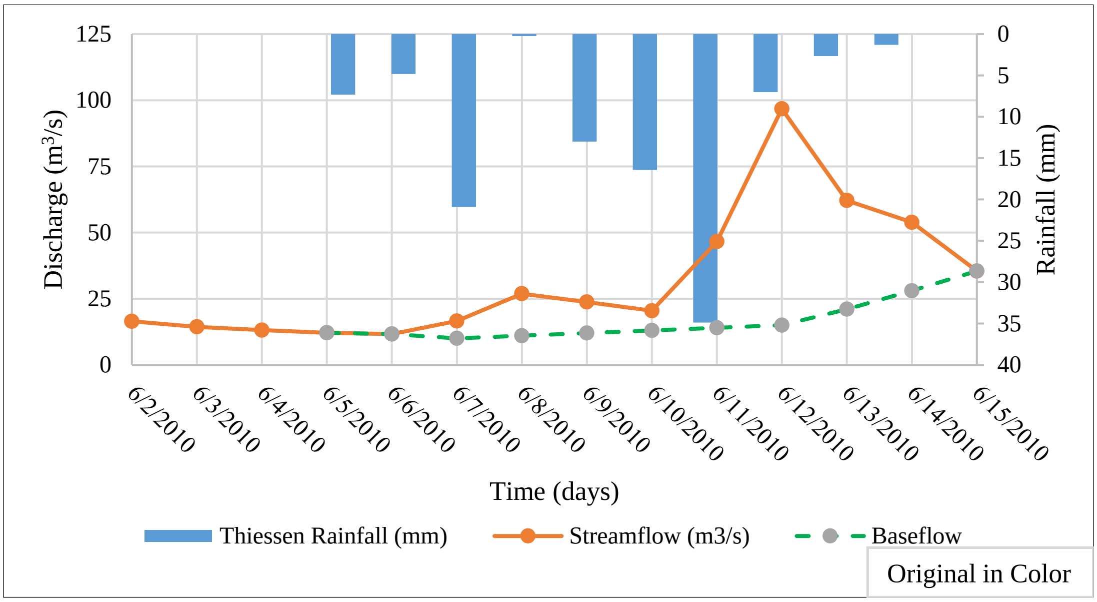


Figure C-10: Observed streamflow and baseflow for event no. E10

Table C-11: Observed rainfall, streamflow and baseflow separation for event no. E11

Event No	*Cumulative Rainfall (mm)*	*Hyetograph Rainfall (mm)*	*Cumulative Abstractions (mm)*		*Cumulative Excess Rainfall (mm)*	*Excess Rainfall Hyetograph*		*Runoff (Qobs) (m^3/s)*		
11										
Date	P_{cum}	*P*	*Ia*	*Fa*	*Pe*	*mm*	*cm*	*Q*	*Baseflow*	*DRO*
11/19/2007	22.75	22.75	10.08	10.13	2.55	2.55	0.25	18.20	18.20	0.00
11/20/2007	24.34	1.58	10.08	11.11	3.15	0.60	0.06	31.49	17.00	14.49
11/21/2007	25.42	1.09	10.08	11.76	3.58	0.44	0.04	27.03	19.00	8.03
11/22/2007	39.63	14.21	10.08	18.63	10.93	7.34	0.73	23.20	23.20	0.00
11/23/2007	39.63	0.00	10.08	18.63	10.93	0.00	0.00	70.93	19.00	51.93
11/24/2007	39.63	0.00	10.08	18.63	10.93	0.00	0.00	36.98	19.00	17.98
11/25/2007	39.63	0.00	10.08	18.63	10.93	0.00	0.00	23.06	18.00	5.06
11/26/2007	39.63	0.00	10.08	18.63	10.93	0.00	0.00	17.96	17.96	0.00
						Total	1.09	248.85	151.35	97.50

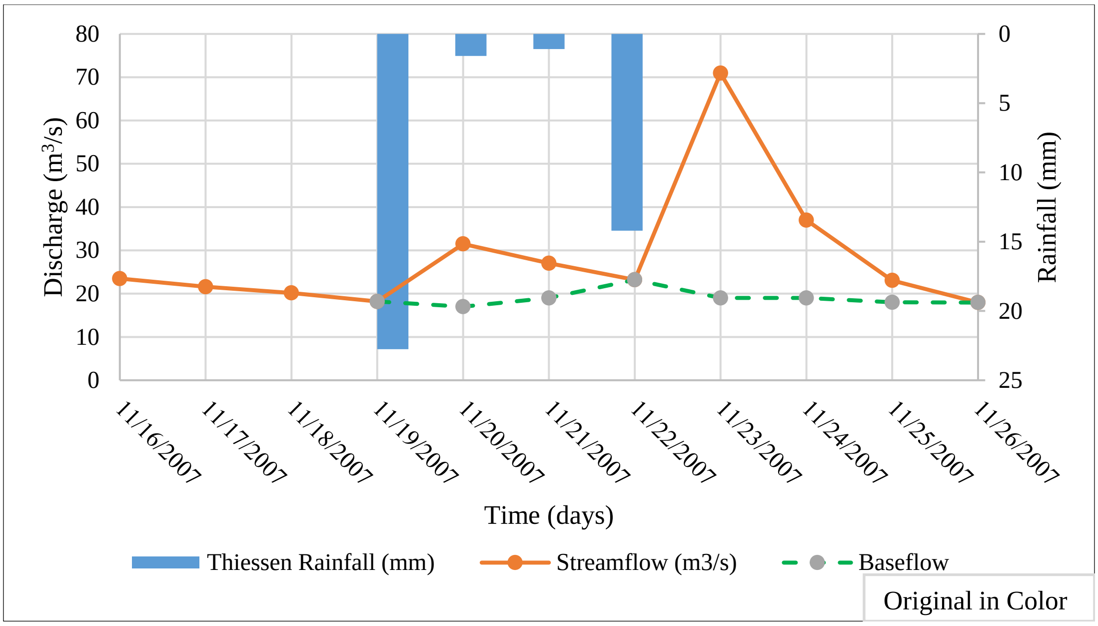


Figure C-11: Observed streamflow and baseflow for event no. E11

Table C-12: Observed rainfall, streamflow and baseflow separation for event no. E12

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
12										
Date	P_{cum}	*P*	*Ia*	*Fa*	*Pe*	*mm*	*cm*	*Q*	*Baseflow*	*DRO*
8/20/2010	31.59	31.59	10.08	15.08	6.44	6.44	0.64	6.07	6.07	0.00
8/21/2010	39.85	8.26	10.08	18.72	11.06	4.62	0.46	23.06	5.00	18.06
8/22/2010	39.85	0.00	10.08	18.72	11.06	0.00	0.00	54.47	4.00	50.47
8/23/2010	39.85	0.00	10.08	18.72	11.06	0.00	0.00	31.65	10.00	21.65
8/24/2010	40.06	0.21	10.08	18.80	11.19	0.13	0.01	13.51	10.00	3.51
8/25/2010	40.56	0.50	10.08	18.99	11.49	0.30	0.03	10.80	10.80	0.00
						Total	1.15	139.56	45.86	93.69

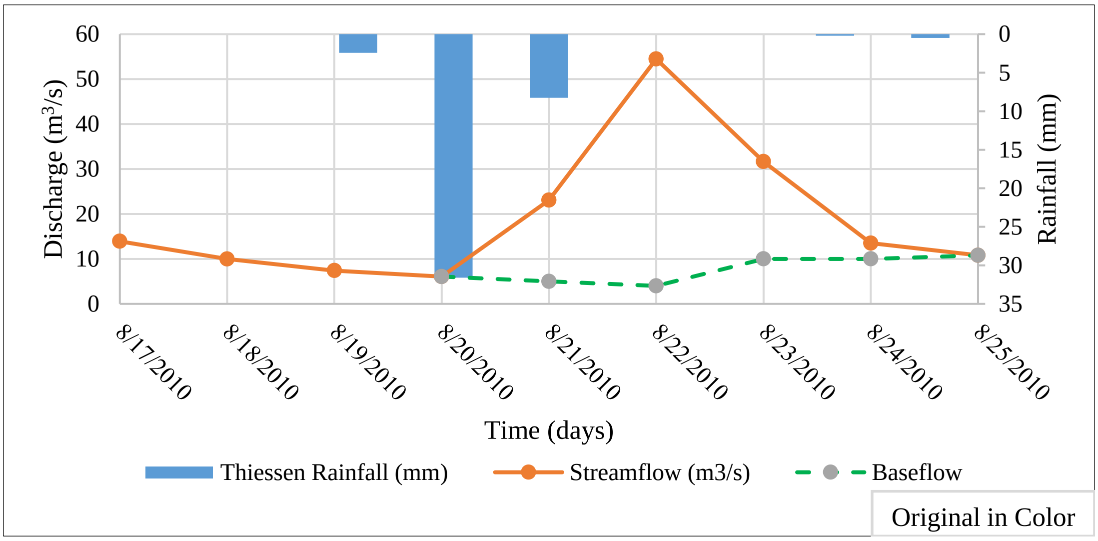


Figure C-12: Observed streamflow and baseflow for event no. E12

Table C-13: Observed rainfall, streamflow and baseflow separation for event no. E13

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
13										
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
4/15/2006	17.63	17.63	10.08	6.57	0.99	0.99	0.10	7.04	7.04	0.00
4/16/2006	43.60	25.97	10.08	20.13	13.40	12.41	1.24	30.38	7.00	23.38
4/17/2006	62.86	19.26	10.08	25.78	27.01	13.61	1.36	53.00	6.00	47.00
4/18/2006	80.41	17.55	10.08	29.35	40.98	13.97	1.40	30.54	9.00	21.54
4/19/2006	81.67	1.26	10.08	29.57	42.02	1.04	0.10	32.29	10.00	22.29
4/20/2006	82.79	1.12	10.08	29.76	42.96	0.93	0.09	50.74	5.00	45.74
4/21/2006	84.97	2.17	10.08	30.12	44.77	1.82	0.18	20.17	8.00	12.17
4/22/2006	85.74	0.77	10.08	30.24	45.42	0.65	0.06	19.05	10.00	9.05
4/23/2006	85.74	0.00	10.08	30.24	45.42	0.00	0.00	16.44	16.44	0.00
						Total	4.54	259.65	78.48	181.17

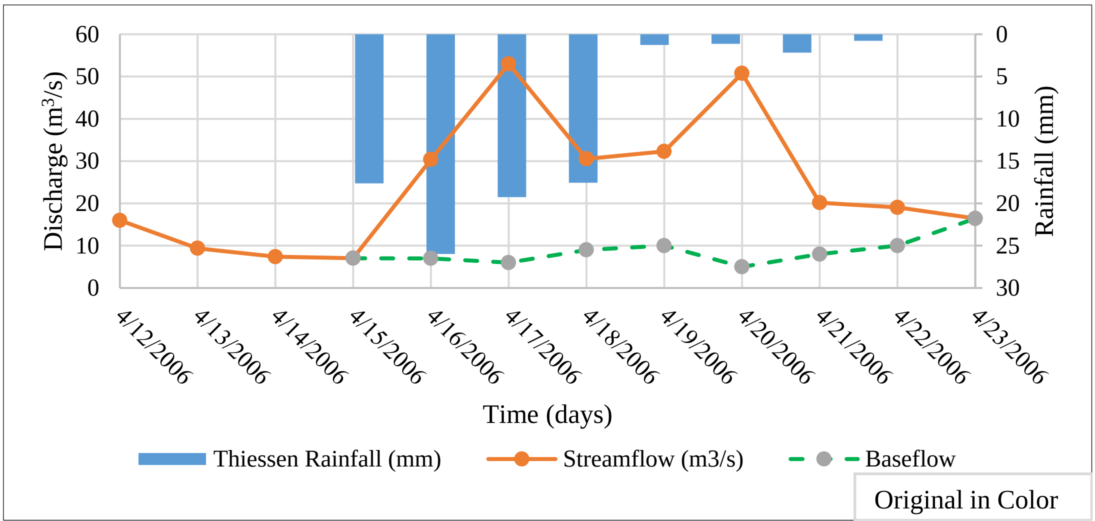


Figure C-13: Observed streamflow and baseflow for event no. E13

Table C-14: Observed rainfall, streamflow and baseflow separation for event no. E14

Event No 14	Cumulative Rainfall (mm)	Hyetograph Rainfall (mm)	Cumulative Abstractions (mm)		Cumulative Excess Rainfall (mm)	Excess Rainfall Hyetograph		Runoff (Qobs) (m^3/s)		
Date	P_{cum}	P	Ia	Fa	Pe	mm	cm	Q	Baseflow	DRO
3/3/2011	4.27	4.27	4.27	0.00	0.00	0.00	0.00	9.30	9.30	0.00
3/4/2011	21.87	17.60	10.08	9.55	2.24	2.24	0.22	10.34	10.34	0.00
3/5/2011	45.11	23.24	10.08	20.66	14.37	12.13	1.21	28.99	11.00	17.99
3/6/2011	47.98	2.87	10.08	21.63	16.27	1.91	0.19	41.81	12.00	29.81
3/7/2011	47.98	0.00	10.08	21.63	16.27	0.00	0.00	19.54	12.00	7.54
3/8/2011	47.98	0.00	10.08	21.63	16.27	0.00	0.00	13.10	13.10	0.00
3/9/2011	47.98	0.00	10.08	21.63	16.27	0.00	0.00	11.07	11.07	0.00
						Total	1.63	134.17	78.82	55.34

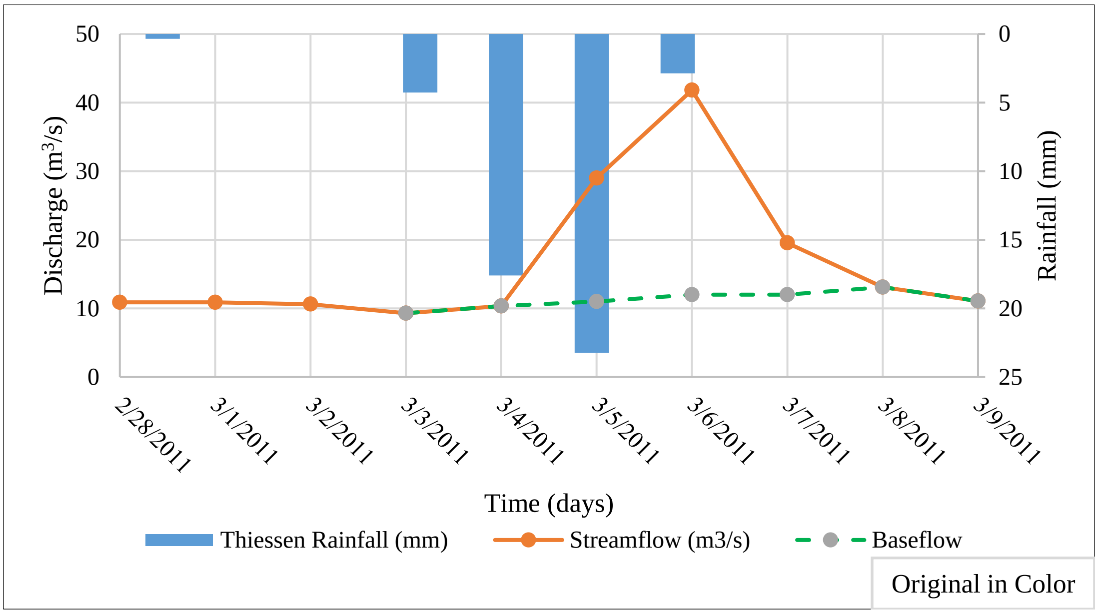


Figure C-14: Observed streamflow and baseflow for event no. E14

Table C-15: Observed rainfall, streamflow and baseflow separation for event no. E15

Event No 15	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
3/29/2006	9.90	9.90	9.90	0.00	0.00	0.00	0.00	7.63	7.63	0.00
3/30/2006	19.34	9.44	10.08	7.82	1.44	1.44	0.14	7.70	7.70	0.00
3/31/2006	28.11	8.77	10.08	13.28	4.75	3.31	0.33	15.32	7.00	8.32
4/1/2006	36.58	8.48	10.08	17.37	9.14	4.39	0.44	25.87	6.90	18.97
4/2/2006	36.58	0.00	10.08	17.37	9.14	0.00	0.00	20.30	9.00	11.30
4/3/2006	36.58	0.00	10.08	17.37	9.14	0.00	0.00	18.92	12.00	6.92
4/4/2006	36.58	0.00	10.08	17.37	9.14	0.00	0.00	14.24	14.24	0.00
						Total	0.91	109.98	64.47	45.51

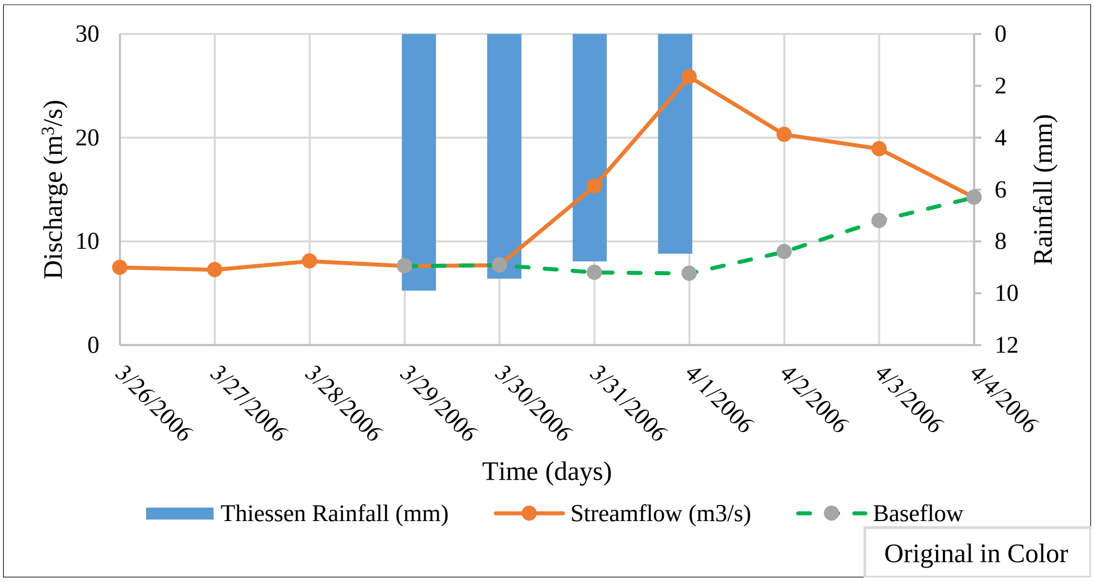


Figure C-15: Observed streamflow and baseflow for event no. E15

Table C-16: Observed rainfall, streamflow and baseflow separation for event no. E16

Event No 16	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
12/15/2008	13.05	13.05	10.08	2.81	0.17	0.17	0.02	16.90	16.90	0.00
12/16/2008	19.20	6.15	10.08	7.72	1.40	1.23	0.12	26.50	15.00	11.50
12/17/2008	34.98	15.78	10.08	16.67	8.24	6.84	0.68	24.00	16.50	7.50
12/18/2008	34.98	0.00	10.08	16.67	8.24	0.00	0.00	23.50	18.00	5.50
12/19/2008	34.98	0.00	10.08	16.67	8.24	0.00	0.00	20.00	20.00	0.00
						Total	0.82	110.90	86.40	24.50

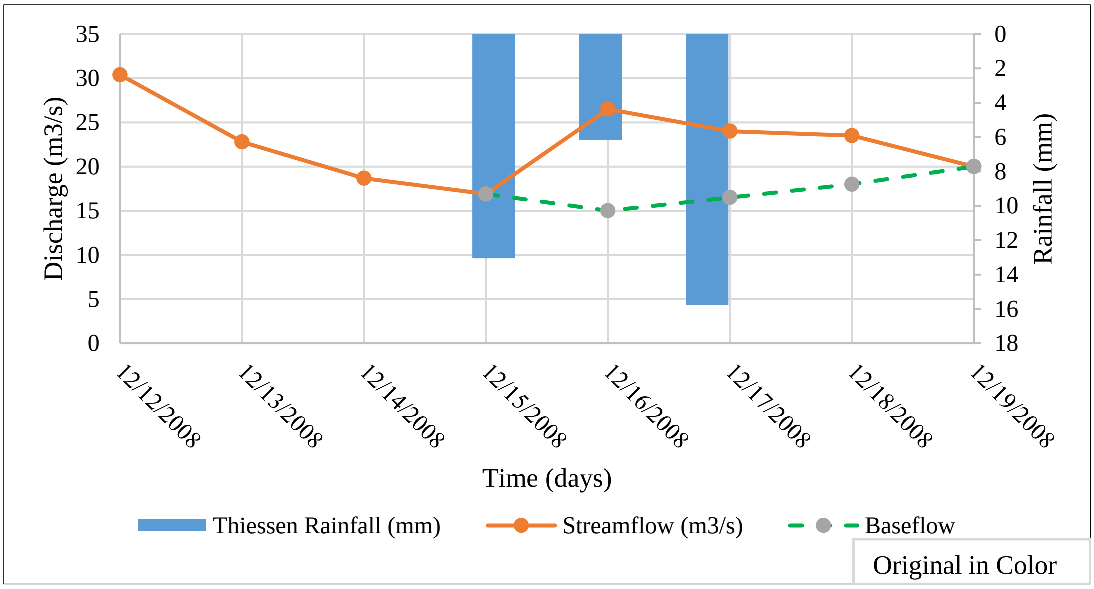


Figure C-16: Observed streamflow and baseflow for event no. E16

Table C-17: Observed rainfall, streamflow and baseflow separation for event no. E17

Event No 17	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
7/31/2007	0.57	0.57	0.57	0.00	0.00	0.00	0.00	7.93	7.93	0.00
8/1/2007	6.09	5.53	6.09	0.00	0.00	0.00	0.00	7.70	7.70	0.00
8/2/2007	7.55	1.46	7.55	0.00	0.00	0.00	0.00	7.48	7.48	0.00
8/3/2007	14.74	7.19	10.08	4.27	0.40	0.40	0.04	10.08	7.30	2.78
8/4/2007	14.74	0.00	10.08	4.27	0.40	0.00	0.00	15.76	6.80	8.96
8/5/2007	14.74	0.00	10.08	4.27	0.40	0.00	0.00	11.54	7.20	4.34
8/6/2007	14.74	0.00	10.08	4.27	0.40	0.00	0.00	8.73	7.40	1.33
8/7/2007	14.74	0.00	10.08	4.27	0.40	0.00	0.00	7.26	7.26	0.00
						Total	0.04	76.48	59.07	17.41

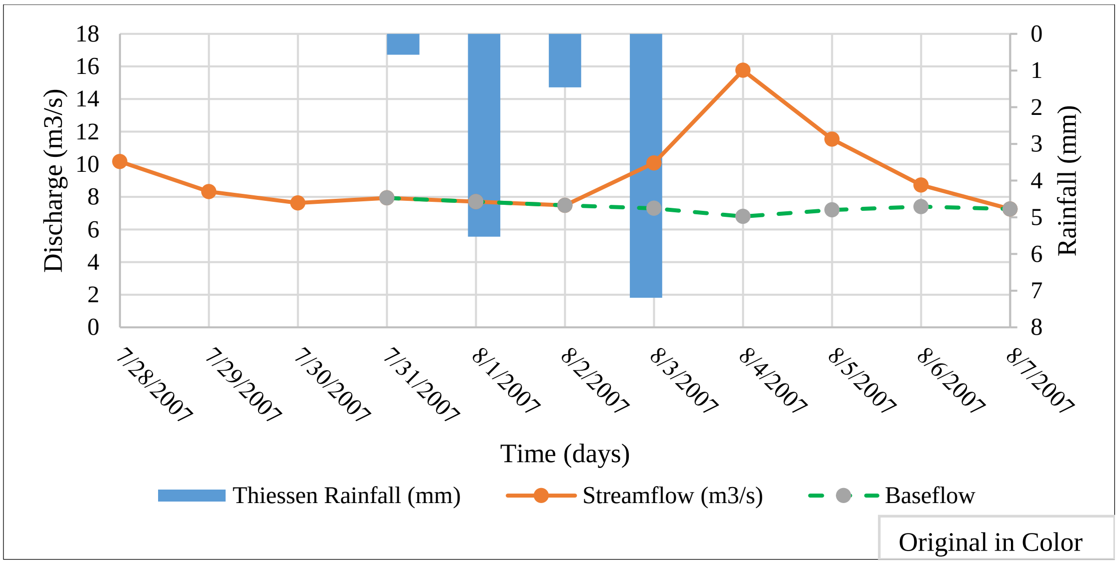


Figure C-17: Observed streamflow and baseflow for event no. E17

Table C-18: Observed rainfall, streamflow and baseflow separation for event no. E18

Event No 18	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
8/15/2011	4.85	4.85	4.85	0.00	0.00	0.00	0.00	2.40	2.40	0.00
8/16/2011	8.11	3.26	8.11	0.00	0.00	0.00	0.00	2.75	2.75	0.00
8/17/2011	11.23	3.12	10.08	1.13	0.03	0.03	0.00	15.32	3.40	11.92
8/18/2011	13.62	2.39	10.08	3.31	0.23	0.21	0.02	7.86	3.50	4.36
8/19/2011	13.62	0.00	10.08	3.31	0.23	0.00	0.00	4.94	3.70	1.24
8/20/2011	13.62	0.00	10.08	3.31	0.23	0.00	0.00	3.85	3.85	0.00
						Total	0.02	37.12	19.61	17.52

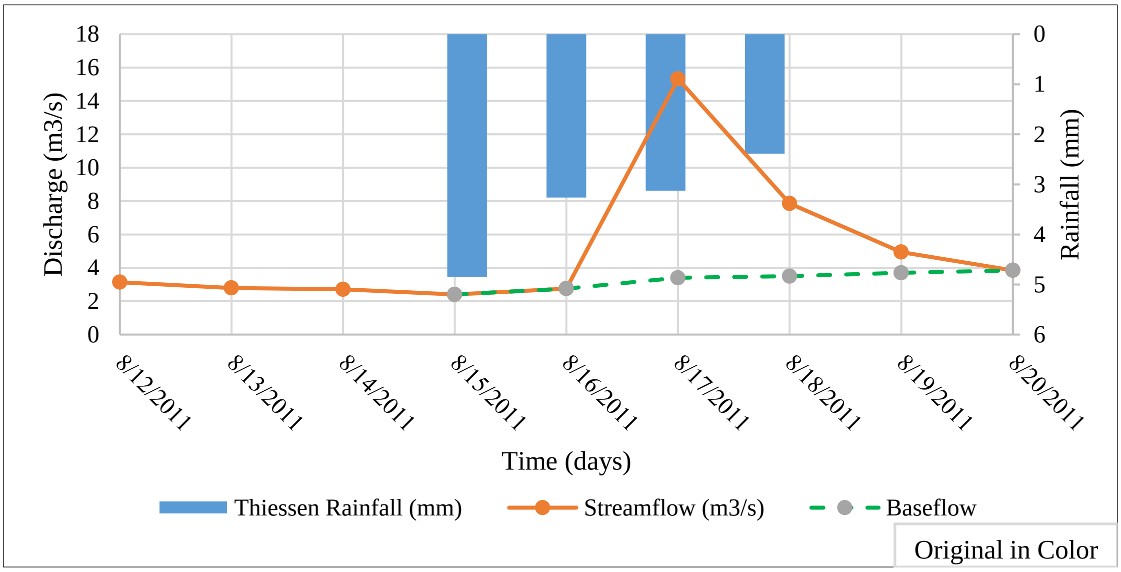


Figure C-18: Observed streamflow and baseflow for event no. E18

Table C-19: Observed rainfall, streamflow and baseflow separation for event no. E19

Event No	*Cumulative Rainfall (mm)*	*Hyetograph Rainfall (mm)*	*Cumulative Abstractions (mm)*		*Cumulative Excess Rainfall (mm)*	*Excess Rainfall Hyetograph*		*Runoff (Qobs) (m^3/s)*		
19										
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
3/12/2007	11.48	11.48	10.08	1.36	0.04	0.04	0.00	1.44	1.44	0.00
3/13/2007	41.54	30.07	10.08	19.37	12.10	12.06	1.21	1.37	1.37	0.00
3/14/2007	41.54	0.00	10.08	19.37	12.10	0.00	0.00	2.44	1.20	1.24
3/15/2007	46.76	5.22	10.08	21.23	15.46	3.36	0.34	5.00	1.10	3.90
3/16/2007	61.86	15.10	10.08	25.54	26.25	10.79	1.08	5.30	1.00	4.30
3/17/2007	61.86	0.00	10.08	25.54	26.25	0.00	0.00	11.07	2.50	8.57
3/18/2007	61.86	0.00	10.08	25.54	26.25	0.00	0.00	9.39	2.60	6.79
3/19/2007	61.86	0.00	10.08	25.54	26.25	0.00	0.00	5.94	3.00	2.94
3/20/2007	61.86	0.00	10.08	25.54	26.25	0.00	0.00	3.90	3.90	0.00
						Total	2.62	45.84	18.10	27.74

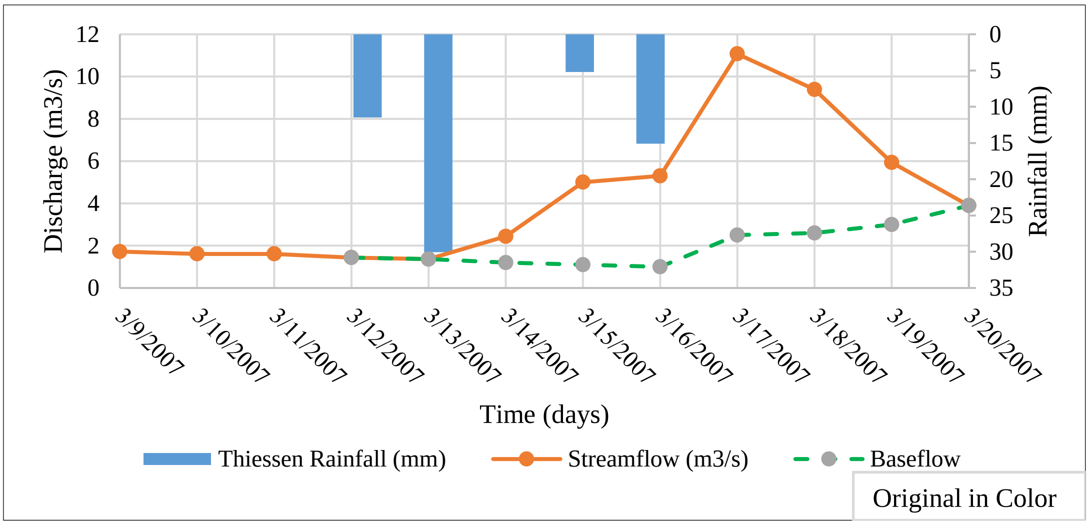


Figure C-19: Observed streamflow and baseflow for event no. E19

Table C-20: Observed rainfall, streamflow and baseflow separation for event no. E20

Event No	*Cumulative Rainfall (mm)*	*Hyetograph Rainfall (mm)*	*Cumulative Abstractions (mm)*		*Cumulative Excess Rainfall (mm)*	*Excess Rainfall Hyetograph*		*Runoff (Qobs) (m^3/s)*		
20										
Date	P_{cum}	*P*	*Ia*	*Fa*	*Pe*	*mm*	*cm*	*Q*	*Baseflow*	*DRO*
3/20/2011	11.53	11.53	10.08	1.42	0.04	0.04	0.00	4.54	4.54	0.00
3/21/2011	15.03	3.50	10.08	4.51	0.44	0.40	0.04	9.39	4.00	5.39
3/22/2011	19.03	4.00	10.08	7.61	1.35	0.91	0.09	15.99	3.50	12.49
3/23/2011	22.53	3.50	10.08	9.99	2.47	1.12	0.11	20.81	2.80	18.01
3/24/2011	22.53	0.00	10.08	9.99	2.47	0.00	0.00	17.60	5.00	12.60
3/25/2011	22.53	0.00	10.08	9.99	2.47	0.00	0.00	12.70	7.00	5.70
3/26/2011	24.03	1.50	10.08	10.93	3.03	0.56	0.06	10.70	10.70	0.00
						Total	0.30	91.73	37.54	54.19

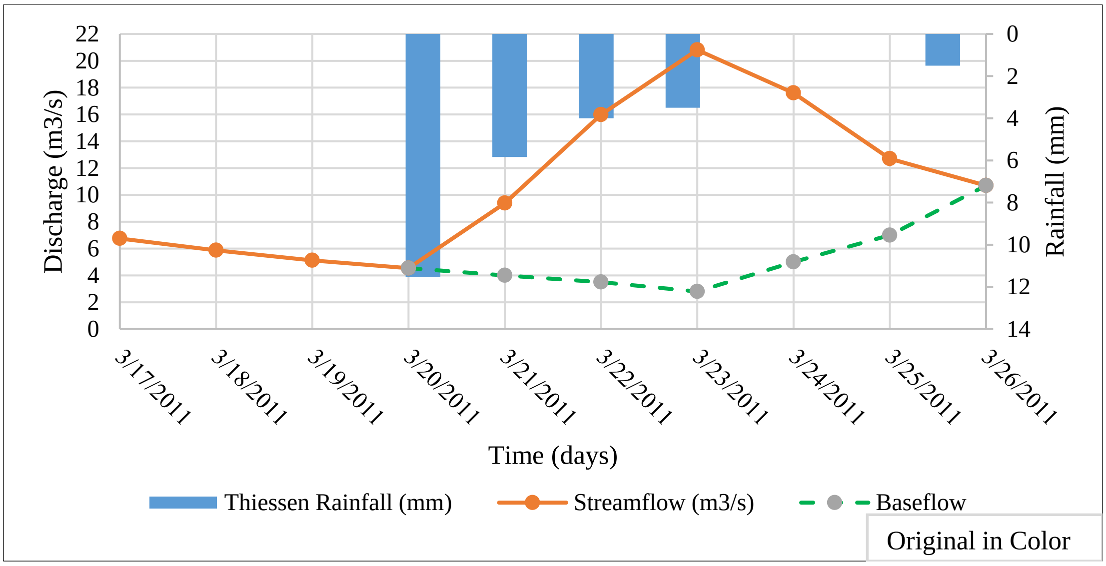


Figure C-20: Observed streamflow and baseflow for event no. E20

Table C-21: Observed rainfall, streamflow and baseflow separation for event no. E21

Event No 21	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m³/s)***		
Date	***P_{cum}***	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
10/15/2014	34.51	34.51	10.08	16.45	7.98	7.98	0.80	12.50	12.50	0.00
10/16/2014	48.72	14.21	10.08	21.87	16.78	8.80	0.88	46.16	46.16	0.00
10/17/2014	103.13	54.41	10.08	32.68	60.37	43.59	4.36	64.84	64.84	0.00
10/18/2014	107.20	4.07	10.08	33.17	63.95	3.58	0.36	338.32	80.00	258.32
10/19/2014	109.90	2.70	10.08	33.48	66.34	2.39	0.24	146.09	60.00	86.09
10/20/2014	122.70	12.81	10.08	34.81	77.82	11.48	1.15	48.32	45.00	3.32
10/21/2014	170.02	47.32	10.08	38.31	121.64	43.82	4.38	81.62	25.00	56.62
10/22/2014	208.24	38.22	10.08	40.17	158.00	36.36	3.64	332.84	20.00	312.84
10/23/2014	220.31	12.07	10.08	40.64	169.59	11.59	1.16	424.47	20.00	404.47
10/24/2014	225.27	4.96	10.08	40.82	174.37	4.78	0.48	171.37	35.00	136.37
10/25/2014	246.11	20.85	10.08	41.52	194.52	20.15	2.02	110.67	50.00	60.67
10/26/2014	265.14	19.02	10.08	42.07	212.99	18.47	1.85	140.73	50.00	90.73
10/27/2014	269.37	4.24	10.08	42.18	217.12	4.12	0.41	151.93	40.00	111.93
10/28/2014	302.08	32.71	10.08	42.97	249.04	31.93	3.19	107.17	35.00	72.17
10/29/2014	310.96	8.87	10.08	43.15	257.73	8.68	0.87	236.77	30.00	206.77
10/30/2014	391.55	80.60	10.08	44.50	336.98	79.25	7.92	144.75	25.00	119.75
10/31/2014	391.55	0.00	10.08	44.50	336.98	0.00	0.00	567.36	15.00	552.36
11/1/2014	392.94	1.39	10.08	44.52	338.35	1.37	0.14	182.78	60.00	122.78
11/2/2014	414.72	21.78	10.08	44.80	359.85	21.50	2.15	148.78	120.00	28.78
11/3/2014	434.62	19.90	10.08	45.03	379.51	19.67	1.97	156.88	156.88	0.00
						Total	37.95	3614.37	990.39	2623.98

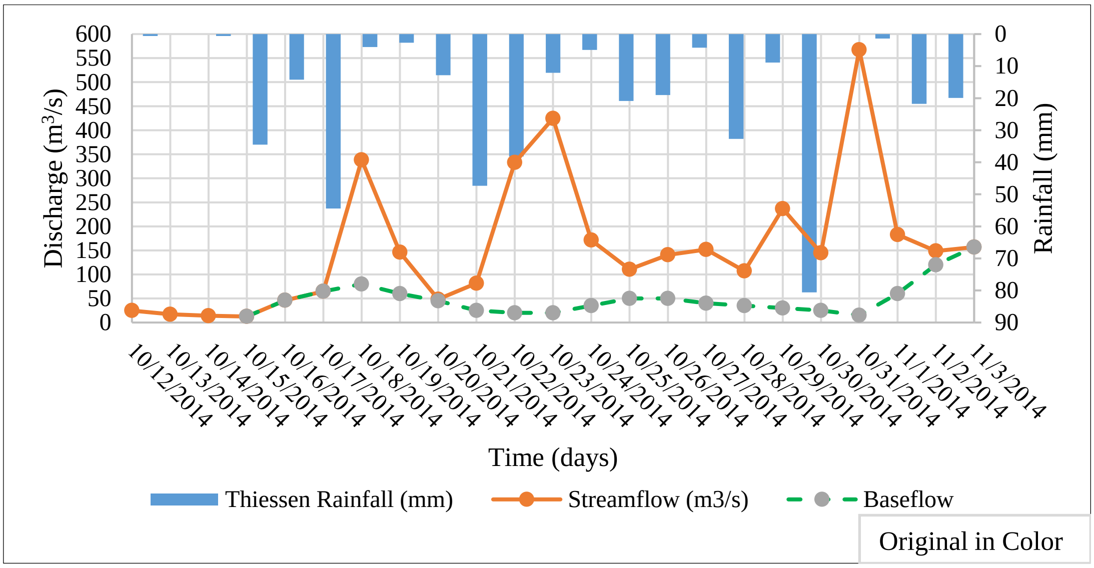


Figure C-21: Observed streamflow and baseflow for event no. E21

Table C-22: Observed rainfall, streamflow and baseflow separation for event no. E22

Event No 22	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
Date	***P_{cum}***	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
9/4/2013	6.93	6.93	6.93	0.00	0.00	0.00	0.00	3.85	3.85	0.00
9/5/2013	19.68	12.75	10.08	8.06	1.54	1.54	0.15	3.65	3.65	0.00
9/6/2013	62.90	43.22	10.08	25.79	27.04	25.50	2.55	5.30	3.20	2.10
9/7/2013	91.26	28.36	10.08	31.09	50.10	23.06	2.31	36.98	3.00	33.98
9/8/2013	98.41	7.15	10.08	32.08	56.26	6.16	0.62	86.78	2.50	84.28
9/9/2013	104.55	6.13	10.08	32.86	61.62	5.36	0.54	34.93	4.00	30.93
9/10/2013	117.13	12.58	10.08	34.26	72.80	11.18	1.12	27.33	10.00	17.33
9/11/2013	139.94	22.81	10.08	36.30	93.57	20.77	2.08	31.33	15.00	16.33
9/12/2013	246.86	106.91	10.08	41.54	195.24	101.67	10.17	63.24	8.00	55.24
9/13/2013	252.61	5.75	10.08	41.71	200.82	5.58	0.56	544.21	5.00	539.21
9/14/2013	254.39	1.78	10.08	41.77	202.55	1.73	0.17	231.10	6.00	225.10
9/15/2013	259.38	4.99	10.08	41.91	207.40	4.85	0.48	92.40	10.00	82.40
9/16/2013	280.71	21.33	10.08	42.47	228.17	20.77	2.08	50.74	15.00	35.74
9/17/2013	296.19	15.48	10.08	42.84	243.28	15.11	1.51	76.91	20.00	56.91
9/18/2013	305.71	9.52	10.08	43.04	252.59	9.31	0.93	131.38	8.00	123.38
9/19/2013	307.22	1.51	10.08	43.07	254.07	1.48	0.15	112.86	20.00	92.86
9/20/2013	308.73	1.51	10.08	43.11	255.55	1.48	0.15	64.16	30.00	34.16
9/21/2013	308.73	0.00	10.08	43.11	255.55	0.00	0.00	51.97	51.97	0.00
						Total	25.55	1649.11	219.16	1429.95

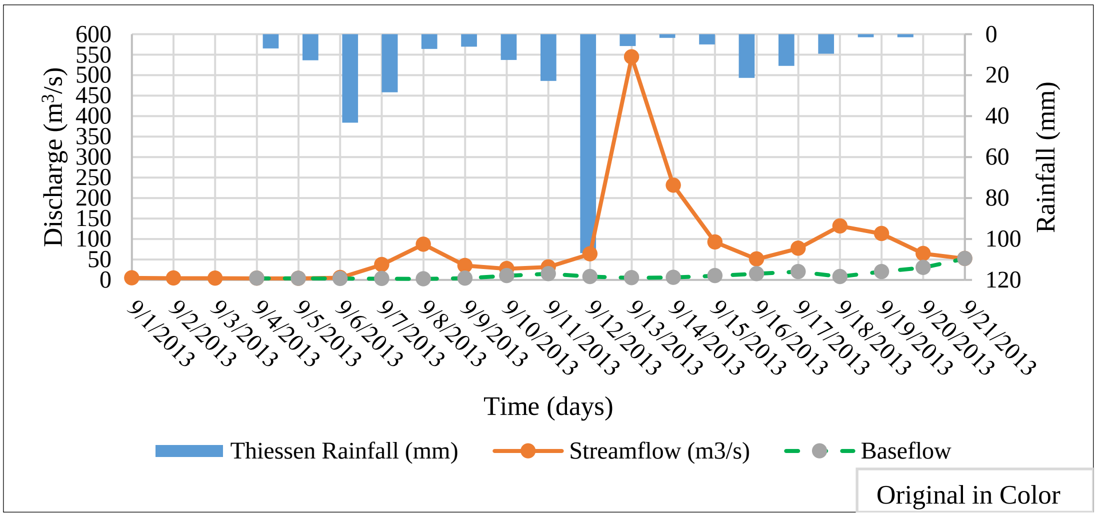


Figure C-22: Observed streamflow and baseflow for event no. E22

Table C-23: Observed rainfall, streamflow and baseflow separation for event no. E23

Event No 23	*Cumulative Rainfall (mm)*	*Hyetograph Rainfall (mm)*	*Cumulative Abstractions (mm)*		*Cumulative Excess Rainfall (mm)*	*Excess Rainfall Hyetograph*		*Runoff (Qobs) (m^3/s)*		
Date	P_{cum}	*P*	*Ia*	*Fa*	*Pe*	*mm*	*cm*	*Q*	*Baseflow*	*DRO*
11/29/2015	14.60	14.60	10.08	4.15	0.37	0.37	0.04	25.44	25.44	0.00
11/30/2015	44.36	29.76	10.08	20.40	13.88	13.51	1.35	51.15	51.15	0.00
12/1/2015	51.89	7.53	10.08	22.85	18.96	5.08	0.51	258.65	78.00	180.65
12/2/2015	67.34	15.45	10.08	26.80	30.46	11.50	1.15	167.74	79.00	88.74
12/3/2015	69.11	1.77	10.08	27.18	31.85	1.39	0.14	131.38	80.00	51.38
12/4/2015	82.86	13.75	10.08	29.77	43.01	11.16	1.12	81.19	81.19	0.00
12/5/2015	100.52	17.66	10.08	32.36	58.09	15.08	1.51	92.83	60.00	32.83
12/6/2015	100.52	0.00	10.08	32.36	58.09	0.00	0.00	103.25	42.00	61.25
12/7/2015	104.93	4.41	10.08	32.90	61.95	3.86	0.39	73.06	45.00	28.06
12/8/2015	151.66	46.73	10.08	37.16	104.43	42.48	4.25	57.90	57.90	0.00
12/9/2015	178.85	27.19	10.08	38.80	129.98	25.55	2.55	361.92	40.00	321.92
12/10/2015	179.28	0.43	10.08	38.82	130.39	0.41	0.04	213.29	57.00	156.29
12/11/2015	179.28	0.00	10.08	38.82	130.39	0.00	0.00	101.94	63.00	38.94
12/12/2015	206.66	27.38	10.08	40.10	156.49	26.10	2.61	79.91	79.91	0.00
						Total	15.65	1799.63	839.58	960.05

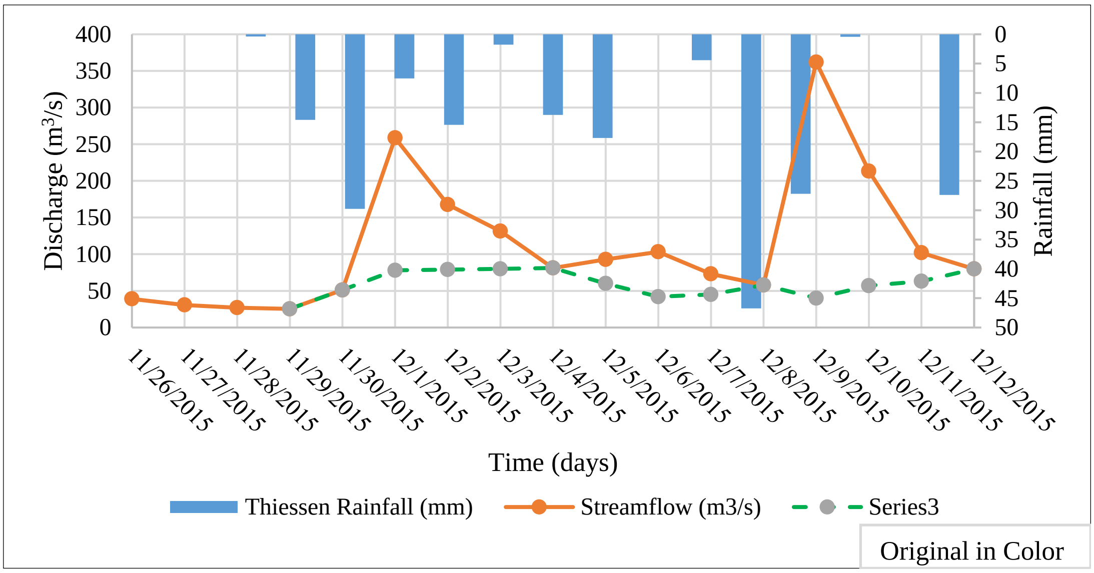


Figure C-23: Observed streamflow and baseflow for event no. E23

Table C-24: Observed rainfall, streamflow and baseflow separation for event no. E24

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
24										
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
5/12/2013	0.79	0.79	0.79	0.00	0.00	0.00	0.00	8.48	8.48	0.00
5/13/2013	74.57	73.78	10.08	28.28	36.21	36.21	3.62	8.73	8.73	0.00
5/14/2013	74.57	0.00	10.08	28.28	36.21	0.00	0.00	264.40	9.00	255.40
5/15/2013	74.57	0.00	10.08	28.28	36.21	0.00	0.00	70.50	12.00	58.50
5/16/2013	74.57	0.00	10.08	28.28	36.21	0.00	0.00	30.07	15.00	15.07
5/17/2013	74.57	0.00	10.08	28.28	36.21	0.00	0.00	21.86	21.86	0.00
						Total	3.62	404.04	75.07	328.97

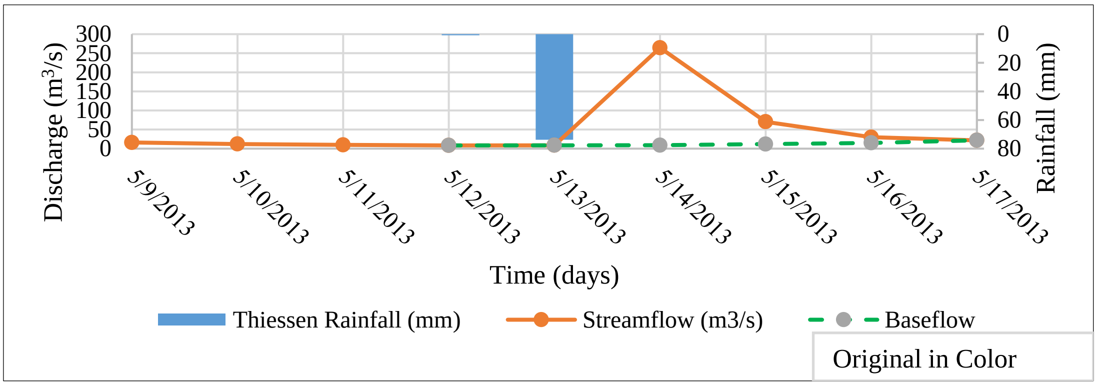


Figure C-24: Observed streamflow and baseflow for event no. E24

Table C-25: Observed rainfall, streamflow and baseflow separation for event no. E25

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
25										
Date	P_{cum}	*P*	*Ia*	*Fa*	*Pe*	*mm*	*cm*	*Q*	*Baseflow*	*DRO*
4/8/2013	2.97	2.97	2.97	0.00	0.00	0.00	0.00	4.88	4.88	0.00
4/9/2013	56.10	53.13	10.08	24.05	21.97	21.97	2.20	4.37	4.37	0.00
4/10/2013	56.49	0.40	10.08	24.16	22.26	0.29	0.03	20.05	4.00	16.05
4/11/2013	56.65	0.16	10.08	24.20	22.37	0.11	0.01	47.14	3.80	43.34
4/12/2013	57.11	0.46	10.08	24.32	22.71	0.33	0.03	19.42	5.00	14.42
4/13/2013	101.09	43.99	10.08	32.43	58.59	35.88	3.59	35.61	6.00	29.61
4/14/2013	101.19	0.10	10.08	32.44	58.68	0.09	0.01	185.08	2.00	183.08
4/15/2013	102.55	1.35	10.08	32.61	59.86	1.18	0.12	47.73	8.00	39.73
4/16/2013	102.55	0.00	10.08	32.61	59.86	0.00	0.00	28.68	16.00	12.68
4/17/2013	102.55	0.00	10.08	32.61	59.86	0.00	0.00	21.72	21.72	0.00
						Total	5.99	414.68	75.78	338.90

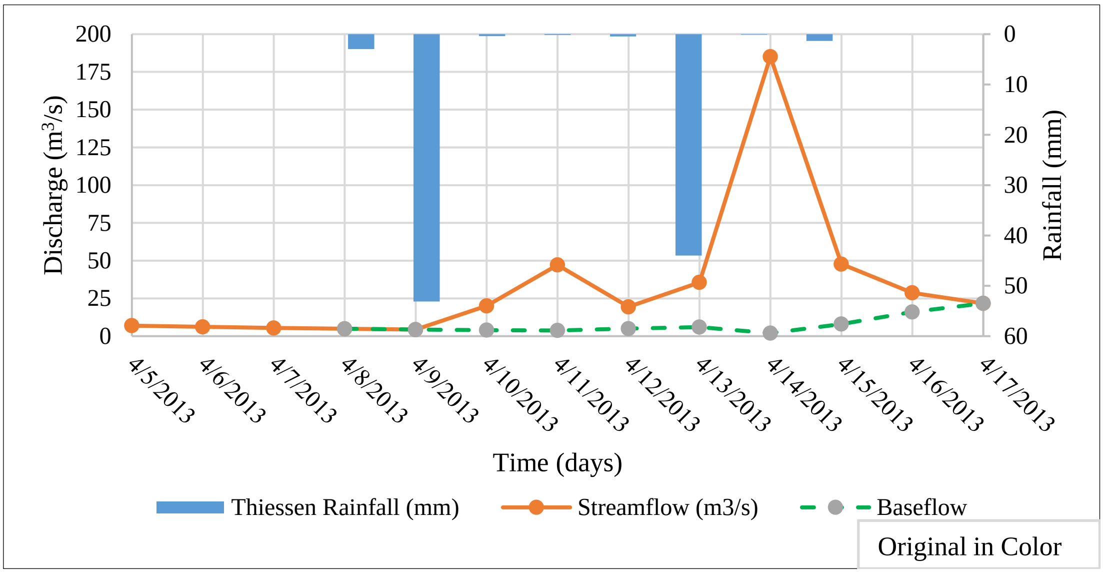


Figure C-25: Observed streamflow and baseflow for event no. E25

Table C-26: Observed rainfall, streamflow and baseflow separation for event no. E26

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m³/s)***		
26										
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
11/23/2012	10.39	10.39	10.08	0.31	0.00	0.00	0.00	14.78	14.78	0.00
11/24/2012	35.08	24.69	10.08	16.71	8.29	8.29	0.83	37.33	10.00	27.33
11/25/2012	41.18	6.11	10.08	19.23	11.88	3.58	0.36	51.35	7.00	44.35
11/26/2012	52.74	11.55	10.08	23.10	19.56	7.69	0.77	47.14	10.00	37.14
11/27/2012	87.58	34.84	10.08	30.53	46.97	27.41	2.74	60.10	12.00	48.10
11/28/2012	87.58	0.00	10.08	30.53	46.97	0.00	0.00	166.83	9.00	157.83
11/29/2012	87.58	0.00	10.08	30.53	46.97	0.00	0.00	82.05	15.00	67.05
11/30/2012	87.58	0.00	10.08	30.53	46.97	0.00	0.00	39.99	21.00	18.99
12/1/2012	87.58	0.00	10.08	30.53	46.97	0.00	0.00	30.07	30.07	0.00
						Total	4.70	529.63	128.84	400.78

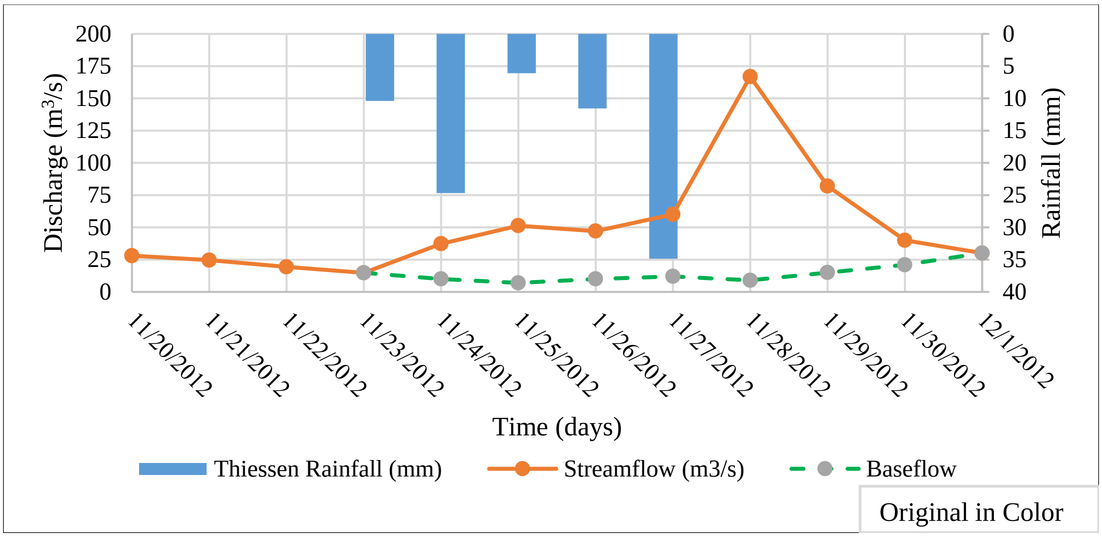


Figure C-26: Observed streamflow and baseflow for event no. E26

Table C-27: Observed rainfall, streamflow and baseflow separation for event no. E27

Event No 27	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
10/29/2016	0.40	0.40	0.40	0.00	0.00	0.00	0.00	4.33	4.33	0.00
10/30/2016	2.37	1.97	2.37	0.00	0.00	0.00	0.00	3.59	3.59	0.00
10/31/2016	42.23	39.86	10.08	19.63	12.53	12.53	1.25	3.03	3.03	0.00
11/1/2016	74.27	32.04	10.08	28.23	35.97	23.44	2.34	14.11	2.50	11.61
11/2/2016	100.32	26.05	10.08	32.33	57.92	21.95	2.19	85.20	2.00	83.20
11/3/2016	105.99	5.67	10.08	33.03	62.89	4.97	0.50	71.98	6.00	65.98
11/4/2016	116.42	10.43	10.08	34.18	72.16	9.27	0.93	38.87	20.00	18.87
11/5/2016	116.78	0.36	10.08	34.22	72.48	0.32	0.03	34.34	34.34	0.00
						Total	7.25	255.43	75.78	179.65

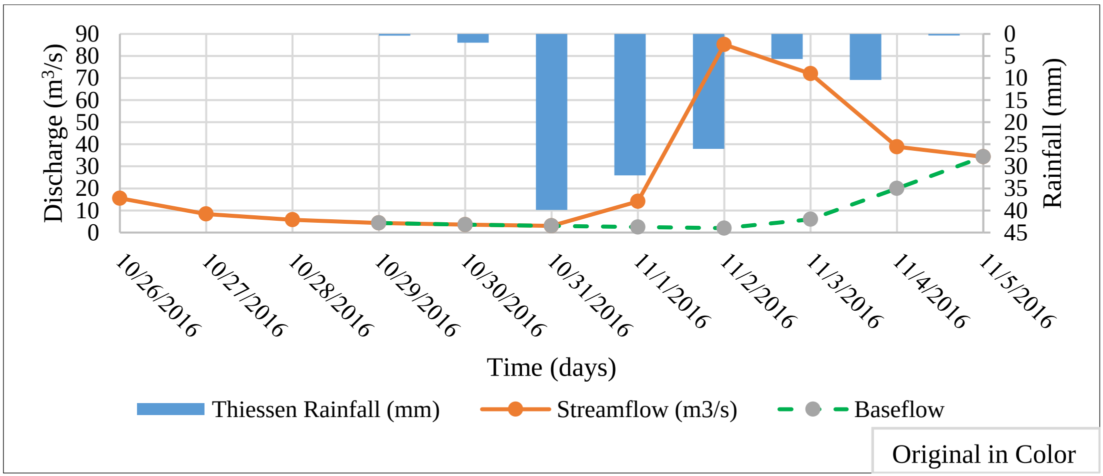


Figure C-27: Observed streamflow and baseflow for event no. E27

Table C-28: Observed rainfall, streamflow and baseflow separation for event no. E28

Event No 28	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m³/s)***		
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
7/6/2012	1.26	1.26	1.26	0.00	0.00	0.00	0.00	6.82	6.82	0.00
7/7/2012	4.28	3.01	4.28	0.00	0.00	0.00	0.00	5.00	5.00	0.00
7/8/2012	12.30	8.02	10.08	2.13	0.09	0.09	0.01	4.05	4.05	0.00
7/9/2012	27.86	15.56	10.08	13.14	4.64	4.54	0.45	3.80	3.80	0.00
7/10/2012	56.94	29.08	10.08	24.28	22.59	17.95	1.79	61.66	3.00	58.66
7/11/2012	56.94	0.00	10.08	24.28	22.59	0.00	0.00	33.11	5.00	28.11
7/12/2012	56.94	0.00	10.08	24.28	22.59	0.00	0.00	21.07	9.00	12.07
7/13/2012	56.94	0.00	10.08	24.28	22.59	0.00	0.00	14.24	14.24	0.00
						Total	2.26	149.75	50.92	98.83

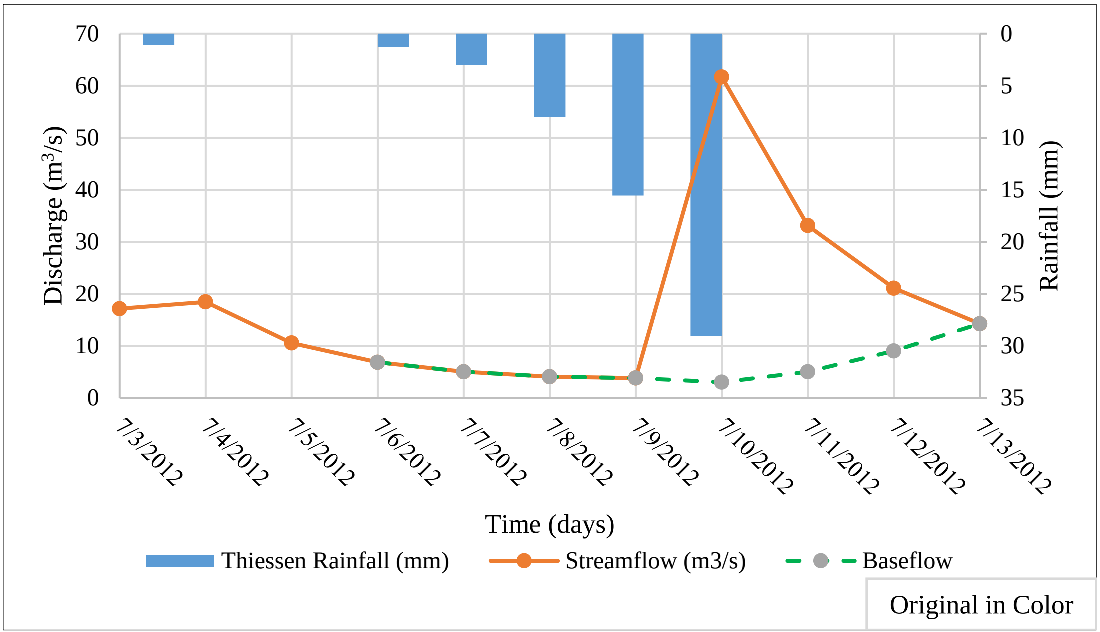


Figure C-28: Observed streamflow and baseflow for event no. E28

Table C-29: Observed rainfall, streamflow and baseflow separation for event no. E29

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
29										
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
2/23/2015	4.95	4.95	4.95	0.00	0.00	0.00	0.00	1.95	1.95	0.00
2/24/2015	46.48	41.53	10.08	21.13	15.27	15.27	1.53	1.65	1.65	0.00
2/25/2015	54.69	8.21	10.08	23.66	20.95	5.68	0.57	25.87	1.50	24.37
2/26/2015	63.24	8.55	10.08	25.87	27.30	6.35	0.63	28.99	1.50	27.49
2/27/2015	72.82	9.58	10.08	27.94	34.81	7.51	0.75	42.37	1.50	40.87
2/28/2015	74.16	1.34	10.08	28.21	35.88	1.07	0.11	41.63	4.00	37.63
3/1/2015	103.45	29.29	10.08	32.72	60.65	24.77	2.48	21.86	6.00	15.86
3/2/2015	104.26	0.82	10.08	32.82	61.37	0.72	0.07	36.12	5.00	31.12
3/3/2015	104.26	0.00	10.08	32.82	61.37	0.00	0.00	30.38	4.00	26.38
3/4/2015	145.23	40.96	10.08	36.70	98.45	37.09	3.71	10.17	3.50	6.67
3/5/2015	145.23	0.00	10.08	36.70	98.45	0.00	0.00	32.78	1.00	31.78
3/6/2015	145.23	0.00	10.08	36.70	98.45	0.00	0.00	14.56	3.00	11.56
3/7/2015	145.23	0.00	10.08	36.70	98.45	0.00	0.00	8.89	5.00	3.89
3/8/2015	145.23	0.00	10.08	36.70	98.45	0.00	0.00	7.18	7.18	0.00
						Total	9.85	304.39	46.79	257.60

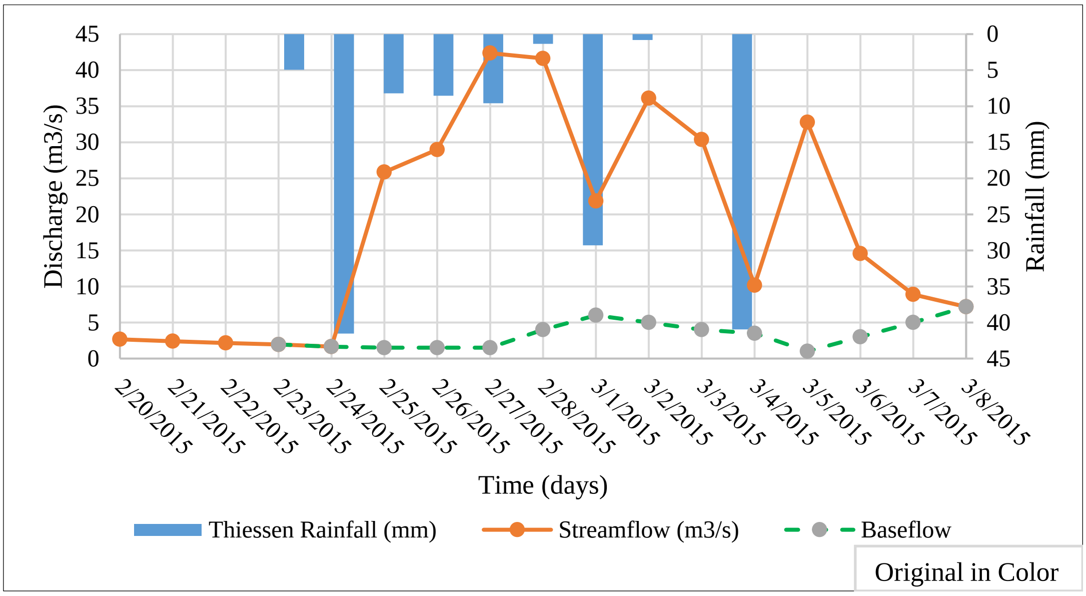


Figure C-29: Observed streamflow and baseflow for event no. E29

Table C-30: Observed rainfall, streamflow and baseflow separation for event no. E30

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
30										
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
5/31/2015	2.47	2.47	2.47	0.00	0.00	0.00	0.00	4.37	4.37	0.00
6/1/2015	3.98	1.51	3.98	0.00	0.00	0.00	0.00	4.21	4.21	0.00
6/2/2015	5.42	1.44	5.42	0.00	0.00	0.00	0.00	7.04	4.00	3.04
6/3/2015	10.13	4.71	10.08	0.05	0.00	0.00	0.00	8.64	3.90	4.74
6/4/2015	14.84	4.71	10.08	4.35	0.41	0.41	0.04	6.41	3.00	3.41
6/5/2015	38.08	23.24	10.08	18.00	10.01	9.60	0.96	11.16	2.50	8.66
6/6/2015	38.08	0.00	10.08	18.00	10.01	0.00	0.00	35.44	2.00	33.44
6/7/2015	38.08	0.00	10.08	18.00	10.01	0.00	0.00	18.92	3.50	15.42
6/8/2015	38.08	0.00	10.08	18.00	10.01	0.00	0.00	9.14	5.00	4.14
6/9/2015	38.08	0.00	10.08	18.00	10.01	0.00	0.00	6.97	6.97	0.00
						Total	1.00	112.31	39.45	72.85

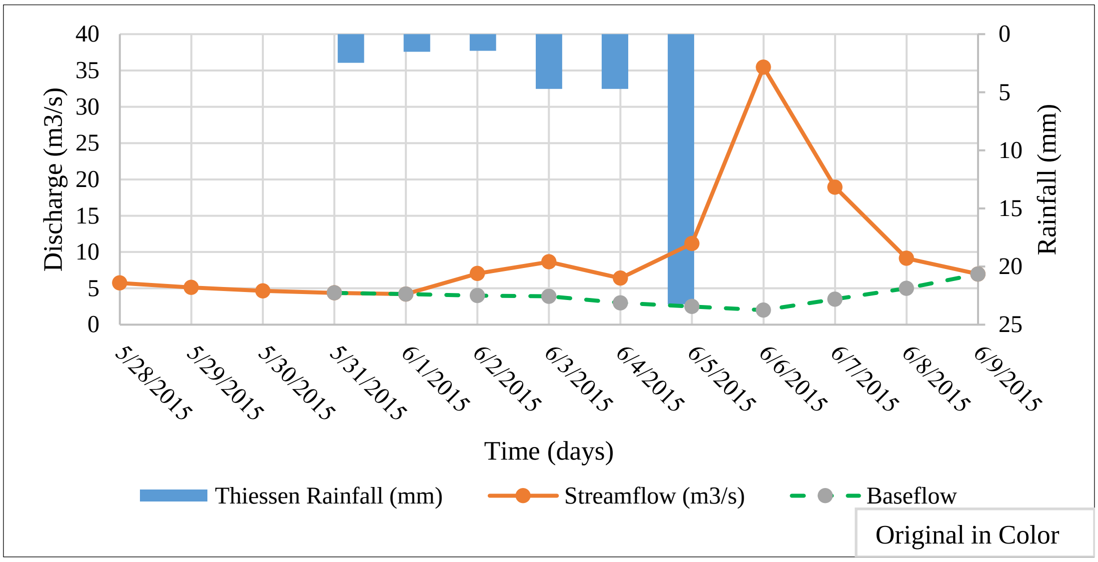


Figure C-30: Observed streamflow and baseflow for event no. E30

Table C-31: Observed rainfall, streamflow and baseflow separation for event no. E31

Event No 31	*Cumulative Rainfall (mm)*	*Hyetograph Rainfall (mm)*	*Cumulative Abstractions (mm)*		*Cumulative Excess Rainfall (mm)*	*Excess Rainfall Hyetograph*		*Runoff (Qobs) (m^3/s)*		
Date	P_{cum}	*P*	*Ia*	*Fa*	*Pe*	*mm*	*cm*	*Q*	*Baseflow*	*DRO*
2/12/2013	2.47	2.47	2.47	0.00	0.00	0.00	0.00	4.88	4.88	0.00
2/13/2013	10.14	7.66	10.08	0.06	0.00	0.00	0.00	4.43	4.43	0.00
2/14/2013	17.28	7.14	10.08	6.30	0.90	0.90	0.09	4.05	4.05	0.00
2/15/2013	17.28	0.00	10.08	6.30	0.90	0.00	0.00	9.47	3.50	5.97
2/16/2013	26.02	8.75	10.08	12.11	3.84	2.93	0.29	18.20	3.00	15.20
2/17/2013	26.02	0.00	10.08	12.11	3.84	0.00	0.00	20.17	2.50	17.67
2/18/2013	44.17	18.14	10.08	20.33	13.76	9.93	0.99	16.90	4.00	12.90
2/19/2013	49.44	5.27	10.08	22.10	17.26	3.50	0.35	14.30	6.50	7.80
2/20/2013	49.44	0.00	10.08	22.10	17.26	0.00	0.00	7.86	7.86	0.00
						Total	1.73	100.26	40.72	59.54

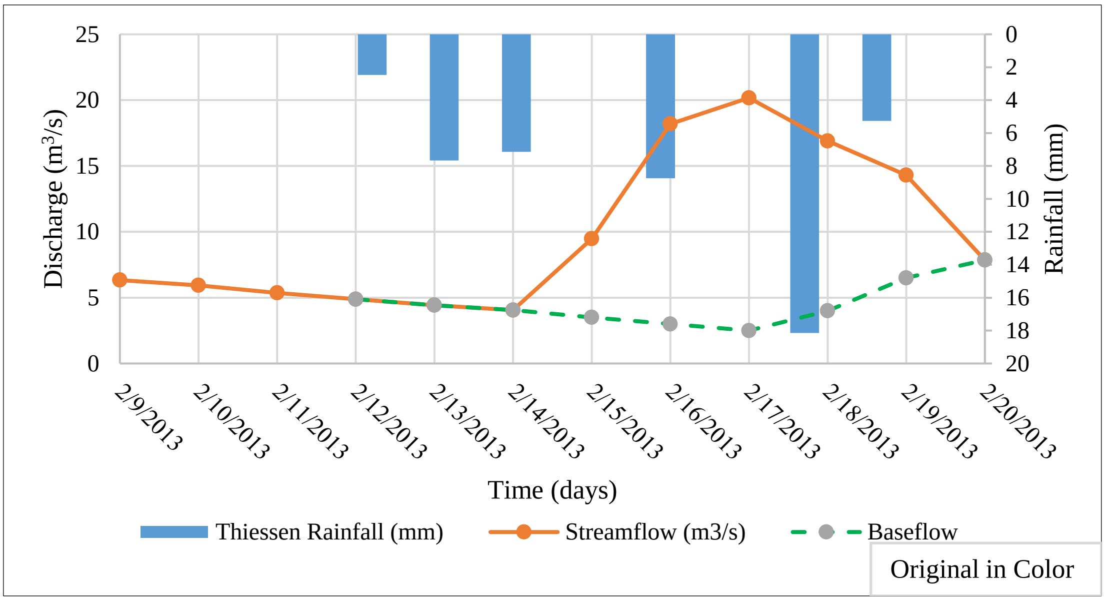


Figure C-31: Observed streamflow and baseflow for event no. E31

Table C-32: Observed rainfall, streamflow and baseflow separation for event no. E32

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m³/s)***		
32										
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
6/18/2014	3.45	3.45	3.45	0.00	0.00	0.00	0.00	7.07	7.07	0.00
6/19/2014	17.83	14.38	10.08	6.72	1.03	1.03	0.10	5.80	5.80	0.00
6/20/2014	22.93	5.10	10.08	10.24	2.61	1.58	0.16	12.52	4.00	8.52
6/21/2014	28.50	5.57	10.08	13.49	4.93	2.32	0.23	19.68	2.50	17.18
6/22/2014	28.50	0.00	10.08	13.49	4.93	0.00	0.00	13.59	3.00	10.59
6/23/2014	28.50	0.00	10.08	13.49	4.93	0.00	0.00	9.27	5.00	4.27
6/24/2014	29.45	0.95	10.08	13.99	5.38	0.45	0.04	6.55	6.55	0.00
						Total	0.54	74.48	33.92	40.56

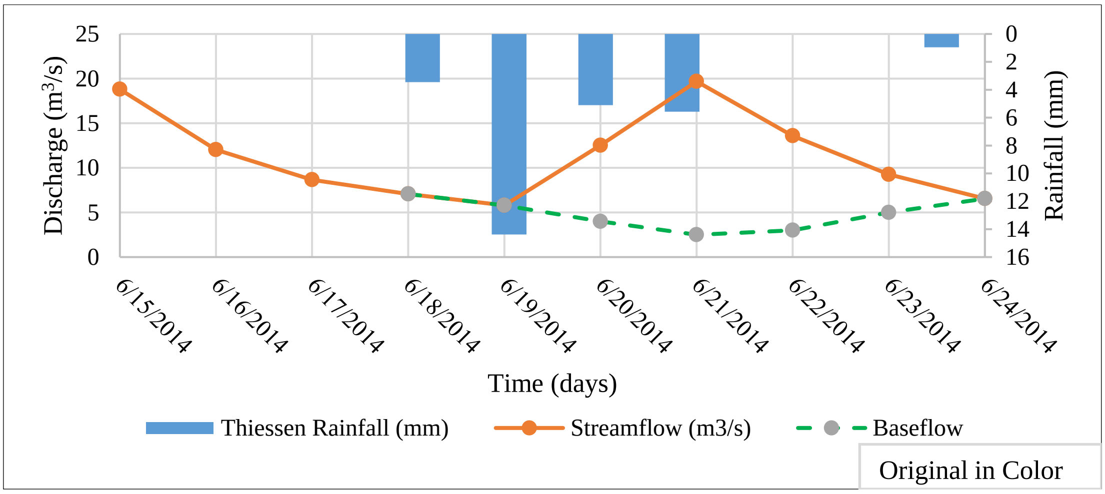


Figure C-32: Observed streamflow and baseflow for event no. E32

Table C-33: Observed rainfall, streamflow and baseflow separation for event no. E33

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
33										
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
2/14/2012	20.08	20.08	10.08	8.35	1.66	1.66	0.17	2.56	2.56	0.00
2/15/2012	28.21	8.13	10.08	13.34	4.80	3.14	0.31	10.70	2.00	8.70
2/16/2012	28.21	0.00	10.08	13.34	4.80	0.00	0.00	15.76	1.00	14.76
2/17/2012	53.42	25.21	10.08	23.30	20.05	15.25	1.52	7.18	2.00	5.18
2/18/2012	53.42	0.00	10.08	23.30	20.05	0.00	0.00	14.14	2.50	11.64
2/19/2012	53.42	0.00	10.08	23.30	20.05	0.00	0.00	14.14	3.50	10.64
2/20/2012	53.42	0.00	10.08	23.30	20.05	0.00	0.00	7.26	3.50	3.76
2/21/2012	53.42	0.00	10.08	23.30	20.05	0.00	0.00	5.00	3.60	1.40
2/22/2012	53.42	0.00	10.08	23.30	20.05	0.00	0.00	3.75	3.75	0.00
						Total	2.00	80.48	24.40	56.08

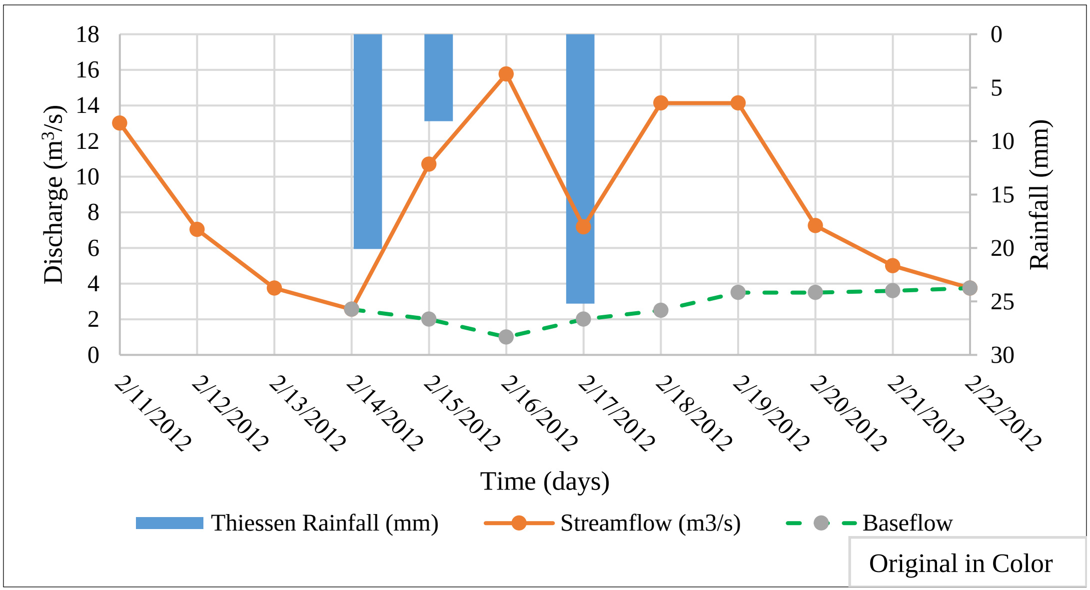


Figure C-33: Observed streamflow and baseflow for event no. E33

Table C-34: Observed rainfall, streamflow and baseflow separation for event no. E34

Event No	*Cumulative Rainfall (mm)*	*Hyetograph Rainfall (mm)*	*Cumulative Abstractions (mm)*		*Cumulative Excess Rainfall (mm)*	*Excess Rainfall Hyetograph*		*Runoff (Qobs) (m^3/s)*		
34										
Date	P_{cum}	*P*	*Ia*	*Fa*	*Pe*	*mm*	*cm*	*Q*	*Baseflow*	*DRO*
8/16/2017	2.34	2.34	2.34	0.00	0.00	0.00	0.00	4.35	4.35	0.00
8/17/2017	16.53	14.19	10.08	5.72	0.73	0.73	0.07	4.12	4.12	0.00
8/18/2017	44.37	27.83	10.08	20.40	13.89	13.15	1.32	4.00	4.00	0.00
8/19/2017	52.01	7.64	10.08	22.88	19.05	5.16	0.52	4.75	4.75	0.00
8/20/2017	54.35	2.34	10.08	23.56	20.71	1.66	0.17	14.42	6.00	8.42
8/21/2017	54.93	0.57	10.08	23.73	21.12	0.41	0.04	11.04	6.50	4.54
8/22/2017	54.93	0.00	10.08	23.73	21.12	0.00	0.00	8.59	7.00	1.59
8/23/2017	54.93	0.00	10.08	23.73	21.12	0.00	0.00	7.41	7.41	0.00
						Total	2.11	58.67	44.12	14.55

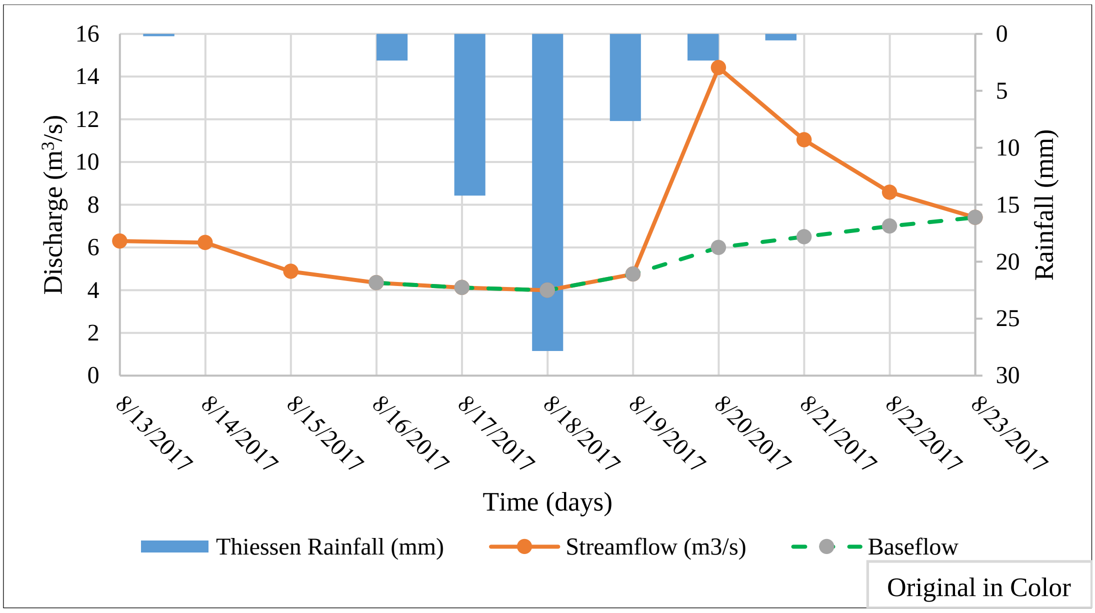


Figure C-34: Observed streamflow and baseflow for event no. E34

Table C-35: Observed rainfall, streamflow and baseflow separation for event no. E35

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
35										
Date	P_{cum}	*P*	*Ia*	*Fa*	*Pe*	*mm*	*cm*	*Q*	*Baseflow*	*DRO*
2/27/2012	9.95	9.95	9.95	0.00	0.00	0.00	0.00	1.06	1.06	0.00
2/28/2012	18.80	8.85	10.08	7.44	1.29	1.29	0.13	1.31	1.31	0.00
2/29/2012	18.80	0.00	10.08	7.44	1.29	0.00	0.00	4.60	1.50	3.10
3/1/2012	19.20	0.40	10.08	7.73	1.40	0.11	0.01	8.01	1.80	6.21
3/2/2012	19.20	0.00	10.08	7.73	1.40	0.00	0.00	4.77	2.00	2.77
3/3/2012	19.20	0.00	10.08	7.73	1.40	0.00	0.00	3.41	2.30	1.11
3/4/2012	19.20	0.00	10.08	7.73	1.40	0.00	0.00	2.79	2.79	0.00
						Total	0.14	25.94	12.76	13.18

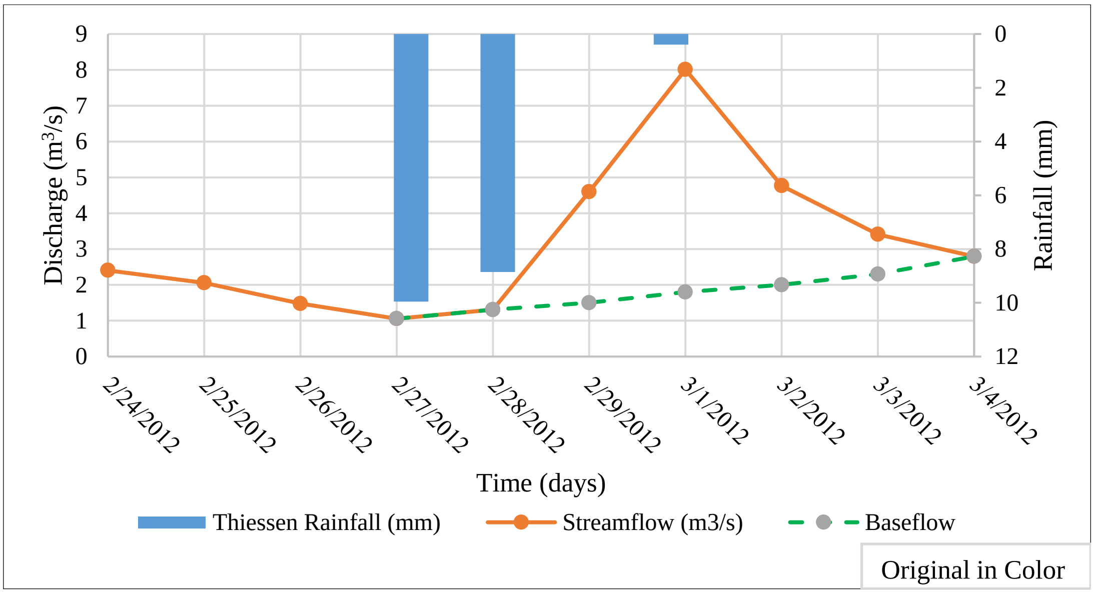


Figure C-35: Observed streamflow and baseflow for event no. E35

Table C-36: Observed rainfall, streamflow and baseflow separation for event no. E36

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
36										
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
7/9/2014	5.39	5.39	5.39	0.00	0.00	0.00	0.00	3.64	3.64	0.00
7/10/2014	22.07	16.68	10.08	9.69	2.31	2.31	0.23	3.27	3.27	0.00
7/11/2014	22.07	0.00	10.08	9.69	2.31	0.00	0.00	6.09	3.00	3.09
7/12/2014	22.07	0.00	10.08	9.69	2.31	0.00	0.00	9.48	2.70	6.78
7/13/2014	22.47	0.40	10.08	9.95	2.45	0.14	0.01	6.00	2.90	3.10
7/14/2014	22.47	0.00	10.08	9.95	2.45	0.00	0.00	4.26	3.10	1.16
7/15/2014	22.47	0.00	10.08	9.95	2.45	0.00	0.00	3.22	3.22	0.00
						Total	0.24	35.95	21.83	14.12

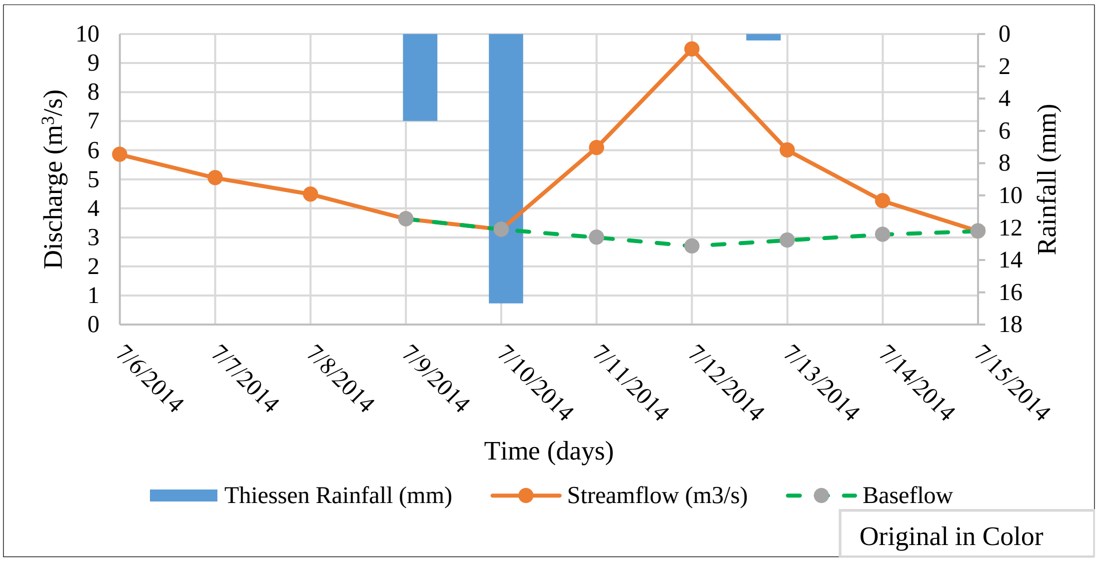


Figure C-36: Observed streamflow and baseflow for event no. E36

Table C-37: Observed rainfall, streamflow and baseflow separation for event no. E37

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m³/s)***		
37										
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
2/15/2016	8.50	8.50	8.50	0.00	0.00	0.00	0.00	1.15	1.15	0.00
2/16/2016	18.10	9.60	10.08	6.92	1.10	1.10	0.11	4.00	1.50	2.50
2/17/2016	25.10	7.00	10.08	11.57	3.45	2.35	0.23	1.21	1.21	0.00
2/18/2016	25.98	0.88	10.08	12.09	3.82	0.36	0.04	0.96	0.96	0.00
2/19/2016	25.98	0.00	10.08	12.09	3.82	0.00	0.00	0.84	0.84	0.00
						Total	0.38	8.16	5.66	2.50

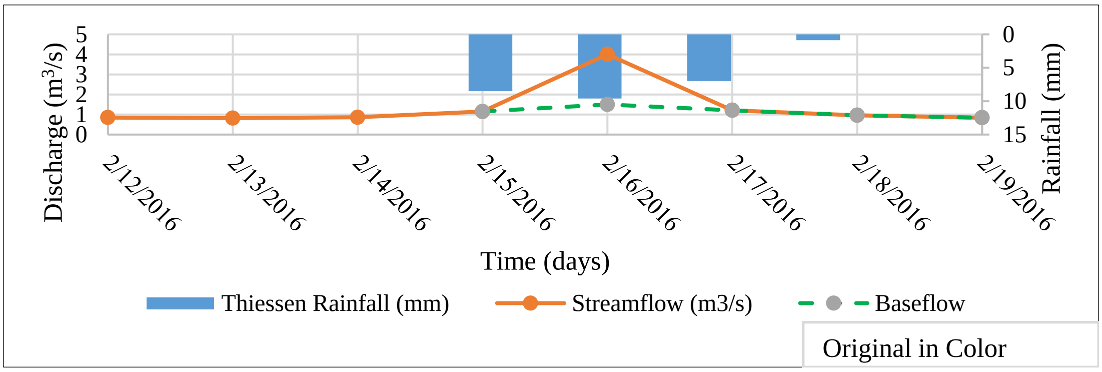


Figure C-37: Observed streamflow and baseflow for event no. E37

Table C-38: Observed rainfall, streamflow and baseflow separation for event no. E38

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
38										
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
9/20/2012	1.31	1.31	1.31	0.00	0.00	0.00	0.00	1.69	1.69	0.00
9/21/2012	9.91	8.60	9.91	0.00	0.00	0.00	0.00	1.73	1.73	0.00
9/22/2012	19.67	9.76	10.08	8.06	1.53	1.53	0.15	2.43	1.80	0.63
9/23/2012	23.69	4.02	10.08	10.72	2.90	1.36	0.14	1.84	1.75	0.09
9/24/2012	24.24	0.55	10.08	11.05	3.11	0.21	0.02	1.60	1.60	0.00
9/25/2012	24.24	0.00	10.08	11.05	3.11	0.00	0.00	1.51	1.51	0.00
						Total	0.31	10.79	10.08	0.72

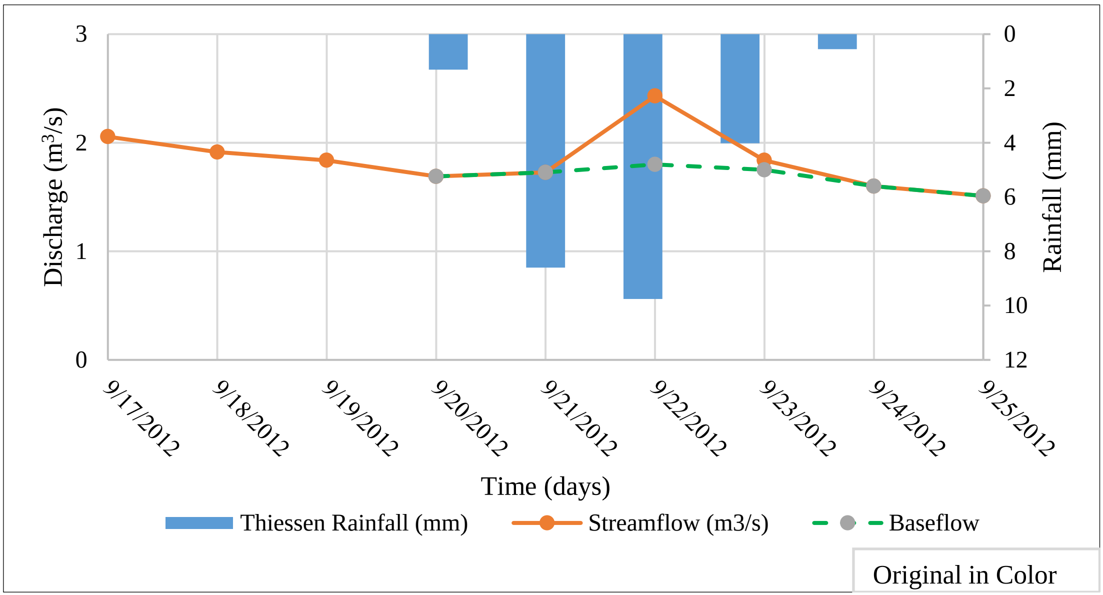


Figure C-38: Observed streamflow and baseflow for event no. E38

Table C-39: Observed rainfall, streamflow and baseflow separation for event no. E39

Event No	*Cumulative Rainfall (mm)*	*Hyetograph Rainfall (mm)*	*Cumulative Abstractions (mm)*		*Cumulative Excess Rainfall (mm)*	*Excess Rainfall Hyetograph*		*Runoff (Qobs) (m^3/s)*		
39										
Date	P_{cum}	*P*	*Ia*	*Fa*	*Pe*	*mm*	*cm*	*Q*	*Baseflow*	*DRO*
10/12/2016	11.08	11.08	10.08	0.98	0.02	0.02	0.00	1.55	1.55	0.00
10/13/2016	21.77	10.69	10.08	9.49	2.20	2.18	0.22	2.43	1.50	0.93
10/14/2016	31.82	10.04	10.08	15.19	6.55	4.35	0.44	1.42	1.42	0.00
10/15/2016	31.82	0.00	10.08	15.19	6.55	0.00	0.00	1.36	1.36	0.00
10/16/2016	31.82	0.00	10.08	15.19	6.55	0.00	0.00	1.32	1.32	0.00
						Total	0.66	8.08	7.15	0.93

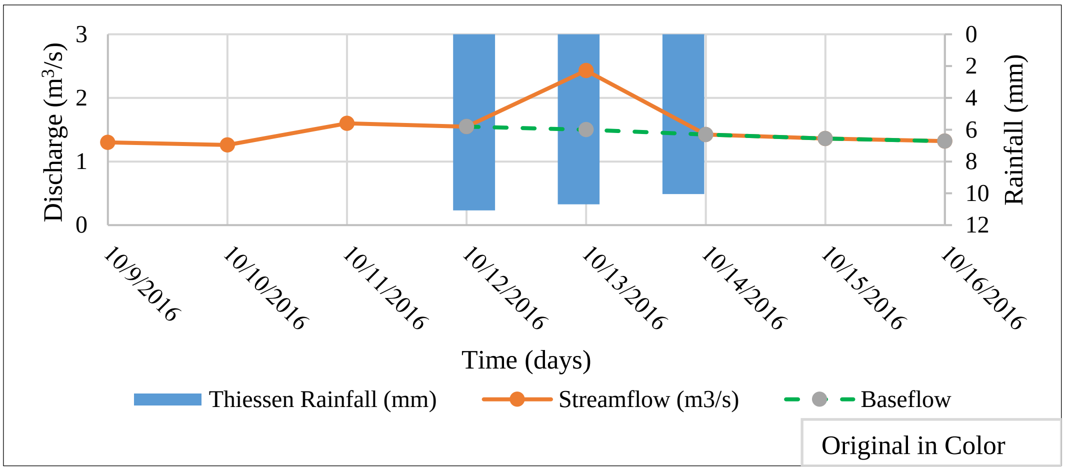


Figure C-39: Observed streamflow and baseflow for event no. E39

Table C-40: Observed rainfall, streamflow and baseflow separation for event no. E40

Event No	***Cumulative Rainfall (mm)***	***Hyetograph Rainfall (mm)***	***Cumulative Abstractions (mm)***		***Cumulative Excess Rainfall (mm)***	***Excess Rainfall Hyetograph***		***Runoff (Qobs) (m^3/s)***		
40										
Date	P_{cum}	***P***	***Ia***	***Fa***	***Pe***	***mm***	***cm***	***Q***	***Baseflow***	***DRO***
7/15/2015	7.60	7.60	7.60	0.00	0.00	0.00	0.00	1.10	1.10	0.00
7/16/2015	11.80	4.20	10.08	1.67	0.06	0.06	0.01	1.34	1.34	0.00
7/17/2015	18.10	6.30	10.08	6.92	1.10	1.05	0.10	2.42	1.60	0.82
7/18/2015	22.60	4.50	10.08	10.03	2.49	1.39	0.14	2.30	1.62	0.68
7/19/2015	24.77	2.17	10.08	11.38	3.32	0.82	0.08	1.99	1.65	0.34
7/20/2015	25.72	0.95	10.08	11.94	3.71	0.39	0.04	1.69	1.69	0.00
						Total	0.37	10.84	9.00	1.84

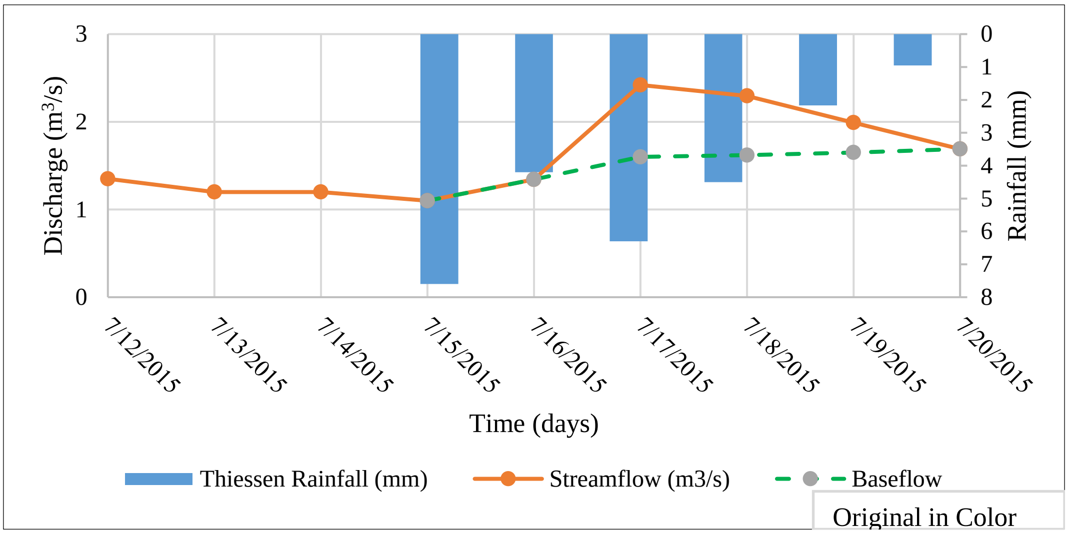


Figure C-40: Observed streamflow and baseflow for event no. E40

Appendix D: UH computation values

Table D-1: Ordinates of unit hydrograph

Time Ratios	Discharge ratios	t (min)	q (m^3/s)	$\left(\frac{q_2+q_1}{2}\right)\times((t_2-t_1)\times 60)$
(t/Tp)	q/qp			Sum
0.00	0.000	0.0	0.0	0.0
0.10	0.030	114.4	4.4	15017.5
0.20	0.100	228.7	14.6	65075.9
0.30	0.190	343.1	27.7	145169.4
0.40	0.310	457.4	45.2	250292.0
0.50	0.470	571.8	68.6	390455.5
0.60	0.660	686.1	96.3	565660.0
0.70	0.820	800.5	119.6	740864.4
0.80	0.930	914.9	135.7	876022.1
0.90	0.990	1029.2	144.5	961121.3
1.00	1.000	1143.6	145.9	996162.2
1.10	0.990	1257.9	144.5	996162.2
1.20	0.930	1372.3	135.7	961121.3
1.30	0.860	1486.6	125.5	896045.4
1.40	0.780	1601.0	113.8	820957.8
1.50	0.680	1715.4	99.2	730852.7
1.60	0.560	1829.7	81.7	620724.2
1.70	0.460	1944.1	67.1	510595.7
1.80	0.390	2058.4	56.9	425496.4
1.90	0.330	2172.8	48.2	360420.5
2.00	0.280	2287.1	40.9	305356.3
2.10	0.244	2401.5	35.5	262055.7
2.20	0.207	2515.8	30.2	225513.1
2.30	0.177	2630.2	25.8	192224.3
2.40	0.147	2744.6	21.4	162189.2
2.50	0.127	2858.9	18.5	137160.0
2.60	0.107	2973.3	15.6	117136.7
2.70	0.092	3087.6	13.4	99616.2
2.80	0.077	3202.0	11.2	84598.7
2.90	0.066	3316.3	9.6	71583.5
3.00	0.055	3430.7	8.0	60570.7
3.10	0.048	3545.1	6.9	51309.9
3.20	0.040	3659.4	5.8	43801.1
3.30	0.035	3773.8	5.0	37293.5

Time Ratios	Discharge ratios	t (min)	q (m^3/s)	$\left(\frac{q_2+q_1}{2}\right)*\left((t_2-t_1)*60\right)$
(t/Tp)	q/qp			Sum
3.40	0.029	3888.1	4.2	31787.1
3.50	0.025	4002.5	3.6	27031.5
3.60	0.021	4116.8	3.1	23026.9
3.70	0.018	4231.2	2.6	19522.8
3.80	0.015	4345.6	2.2	16519.3
3.90	0.013	4459.9	1.9	14016.4
4.00	0.011	4574.3	1.6	12014.0
4.10	0.010	4688.6	1.4	10412.1
4.20	0.009	4803.0	1.3	9210.7
4.30	0.007	4917.3	1.1	8009.3
4.40	0.006	5031.7	0.9	6807.9
4.50	0.005	5146.1	0.7	5606.5
4.60	0.004	5260.4	0.6	4505.3
4.70	0.003	5374.8	0.4	3504.1
4.80	0.002	5489.1	0.3	2502.9
4.90	0.001	5603.5	0.1	1501.8
5.00	0.000	5717.8	0.0	500.6
[(Sum/Area in Sqm)*100], Thus SUM				1.000

Appendix E: Evaluation of streamflow estimation using CN_{II} from handbook

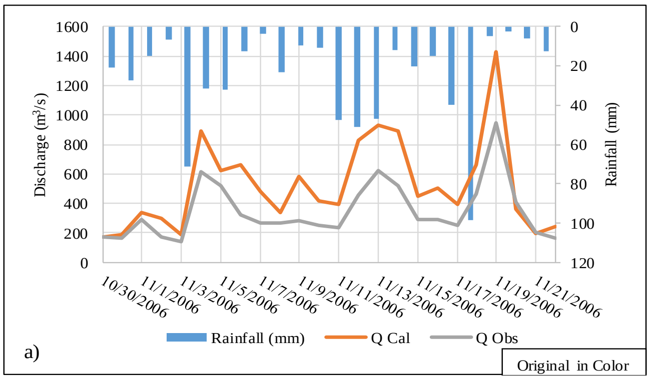
Table E-1: Details of all events using CN_{II} from rainfall-runoff data

Event ID	From	To	Total RF (mm)	CN	Qp (m3/s)		Tp (day)		Tb (day)		Vol (MMC)		Error (RAE)				Event MRAE	Event RAEM
					Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Qp	Tp	Tb	Vol		
E1	10/30/2006	11/22/2006	621.6	83.45	1431.4	944.6	20	20	5	5	1076.1	717.8	0.52	0.00	0.00	0.50	0.50	0.51
E2	7/11/2008	7/27/2008	172.6	83.45	402.2	494.3	12	8	6	10	175.8	119.8	0.19	0.50	0.40	0.47	0.99	0.96
E3	5/22/2011	6/5/2011	209.0	83.45	874.6	422.4	5	5	11	11	248.9	150.1	1.07	0.00	0.00	0.66	0.90	0.83
E4	9/27/2010	10/10/2010	251.9	83.45	820.5	312.0	5	5	9	9	311.1	142.8	1.63	0.00	0.00	1.18	1.07	1.18
E5	4/24/2008	5/2/2008	115.9	83.45	601.9	233.0	4	5	6	5	123.1	77.6	1.58	0.20	0.20	0.59	0.30	0.59
E6	12/16/2006	12/23/2006	32.5	83.45	117.3	188.3	4	4	5	5	27.0	35.5	0.38	0.00	0.00	0.24	0.11	0.24
E7	1/4/2006	1/17/2006	84.3	83.45	262.0	158.7	8	10	7	5	76.9	48.3	0.39	0.25	0.29	0.59	1.24	0.83
E8	6/19/2006	6/27/2006	195.0	83.45	820.0	156.9	2	5	8	5	209.2	65.3	0.81	1.50	0.38	2.20	3.49	2.27
E9	1/29/2005	2/5/2005	96.5	83.45	414.5	117.7	4	4	5	5	77.7	20.6	0.72	0.00	0.00	2.77	2.32	2.77
E10	6/5/2010	6/15/2010	108.7	83.45	409.6	96.7	7	7	5	5	100.1	35.1	0.76	0.00	0.00	1.85	1.51	1.88
E11	11/19/2007	11/26/2007	39.6	83.45	115.1	70.9	4	4	5	5	27.2	21.5	0.38	0.00	0.00	0.27	0.25	0.33
E12	8/20/2010	8/25/2010	40.6	83.45	88.5	54.5	1	2	6	5	18.4	12.1	0.38	1.00	0.17	0.53	0.66	0.73
E13	4/15/2006	4/23/2006	85.7	83.45	218.5	53.0	4	2	6	8	65.5	22.4	0.76	0.50	0.33	1.92	1.78	2.03
E14	3/3/2011	3/9/2011	48.0	83.45	173.3	41.8	3	3	5	5	27.9	11.6	0.76	0.00	0.00	1.41	0.87	1.41
E15	3/29/2006	4/4/2006	36.6	83.45	72.2	25.9	4	3	4	5	17.4	9.5	0.64	0.25	0.25	0.83	0.63	0.83
E16	12/15/2008	12/19/2008	35.0	83.45	108.9	26.5	3	1	3	4	18.0	9.6	0.76	0.67	0.33	0.88	1.00	1.05
E17	7/31/2007	8/7/2007	14.7	83.45	11.9	15.8	4	4	5	5	5.6	6.6	0.32	0.00	0.00	0.15	0.12	0.15
E18	8/15/2011	8/20/2011	13.6	83.45	6.4	15.3	4	2	3	5	2.0	3.2	1.38	0.50	0.67	0.38	0.28	0.48
E19	3/12/2007	3/20/2007	61.9	83.45	157.6	11.1	2	5	8	5	35.6	4.0	0.93	1.50	0.38	7.98	9.92	8.00
E20	3/20/2011	3/26/2011	24.0	83.45	21.2	20.8	4	3	4	5	6.4	7.9	0.02	0.25	0.25	0.19	0.25	0.27

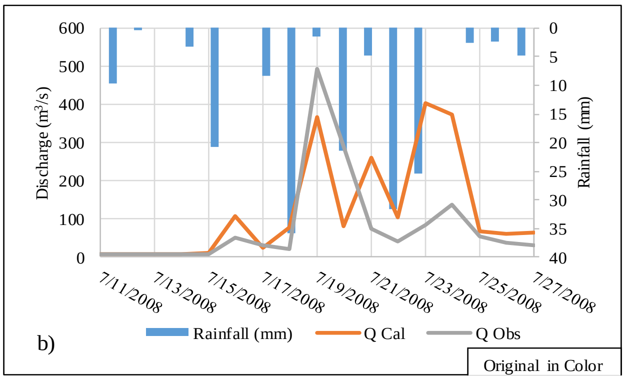
Continued….

Event ID	From	To	Total RF (mm)	CN	Qp (m3/s)		Tp (day)		Tb (day)		Vol (MMC)		Error (RAE)				Event MRAE	Event RAEM
					Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Qp	Tp	Tb	Vol		
E21	10/15/2014	11/3/2014	434.6	83.45	1065.4	567.4	16	16	5	5	547.9	312.3	0.88	0.00	0.00	0.75	0.81	0.75
E22	9/4/2013	9/21/2013	308.7	83.45	1363.1	544.2	9	9	10	10	349.7	142.5	1.50	0.00	0.00	1.45	1.96	1.49
E23	11/29/2015	12/12/2015	206.7	83.45	597.7	361.9	10	10	5	5	241.4	155.5	0.65	0.00	0.00	0.55	0.52	0.56
E24	5/12/2013	5/17/2013	74.6	83.45	478.5	264.4	2	2	5	5	53.4	34.9	0.81	0.00	0.00	0.53	0.19	0.56
E25	4/8/2013	4/17/2013	102.5	83.45	467.9	185.1	6	6	5	5	84.1	35.8	1.53	0.00	0.00	1.35	1.71	1.50
E26	11/23/2012	12/1/2012	87.6	83.45	379.0	166.8	5	5	5	5	72.0	45.8	1.27	0.00	0.00	0.57	0.58	0.78
E27	10/29/2016	11/5/2016	116.8	83.45	335.6	85.2	5	4	4	5	98.3	22.1	2.94	0.20	0.25	3.45	2.93	3.45
E28	7/6/2012	7/13/2012	56.9	83.45	245.9	61.7	5	4	4	5	33.7	12.9	2.99	0.20	0.25	1.60	1.01	1.60
E29	2/23/2015	3/8/2015	145.2	83.45	482.0	42.4	10	4	5	11	131.6	26.3	10.38	0.60	1.20	4.00	2.86	4.00
E30	5/31/2015	6/9/2015	38.1	83.45	127.2	35.4	6	6	5	5	16.4	9.7	2.59	0.00	0.00	0.69	0.47	0.98
E31	2/12/2013	2/20/2013	49.4	83.45	135.9	20.2	7	5	3	5	25.1	8.7	0.85	0.29	0.67	1.89	2.15	2.32
E32	6/18/2014	6/24/2014	29.5	83.45	36.2	19.7	4	3	4	5	9.3	6.4	0.84	0.25	0.25	0.45	0.24	0.31
E33	2/14/2012	2/22/2012	53.4	83.45	200.9	15.8	4	2	6	8	28.1	7.0	11.74	0.50	0.33	3.04	1.99	3.08
E34	8/16/2017	8/23/2017	54.9	83.45	176.6	14.4	3	4	6	5	31.2	5.1	11.25	0.33	0.17	5.15	6.00	5.15
E35	2/27/2012	3/4/2012	19.2	83.45	18.2	8.0	2	3	6	5	2.9	2.2	1.27	0.50	0.17	0.30	0.56	0.75
E36	7/9/2014	7/15/2014	22.5	83.45	32.9	9.5	2	3	6	5	5.1	3.1	2.47	0.50	0.17	0.63	0.76	0.92
E37	2/15/2016	2/19/2016	26.0	83.45	33.4	4.0	3	1	3	5	5.3	0.7	7.35	0.67	0.67	6.55	11.43	7.16
E38	9/20/2012	9/25/2012	24.2	83.45	22.0	2.4	4	2	3	5	4.8	0.9	8.06	0.50	0.67	4.18	4.58	4.30
E39	10/12/2016	10/16/2016	31.8	83.45	61.7	2.4	3	1	3	5	9.0	0.7	24.39	0.67	0.67	11.92	14.17	12.09
E40	7/15/2015	7/20/2015	25.7	83.45	21.6	2.4	4	2	3	5	4.9	0.9	7.92	0.50	0.67	4.24	3.91	4.25
												Max	***24.39***	***1.50***	***1.20***	***11.92***	***14.17***	***12.09***
												Min	***0.02***	***0.00***	***0.00***	***0.15***	***0.11***	***0.15***
												Average	***2.90***	***0.32***	***0.24***	***1.97***	***2.18***	***2.08***

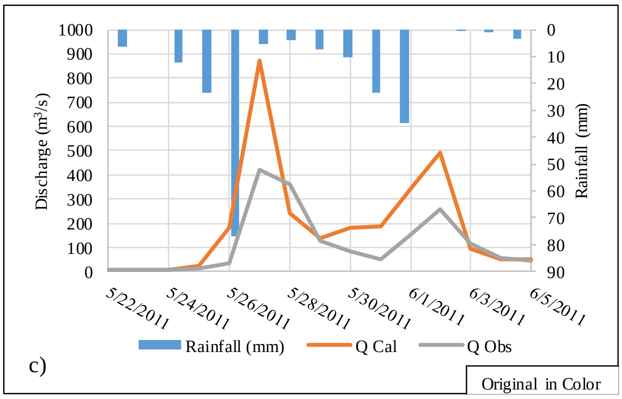
Appendix F: Streamflow graphs for all events using CN_{II} from handbook



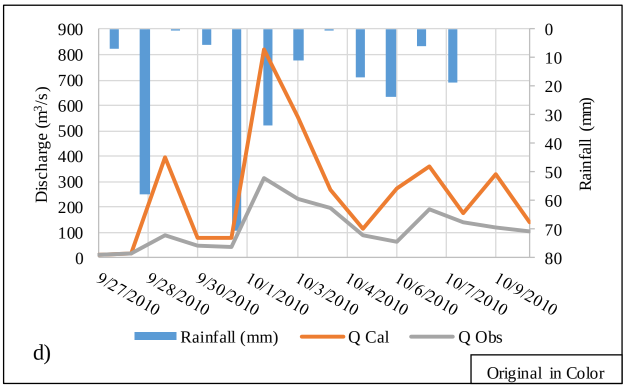
Event No.	E1	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	944.58	1431.35	0.340
T_p (day)	20	20	0.000
T_b (day)	5	5	0.000
Vol (MCM)	717.75	1076.07	0.499
Event MRAE		0.50	
Event RAME		0.51	



Event No.	E2	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	494.26	402.22	0.229
T_p (day)	8	12	0.500
T_b (day)	10	6	0.400
SF Vol (MCM)	119.8	175.8	0.467
Event MRAE		0.99	
Event RAME		0.96	

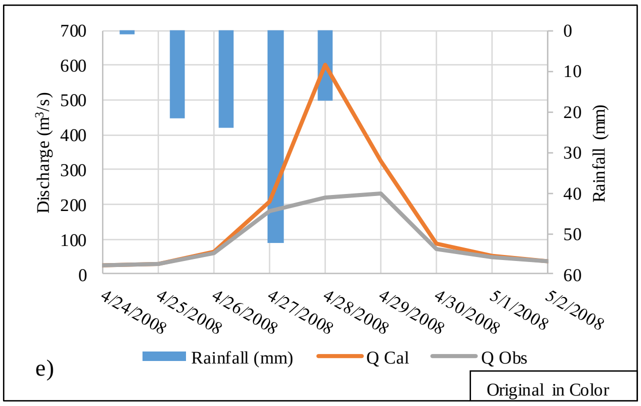


Event No.	E3	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	422.39	874.60	0.517
T_p (day)	5	5	0.000
T_b (day)	11	11	0.000
Vol (MCM)	150.09	248.95	0.659
Event MRAE		0.90	
Event RAME		0.83	

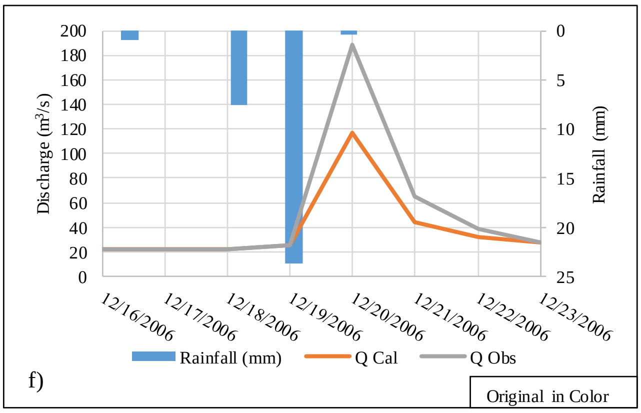


Event No.	E4	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	312.05	820.48	0.620
T_p (day)	5	5	0.000
T_b (day)	9	9	0.000
SF Vol (MCM)	142.81	311.12	1.179
Event MRAE		1.07	
Event RAME		1.18	

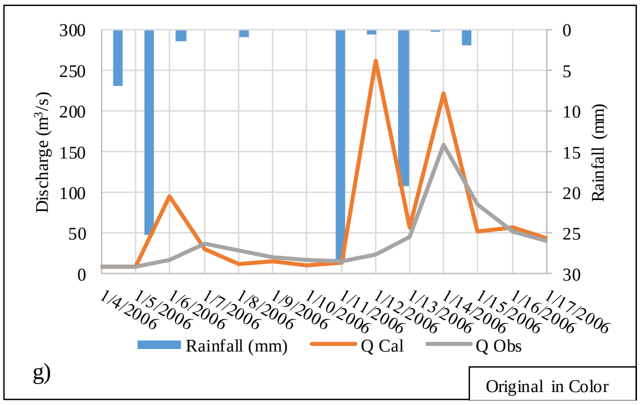
Figure F-1 (a-d): Calculated and observed streamflow graphs of events: E1-E4



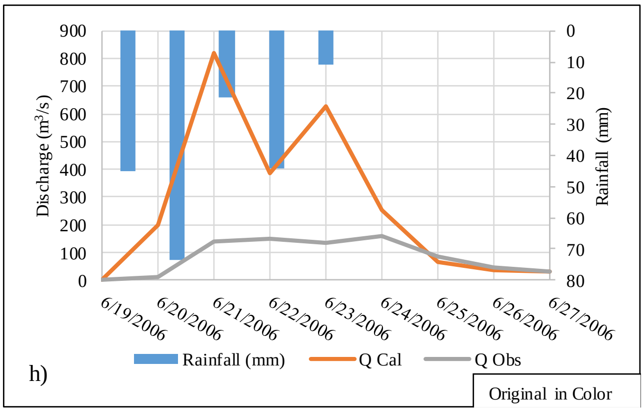
Event No.	E5	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	232.99	601.85	0.613
T_p (day)	5	4	0.200
T_b (day)	5	6	0.200
SF Vol (MCM)	77.60	123.1101	0.586
Event MRAE		0.30	
Event RAME		0.59	



Event No.	E6	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	188.29	117.28	0.605
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	35.47	27.02	0.238
Event MRAE		0.11	
Event RAME		0.24	

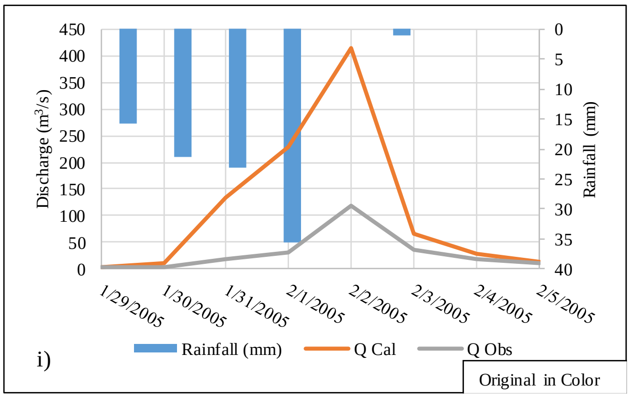


Event No.	E7	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	158.68	262.00	0.394
T_p (day)	8	10	0.250
T_b (day)	7	5	0.286
SF Vol (MCM)	48.29	76.86	0.592
Event MRAE		1.24	
Event RAME		0.83	

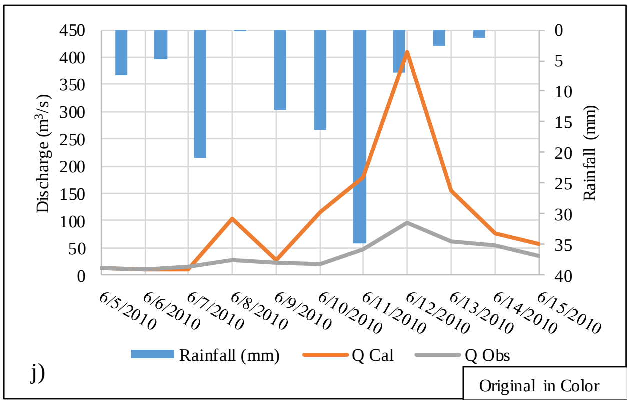


Event No.	E8	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	156.88	819.95	0.809
T_p (day)	2	5	1.500
T_b (day)	8	5	0.375
SF Vol (MCM)	65.34	209.16	2.201
Event MRAE		3.49	
Event RAME		2.27	

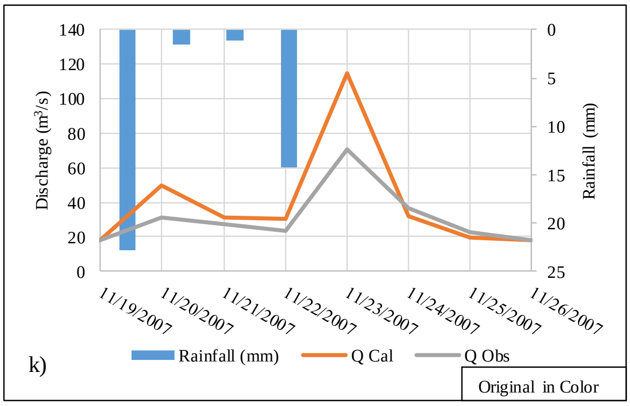
Figure F-2 (e-h): Calculated and observed streamflow graphs of events: E5-E8



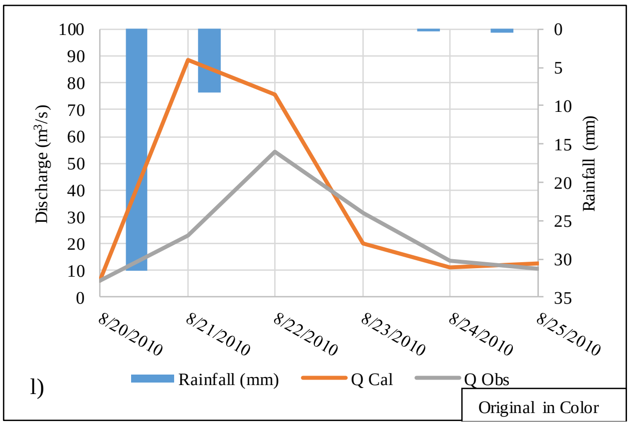
Event No.	E9	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	117.69	414.55	0.716
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
Vol (MCM)	20.59	77.69	2.774
Event MRAE		2.32	
Event RAME		2.77	



Event No.	E10	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	96.73	409.61	0.764
T_p (day)	7	7	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	35.08	100.09	1.853
Event MRAE		1.51	
Event RAME		1.88	

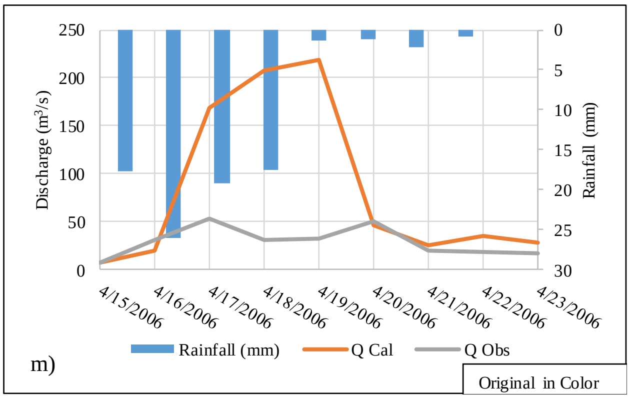


Event No.	E11	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	70.93	115.14	0.384
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
Vol (MCM)	21.50	27.23	0.267
Event MRAE		0.25	
Event RAME		0.33	

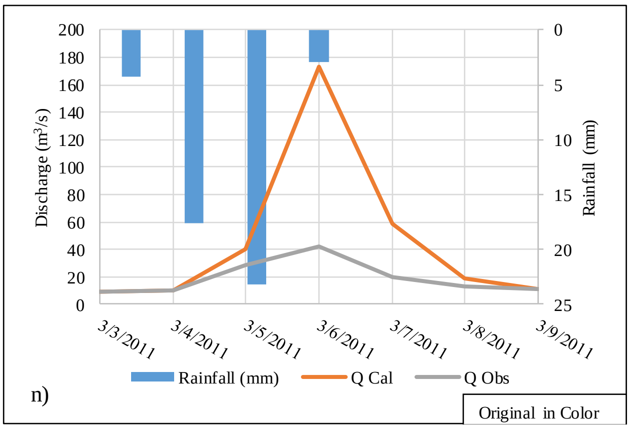


Event No.	E12	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	54.47	88.50	0.385
T_p (day)	1	2	1.000
T_b (day)	6	5	0.167
Vol (MCM)	12.06	18.44	0.529
Event MRAE		0.66	
Event RAME		0.73	

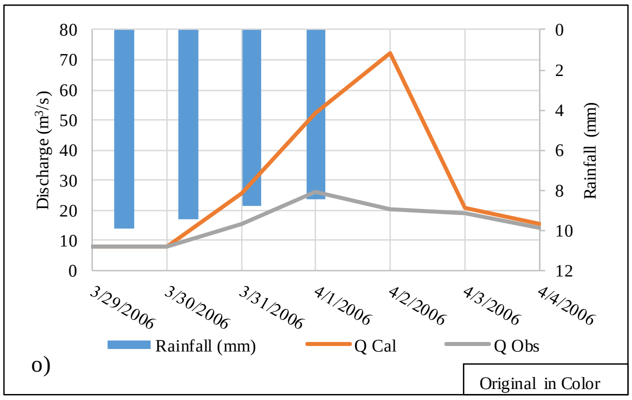
Figure F-3 (i-l): Calculated and observed streamflow graphs of events: E9-E12



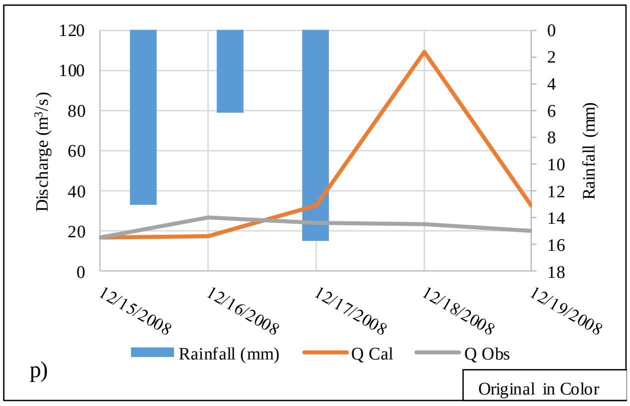
Event No.	E13	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	53.00	218.51	0.757
T_p (day)	4	2	0.500
T_b (day)	6	8	0.333
SF Vol (MCM)	22.43	65.47	1.918
Event MRAE		1.78	
Event RAME		2.03	



Event No.	E14	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	41.81	173.31	0.759
T_p (day)	3	3	0.000
T_b (day)	5	5	0.000
Vol (MCM)	11.59	27.89	1.406
Event MRAE		0.87	
Event RAME		1.41	

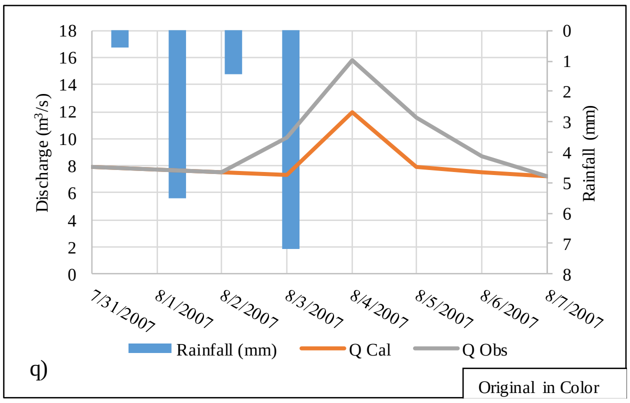


Event No.	E15	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	25.87	72.17	0.642
T_p (day)	4	3	0.250
T_b (day)	4	5	0.250
SF Vol (MCM)	9.50	17.41	0.832
Event MRAE		0.63	
Event RAME		0.83	

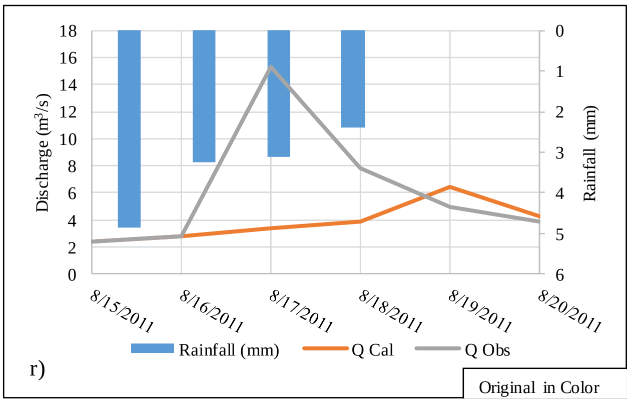


Event No.	E16	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	26.50	108.94	0.757
T_p (day)	3	1	0.667
T_b (day)	3	4	0.333
SF Vol (MCM)	9.582	18.002	0.879
Event MRAE		1.00	
Event RAME		1.05	

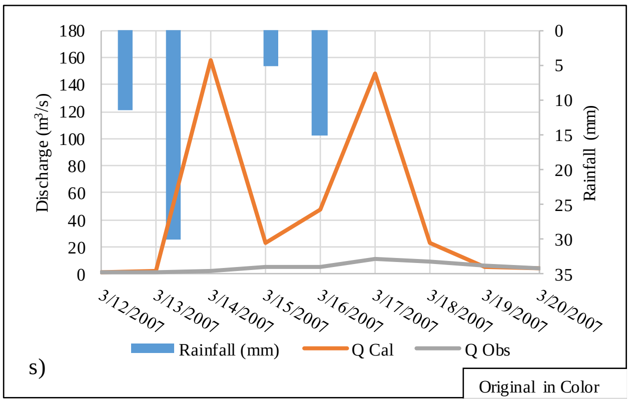
Figure F-4 (m-p): Calculated and observed streamflow graphs of events: E13-E16



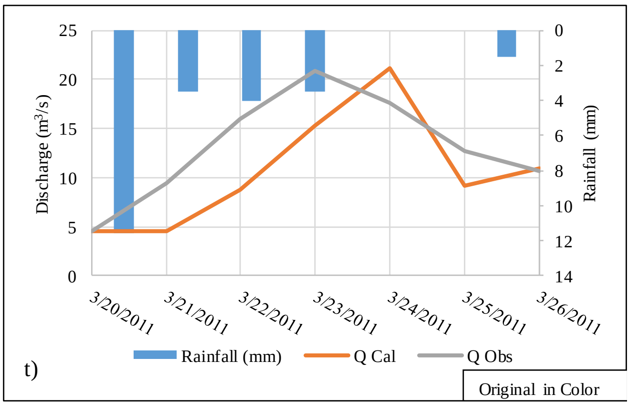
Event No.	E17	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.76	11.93	0.321
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	6.61	5.62	0.150
Event MRAE		0.12	
Event RAME		0.15	



Event No.	E18	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.32	6.43	1.382
T_p (day)	4	2	0.500
T_b (day)	3	5	0.667
SF Vol (MCM)	3.21	1.99	0.379
Event MRAE		0.28	
Event RAME		0.48	

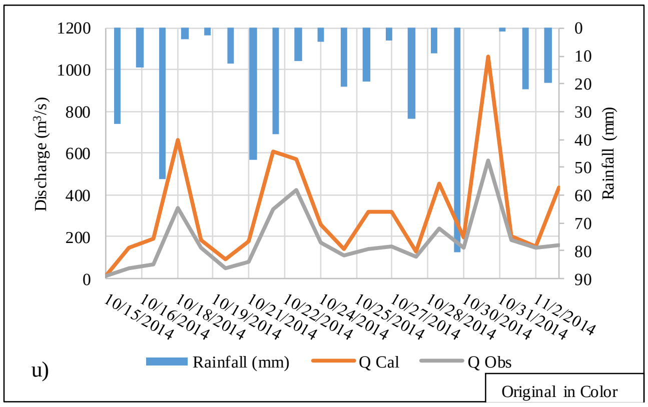


Event No.	E19	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	11.07	157.64	0.930
T_p (day)	2	5	1.500
T_b (day)	8	5	0.375
Vol (MCM)	3.96	35.57	7.980
Event MRAE		9.92	
Event RAME		8.00	

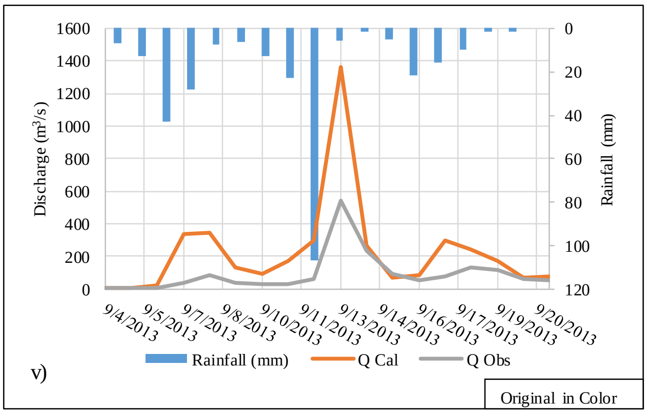


Event No.	E20	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	20.81	21.22	0.019
T_p (day)	4	3	0.250
T_b (day)	4	5	0.250
Vol (MCM)	7.93	6.44	0.187
Event MRAE		0.25	
Event RAME		0.27	

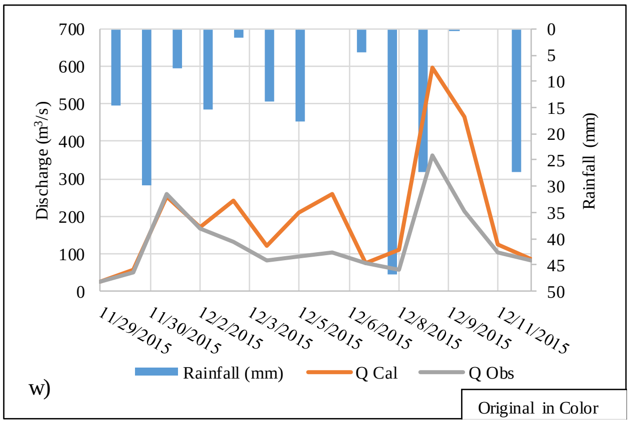
Figure F-5 (q-t): Calculated and observed streamflow graphs of events: E17-E20



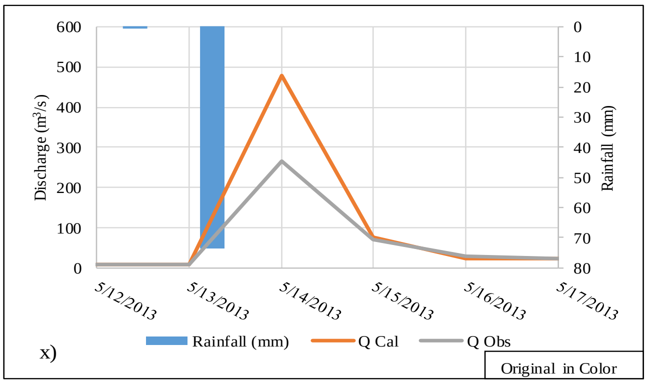
Event No.	E21	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	567.4	1065.4	0.878
T_p (day)	16	16	0.000
T_b (day)	5	5	0.000
Vol (MCM)	312.3	547.9	0.755
Event MRAE		0.81	
Event RAME		0.75	



Event No.	E22	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	544.2	1363.1	1.505
T_p (day)	9	9	0.000
T_b (day)	10	10	0.000
Vol (MCM)	142.5	349.7	1.454
Event MRAE		1.96	
Event RAME		1.49	

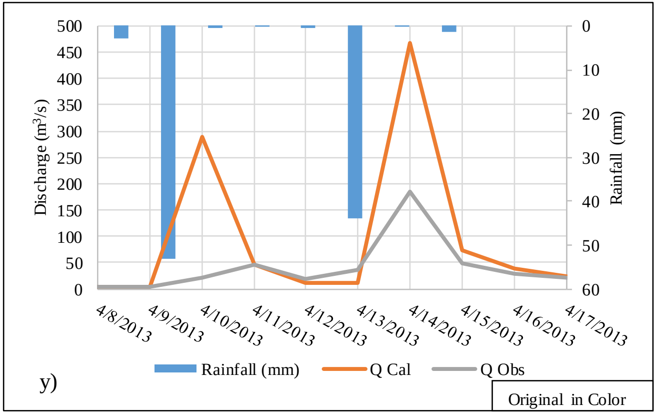


Event No.	E23	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	361.92	597.65	0.651
T_p (day)	10	10	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	155.49	241.43	0.553
Event MRAE		0.52	
Event RAME		0.56	

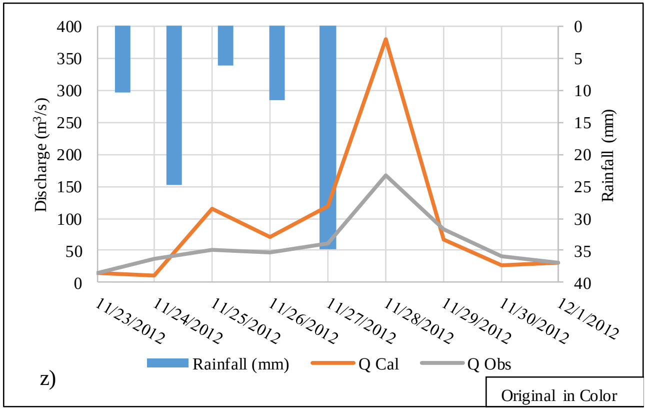


Event No.	E24	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	264.40	478.45	0.810
T_p (day)	2	2	0.000
T_b (day)	5	5	0.000
Vol (MCM)	34.91	53.39	0.529
Event MRAE		0.19	
Event RAME		0.56	

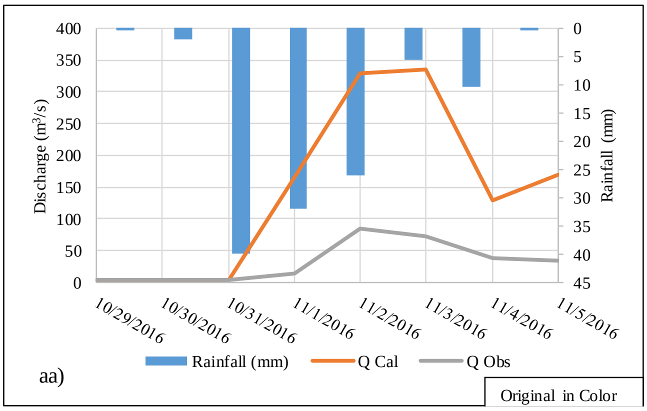
Figure F-6 (u-x): Calculated and observed streamflow graphs of events: E21-E24



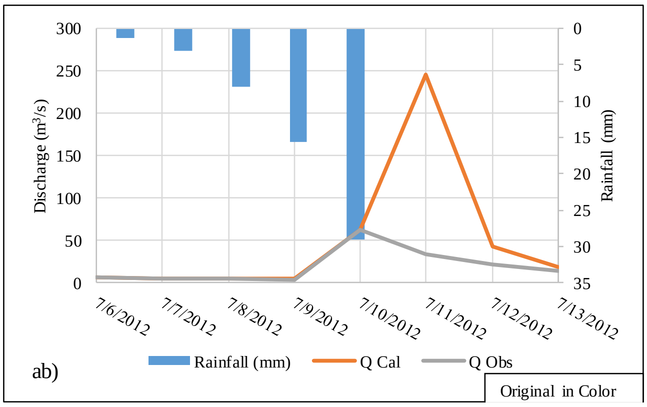
Event No.	E25	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	185.08	467.86	1.528
T_p (day)	6	6	0.000
T_b (day)	5	5	0.000
Vol (MCM)	35.83	84.07	1.346
Event MRAE		1.71	
Event RAME		1.50	



Event No.	E26	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	166.83	378.98	1.272
T_p (day)	5	5	0.000
T_b (day)	5	5	0.000
Vol (MCM)	45.76	71.98	0.573
Event MRAE		0.58	
Event RAME		0.78	

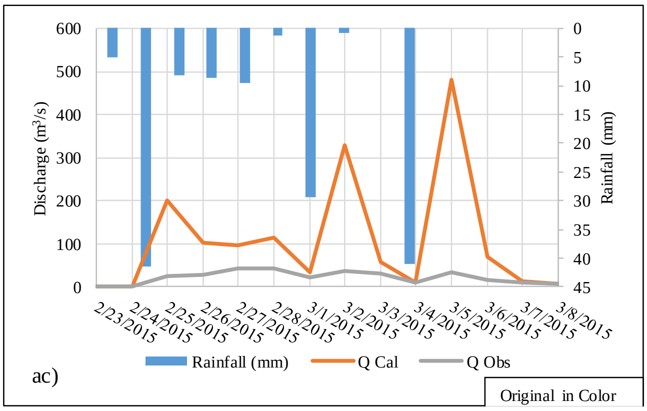


Event No.	E27	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	85.20	335.62	2.939
T_p (day)	5	4	0.200
T_b (day)	4	5	0.250
Vol (MCM)	22.07	98.30	3.454
Event MRAE		2.93	
Event RAME		3.45	

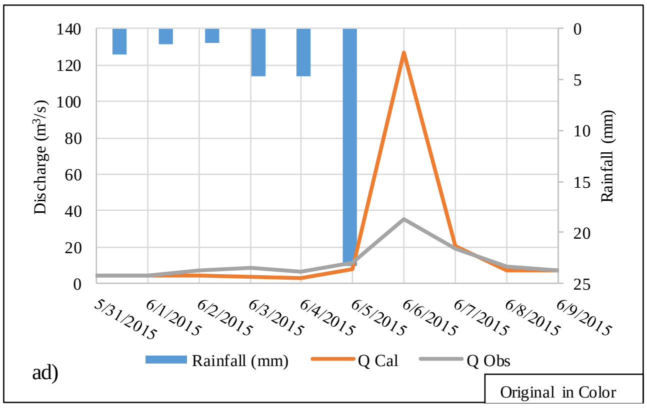


Event No.	E28	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	61.66	245.89	2.988
T_p (day)	5	4	0.200
T_b (day)	4	5	0.250
Vol (MCM)	12.94	33.66	1.601
Event MRAE		1.01	
Event RAME		1.60	

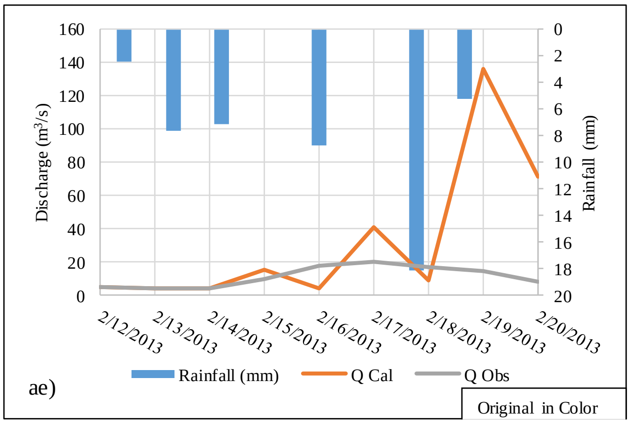
Figure F-7 (y-ab): Calculated and observed streamflow graphs of events: E25-E28



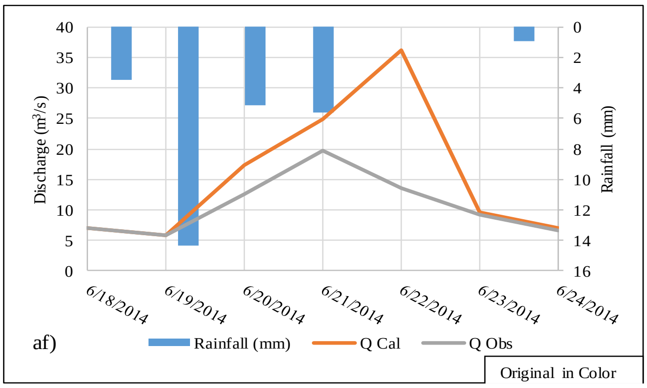
Event No.	E29	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	42.37	481.98	10.376
T_p (day)	10	4	0.600
T_b (day)	5	11	1.200
Vol (MCM)	26.30	131.58	4.003
Event MRAE		2.86	
Event RAME		4.00	



Event No.	E30	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	35.44	127.16	2.588
T_p (day)	6	6	0.000
T_b (day)	5	5	0.000
Vol (MCM)	9.70	16.37	0.687
Event MRAE		0.47	
Event RAME		0.98	

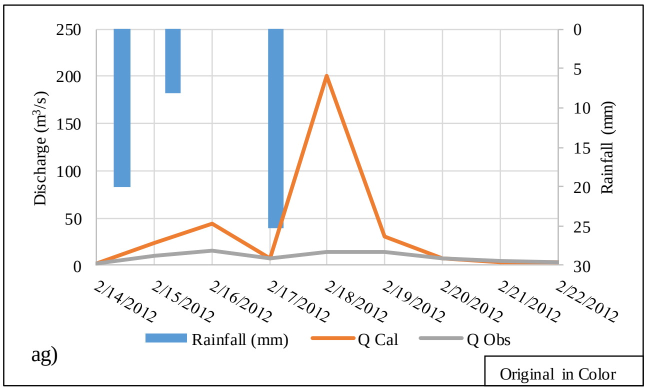


Event No.	E31	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	20.17	135.86	0.852
T_p (day)	7	5	0.286
T_b (day)	3	5	0.667
Vol (MCM)	8.66	25.07244	1.894
Event MRAE		2.15	
Event RAME		2.32	

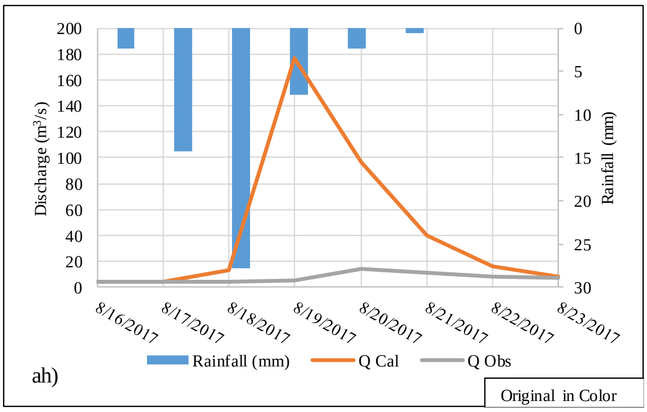


Event No.	E32	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	19.68	36.18	0.838
T_p (day)	4	3	0.250
T_b (day)	4	5	0.250
Vol (MCM)	6.44	9.32	0.449
Event MRAE		0.35	
Event RAME		0.45	

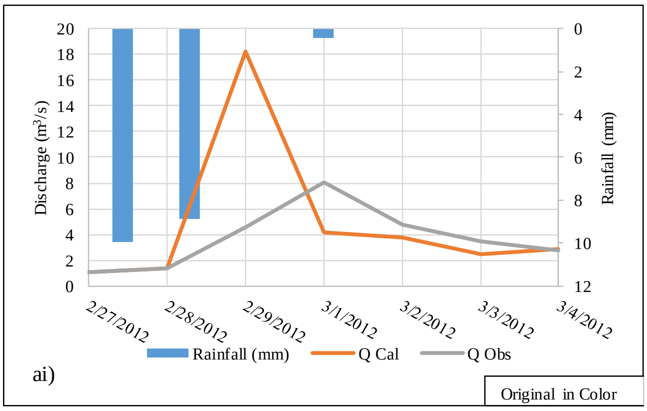
Figure F-8 (ac-af): Calculated and observed streamflow graphs of events: E29-E32



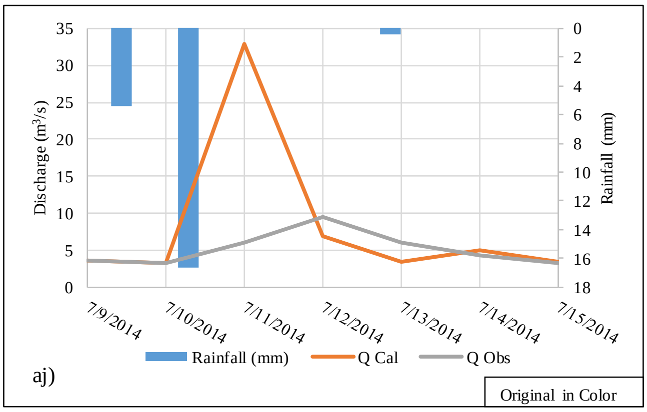
Event No.	E33	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.76	200.88	11.744
T_p (day)	4	2	0.500
T_b (day)	6	8	0.333
Vol (MCM)	6.95	28.08	3.038
Event MRAE		1.99	
Event RAME		3.08	



Event No.	E34	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	14.42	176.61	11.246
T_p (day)	3	4	0.333
T_b (day)	6	5	0.167
Vol (MCM)	5.07	31.17	5.149
Event MRAE		6.00	
Event RAME		5.15	

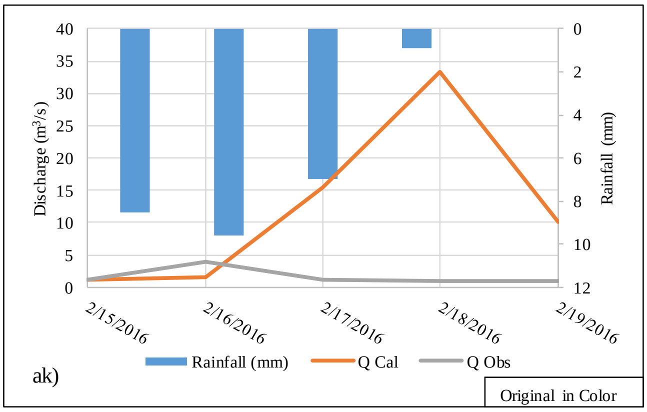


Event No.	E35	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	8.01	18.21	1.274
T_p (day)	2	3	0.500
T_b (day)	6	5	0.167
Vol (MCM)	2.24	2.92	0.301
Event MRAE		0.56	
Event RAME		0.75	

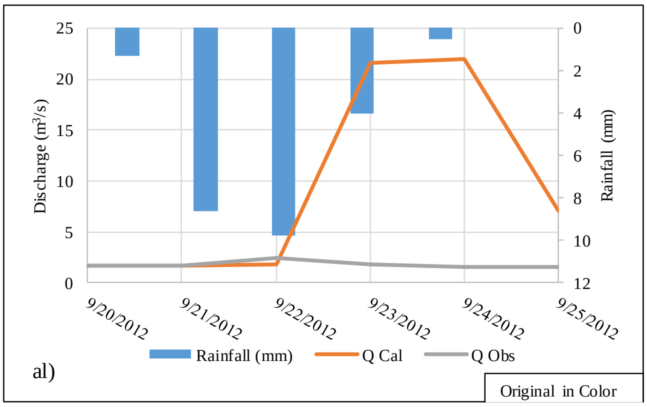


Event No.	E36	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	9.48	32.91	2.472
T_p (day)	2	3	0.500
T_b (day)	6	5	0.167
Vol (MCM)	3.11	5.05	0.626
Event MRAE		0.76	
Event RAME		0.92	

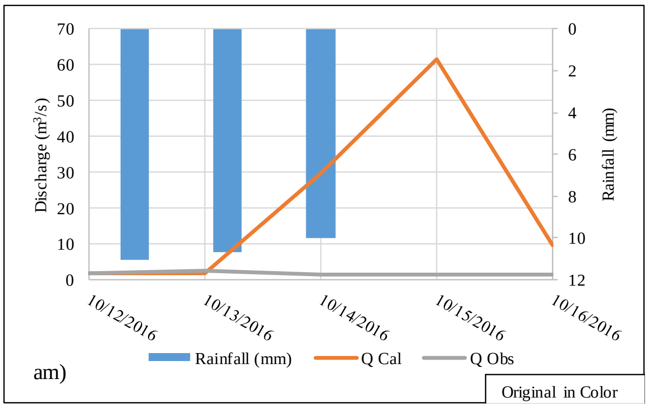
Figure F-9 (ag-aj): Calculated and observed streamflow graphs of events: E33-E36



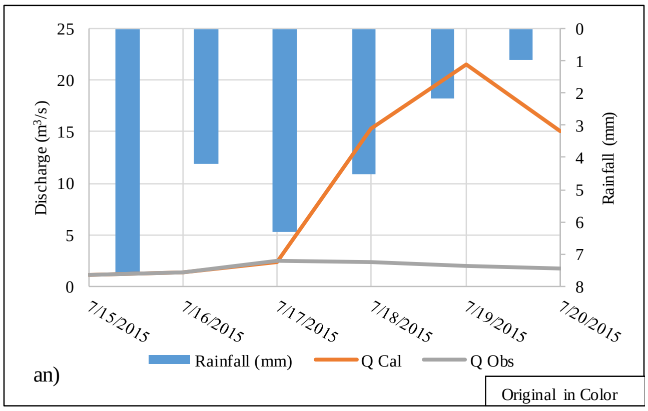
Event No.	E37	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	4.00	33.40	7.349
T_p (day)	3	1	0.667
T_b (day)	3	5	0.667
Vol (MCM)	0.70	5.32	6.549
Event MRAE		11.43	
Event RAME		7.16	



Event No.	E38	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.43	22.01	8.058
T_p (day)	4	2	0.500
T_b (day)	3	5	0.667
Vol (MCM)	0.93	4.83	4.181
Event MRAE		4.58	
Event RAME		4.30	



Event No.	E39	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.43	61.69	24.389
T_p (day)	3	1	0.667
T_b (day)	3	5	0.667
Vol (MCM)	0.70	9.02	11.921
Event MRAE		14.17	
Event RAME		12.09	



Event No.	E40	CN=	83.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.42	21.58	7.918
T_p (day)	4	2	0.500
T_b (day)	3	5	0.667
Vol (MCM)	0.94	4.90	4.236
Event MRAE		3.91	
Event RAME		4.25	

Figure F-10 (ak-an): Calculated and observed streamflow graphs of events: E37-E40

Appendix G: Evaluation of streamflow estimation using CN_{II} from rainfall-runoff data

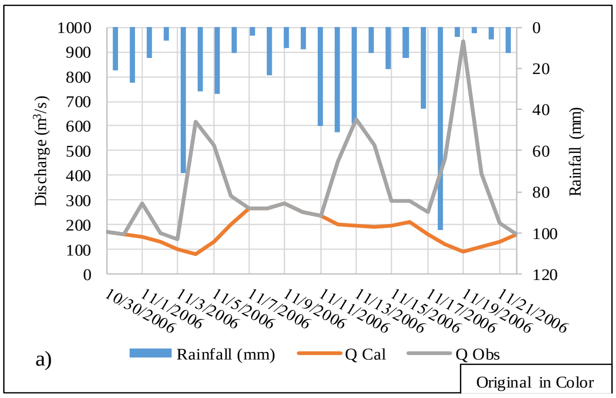
Table G-1: Details of streamflow estimation using CN_{II} from rainfall-runoff data

Event ID	From	To	Total RF (mm)	CN	Qp (m3/s)		Tp (day)		Tb (day)		Vol (MMC)		Error (RAE)				Event MRAE	Event RAEM
					Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Qp	Tp	Tb	Vol		
E1	10/30/2006	11/22/2006	621.6	5.05	284.7	944.6	10	20	15	5	361.5	717.8	2.32	1.00	0.67	0.50	0.36	0.50
E2	7/11/2008	7/27/2008	172.6	26.73	33.2	494.3	16	8	2	10	22.9	119.8	13.91	1.00	0.80	0.81	0.45	0.81
E3	5/22/2011	6/5/2011	209.0	22.51	83.3	422.4	8	5	8	11	49.0	150.1	4.07	0.38	0.38	0.67	0.32	0.67
E4	9/27/2010	10/10/2010	251.9	23.28	116.4	312.0	12	5	3	9	62.2	142.8	1.68	0.58	2.00	0.56	0.43	0.59
E5	4/24/2008	5/2/2008	115.9	36.08	66.4	233.0	5	5	5	5	32.1	77.6	2.51	0.00	0.00	0.59	0.33	0.59
E6	12/16/2006	12/23/2006	32.5	52.01	30.0	188.3	4	4	5	5	18.1	35.5	5.28	0.00	0.00	0.49	0.20	0.49
E7	1/4/2006	1/17/2006	84.3	47.34	44.9	158.7	10	10	5	5	22.8	48.3	2.54	0.00	0.00	0.53	0.39	0.53
E8	6/19/2006	6/27/2006	195.0	34.24	170.1	156.9	4	5	6	5	41.9	65.3	0.08	0.25	0.17	0.36	0.30	0.46
E9	1/29/2005	2/5/2005	96.5	52.04	111.0	117.7	4	4	5	5	18.2	20.6	0.06	0.00	0.00	0.12	0.10	0.12
E10	6/5/2010	6/15/2010	108.7	48.52	91.1	96.7	7	7	5	5	27.7	35.1	0.06	0.00	0.00	0.21	0.27	0.24
E11	11/19/2007	11/26/2007	39.6	66.66	37.6	70.9	4	4	5	5	14.9	21.5	0.89	0.00	0.00	0.31	0.23	0.31
E12	8/20/2010	8/25/2010	40.6	71.93	33.7	54.5	2	2	5	5	8.4	12.1	0.62	0.00	0.00	0.30	0.22	0.32
E13	4/15/2006	4/23/2006	85.7	55.09	67.6	53.0	4	2	6	8	16.9	22.4	0.22	0.50	0.33	0.25	0.46	0.59
E14	3/3/2011	3/9/2011	48.0	68.71	57.5	41.8	3	3	5	5	12.5	11.6	0.27	0.00	0.00	0.08	0.25	0.35
E15	3/29/2006	4/4/2006	36.6	74.20	39.9	25.9	4	3	4	5	9.9	9.5	0.35	0.25	0.25	0.04	0.26	0.32
E16	12/15/2008	12/19/2008	35.0	75.05	58.7	26.5	3	1	3	4	11.5	9.6	0.55	0.67	0.33	0.20	0.50	0.53
E17	7/31/2007	8/7/2007	14.7	85.96	18.0	15.8	4	4	5	5	6.2	6.6	0.13	0.00	0.00	0.06	0.10	0.12
E18	8/15/2011	8/20/2011	13.6	88.55	13.3	15.3	4	2	3	5	3.3	3.2	0.15	0.50	0.67	0.03	0.51	0.62
E19	3/12/2007	3/20/2007	61.9	57.14	32.3	11.1	5	5	5	5	5.0	4.0	0.66	0.00	0.00	0.26	0.40	0.67
E20	3/20/2011	3/26/2011	24.0	79.82	15.3	20.8	4	3	4	5	4.9	7.9	0.36	0.25	0.25	0.38	0.34	0.39

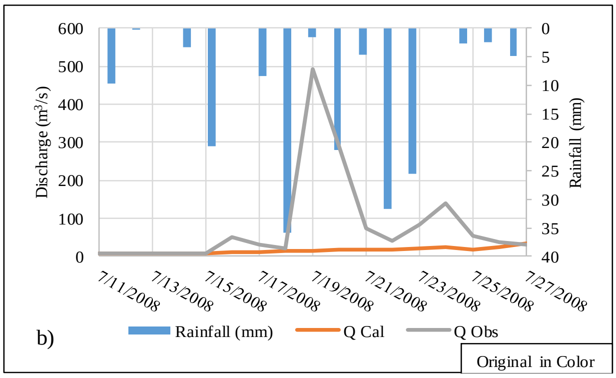
Continued….

Event ID	From	To	Total RF (mm)	CN	Qp (m3/s)		Tp (day)		Tb (day)		Vol (MMC)		Error (RAE)				Event MRAE	Event RAEM
					Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Qp	Tp	Tb	Vol		
E21	10/15/2014	11/3/2014	434.6	12.25	169.0	567.4	19	16	2	5	87.2	312.3	0.70	0.16	1.50	0.72	0.55	0.73
E22	9/4/2013	9/21/2013	308.7	22.32	71.7	544.2	13	9	6	10	41.1	142.5	0.87	0.31	0.67	0.71	0.55	0.72
E23	11/29/2015	12/12/2015	206.7	21.80	81.2	361.9	5	10	10	5	72.5	155.5	0.78	1.00	0.50	0.53	0.35	0.53
E24	5/12/2013	5/17/2013	74.6	54.11	61.1	264.4	2	2	5	5	11.7	34.9	0.77	0.00	0.00	0.67	0.33	0.67
E25	4/8/2013	4/17/2013	102.5	49.47	102.4	185.1	6	6	5	5	17.3	35.8	0.45	0.00	0.00	0.52	0.44	0.52
E26	11/23/2012	12/1/2012	87.6	48.23	55.3	166.8	5	5	5	5	15.8	45.8	0.67	0.00	0.00	0.66	0.56	0.66
E27	10/29/2016	11/5/2016	116.8	46.98	77.4	85.2	7	4	2	5	19.1	22.1	0.09	0.43	1.50	0.14	0.40	0.54
E28	7/6/2012	7/13/2012	56.9	64.87	72.3	61.7	5	4	4	5	11.1	12.9	0.17	0.20	0.25	0.14	0.29	0.68
E29	2/23/2015	3/8/2015	145.2	41.46	128.1	42.4	10	4	5	11	20.2	26.3	2.02	0.60	1.20	0.23	0.66	0.91
E30	5/31/2015	6/9/2015	38.1	73.44	47.1	35.4	6	6	5	5	7.9	9.7	0.33	0.00	0.00	0.18	0.35	0.39
E31	2/12/2013	2/20/2013	49.4	67.44	41.4	20.2	7	5	3	5	8.6	8.7	0.51	0.29	0.67	0.00	0.90	1.03
E32	6/18/2014	6/24/2014	29.5	78.09	23.0	19.7	4	3	4	5	6.0	6.4	0.17	0.25	0.25	0.07	0.18	0.23
E33	2/14/2012	2/22/2012	53.4	64.44	53.0	15.8	4	2	6	8	7.2	7.0	2.36	0.50	0.33	0.03	0.68	0.94
E34	8/16/2017	8/23/2017	54.9	61.99	26.4	14.4	4	4	5	5	7.9	5.1	0.83	0.00	0.00	0.56	0.55	0.56
E35	2/27/2012	3/4/2012	19.2	83.12	17.0	8.0	2	3	6	5	2.8	2.2	1.13	0.50	0.17	0.25	0.53	0.72
E36	7/9/2014	7/15/2014	22.5	81.36	23.5	9.5	2	3	6	5	4.1	3.1	1.48	0.50	0.17	0.31	0.55	0.69
E37	2/15/2016	2/19/2016	26.0	71.60	4.0	4.0	3	1	3	5	0.9	0.7	0.01	0.67	0.67	0.25	1.12	0.86
E38	9/20/2012	9/25/2012	24.2	75.43	7.7	2.4	4	2	3	5	1.7	0.9	2.17	0.50	0.67	0.82	1.02	0.93
E39	10/12/2016	10/16/2016	31.8	68.09	7.9	2.4	3	1	3	5	1.3	0.7	2.25	0.67	0.67	0.81	1.18	1.04
E40	7/15/2015	7/20/2015	25.7	74.12	5.6	2.4	5	2	2	5	1.4	0.9	1.30	0.60	1.50	0.49	0.73	0.76
												Max	***13.91***	***1.00***	***2.00***	***0.82***	***1.18***	***1.04***
												Min	***0.01***	***0.00***	***0.00***	***0.00***	***0.10***	***0.12***
												Average	***1.39***	***0.31***	***0.41***	***0.37***	***0.46***	***0.58***

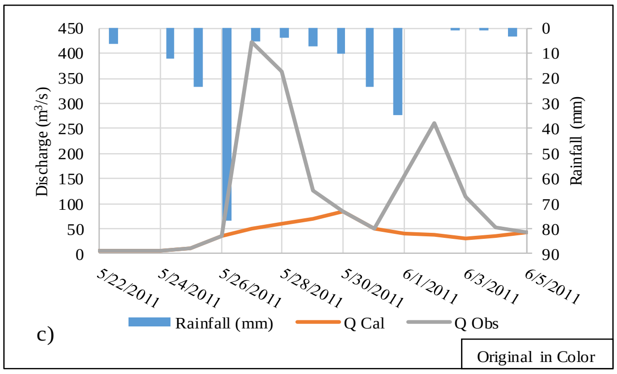
Appendix H: Streamflow graphs for all events using CN_{II} from rainfall-runoff data



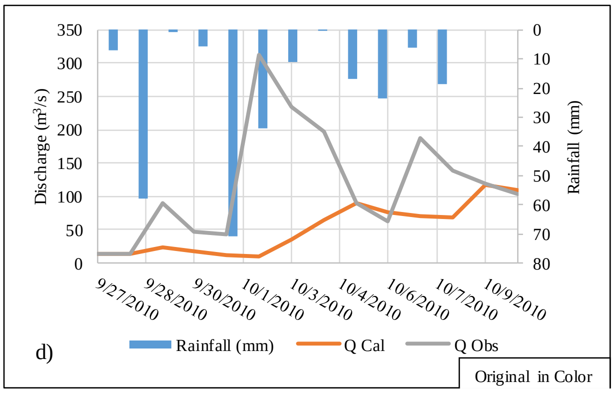
Event No.	E1	CN=	5.05
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	944.58	284.67	2.318
T_p (day)	10	20	1.000
T_b (day)	15	5	0.667
Vol (MCM)	717.75	361.47	0.496
Event MRAE		0.36	
Event RAME		0.50	



Event No.	E2	CN=	26.73
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	494.26	33.15	13.910
T_p (day)	8	16	1.000
T_b (day)	10	2	0.800
SF Vol (MCM)	119.8	22.9	0.809
Event MRAE		0.45	
Event RAME		0.81	

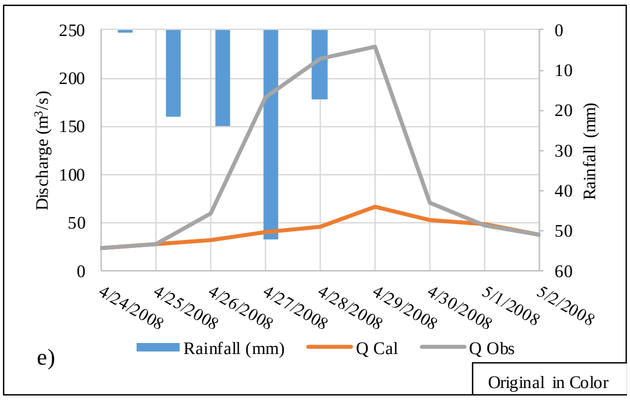


Event No.	E3	CN=	22.51
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	422.39	83.34	4.068
T_p (day)	8	5	0.375
T_b (day)	8	11	0.375
Vol (MCM)	150.09	49.01	0.673
Event MRAE		0.32	
Event RAME		0.67	

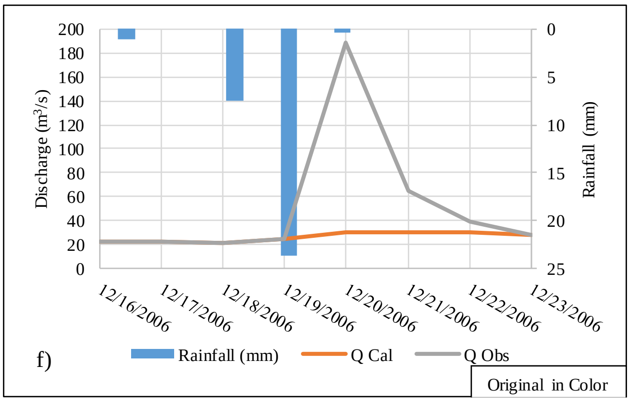


Event No.	E4	CN=	23.28
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	312.05	116.36	1.682
T_p (day)	12	5	0.583
T_b (day)	3	9	2.000
SF Vol (MCM)	142.81	62.23	0.564
Event MRAE		0.43	
Event RAME		0.59	

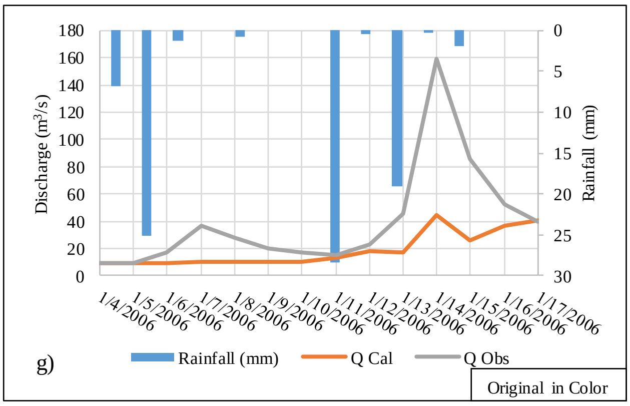
Figure H-1 (a-d): Calculated and observed streamflow graphs of events: E1-E4



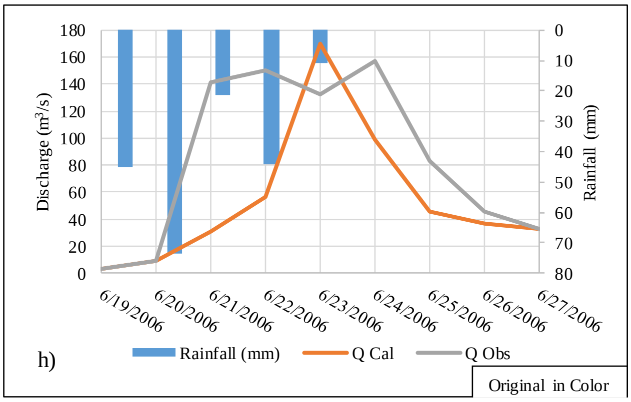
Event No.	E5	CN=	36.08
Description	Observed	Calculated	RAE
Q_p (m^3/s)	232.99	66.45	2.507
T_p (day)	5	5	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	77.60	32.09106	0.586
Event MRAE		0.33	
Event RAME		0.59	



Event No.	E6	CN=	52.01
Description	Observed	Calculated	RAE
Q_p (m^3/s)	188.29	30.00	5.276
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	35.47	18.06	0.491
Event MRAE		0.20	
Event RAME		0.49	

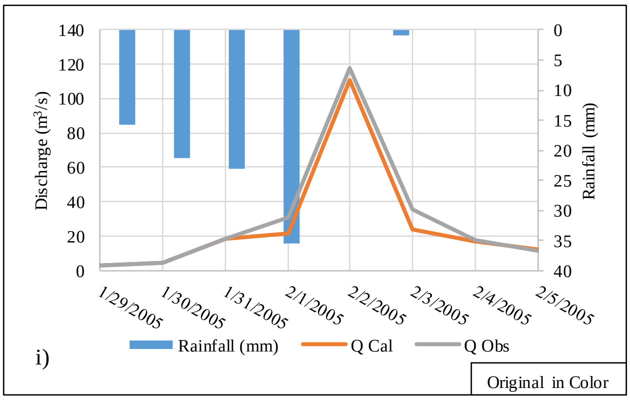


Event No.	E7	CN=	47.34
Description	Observed	Calculated	RAE
Q_p (m^3/s)	158.68	44.86	2.538
T_p (day)	10	10	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	48.29	22.81	0.528
Event MRAE		0.39	
Event RAME		0.53	

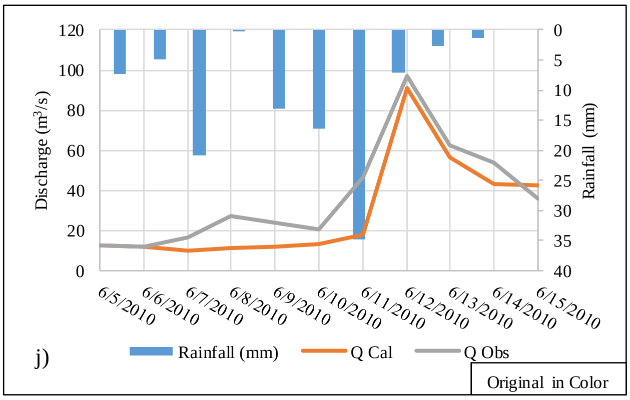


Event No.	E8	CN=	34.24
Description	Observed	Calculated	RAE
Q_p (m^3/s)	156.88	170.11	0.078
T_p (day)	4	5	0.250
T_b (day)	6	5	0.167
SF Vol (MCM)	65.34	41.93	0.358
Event MRAE		0.30	
Event RAME		0.46	

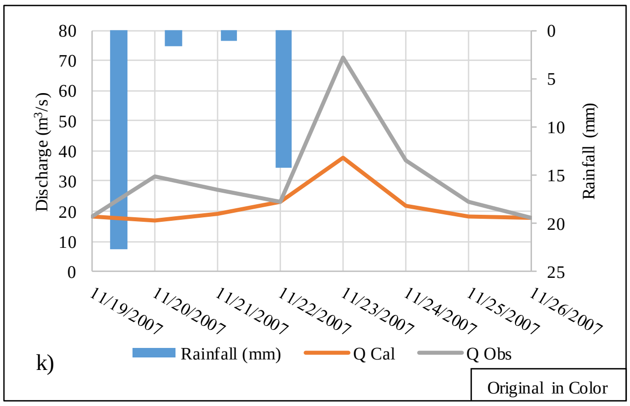
Figure H-2 (e-h): Calculated and observed streamflow graphs of events: E5-E8



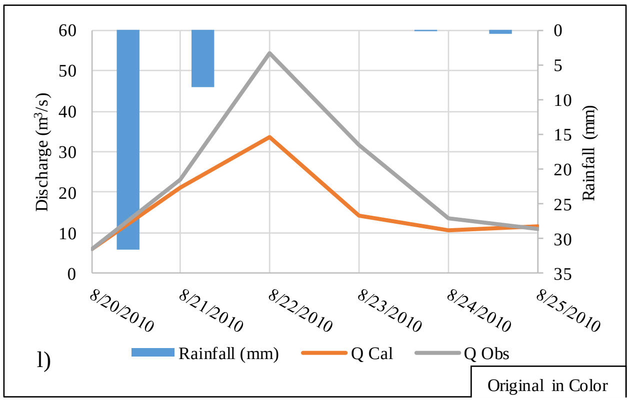
Event No.	E9	CN=	52.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	117.69	111.00	0.060
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
Vol (MCM)	20.59	18.20	0.116
Event MRAE		0.10	
Event RAME		0.12	



Event No.	E10	CN=	48.52
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	96.73	91.13	0.061
T_p (day)	7	7	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	35.08	27.73	0.210
Event MRAE		0.27	
Event RAME		0.24	

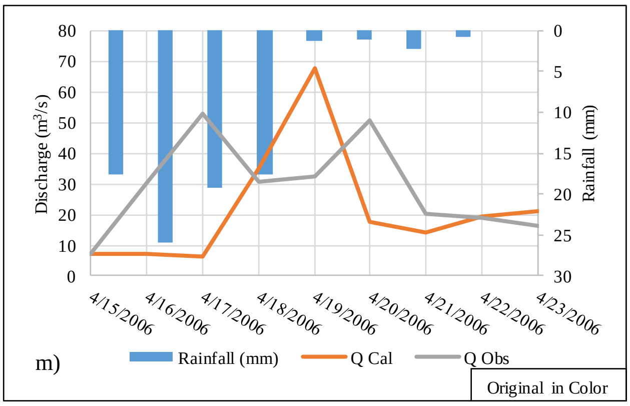


Event No.	E11	CN=	66.66
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	70.93	37.59	0.887
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
Vol (MCM)	21.50	14.93	0.305
Event MRAE		0.23	
Event RAME		0.31	

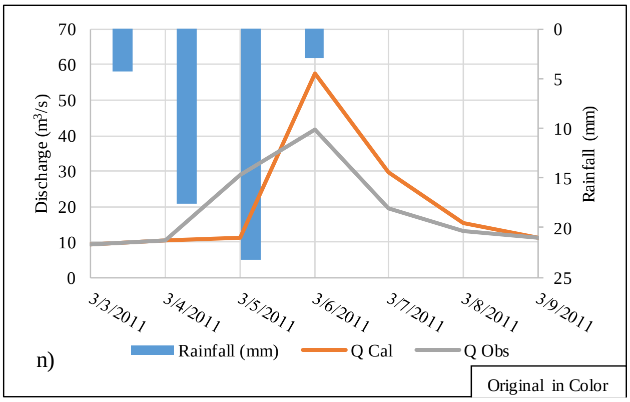


Event No.	E12	CN=	71.93
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	54.47	33.72	0.616
T_p (day)	2	2	0.000
T_b (day)	5	5	0.000
Vol (MCM)	12.06	8.40	0.303
Event MRAE		0.22	
Event RAME		0.32	

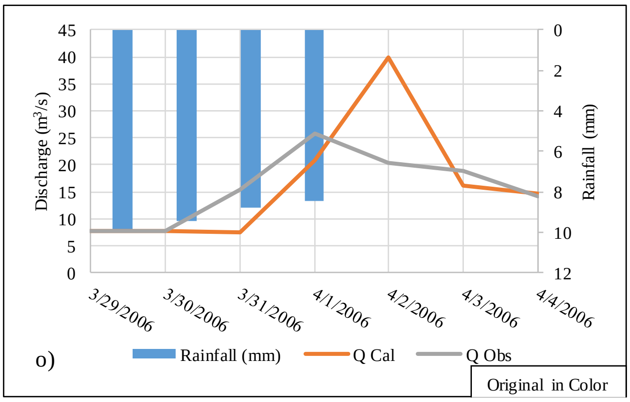
Figure H-3 (i-l): Calculated and observed streamflow graphs of events: E9-E12



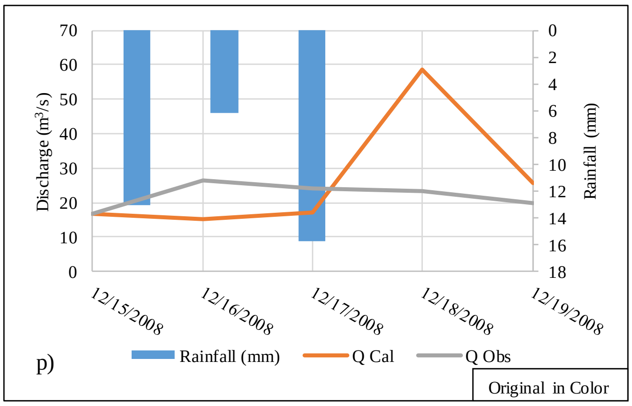
Event No.	E13	CN=	55.09
Description	Observed	Calculated	RAE
Q_p (m^3/s)	53.00	67.64	0.216
T_p (day)	4	2	0.500
T_b (day)	6	8	0.333
SF Vol (MCM)	22.43	16.85	0.249
Event MRAE		0.46	
Event RAME		0.59	



Event No.	E14	CN=	68.71
Description	Observed	Calculated	RAE
Q_p (m^3/s)	41.81	57.45	0.272
T_p (day)	3	3	0.000
T_b (day)	5	5	0.000
Vol (MCM)	11.59	12.50	0.078
Event MRAE		0.25	
Event RAME		0.35	

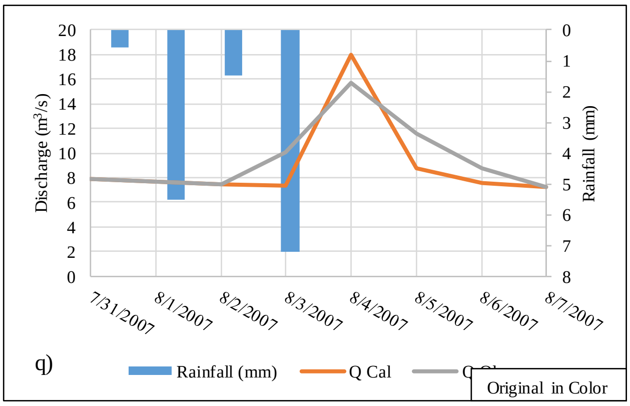


Event No.	E15	CN=	74.20
Description	Observed	Calculated	RAE
Q_p (m^3/s)	25.87	39.91	0.352
T_p (day)	4	3	0.250
T_b (day)	4	5	0.250
SF Vol (MCM)	9.50	9.90	0.041
Event MRAE		0.26	
Event RAME		0.32	

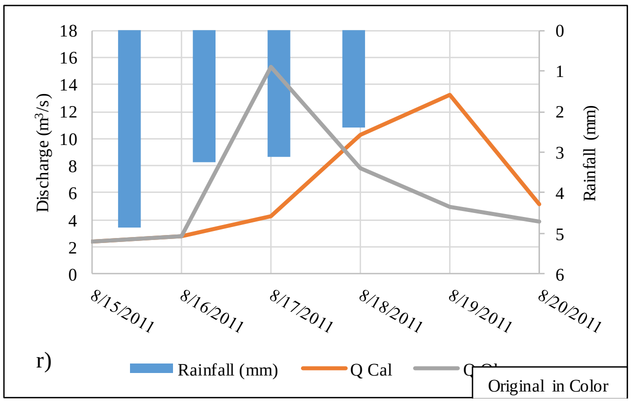


Event No.	E16	CN=	75.05
Description	Observed	Calculated	RAE
Q_p (m^3/s)	26.50	58.72	0.549
T_p (day)	3	1	0.667
T_b (day)	3	4	0.333
SF Vol (MCM)	9.582	11.540	0.204
Event MRAE		0.50	
Event RAME		0.53	

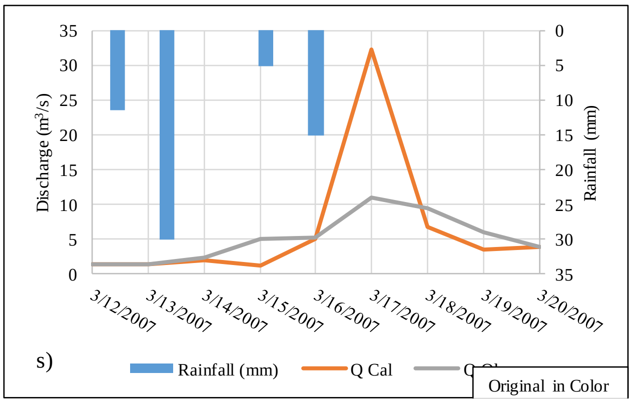
Figure H-4 (m-p): Calculated and observed streamflow graphs of events: E13-E16



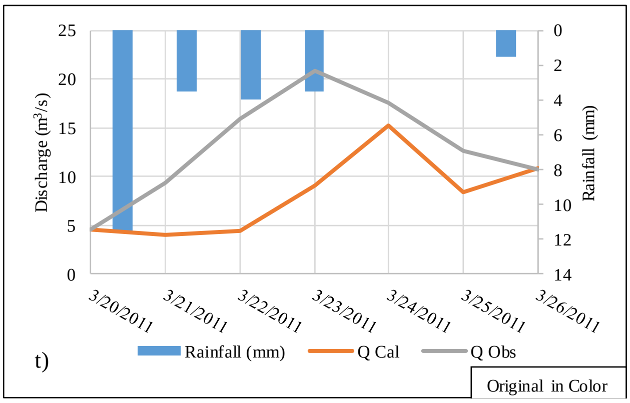
Event No.	E17	CN=	85.96
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.76	18.03	0.126
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	6.61	6.23	0.058
Event MRAE		0.10	
Event RAME		0.12	



Event No.	E18	CN=	88.55
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.32	13.27	0.155
T_p (day)	4	2	0.500
T_b (day)	3	5	0.667
SF Vol (MCM)	3.21	3.29	0.027
Event MRAE		0.51	
Event RAME		0.62	

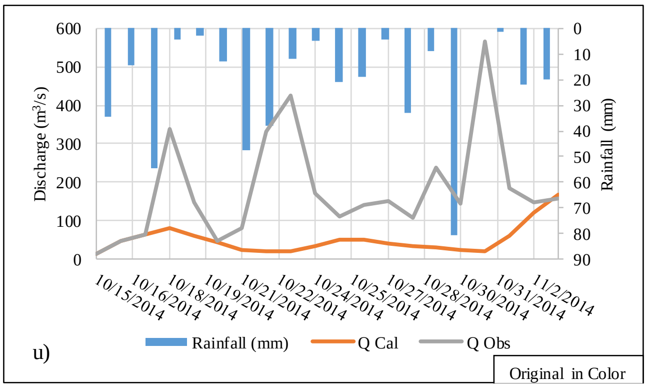


Event No.	E19	CN=	57.14
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	11.07	32.35	0.658
T_p (day)	5	5	0.000
T_b (day)	5	5	0.000
Vol (MCM)	3.96	4.98	0.257
Event MRAE		0.40	
Event RAME		0.67	

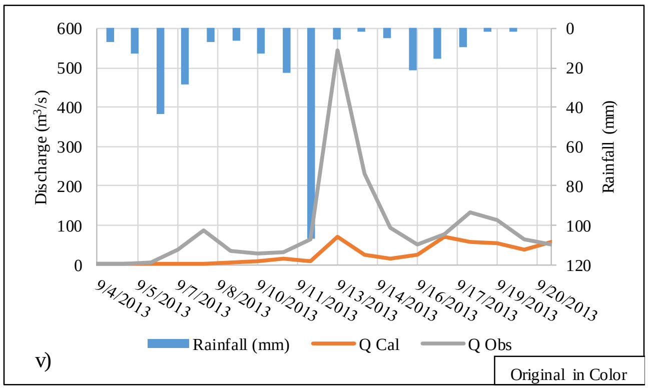


Event No.	E20	CN=	79.82
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	20.81	15.28	0.362
T_p (day)	4	3	0.250
T_b (day)	4	5	0.250
Vol (MCM)	7.93	4.89	0.383
Event MRAE		0.34	
Event RAME		0.39	

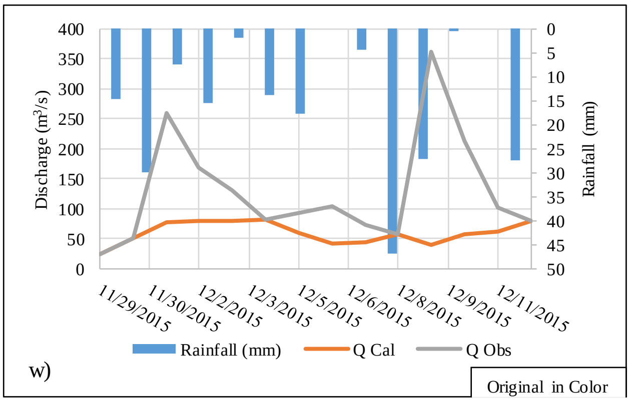
Figure H-5 (q-t): Calculated and observed streamflow graphs of events: E17-E20



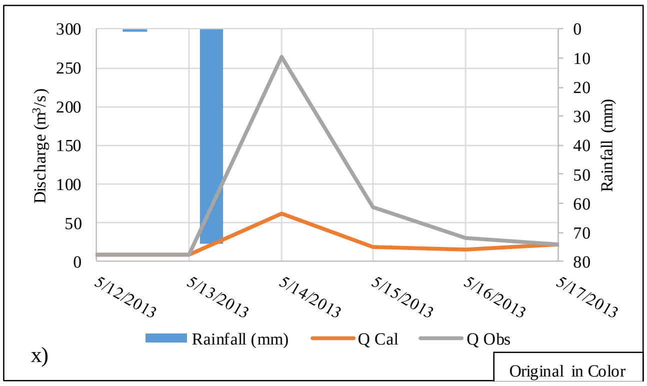
Event No.	E21	CN=	12.25
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	567.4	169.0	0.702
T_p (day)	19	16	0.158
T_b (day)	2	5	1.500
Vol (MCM)	312.3	87.2	0.721
Event MRAE		0.55	
Event RAME		0.73	



Event No.	E22	CN=	22.32
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	544.2	71.7	0.868
T_p (day)	13	9	0.308
T_b (day)	6	10	0.667
Vol (MCM)	142.5	41.1	0.712
Event MRAE		0.55	
Event RAME		0.72	

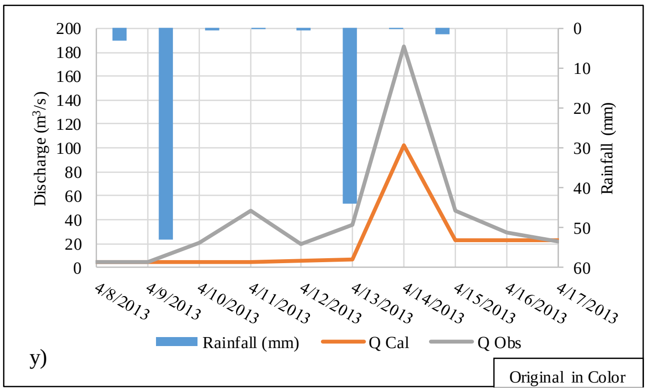


Event No.	E23	CN=	21.80
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	361.92	81.19	0.776
T_p (day)	5	10	1.000
T_b (day)	10	5	0.500
SF Vol (MCM)	155.49	72.54	0.533
Event MRAE		0.35	
Event RAME		0.53	

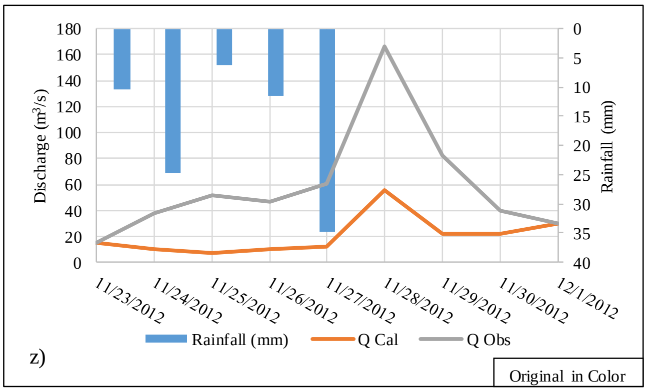


Event No.	E24	CN=	54.11
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	264.40	61.09	0.769
T_p (day)	2	2	0.000
T_b (day)	5	5	0.000
Vol (MCM)	34.91	11.69	0.665
Event MRAE		0.33	
Event RAME		0.67	

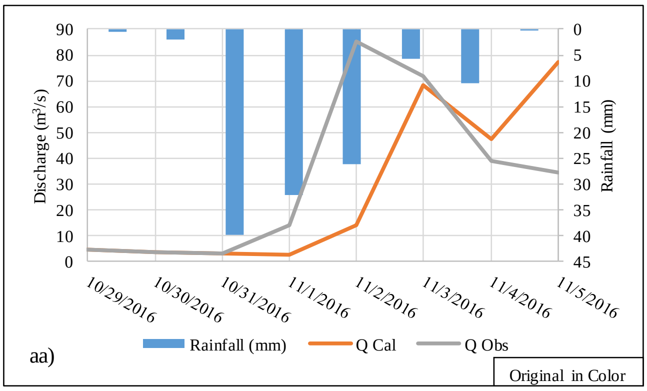
Figure H-6 (u-x): Calculated and observed streamflow graphs of events: E21-E24



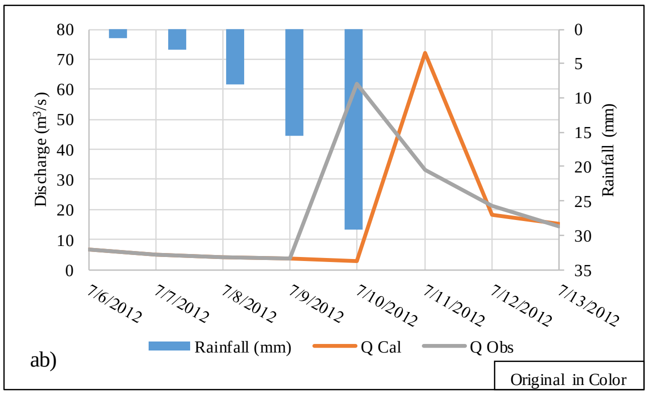
Event No.	E25	CN=	49.47
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	185.08	102.38	0.447
T_p (day)	6	6	0.000
T_b (day)	5	5	0.000
Vol (MCM)	35.83	17.26	0.518
Event MRAE		0.44	
Event RAME		0.52	



Event No.	E26	CN=	48.23
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	166.83	55.31	0.668
T_p (day)	5	5	0.000
T_b (day)	5	5	0.000
Vol (MCM)	45.76	15.76	0.656
Event MRAE		0.56	
Event RAME		0.66	

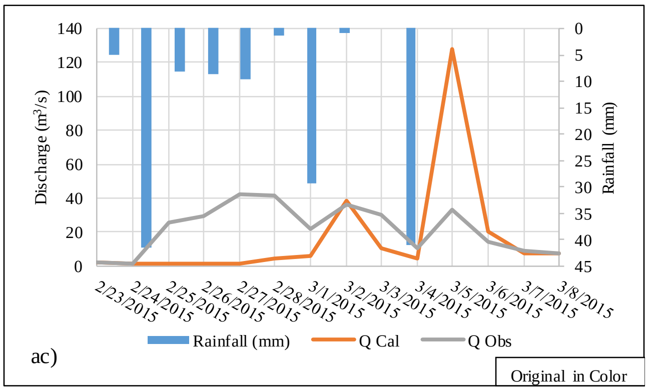


Event No.	E27	CN=	46.98
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	85.20	77.39	0.092
T_p (day)	7	4	0.429
T_b (day)	2	5	1.500
Vol (MCM)	22.07	19.07	0.136
Event MRAE		0.40	
Event RAME		0.54	

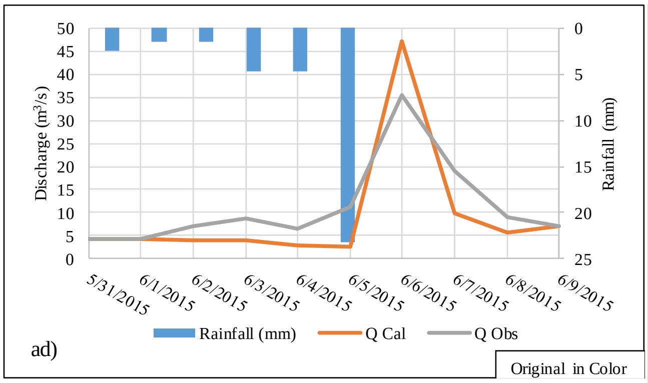


Event No.	E28	CN=	64.87
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	61.66	72.28	0.172
T_p (day)	5	4	0.200
T_b (day)	4	5	0.250
Vol (MCM)	12.94	11.12	0.140
Event MRAE		0.29	
Event RAME		0.68	

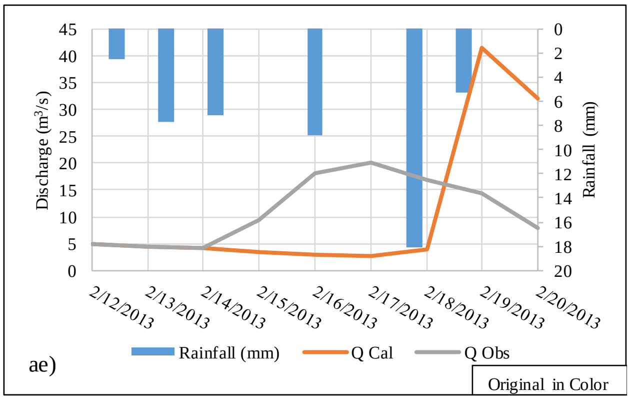
Figure H-7 (y-ab): Calculated and observed streamflow graphs of events: E25-E28



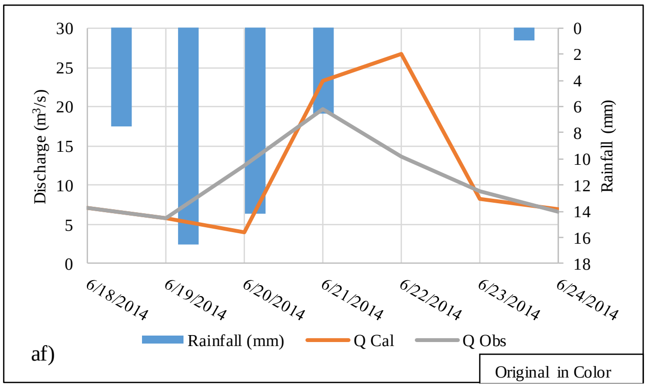
Event No.	E29	CN=	41.46
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	42.37	128.06	2.023
T_p (day)	10	4	0.600
T_b (day)	5	11	1.200
Vol (MCM)	26.30	20.24	0.230
Event MRAE		0.66	
Event RAME		0.91	



Event No.	E30	CN=	73.44
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	35.44	47.13	0.330
T_p (day)	6	6	0.000
T_b (day)	5	5	0.000
Vol (MCM)	9.70	7.92	0.184
Event MRAE		0.35	
Event RAME		0.39	

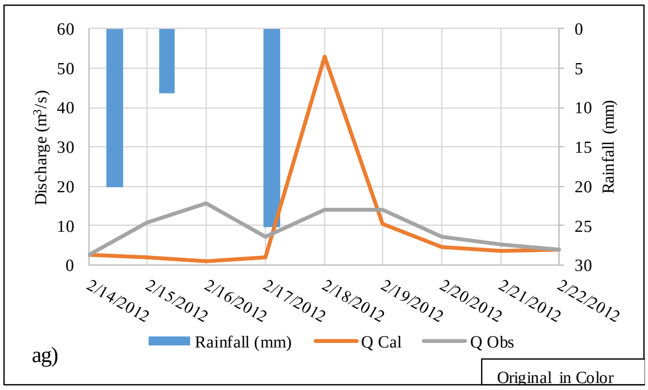


Event No.	31	CN=	67.44
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	20.17	41.41	0.513
T_p (day)	7	5	0.286
T_b (day)	3	5	0.667
Vol (MCM)	8.66	8.648576	0.002
Event MRAE		0.90	
Event RAME		1.03	

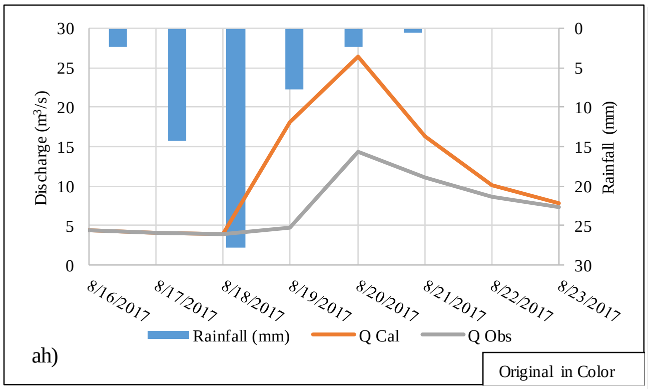


Event No.	E32	CN=	68.28
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	19.68	26.79	0.361
T_p (day)	4	3	0.250
T_b (day)	4	5	0.250
Vol (MCM)	6.44	7.10	0.103
Event MRAE		0.20	
Event RAME		0.25	

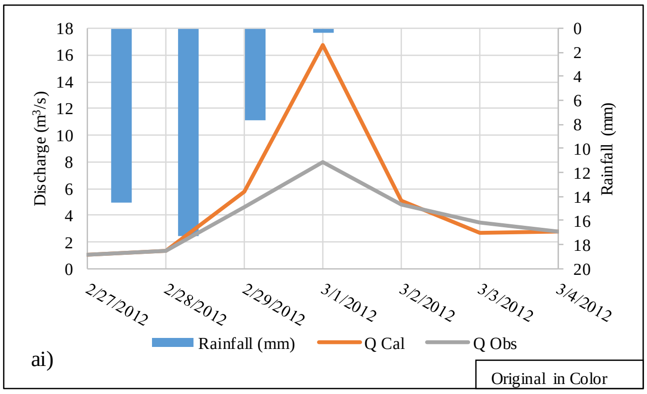
Figure H-8 (ac-af): Calculated and observed streamflow graphs of events: E29-E32



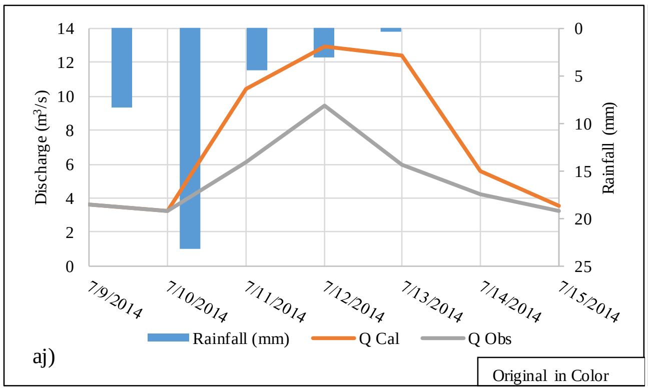
Event No.	E33	CN=	64.44
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.76	52.98	2.361
T_p (day)	4	2	0.500
T_b (day)	6	8	0.333
Vol (MCM)	6.95	7.15	0.029
Event MRAE		0.68	
Event RAME		0.94	



Event No.	E34	CN=	61.99
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	14.42	26.41	0.831
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
Vol (MCM)	5.07	7.89	0.557
Event MRAE		0.55	
Event RAME		0.56	

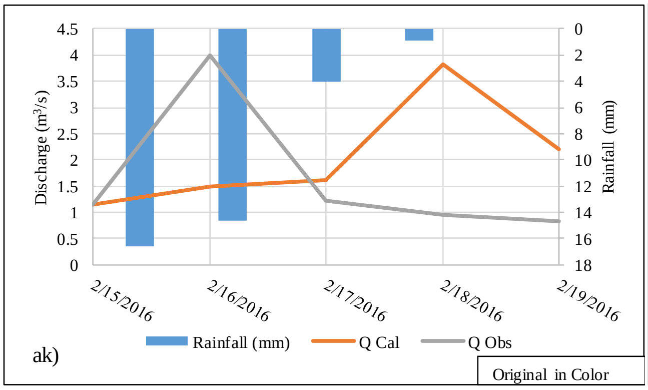


Event No.	E35	CN=	66.87
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	8.01	16.79	1.096
T_p (day)	2	3	0.500
T_b (day)	6	5	0.167
Vol (MCM)	2.24	3.07	0.368
Event MRAE		0.23	
Event RAME		0.42	

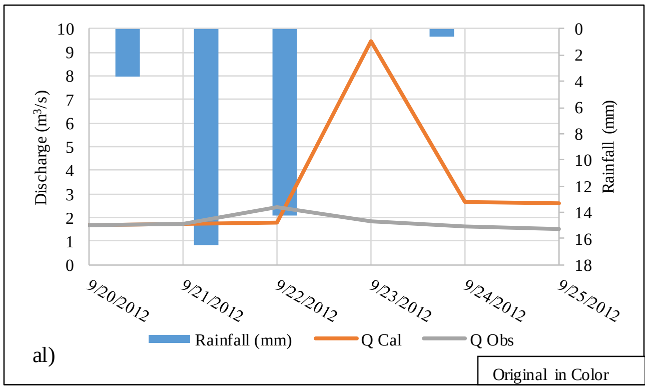


Event No.	E36	CN=	68.75
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	9.48	12.91	0.362
T_p (day)	2	3	0.500
T_b (day)	6	5	0.167
Vol (MCM)	3.11	4.47	0.439
Event MRAE		0.36	
Event RAME		0.44	

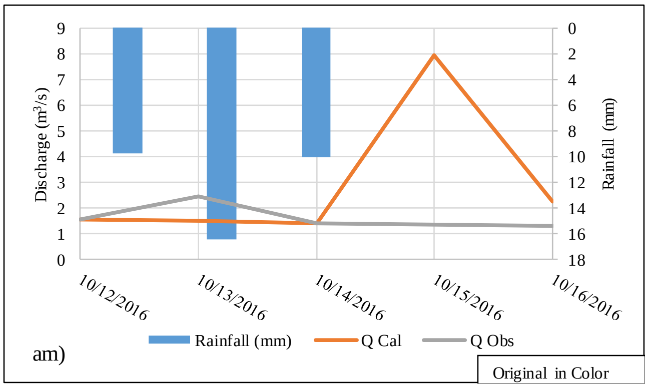
Figure H-9 (ag-aj): Calculated and observed streamflow graphs of events: E33-E36



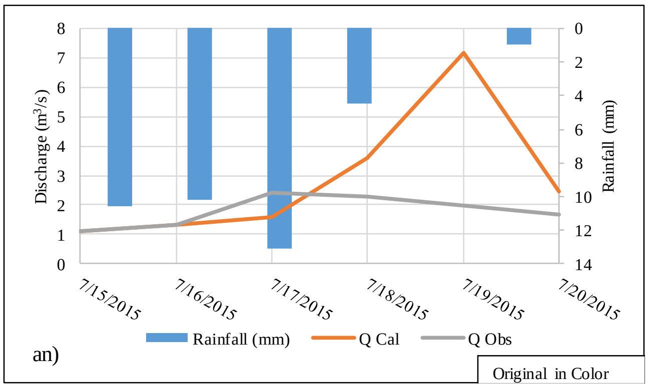
Event No.	E37	CN=	63.60
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	4.00	3.83	0.044
T_p (day)	3	1	0.667
T_b (day)	3	5	0.667
Vol (MCM)	0.70	0.89	0.260
Event MRAE		1.11	
Event RAME		0.87	



Event No.	E38	CN=	66.75
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.43	9.48	2.902
T_p (day)	4	2	0.500
T_b (day)	3	5	0.667
Vol (MCM)	0.93	1.72	0.849
Event MRAE		0.97	
Event RAME		0.97	



Event No.	E39	CN=	64.71
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.43	7.94	2.267
T_p (day)	3	1	0.667
T_b (day)	3	5	0.667
Vol (MCM)	0.70	1.27	0.812
Event MRAE		1.18	
Event RAME		1.04	



Event No.	E40	CN=	63.58
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.42	7.19	1.969
T_p (day)	5	2	0.600
T_b (day)	2	5	1.500
Vol (MCM)	0.94	1.49	0.596
Event MRAE		0.66	
Event RAME		0.75	

Figure H-10 (ak-an): Calculated and observed streamflow graphs of events: E37-E40

Appendix I: Evaluation of streamflow estimation using CN_I from handbook

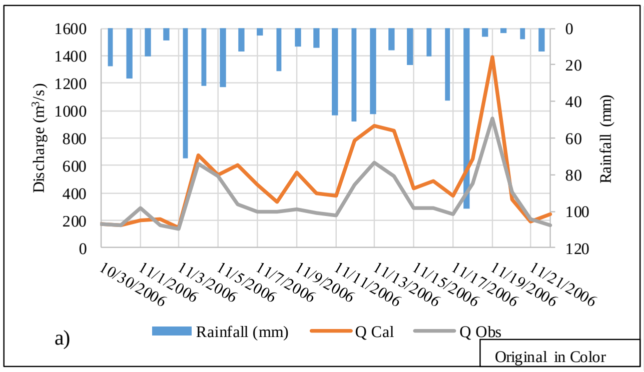
Table I-1: Details of streamflow estimation using CN_I from handbook

Event ID	From	To	Total RF (mm)	CN	Qp (m3/s)		Tp (day)		Tb (day)		Vol (MMC)		Error (RAE)				Event MRAE	Event RAEM
					Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Qp	Tp	Tb	Vol		
E1	10/30/2006	11/22/2006	621.6	68.36	1395.1	944.6	20	20	5	5	992.0	717.8	0.32	0.00	0.00	0.38	0.41	0.42
E2	7/11/2008	7/27/2008	172.6	68.36	316.5	494.3	12	8	6	10	124.0	119.8	0.56	0.50	0.40	0.03	0.66	0.86
E3	5/22/2011	6/5/2011	209.0	68.36	575.5	422.4	5	5	11	11	190.9	150.1	0.27	0.00	0.00	0.27	0.46	0.52
E4	9/27/2010	10/10/2010	251.9	68.36	606.9	312.0	5	5	9	9	247.2	142.8	0.49	0.00	0.00	0.73	0.65	0.74
E5	4/24/2008	5/2/2008	115.9	68.36	381.2	233.0	4	5	6	5	82.9	77.6	0.39	0.20	0.20	0.07	0.21	0.33
E6	12/16/2006	12/23/2006	32.5	68.36	37.7	188.3	4	4	5	5	18.9	35.5	4.00	0.00	0.00	0.47	0.19	0.47
E7	1/4/2006	1/17/2006	84.3	68.36	145.6	158.7	10	10	5	5	46.4	48.3	0.09	0.00	0.00	0.04	0.56	0.43
E8	6/19/2006	6/27/2006	195.0	68.36	533.6	156.9	2	5	8	5	152.7	65.3	0.71	1.50	0.38	1.34	1.37	1.41
E9	1/29/2005	2/5/2005	96.5	68.36	266.0	117.7	4	4	5	5	43.2	20.6	0.56	0.00	0.00	1.10	0.69	1.10
E10	6/5/2010	6/15/2010	108.7	68.36	271.1	96.7	7	7	5	5	62.0	35.1	0.64	0.00	0.00	0.77	0.63	0.88
E11	11/19/2007	11/26/2007	39.6	68.36	43.8	70.9	4	4	5	5	15.6	21.5	0.62	0.00	0.00	0.27	0.22	0.28
E12	8/20/2010	8/25/2010	40.6	68.36	24.0	54.5	2	2	5	5	6.6	12.1	1.27	0.00	0.00	0.45	0.32	0.46
E13	4/15/2006	4/23/2006	85.7	68.36	135.8	53.0	4	2	6	8	34.6	22.4	0.61	0.50	0.33	0.54	0.88	0.95
E14	3/3/2011	3/9/2011	48.0	68.36	55.4	41.8	3	3	5	5	12.3	11.6	0.25	0.00	0.00	0.06	0.23	0.33
E15	3/29/2006	4/4/2006	36.6	68.36	24.0	25.9	4	3	4	5	7.3	9.5	0.08	0.25	0.25	0.24	0.24	0.31
E16	12/15/2008	12/19/2008	35.0	68.36	31.2	26.5	3	1	3	4	8.8	9.6	0.15	0.67	0.33	0.09	0.23	0.26
E17	7/31/2007	8/7/2007	14.7	68.36	7.9	15.8	1	4	8	5	5.1	6.6	0.99	3.00	0.38	0.23	0.17	0.23
E18	8/15/2011	8/20/2011	13.6	68.36	3.8	15.3	5	2	2	5	1.7	3.2	2.98	0.60	1.50	0.47	0.26	0.47
E19	3/12/2007	3/20/2007	61.9	68.36	77.6	11.1	5	5	5	5	13.8	4.0	0.86	0.00	0.00	2.48	2.42	2.55
E20	3/20/2011	3/26/2011	24.0	68.36	10.7	20.8	6	3	2	5	3.2	7.9	0.95	0.50	1.50	0.59	0.48	0.59

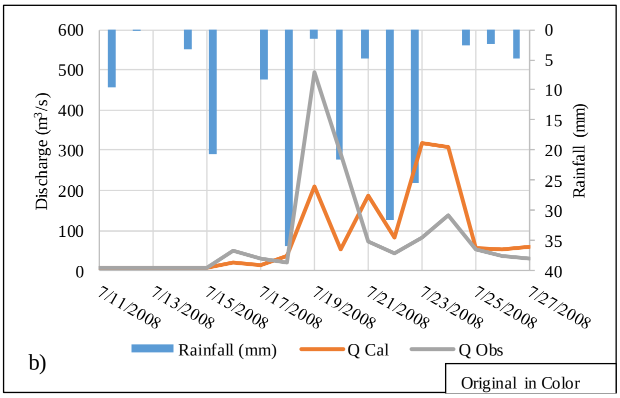
Continued….

Event ID	From	To	Total RF (mm)	CN	Qp (m3/s)		Tp (day)		Tb (day)		Vol (MMC)		Error (RAE)				Event MRAE	Event RAEM
					Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Qp	Tp	Tb	Vol		
E21	10/15/2014	11/3/2014	434.6	68.36	1007.8	567.4	16	16	5	5	471.6	312.3	0.78	0.00	0.00	0.51	0.49	0.51
E22	9/4/2013	9/21/2013	308.7	68.36	1182.4	544.2	9	9	10	10	280.3	142.5	1.17	0.00	0.00	0.97	1.10	1.01
E23	11/29/2015	12/12/2015	206.7	68.36	479.7	361.9	10	10	5	5	187.5	155.5	0.33	0.00	0.00	0.21	0.36	0.43
E24	5/12/2013	5/17/2013	74.6	68.36	209.4	264.4	2	2	5	5	26.5	34.9	0.21	0.00	0.00	0.24	0.17	0.24
E25	4/8/2013	4/17/2013	102.5	68.36	305.4	185.1	6	6	5	5	47.7	35.8	0.65	0.00	0.00	0.33	0.67	0.66
E26	11/23/2012	12/1/2012	87.6	68.36	233.1	166.8	5	5	5	5	40.4	45.8	0.40	0.00	0.00	0.12	0.33	0.37
E27	10/29/2016	11/5/2016	116.8	68.36	224.6	85.2	5	4	4	5	58.4	22.1	1.64	0.20	0.25	1.64	1.14	1.64
E28	7/6/2012	7/13/2012	56.9	68.36	99.2	61.7	5	4	4	5	14.0	12.9	0.61	0.20	0.25	0.08	0.38	0.84
E29	2/23/2015	3/8/2015	145.2	68.36	377.5	42.4	10	4	5	11	84.2	26.3	7.91	0.60	1.20	2.20	1.57	2.21
E30	5/31/2015	6/9/2015	38.1	68.36	22.8	35.4	6	6	5	5	5.5	9.7	0.36	0.00	0.00	0.43	0.37	0.43
E31	2/12/2013	2/20/2013	49.4	68.36	45.8	20.2	7	5	3	5	9.2	8.7	0.56	0.29	0.67	0.07	0.96	1.08
E32	6/18/2014	6/24/2014	29.5	68.36	7.1	19.7	1	3	7	5	3.2	6.4	0.64	2.00	0.29	0.50	0.26	0.35
E33	2/14/2012	2/22/2012	53.4	68.36	78.8	15.8	4	2	6	8	10.0	7.0	4.00	0.50	0.33	0.43	0.83	1.17
E34	8/16/2017	8/23/2017	54.9	68.36	45.5	14.4	3	4	6	5	12.4	5.1	2.15	0.33	0.17	1.44	1.51	1.44
E35	2/27/2012	3/4/2012	19.2	68.36	2.8	8.0	6	3	2	5	1.1	2.2	0.65	0.50	1.50	0.51	0.34	0.51
E36	7/9/2014	7/15/2014	22.5	68.36	3.6	9.5	1	3	7	5	1.9	3.1	0.62	2.00	0.29	0.39	0.29	0.39
E37	2/15/2016	2/19/2016	26.0	68.36	1.5	4.0	1	1	5	5	0.5	0.7	0.63	0.00	0.00	0.22	0.28	0.39
E38	9/20/2012	9/25/2012	24.2	68.36	1.8	2.4	2	2	5	5	0.9	0.9	0.26	0.00	0.00	0.06	0.06	0.07
E39	10/12/2016	10/16/2016	31.8	68.36	8.5	2.4	3	1	3	5	1.3	0.7	2.48	0.67	0.67	0.88	1.27	1.12
E40	7/15/2015	7/20/2015	25.7	68.36	1.9	2.4	5	2	2	5	0.8	0.9	0.23	0.60	1.50	0.15	0.15	0.19
												Max	***5.95***	***2.50***	***1.50***	***2.34***	***2.00***	***2.38***
												Min	***0.14***	***0.00***	***0.00***	***0.05***	***0.11***	***0.15***
												Average	***1.08***	***0.39***	***0.31***	***0.55***	***0.60***	***0.72***

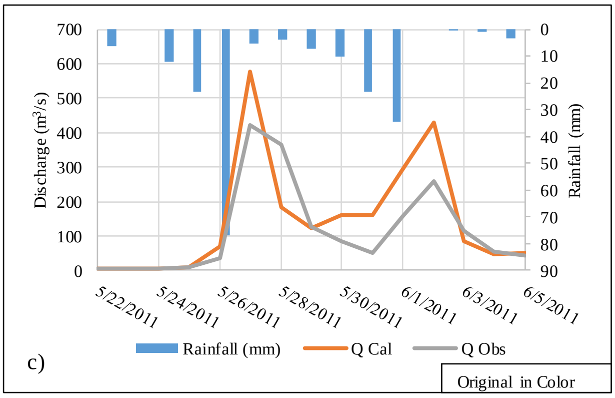
Appendix J: Streamflow graphs for all events using CN_I from handbook



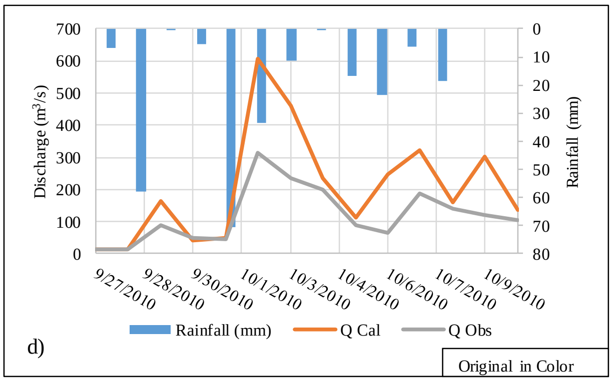
Event No.	E1	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	944.58	1395.07	0.323
T_p (day)	20	20	0.000
T_b (day)	5	5	0.000
Vol (MCM)	717.75	992.04	0.382
Event MRAE		0.41	
Event RAME		0.42	



Event No.	E2	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	494.26	316.49	0.562
T_p (day)	8	12	0.500
T_b (day)	10	6	0.400
SF Vol (MCM)	119.8	124.0	0.035
Event MRAE		0.66	
Event RAME		0.86	

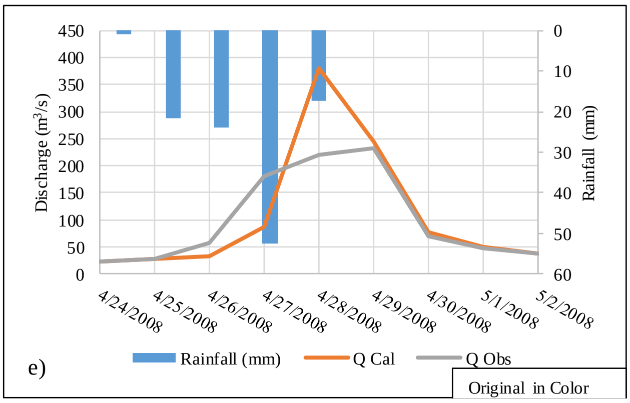


Event No.	3	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	422.39	575.46	0.266
T_p (day)	5	5	0.000
T_b (day)	11	11	0.000
Vol (MCM)	150.09	190.89	0.272
Event MRAE		0.46	
Event RAME		0.52	

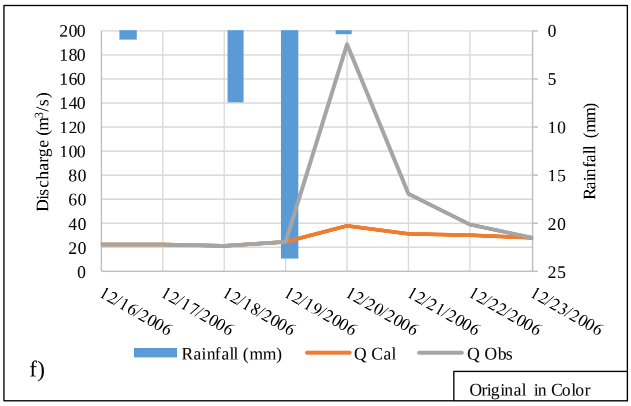


Event No.	E4	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	312.05	606.89	0.486
T_p (day)	5	5	0.000
T_b (day)	9	9	0.000
SF Vol (MCM)	142.81	247.21	0.731
Event MRAE		0.65	
Event RAME		0.74	

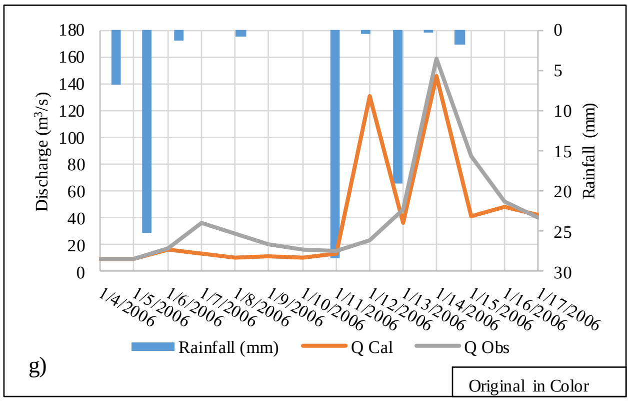
Figure J-1 (a-d): Calculated and observed streamflow graphs of events: E1-E4



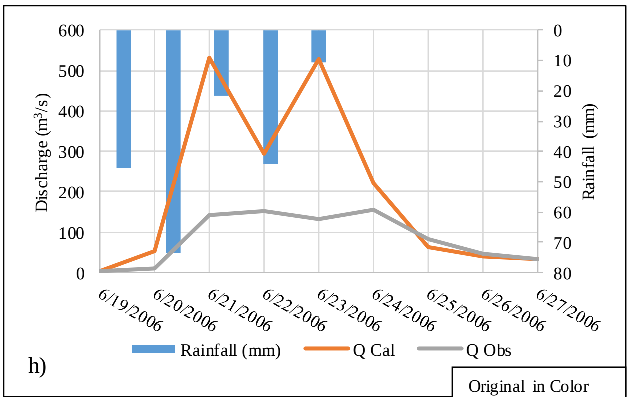
Event No.	E5	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	232.99	381.24	0.389
T_p (day)	5	4	0.200
T_b (day)	5	6	0.200
SF Vol (MCM)	77.60	82.90145	0.068
Event MRAE		0.21	
Event RAME		0.33	



Event No.	E6	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	188.29	37.68	3.997
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	35.47	18.89	0.467
Event MRAE		0.19	
Event RAME		0.47	

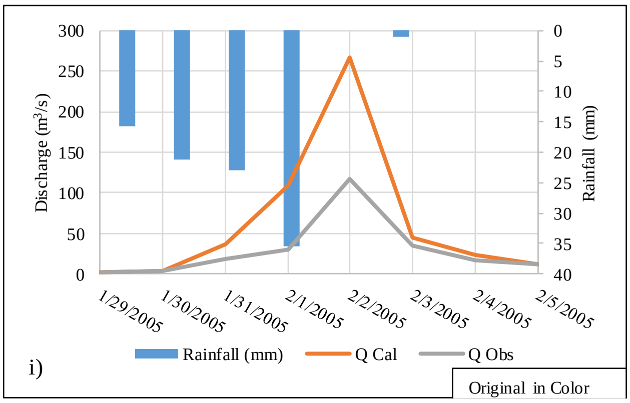


Event No.	E7	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	158.68	145.61	0.090
T_p (day)	10	10	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	48.29	46.42	0.039
Event MRAE		0.56	
Event RAME		0.43	

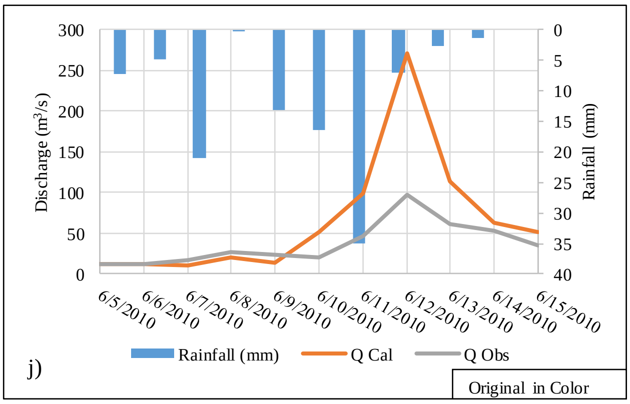


Event No.	E8	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	156.88	533.57	0.706
T_p (day)	2	5	1.500
T_b (day)	8	5	0.375
SF Vol (MCM)	65.34	152.68	1.337
Event MRAE		1.37	
Event RAME		1.41	

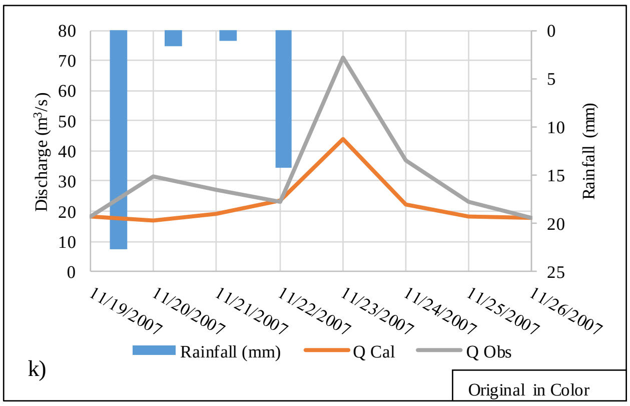
Figure J-2 (e-h): Calculated and observed streamflow graphs of events: E5-E8



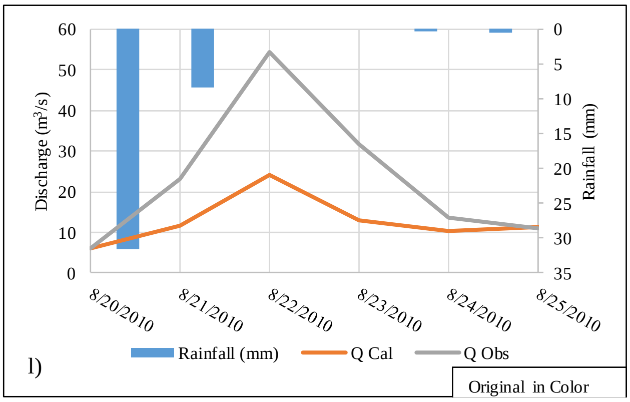
Event No.	E9	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	117.69	265.96	0.557
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
Vol (MCM)	20.59	43.16	1.096
Event MRAE		0.69	
Event RAME		1.10	



Event No.	E10	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	96.73	271.06	0.643
T_p (day)	7	7	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	35.08	61.96	0.766
Event MRAE		0.63	
Event RAME		0.88	

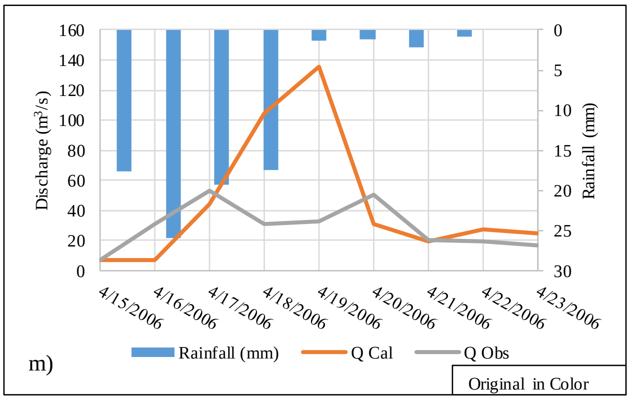


Event No.	E11	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	70.93	43.84	0.618
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
Vol (MCM)	21.50	15.59	0.275
Event MRAE		0.22	
Event RAME		0.28	



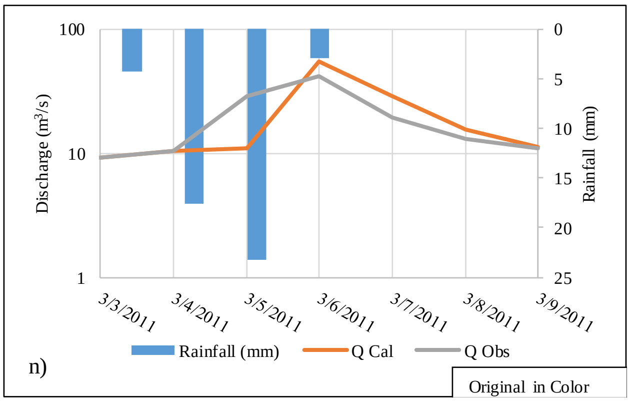
Event No.	E12	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	54.47	24.04	1.265
T_p (day)	2	2	0.000
T_b (day)	5	5	0.000
Vol (MCM)	12.06	6.60	0.453
Event MRAE		0.32	
Event RAME		0.46	

Figure J-3 (i-l): Calculated and observed streamflow graphs of events: E9-E12



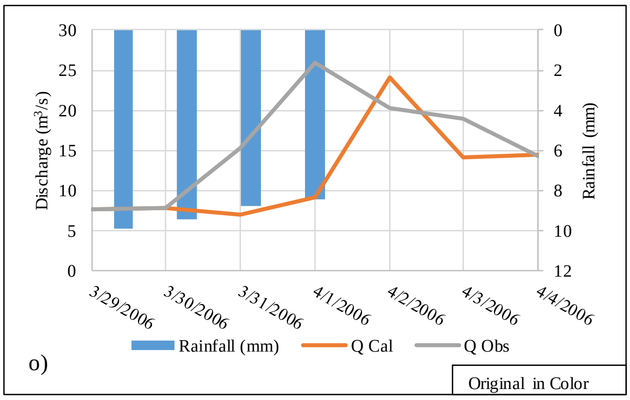
m)

Event No.	E13	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	53.00	135.80	0.610
T_p (day)	4	2	0.500
T_b (day)	6	8	0.333
SF Vol (MCM)	22.43	34.57	0.541
Event MRAE		0.88	
Event RAME		0.95	



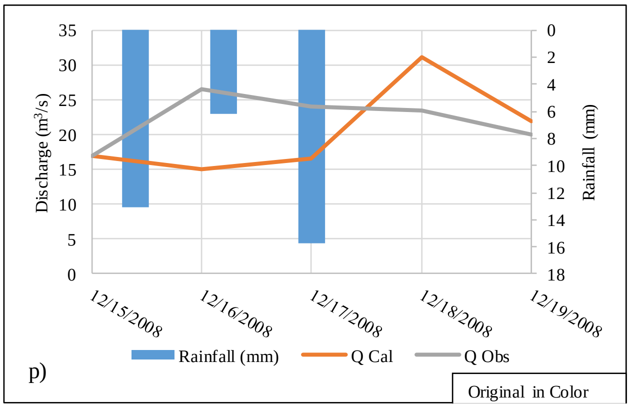
n)

Event No.	E14	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	41.81	55.42	0.246
T_p (day)	3	3	0.000
T_b (day)	5	5	0.000
Vol (MCM)	11.59	12.27	0.058
Event MRAE		0.23	
Event RAME		0.33	



o)

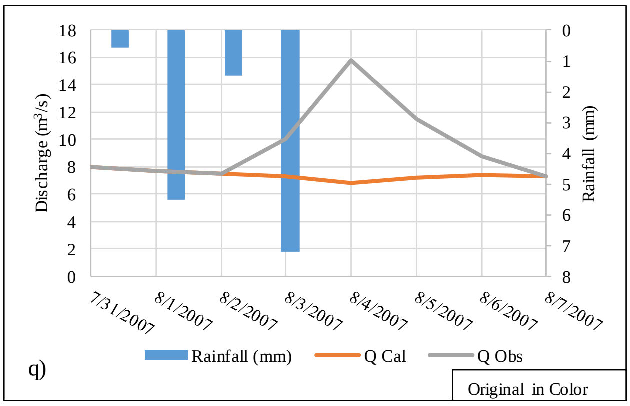
Event No.	E15	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	25.87	24.02	0.077
T_p (day)	4	3	0.250
T_b (day)	4	5	0.250
SF Vol (MCM)	9.50	7.26	0.236
Event MRAE		0.24	
Event RAME		0.31	



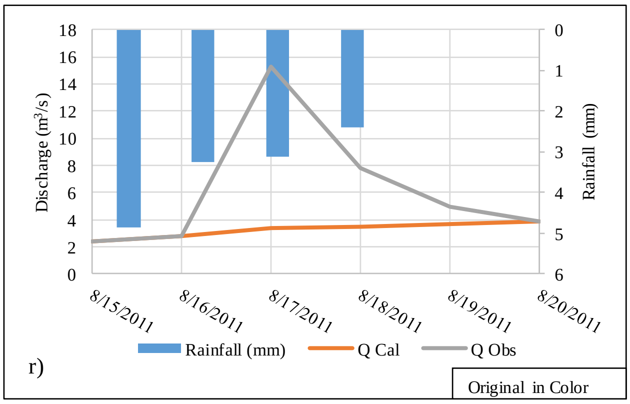
p)

Event No.	E16	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	26.50	31.20	0.151
T_p (day)	3	1	0.667
T_b (day)	3	4	0.333
SF Vol (MCM)	9.582	8.764	0.085
Event MRAE		0.23	
Event RAME		0.26	

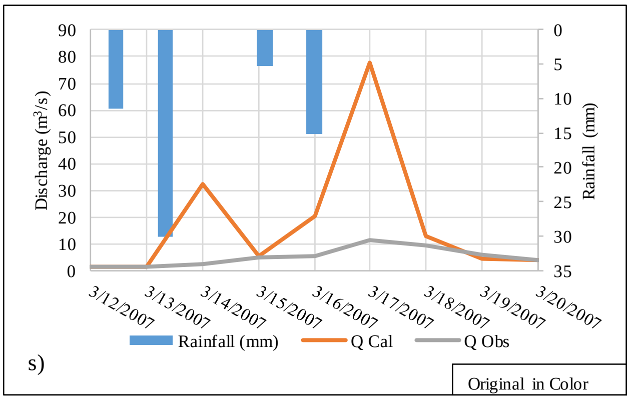
Figure J-4 (m-p): Calculated and observed streamflow graphs of events: E13-E16



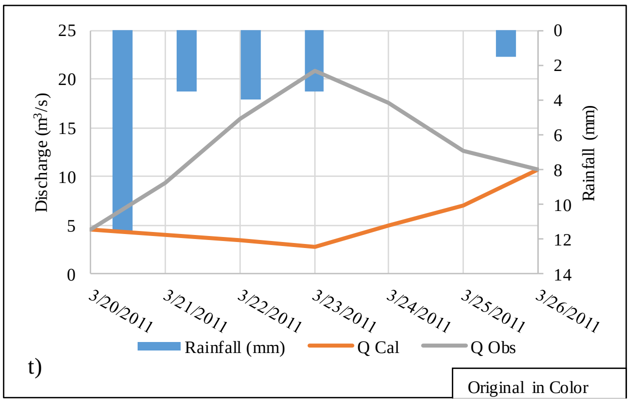
Event No.	E17	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.76	7.93	0.987
T_p (day)	1	4	3.000
T_b (day)	8	5	0.375
SF Vol (MCM)	6.61	5.10	0.228
Event MRAE		0.17	
Event RAME		0.23	



Event No.	E18	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.32	3.85	2.981
T_p (day)	5	2	0.600
T_b (day)	2	5	1.500
SF Vol (MCM)	3.21	1.69	0.472
Event MRAE		0.26	
Event RAME		0.47	

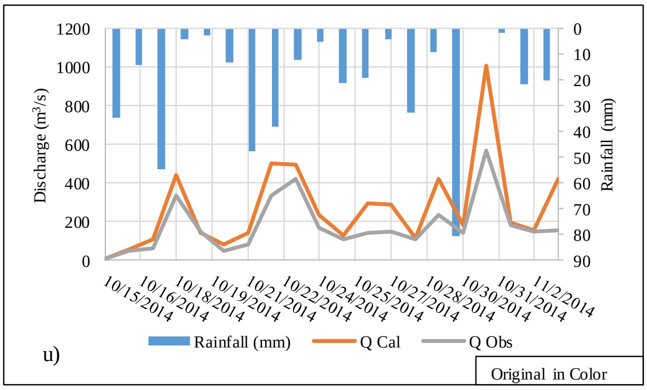


Event No.	E19	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	11.07	77.61	0.857
T_p (day)	5	5	0.000
T_b (day)	5	5	0.000
Vol (MCM)	3.96	13.78	2.479
Event MRAE		2.42	
Event RAME		2.55	

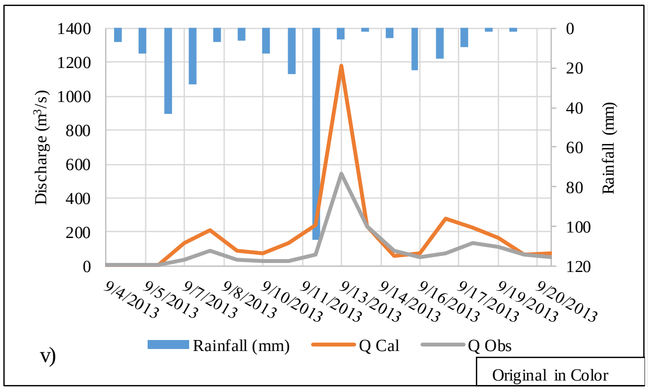


Event No.	E20	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	20.81	10.70	0.945
T_p (day)	6	3	0.500
T_b (day)	2	5	1.500
Vol (MCM)	7.93	3.24	0.591
Event MRAE		0.48	
Event RAME		0.59	

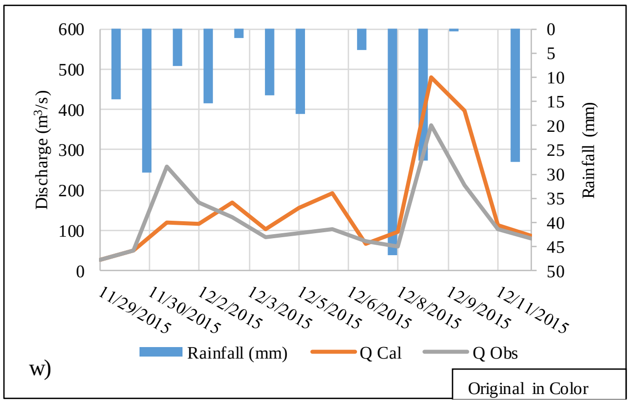
Figure J-5 (q-t): Calculated and observed streamflow graphs of events: E17-E20



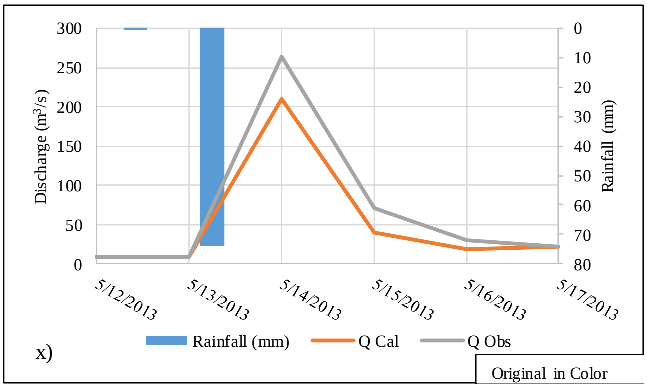
Event No.	E21	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	567.4	1007.8	0.776
T_p (day)	16	16	0.000
T_b (day)	5	5	0.000
Vol (MCM)	312.3	471.6	0.510
Event MRAE		0.49	
Event RAME		0.51	



Event No.	E22	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	544.2	1182.4	1.173
T_p (day)	9	9	0.000
T_b (day)	10	10	0.000
Vol (MCM)	142.5	280.3	0.967
Event MRAE		1.10	
Event RAME		1.01	

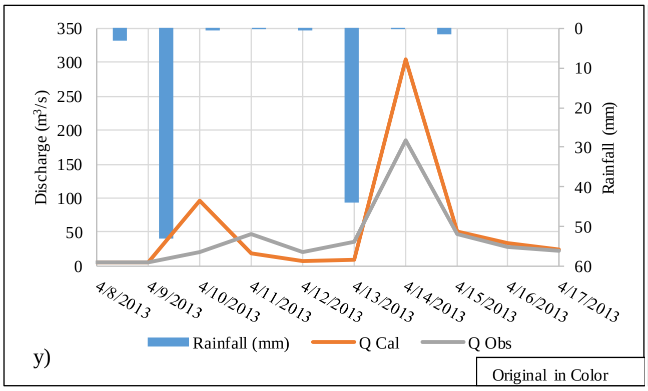


Event No.	E23	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	361.92	479.66	0.325
T_p (day)	10	10	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	155.49	187.52	0.206
Event MRAE		0.36	
Event RAME		0.43	

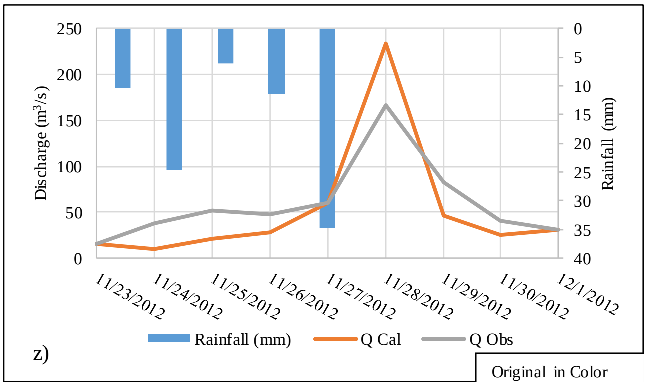


Event No.	E24	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	264.40	209.39	0.208
T_p (day)	2	2	0.000
T_b (day)	5	5	0.000
Vol (MCM)	34.91	26.51	0.241
Event MRAE		0.17	
Event RAME		0.24	

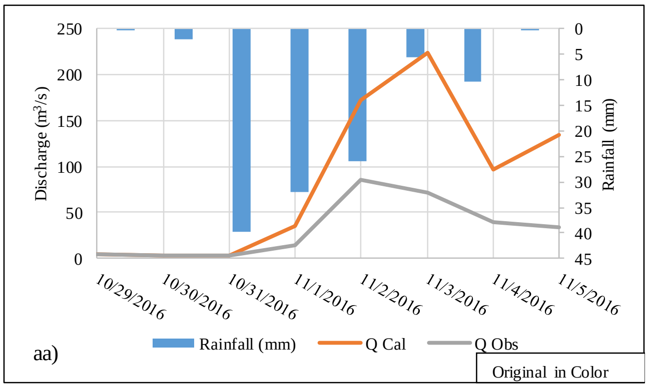
Figure J-6 (u-x): Calculated and observed streamflow graphs of events: E21-E24



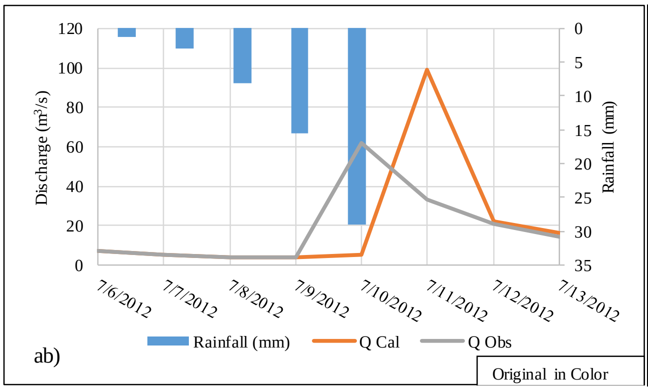
Event No.	E25	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	185.08	305.40	0.650
T_p (day)	6	6	0.000
T_b (day)	5	5	0.000
Vol (MCM)	35.83	47.68	0.331
Event MRAE		0.67	
Event RAME		0.66	



Event No.	E26	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	166.83	233.11	0.397
T_p (day)	5	5	0.000
T_b (day)	5	5	0.000
Vol (MCM)	45.76	40.40	0.117
Event MRAE		0.33	
Event RAME		0.37	

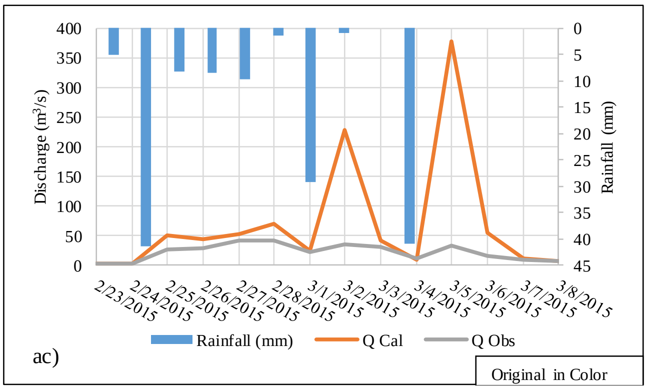


Event No.	E27	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	85.20	224.57	1.636
T_p (day)	5	4	0.200
T_b (day)	4	5	0.250
Vol (MCM)	22.07	58.37	1.645
Event MRAE		1.14	
Event RAME		1.64	

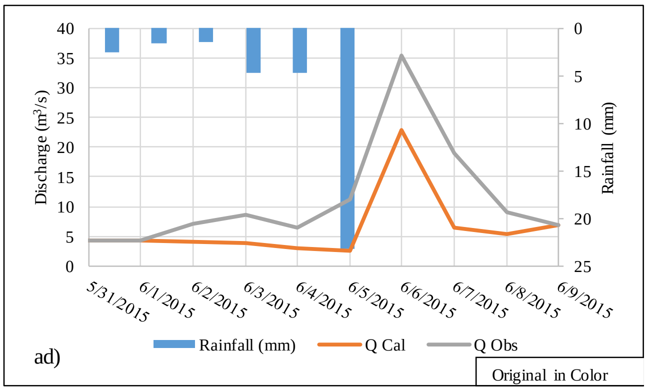


Event No.	E28	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	61.66	99.20	0.609
T_p (day)	5	4	0.200
T_b (day)	4	5	0.250
Vol (MCM)	12.94	13.98	0.081
Event MRAE		0.38	
Event RAME		0.84	

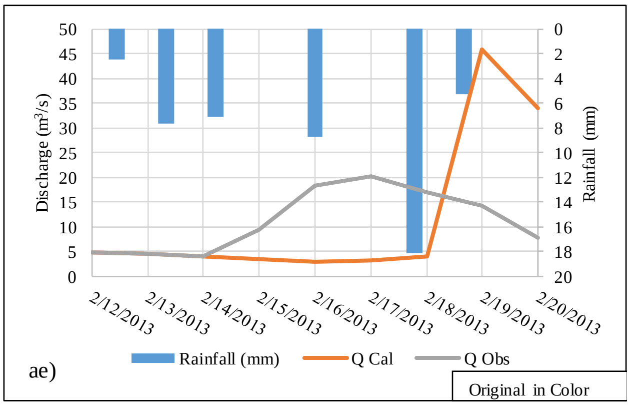
Figure J-7 (y-ab): Calculated and observed streamflow graphs of events: E25-E28



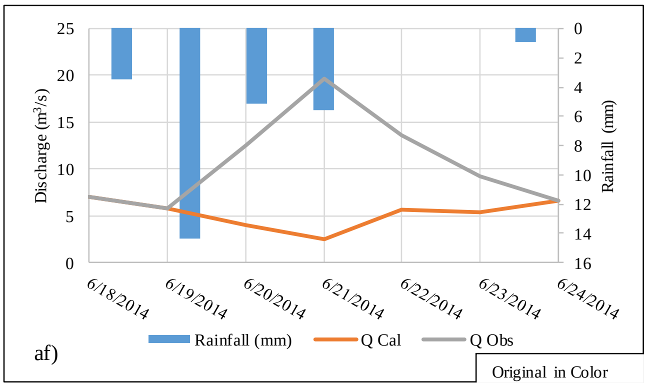
Event No.	E29	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	42.37	377.48	7.910
T_p (day)	10	4	0.600
T_b (day)	5	11	1.200
Vol (MCM)	26.30	84.23	2.203
Event MRAE		1.57	
Event RAME		2.21	



Event No.	E30	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	35.44	22.82	0.356
T_p (day)	6	6	0.000
T_b (day)	5	5	0.000
Vol (MCM)	9.70	5.49	0.434
Event MRAE		0.37	
Event RAME		0.43	

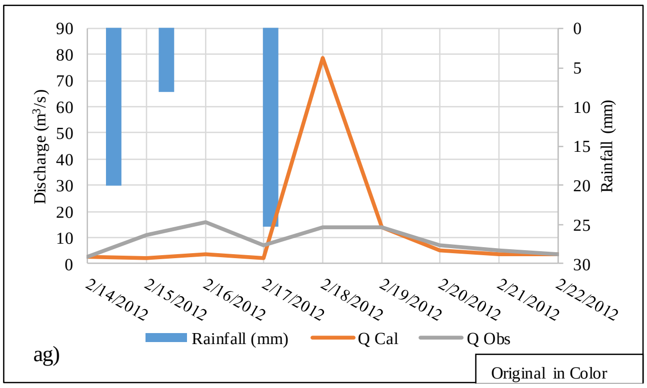


Event No.	E31	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	20.17	45.84	0.560
T_p (day)	7	5	0.286
T_b (day)	3	5	0.667
Vol (MCM)	8.66	9.243933	0.067
Event MRAE		0.96	
Event RAME		1.08	

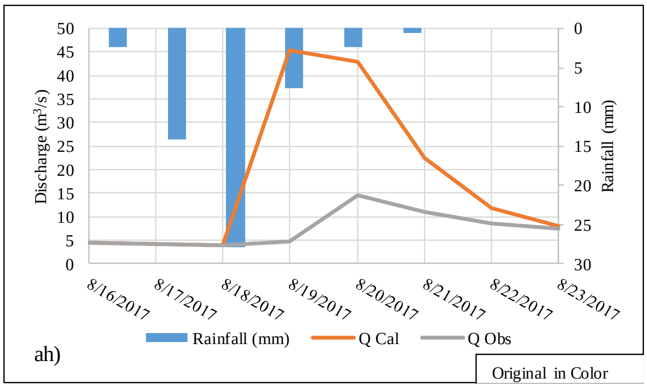


Event No.	E32	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	19.68	7.07	0.641
T_p (day)	1	3	2.000
T_b (day)	7	5	0.286
Vol (MCM)	6.44	3.19	0.504
Event MRAE		0.26	
Event RAME		0.35	

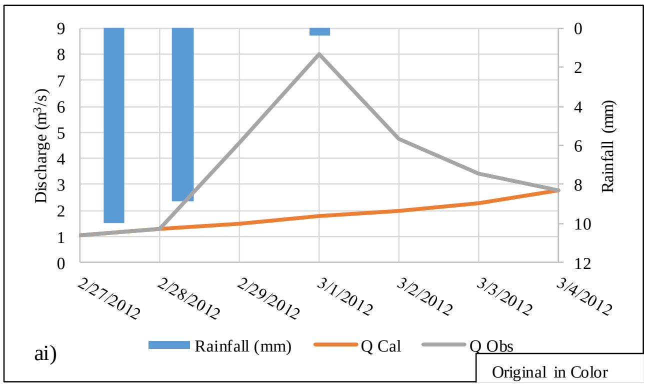
Figure J-8 (ac-af): Calculated and observed streamflow graphs of events: E29-E32



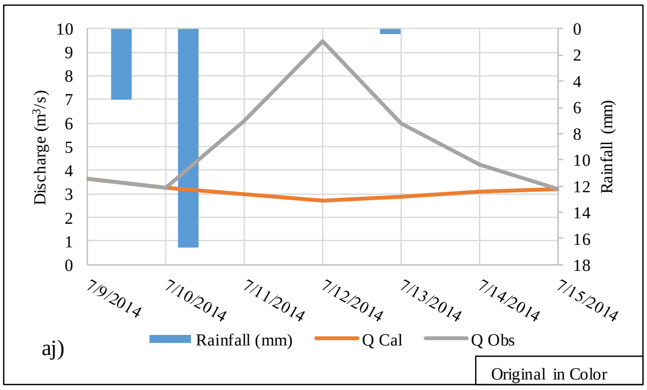
Event No.	E33	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.76	78.82	4.001
T_p (day)	4	2	0.500
T_b (day)	6	8	0.333
Vol (MCM)	6.95	9.96	0.433
Event MRAE		0.83	
Event RAME		1.17	



Event No.	E34	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	14.42	45.47	2.153
T_p (day)	3	4	0.333
T_b (day)	6	5	0.167
Vol (MCM)	5.07	12.39	1.443
Event MRAE		1.51	
Event RAME		1.44	

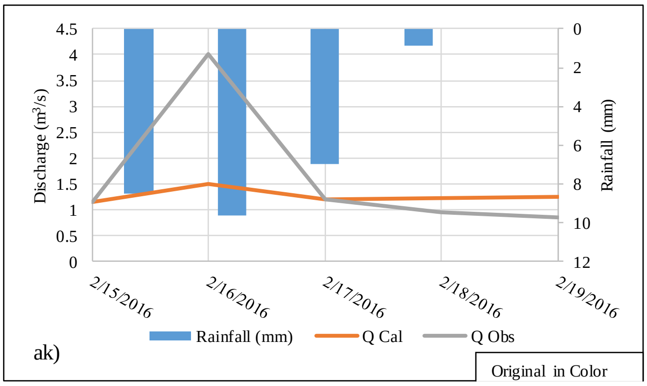


Event No.	E35	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	8.01	2.79	0.651
T_p (day)	6	3	0.500
T_b (day)	2	5	1.500
Vol (MCM)	2.24	1.10	0.508
Event MRAE		0.34	
Event RAME		0.51	

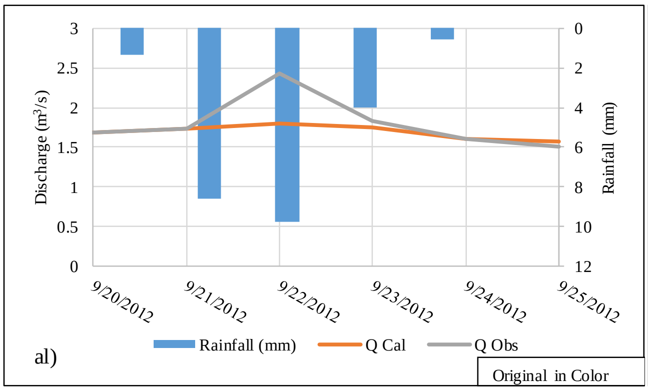


Event No.	E36	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	9.48	3.64	0.616
T_p (day)	1	3	2.000
T_b (day)	7	5	0.286
Vol (MCM)	3.11	1.89	0.393
Event MRAE		0.29	
Event RAME		0.39	

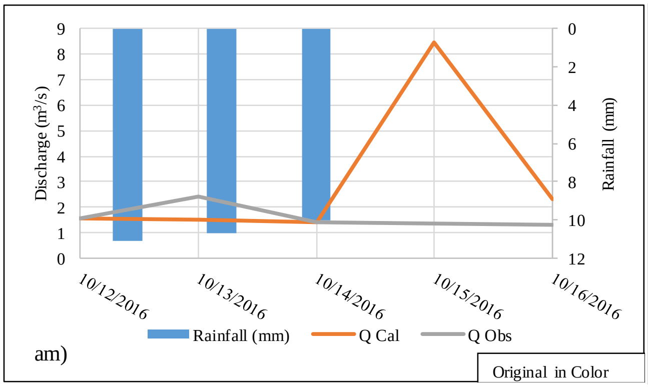
Figure J-9 (ag-aj): Calculated and observed streamflow graphs of events: E33-E36



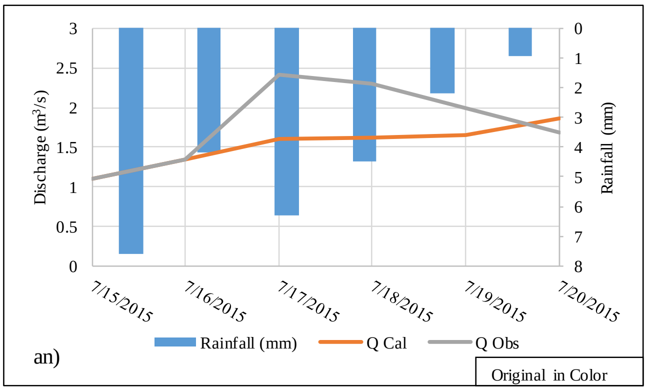
Event No.	E37	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	4.00	1.50	0.625
T_p (day)	1	1	0.000
T_b (day)	5	5	0.000
Vol (MCM)	0.70	0.55	0.222
Event MRAE		0.28	
Event RAME		0.39	



Event No.	E38	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.43	1.80	0.259
T_p (day)	2	2	0.000
T_b (day)	5	5	0.000
Vol (MCM)	0.93	0.88	0.061
Event MRAE		0.06	
Event RAME		0.07	



Event No.	E39	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.43	8.46	2.480
T_p (day)	3	1	0.667
T_b (day)	3	5	0.667
Vol (MCM)	0.70	1.32	0.885
Event MRAE		1.27	
Event RAME		1.12	



Event No.	E40	CN=	68.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.42	1.86	0.231
T_p (day)	5	2	0.600
T_b (day)	2	5	1.500
Vol (MCM)	0.94	0.79	0.154
Event MRAE		0.15	
Event RAME		0.19	

Figure J-10 (ak-an): Calculated and observed streamflow graphs of events: E37-E40

Appendix K: Evaluation of streamflow estimation using CN_I from rainfall-runoff data

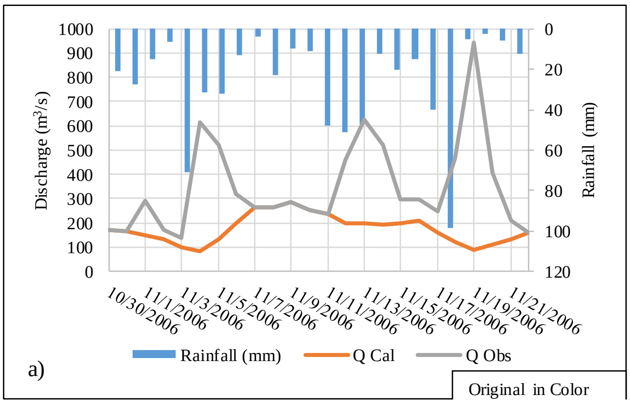
Table K-1: Details of streamflow estimation using CN_I from rainfall-runoff data

Event ID	From	To	Total RF (mm)	CN	Qp (m3/s)		Tp (day)		Tb (day)		Vol (MMC)		Error (RAE)				Event MRAE	Event RAEM
					Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Qp	Tp	Tb	Vol		
E1	10/30/2006	11/22/2006	621.6	2.23	284.7	944.6	10	20	15	5	361.5	717.8	2.32	1.00	0.67	0.50	0.36	0.50
E2	7/11/2008	7/27/2008	172.6	13.52	30.5	494.3	16	8	2	10	21.4	119.8	15.19	1.00	0.80	0.82	0.45	0.82
E3	5/22/2011	6/5/2011	209.0	11.07	83.3	422.4	8	5	8	11	47.7	150.1	4.07	0.38	0.38	0.68	0.33	0.68
E4	9/27/2010	10/10/2010	251.9	11.51	103.2	312.0	13	5	2	10	52.3	142.8	2.02	0.62	4.00	0.63	0.46	0.63
E5	4/24/2008	5/2/2008	115.9	19.48	50.0	233.0	5	5	5	5	30.3	77.6	3.66	0.00	0.00	0.61	0.35	0.61
E6	12/16/2006	12/23/2006	32.5	31.71	30.0	188.3	4	4	5	5	18.1	35.5	5.28	0.00	0.00	0.49	0.20	0.49
E7	1/4/2006	1/17/2006	84.3	27.81	40.0	158.7	13	10	2	5	19.6	48.3	2.97	0.23	1.50	0.59	0.42	0.59
E8	6/19/2006	6/27/2006	195.0	18.24	40.0	156.9	4	5	6	5	20.9	65.3	2.92	0.25	0.17	0.68	0.44	0.68
E9	1/29/2005	2/5/2005	96.5	35.36	18.7	117.7	2	4	7	5	7.0	20.6	5.30	1.00	0.29	0.66	0.33	0.66
E10	6/5/2010	6/15/2010	108.7	28.77	35.4	96.7	10	7	2	5	15.8	35.1	1.73	0.30	1.50	0.55	0.41	0.55
E11	11/19/2007	11/26/2007	39.6	40.78	23.2	70.9	3	4	6	5	13.1	21.5	2.06	0.33	0.17	0.39	0.27	0.39
E12	8/20/2010	8/25/2010	40.6	52.34	10.8	54.5	5	2	2	5	4.0	12.1	4.05	0.60	1.50	0.67	0.44	0.67
E13	4/15/2006	4/23/2006	85.7	34.45	16.4	53.0	8	2	2	8	6.8	22.4	2.22	0.75	3.00	0.70	0.56	0.70
E14	3/3/2011	3/9/2011	48.0	48.47	13.1	41.8	5	3	3	5	6.8	11.6	2.19	0.40	0.67	0.41	0.25	0.41
E15	3/29/2006	4/4/2006	36.6	55.20	14.2	25.9	6	3	2	5	5.6	9.5	0.82	0.50	1.50	0.41	0.31	0.41
E16	12/15/2008	12/19/2008	35.0	56.31	20.0	26.5	4	1	2	5	7.5	9.6	0.33	0.75	1.50	0.22	0.20	0.22
E17	7/31/2007	8/7/2007	14.7	72.40	7.9	15.8	1	4	8	5	5.1	6.6	0.99	3.00	0.38	0.23	0.17	0.23
E18	8/15/2011	8/20/2011	13.6	76.81	3.8	15.3	5	2	2	5	1.7	3.2	2.98	0.60	1.50	0.47	0.26	0.47
E19	3/12/2007	3/20/2007	61.9	36.36	3.9	11.1	8	5	2	5	1.6	4.0	1.84	0.38	1.50	0.61	0.45	0.61
E20	3/20/2011	3/26/2011	24.0	62.89	10.7	20.8	6	3	2	5	3.2	7.9	0.95	0.50	1.50	0.59	0.48	0.59

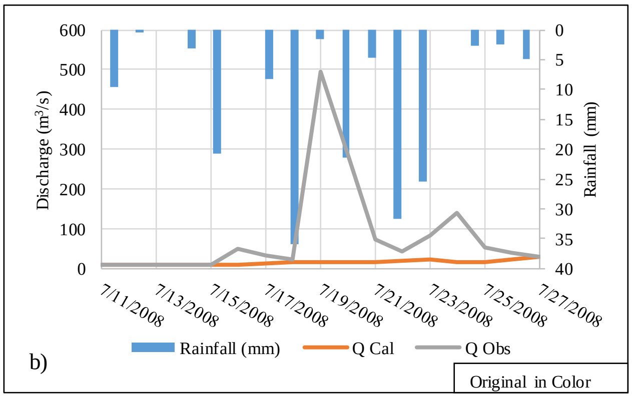
Continued….

Event ID	From	To	Total RF (mm)	CN	Qp (m3/s)		Tp (day)		Tb (day)		Vol (MMC)		Error (RAE)				Event MRAE	Event RAEM
					Cal	**Obs**	**Cal**	**Obs**	**Cal**	**Obs**	**Cal**	**Obs**	**Qp**	**Tp**	**Tb**	**Vol**		
E21	10/15/2014	11/3/2014	434.6	5.64	156.9	567.4	19	16	2	5	85.6	312.3	0.72	0.16	1.50	0.73	0.55	0.73
E22	9/4/2013	9/21/2013	308.7	10.96	52.0	544.2	17	9	2	10	18.9	142.5	0.90	0.47	4.00	0.87	0.66	0.87
E23	11/29/2015	12/12/2015	206.7	10.67	81.2	361.9	5	10	10	5	72.5	155.5	0.78	1.00	0.50	0.53	0.35	0.53
E24	5/12/2013	5/17/2013	74.6	33.57	21.9	264.4	5	2	2	5	6.5	34.9	0.92	0.60	1.50	0.81	0.38	0.81
E25	4/8/2013	4/17/2013	102.5	29.55	21.7	185.1	9	6	2	5	6.5	35.8	0.88	0.33	1.50	0.82	0.56	0.82
E26	11/23/2012	12/1/2012	87.6	28.53	30.1	166.8	8	5	2	5	11.1	45.8	0.82	0.38	1.50	0.76	0.60	0.76
E27	10/29/2016	11/5/2016	116.8	27.52	34.3	85.2	7	4	2	5	6.5	22.1	0.60	0.43	1.50	0.70	0.40	0.70
E28	7/6/2012	7/13/2012	56.9	44.18	14.2	61.7	7	4	2	5	4.4	12.9	0.77	0.43	1.50	0.66	0.30	0.66
E29	2/23/2015	3/8/2015	145.2	23.28	7.2	42.4	13	4	2	11	4.0	26.3	0.83	0.69	4.50	0.85	0.65	0.85
E30	5/31/2015	6/9/2015	38.1	54.22	7.0	35.4	9	6	2	5	3.4	9.7	0.80	0.33	1.50	0.65	0.45	0.65
E31	2/12/2013	2/20/2013	49.4	47.01	7.9	20.2	8	5	2	5	3.5	8.7	1.57	0.38	1.50	0.59	0.41	0.59
E32	6/18/2014	6/24/2014	29.5	60.42	7.1	19.7	1	3	7	5	2.9	6.4	0.64	2.00	0.29	0.54	0.28	0.38
E33	2/14/2012	2/22/2012	53.4	43.71	3.7	15.8	8	2	2	8	2.1	7.0	0.76	0.75	3.00	0.70	0.54	0.70
E34	8/16/2017	8/23/2017	54.9	41.14	7.4	14.4	7	4	2	5	3.8	5.1	0.49	0.43	1.50	0.25	0.15	0.25
E35	2/27/2012	3/4/2012	19.2	67.84	2.8	8.0	6	3	2	5	1.1	2.2	0.65	0.50	1.50	0.51	0.34	0.51
E36	7/9/2014	7/15/2014	22.5	65.15	3.6	9.5	1	3	7	5	1.9	3.1	0.62	2.00	0.29	0.39	0.29	0.39
E37	2/15/2016	2/19/2016	26.0	51.93	1.5	4.0	1	1	5	5	0.5	0.7	0.63	0.00	0.00	0.31	0.13	0.31
E38	9/20/2012	9/25/2012	24.2	56.81	1.8	2.4	2	2	5	5	0.9	0.9	0.26	0.00	0.00	0.07	0.05	0.07
E39	10/12/2016	10/16/2016	31.8	47.76	1.5	2.4	1	1	5	5	0.6	0.7	0.36	0.00	0.00	0.12	0.08	0.12
E40	7/15/2015	7/20/2015	25.7	55.10	1.7	2.4	5	2	2	5	0.8	0.9	0.30	0.60	1.50	0.17	0.13	0.17
												Max	***15.19***	***3.00***	***4.50***	***0.87***	***0.66***	***0.87***
												Min	***0.26***	***0.00***	***0.00***	***0.07***	***0.05***	***0.07***
												Average	***1.95***	***0.60***	***1.29***	***0.55***	***0.36***	***0.54***

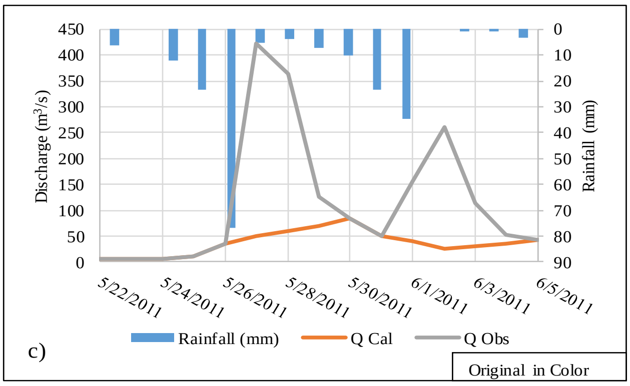
Appendix L: Rainfall-runoff data CN_I graphs for all events



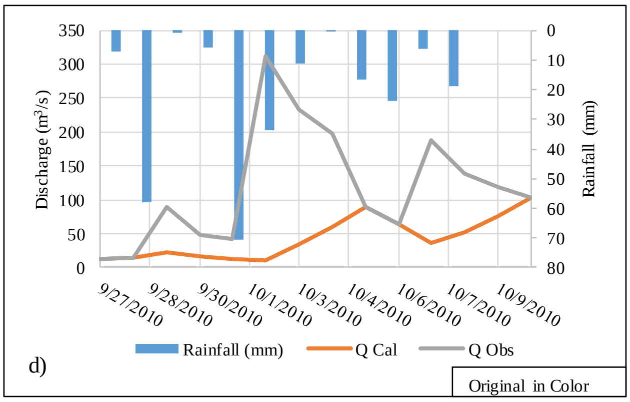
Event No.	E1	CN=	2.23
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	944.58	284.67	2.318
T_p (day)	10	20	1.000
T_b (day)	15	5	0.667
Vol (MCM)	717.75	361.47	0.496
Event MRAE		0.36	
Event RAME		0.50	



Event No.	E2	CN=	13.52
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	494.26	30.54	15.185
T_p (day)	8	16	1.000
T_b (day)	10	2	0.800
SF Vol (MCM)	119.8	21.4	0.821
Event MRAE		0.45	
Event RAME		0.82	

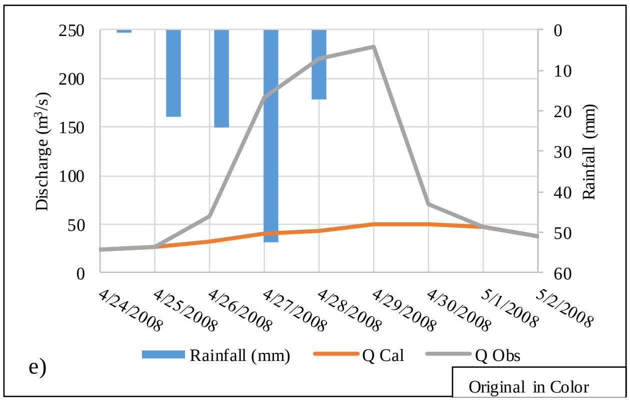


Event No.	E3	CN=	11.07
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	422.39	83.34	4.068
T_p (day)	8	5	0.375
T_b (day)	8	11	0.375
Vol (MCM)	150.09	47.66	0.682
Event MRAE		0.33	
Event RAME		0.68	

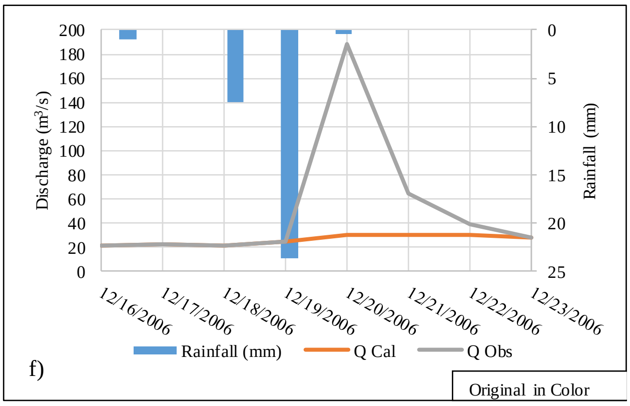


Event No.	E4	CN=	11.51
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	312.05	103.25	2.022
T_p (day)	13	5	0.615
T_b (day)	2	10	4.000
SF Vol (MCM)	142.81	52.25	0.634
Event MRAE		0.46	
Event RAME		0.63	

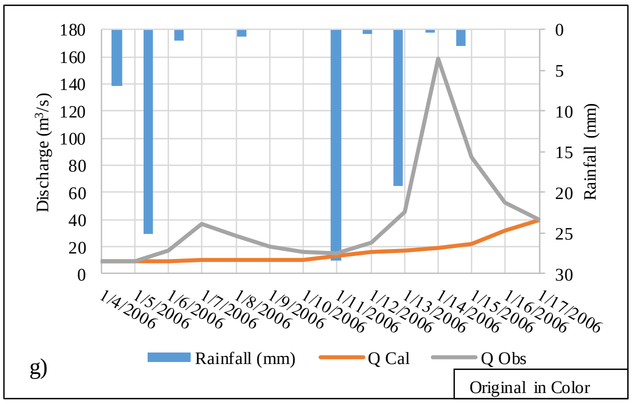
Figure L-1 (a-d): Calculated and observed streamflow graphs of events: E1-E4



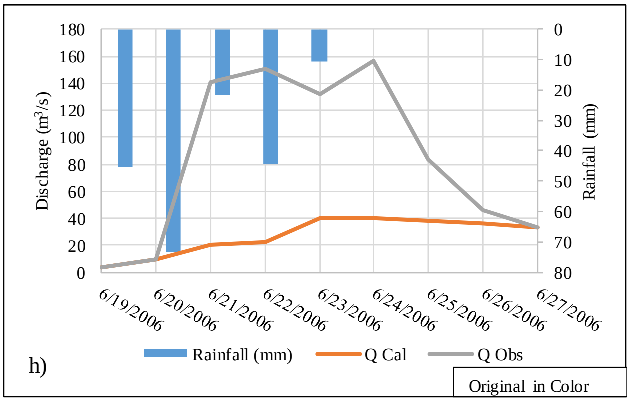
Event No.	E5	CN=	19.48
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	232.99	50.00	3.660
T_p (day)	5	5	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	77.60	30.26772	0.610
Event MRAE		0.35	
Event RAME		0.61	



Event No.	E6	CN=	31.71
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	188.29	30.00	5.276
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	35.47	18.06	0.491
Event MRAE		0.20	
Event RAME		0.49	

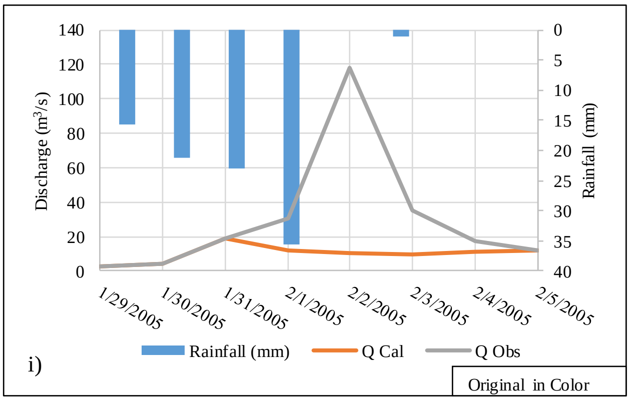


Event No.	E7	CN=	27.81
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	158.68	39.99	2.968
T_p (day)	13	10	0.231
T_b (day)	2	5	1.500
SF Vol (MCM)	48.29	19.59	0.594
Event MRAE		0.42	
Event RAME		0.59	

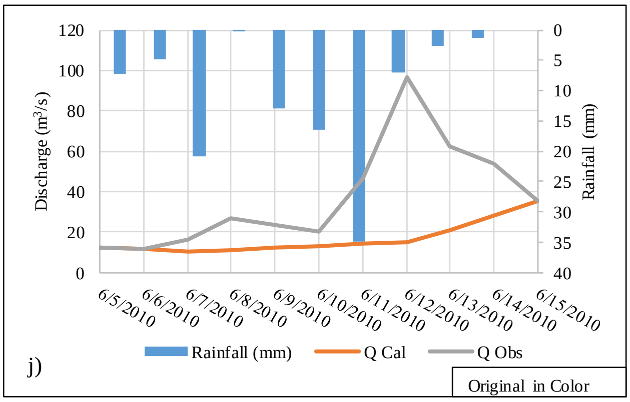


Event No.	E8	CN=	18.24
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	156.88	40.00	2.922
T_p (day)	4	5	0.250
T_b (day)	6	5	0.167
SF Vol (MCM)	65.34	20.92	0.680
Event MRAE		0.44	
Event RAME		0.68	

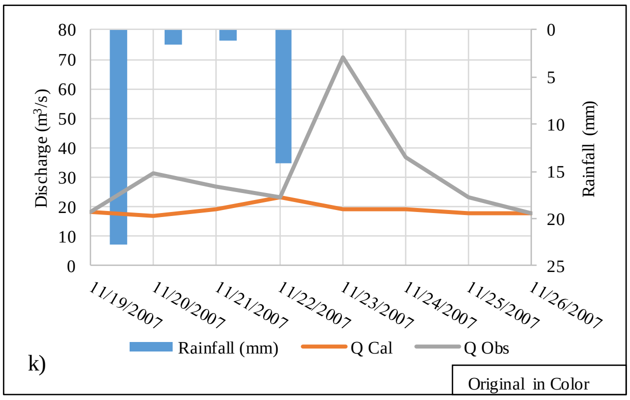
Figure L-2 (e-h): Calculated and observed streamflow graphs of events: E5-E8



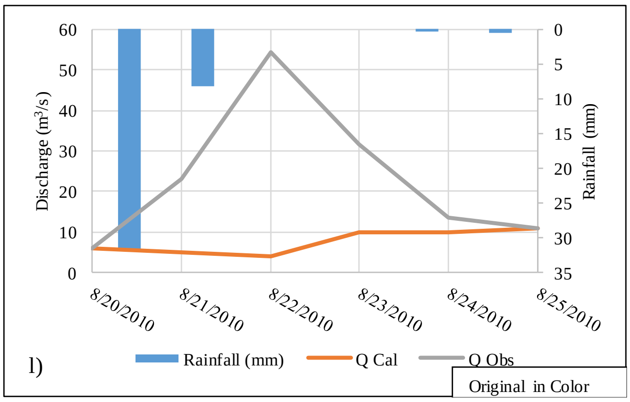
Event No.	E9	CN=	35.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	117.69	18.68	5.300
T_p (day)	2	4	1.000
T_b (day)	7	5	0.286
Vol (MCM)	20.59	6.96	0.662
Event MRAE		0.33	
Event RAME		0.66	



Event No.	E10	CN=	28.77
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	96.73	35.44	1.729
T_p (day)	10	7	0.300
T_b (day)	2	5	1.500
SF Vol (MCM)	35.08	15.83	0.549
Event MRAE		0.41	
Event RAME		0.55	

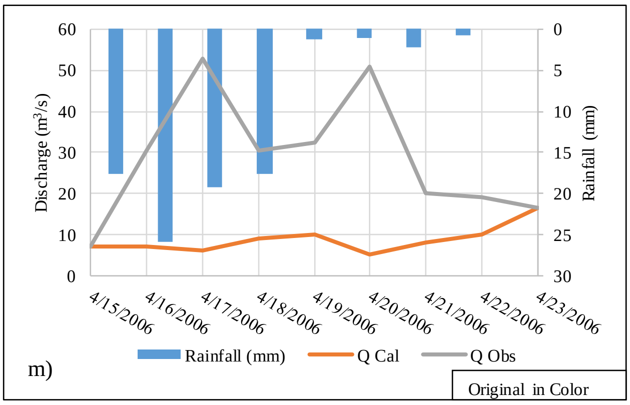


Event No.	E11	CN=	40.78
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	70.93	23.20	2.057
T_p (day)	3	4	0.333
T_b (day)	6	5	0.167
Vol (MCM)	21.50	13.08	0.392
Event MRAE		0.27	
Event RAME		0.39	

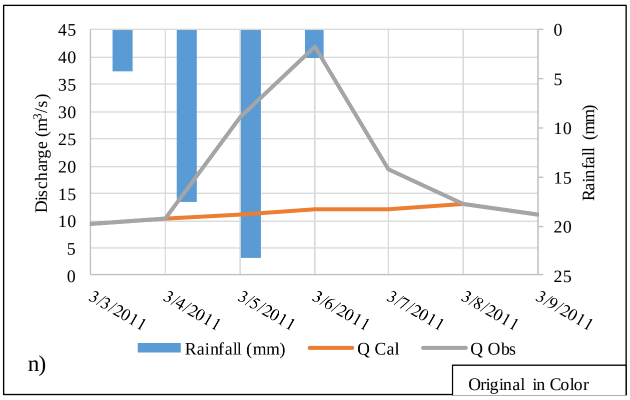


Event No.	E12	CN=	52.34
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	54.47	10.80	4.046
T_p (day)	5	2	0.600
T_b (day)	2	5	1.500
Vol (MCM)	12.06	3.96	0.671
Event MRAE		0.44	
Event RAME		0.67	

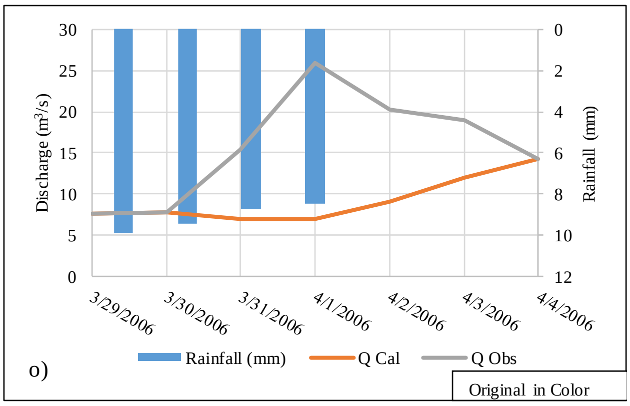
Figure L-3 (i-l): Calculated and observed streamflow graphs of events: E9-E12



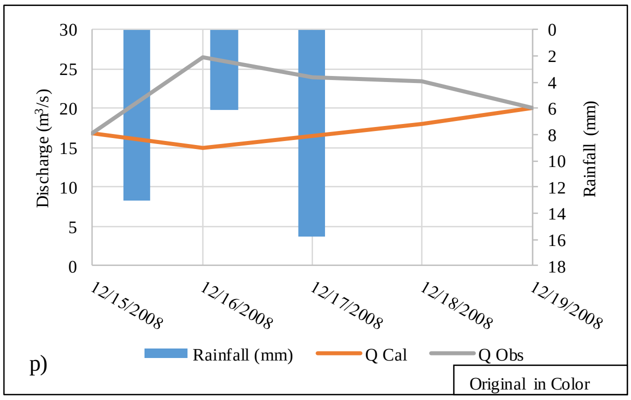
Event No.	E13	CN=	34.45
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	53.00	16.44	2.224
T_p (day)	8	2	0.750
T_b (day)	2	8	3.000
SF Vol (MCM)	22.43	6.78	0.698
Event MRAE		0.56	
Event RAME		0.70	



Event No.	E14	CN=	48.47
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	41.81	13.10	2.191
T_p (day)	5	3	0.400
T_b (day)	3	5	0.667
Vol (MCM)	11.59	6.81	0.412
Event MRAE		0.25	
Event RAME		0.41	

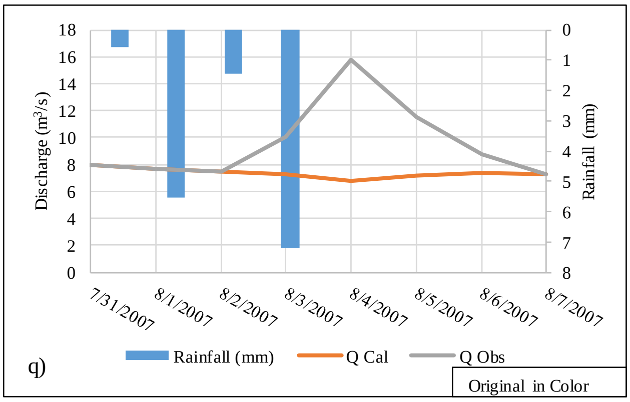


Event No.	E15	CN=	55.20
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	25.87	14.24	0.816
T_p (day)	6	3	0.500
T_b (day)	2	5	1.500
SF Vol (MCM)	9.50	5.57	0.414
Event MRAE		0.31	
Event RAME		0.41	

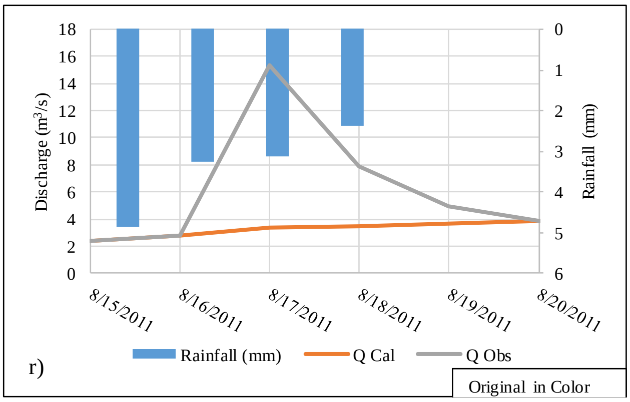


Event No.	E16	CN=	56.31
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	26.50	20.00	0.325
T_p (day)	4	1	0.750
T_b (day)	2	5	1.500
SF Vol (MCM)	9.582	7.465	0.221
Event MRAE		0.20	
Event RAME		0.22	

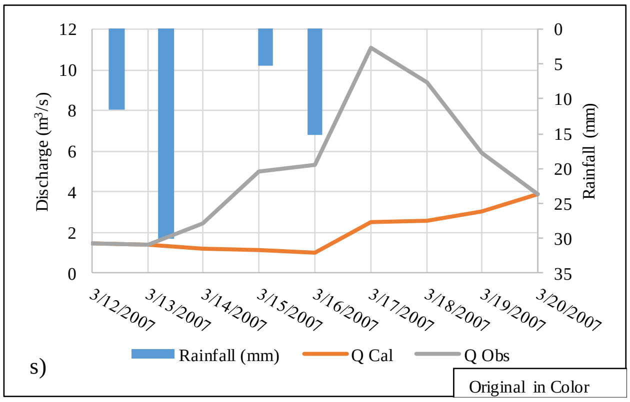
Figure L-4 (m-p): Calculated and observed streamflow graphs of events: E13-E16



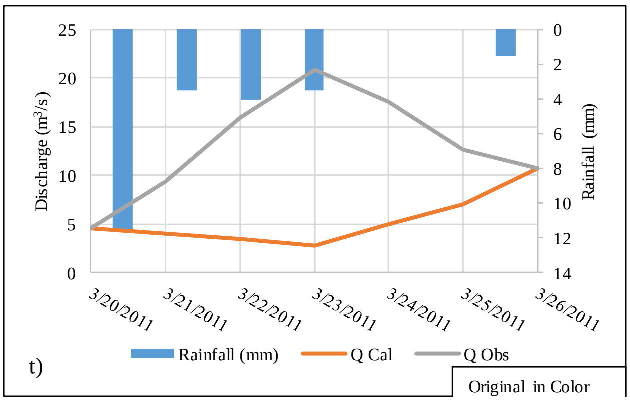
Event No.	E17	CN=	72.40
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.76	7.93	0.987
T_p (day)	1	4	3.000
T_b (day)	8	5	0.375
SF Vol (MCM)	6.61	5.10	0.228
Event MRAE		0.17	
Event RAME		0.23	



Event No.	E18	CN=	76.81
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.32	3.85	2.981
T_p (day)	5	2	0.600
T_b (day)	2	5	1.500
SF Vol (MCM)	3.21	1.69	0.472
Event MRAE		0.26	
Event RAME		0.47	

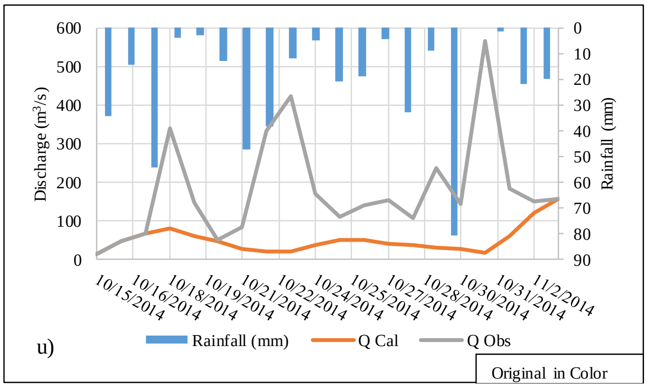


Event No.	E19	CN=	36.36
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	11.07	3.90	1.840
T_p (day)	8	5	0.375
T_b (day)	2	5	1.500
Vol (MCM)	3.96	1.56	0.605
Event MRAE		0.45	
Event RAME		0.61	

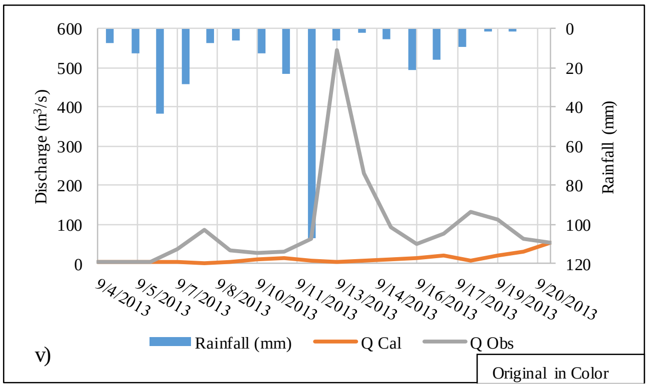


Event No.	E20	CN=	62.89
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	20.81	10.70	0.945
T_p (day)	6	3	0.500
T_b (day)	2	5	1.500
Vol (MCM)	7.93	3.24	0.591
Event MRAE		0.48	
Event RAME		0.59	

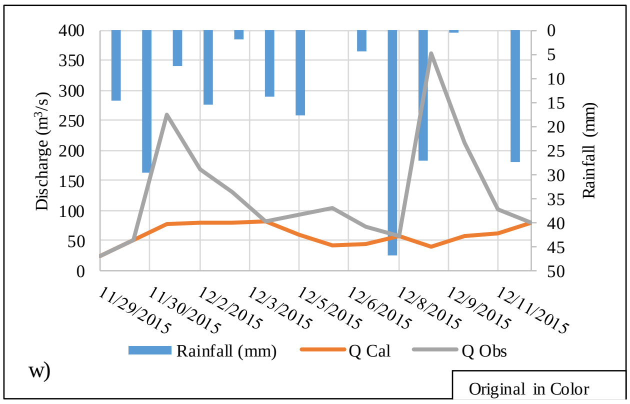
Figure L-5 (q-t): Calculated and observed streamflow graphs of events: E17-E20



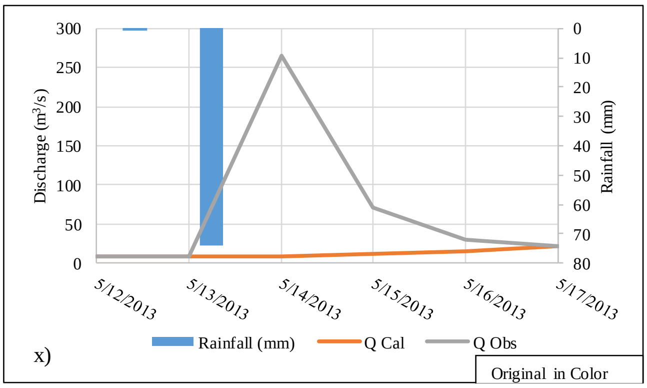
Event No.	E21	CN=	5.64
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	567.4	156.9	0.723
T_p (day)	19	16	0.158
T_b (day)	2	5	1.500
Vol (MCM)	312.3	85.6	0.726
Event MRAE		0.55	
Event RAME		0.73	



Event No.	E22	CN=	10.96
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	544.2	52.0	0.905
T_p (day)	17	9	0.471
T_b (day)	2	10	4.000
Vol (MCM)	142.5	18.9	0.867
Event MRAE		0.66	
Event RAME		0.87	

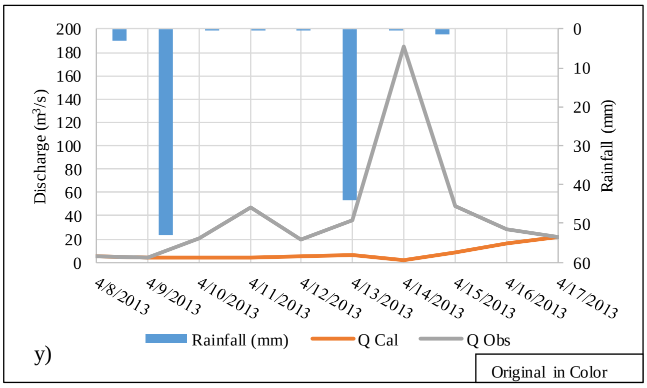


Event No.	E23	CN=	10.67
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	361.92	81.19	0.776
T_p (day)	5	10	1.000
T_b (day)	10	5	0.500
SF Vol (MCM)	155.49	72.54	0.533
Event MRAE		0.35	
Event RAME		0.53	

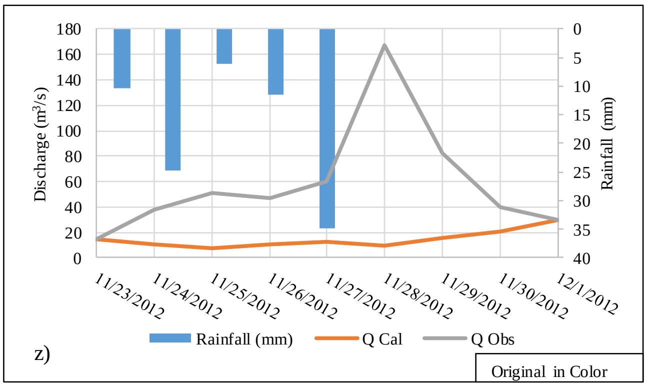


Event No.	E24	CN=	33.57
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	264.40	21.86	0.917
T_p (day)	5	2	0.600
T_b (day)	2	5	1.500
Vol (MCM)	34.91	6.49	0.814
Event MRAE		0.38	
Event RAME		0.81	

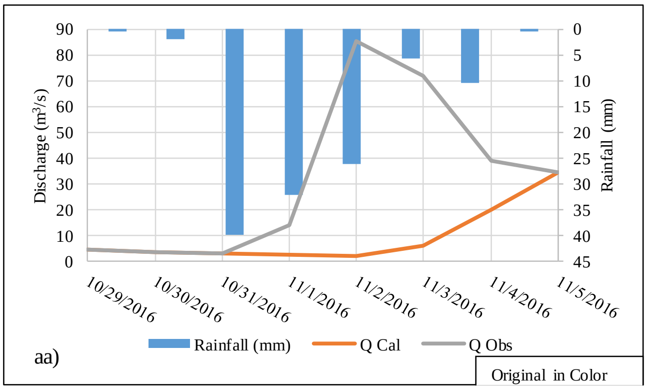
Figure L-6 (u-x): Calculated and observed streamflow graphs of events: E21-E24



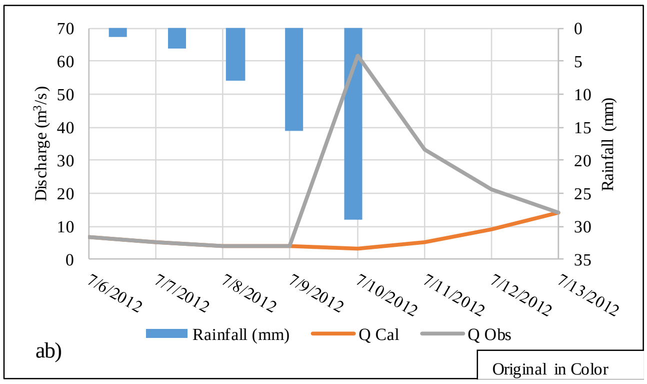
Event No.	E25	CN=	29.55
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	185.08	21.72	0.883
T_p (day)	9	6	0.333
T_b (day)	2	5	1.500
Vol (MCM)	35.83	6.55	0.817
Event MRAE		0.56	
Event RAME		0.82	



Event No.	E26	CN=	28.53
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	166.83	30.07	0.820
T_p (day)	8	5	0.375
T_b (day)	2	5	1.500
Vol (MCM)	45.76	11.13	0.757
Event MRAE		0.60	
Event RAME		0.76	

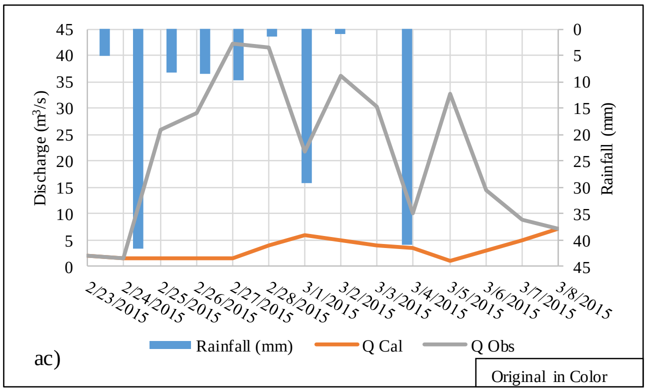


Event No.	E27	CN=	27.52
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	85.20	34.34	0.597
T_p (day)	7	4	0.429
T_b (day)	2	5	1.500
Vol (MCM)	22.07	6.55	0.703
Event MRAE		0.40	
Event RAME		0.70	

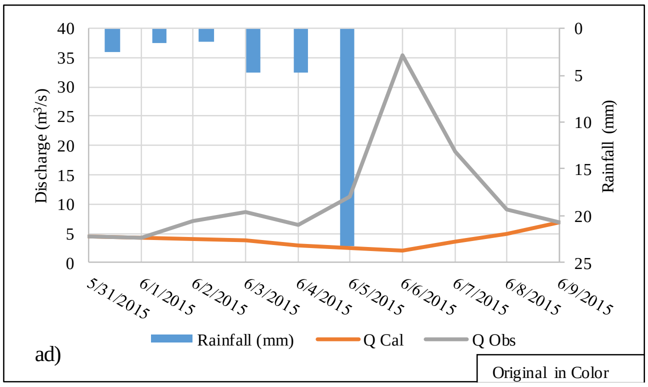


Event No.	E28	CN=	44.18
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	61.66	14.24	0.769
T_p (day)	7	4	0.429
T_b (day)	2	5	1.500
Vol (MCM)	12.94	4.40	0.660
Event MRAE		0.30	
Event RAME		0.66	

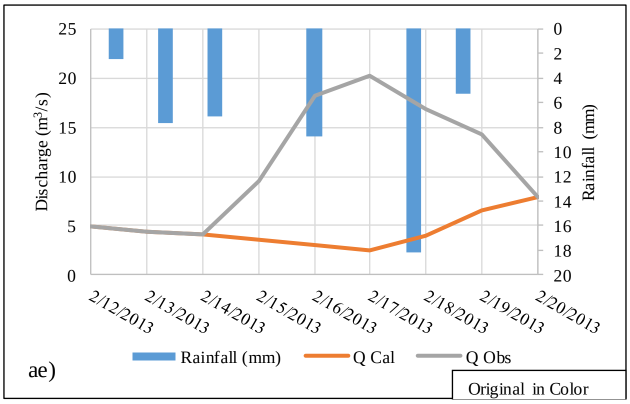
Figure L-7 (y-ab): Calculated and observed streamflow graphs of events: E25-E28



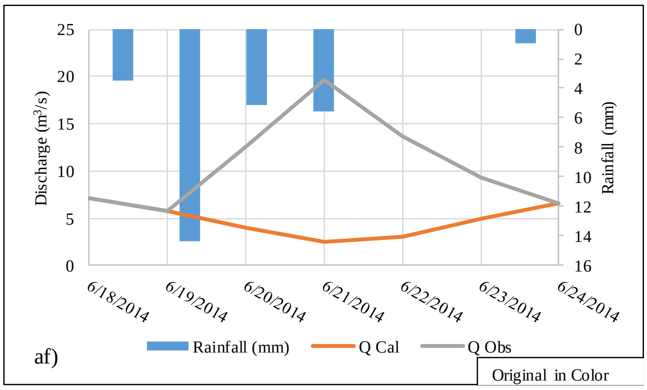
Event No.	E29	CN=	23.28
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	42.37	7.18	0.830
T_p (day)	13	4	0.692
T_b (day)	2	11	4.500
Vol (MCM)	26.30	4.04	0.846
Event MRAE		0.65	
Event RAME		0.85	



Event No.	E30	CN=	54.22
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	35.44	6.97	0.803
T_p (day)	9	6	0.333
T_b (day)	2	5	1.500
Vol (MCM)	9.70	3.41	0.649
Event MRAE		0.45	
Event RAME		0.65	

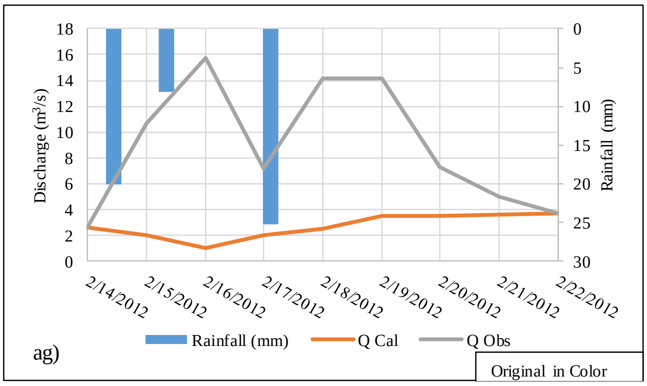


Event No.	31	CN=	47.01
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	20.17	7.86	1.567
T_p (day)	8	5	0.375
T_b (day)	2	5	1.500
Vol (MCM)	8.66	3.518488	0.594
Event MRAE		0.41	
Event RAME		0.59	

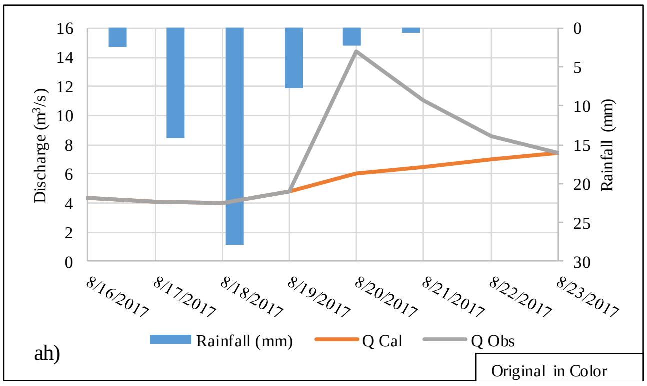


Event No.	E32	CN=	60.42
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	19.68	7.07	0.641
T_p (day)	1	3	2.000
T_b (day)	7	5	0.286
Vol (MCM)	6.44	2.93	0.545
Event MRAE		0.28	
Event RAME		0.38	

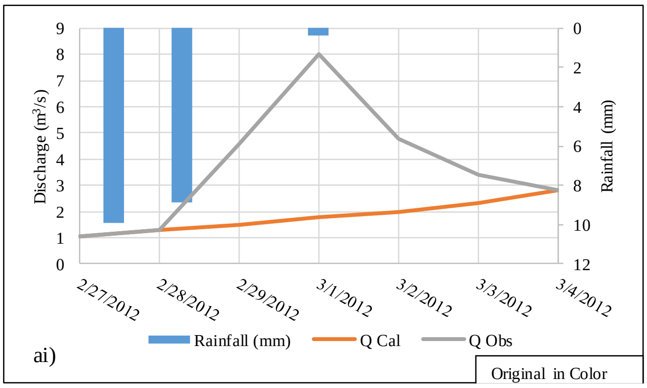
Figure L-8 (ac-af): Calculated and observed streamflow graphs of events: E29-E32



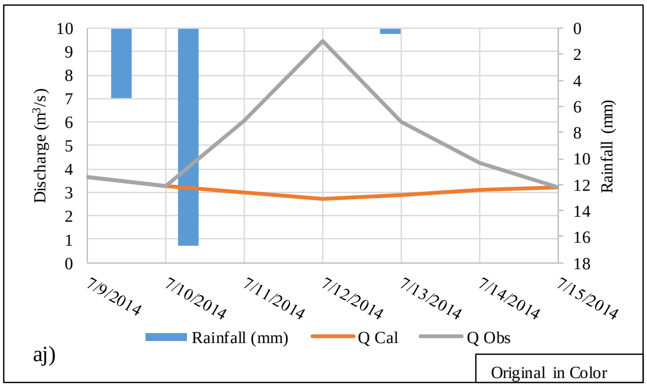
Event No.	E33	CN=	43.71
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.76	3.75	0.762
T_p (day)	8	2	0.750
T_b (day)	2	8	3.000
Vol (MCM)	6.95	2.11	0.697
Event MRAE		0.54	
Event RAME		0.70	



Event No.	E34	CN=	41.14
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	14.42	7.41	0.486
T_p (day)	7	4	0.429
T_b (day)	2	5	1.500
Vol (MCM)	5.07	3.81	0.248
Event MRAE		0.15	
Event RAME		0.25	

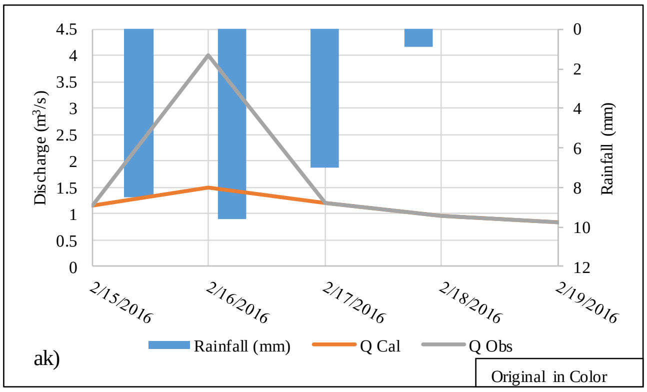


Event No.	E35	CN=	67.84
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	8.01	2.79	0.651
T_p (day)	6	3	0.500
T_b (day)	2	5	1.500
Vol (MCM)	2.24	1.10	0.508
Event MRAE		0.34	
Event RAME		0.51	

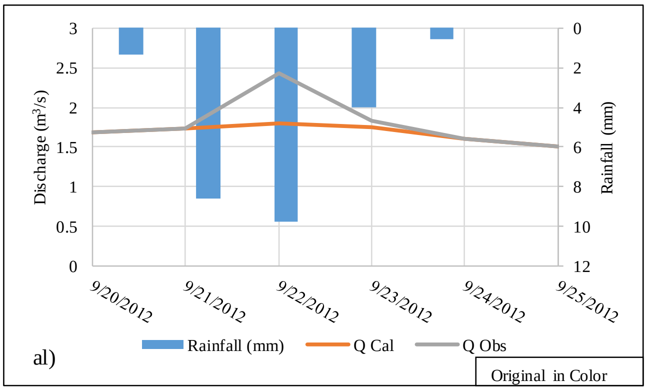


Event No.	E36	CN=	65.15
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	9.48	3.64	0.616
T_p (day)	1	3	2.000
T_b (day)	7	5	0.286
Vol (MCM)	3.11	1.89	0.393
Event MRAE		0.29	
Event RAME		0.39	

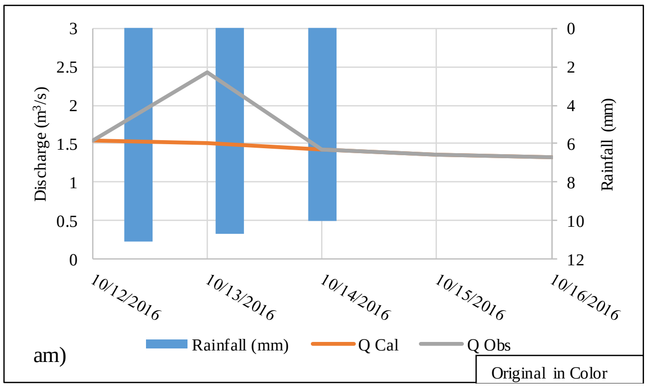
Figure L-9 (ag-aj): Calculated and observed streamflow graphs of events: E33-E36



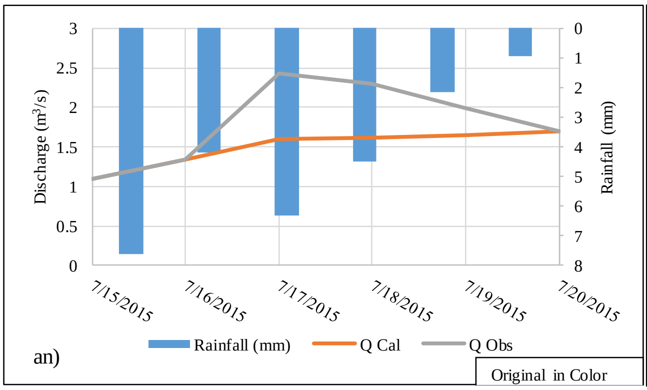
Event No.	E37	CN=	51.93
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	4.00	1.50	0.625
T_p (day)	1	1	0.000
T_b (day)	5	5	0.000
Vol (MCM)	0.70	0.49	0.306
Event MRAE		0.13	
Event RAME		0.31	



Event No.	E38	CN=	56.81
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.43	1.80	0.259
T_p (day)	2	2	0.000
T_b (day)	5	5	0.000
Vol (MCM)	0.93	0.87	0.066
Event MRAE		0.05	
Event RAME		0.07	



Event No.	E39	CN=	47.76
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.43	1.55	0.363
T_p (day)	1	1	0.000
T_b (day)	5	5	0.000
Vol (MCM)	0.70	0.62	0.115
Event MRAE		0.08	
Event RAME		0.12	



Event No.	E40	CN=	55.10
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.42	1.69	0.302
T_p (day)	5	2	0.600
T_b (day)	2	5	1.500
Vol (MCM)	0.94	0.78	0.169
Event MRAE		0.13	
Event RAME		0.17	

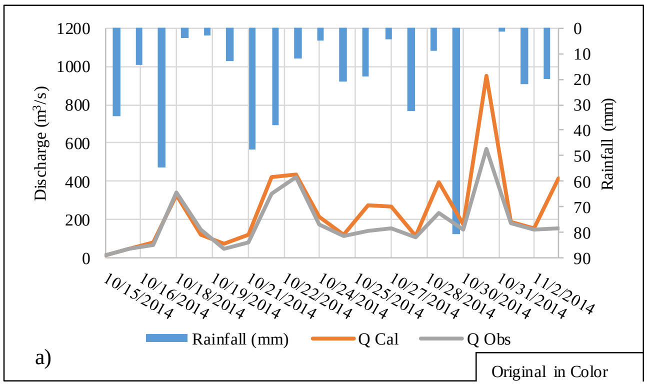
Figure L-10 (ak-an): Calculated and observed streamflow graphs of events: E37-E40

Appendix M: Evaluation of streamflow estimation on verification events

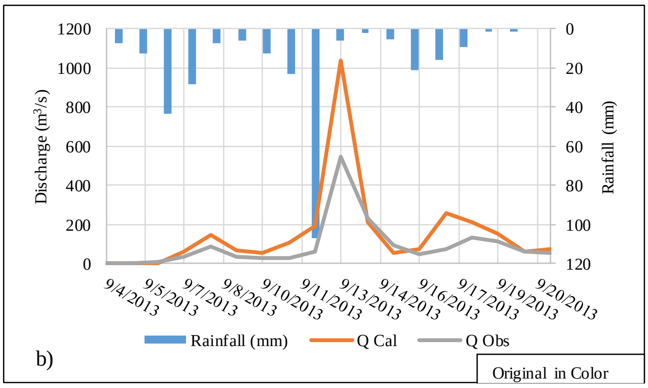
Table M-1: Details of streamflow estimation on verification events

Event ID	From	To	Total RF (mm)	CN	Qp (m3/s)		Tp (day)		Tb (day)		Vol (MMC)		Error (RAE)				Event MRAE	Event RAEM
					Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Qp	Tp	Tb	Vol		
E21	10/15/2014	11/3/2014	434.6	60.04	952.8	567.4	16	16	5	5	423.8	312.3	0.68	0.00	0.00	0.36	0.35	0.38
E22	9/4/2013	9/21/2013	308.7	60.04	1040.0	544.2	9	9	10	10	239.2	142.5	0.91	0.00	0.00	0.68	0.76	0.75
E23	11/29/2015	12/12/2015	206.7	60.04	398.5	361.9	10	10	5	5	159.7	155.5	0.10	0.00	0.00	0.03	0.26	0.31
E24	5/12/2013	5/17/2013	74.6	60.04	111.6	264.4	2	2	5	5	16.7	34.9	0.58	0.00	0.00	0.52	0.27	0.52
E25	4/8/2013	4/17/2013	102.5	60.04	213.9	185.1	6	6	5	5	32.3	35.8	0.16	0.00	0.00	0.10	0.36	0.33
E26	11/23/2012	12/1/2012	87.6	60.04	155.4	166.8	5	5	5	5	27.9	45.8	0.07	0.00	0.00	0.39	0.42	0.39
E27	10/29/2016	11/5/2016	116.8	60.04	161.6	85.2	5	4	4	5	40.6	22.1	0.90	0.20	0.25	0.84	0.65	0.89
E28	7/6/2012	7/13/2012	56.9	60.04	41.1	61.7	5	4	4	5	8.0	12.9	0.33	0.20	0.25	0.38	0.20	0.50
E29	2/23/2015	3/8/2015	145.2	60.04	306.2	42.4	10	4	5	11	61.4	26.3	6.23	0.60	1.20	1.33	1.14	1.59
E30	5/31/2015	6/9/2015	38.1	60.04	7.0	35.4	9	6	2	5	3.5	9.7	0.80	0.33	1.50	0.63	0.44	0.63
E31	2/12/2013	2/20/2013	49.4	60.04	18.3	20.2	8	5	2	5	5.1	8.7	0.10	0.38	1.50	0.41	0.49	0.62
E32	6/18/2014	6/24/2014	29.5	60.04	7.1	19.7	1	3	7	5	2.9	6.4	0.64	2.00	0.29	0.54	0.28	0.38
E33	2/14/2012	2/22/2012	53.4	60.04	28.9	15.8	4	2	6	8	4.7	7.0	0.83	0.50	0.33	0.32	0.53	0.68
E34	8/16/2017	8/23/2017	54.9	60.04	22.0	14.4	4	4	5	5	6.8	5.1	0.53	0.00	0.00	0.35	0.34	0.35
E35	2/27/2012	3/4/2012	19.2	60.04	2.8	8.0	6	3	2	5	1.1	2.2	0.65	0.50	1.50	0.51	0.34	0.51
E36	7/9/2014	7/15/2014	22.5	60.04	3.6	9.5	1	3	7	5	1.9	3.1	0.62	2.00	0.29	0.39	0.29	0.39
E37	2/15/2016	2/19/2016	26.0	60.04	1.5	4.0	1	1	5	5	0.5	0.7	0.63	0.00	0.00	0.31	0.13	0.31
E38	9/20/2012	9/25/2012	24.2	60.04	1.8	2.4	2	2	5	5	0.9	0.9	0.26	0.00	0.00	0.07	0.05	0.07
E39	10/12/2016	10/16/2016	31.8	60.04	1.5	2.4	1	1	5	5	0.6	0.7	0.36	0.00	0.00	0.12	0.08	0.12
E40	7/15/2015	7/20/2015	25.7	60.04	1.7	2.4	5	2	2	5	0.8	0.9	0.30	0.60	1.50	0.17	0.13	0.17
												Max	***6.23***	***2.00***	***1.50***	***1.33***	***1.14***	***1.59***
												Min	***0.07***	***0.00***	***0.00***	***0.03***	***0.05***	***0.07***
												Average	***0.78***	***0.37***	***0.43***	***0.42***	***0.37***	***0.49***

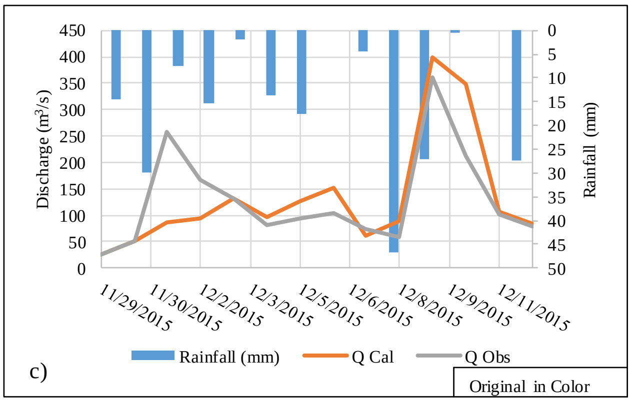
Appendix N: Verification graphs for 20 events (E21-E40)



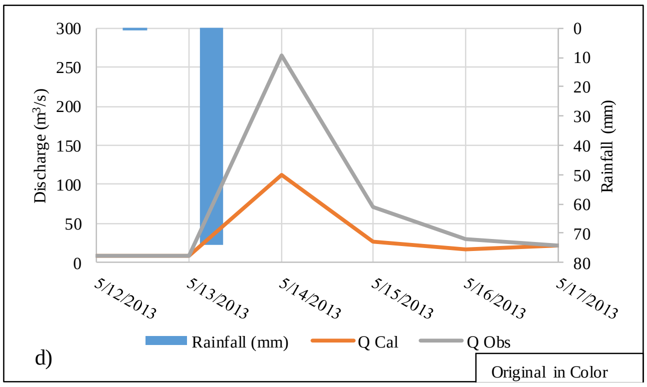
Event No.	E21	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	567.4	952.8	0.679
T_p (day)	16	16	0.000
T_b (day)	5	5	0.000
Vol (MCM)	312.3	423.8	0.357
Event MRAE		0.35	
Event RAME		0.38	



Event No.	E22	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	544.2	1040.0	0.911
T_p (day)	9	9	0.000
T_b (day)	10	10	0.000
Vol (MCM)	142.5	239.2	0.679
Event MRAE		0.76	
Event RAME		0.75	

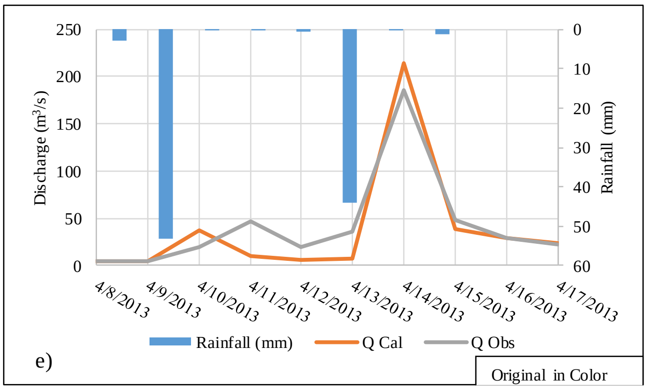


Event No.	E23	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	361.92	398.48	0.101
T_p (day)	10	10	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	155.49	159.68	0.027
Event MRAE		0.26	
Event RAME		0.31	

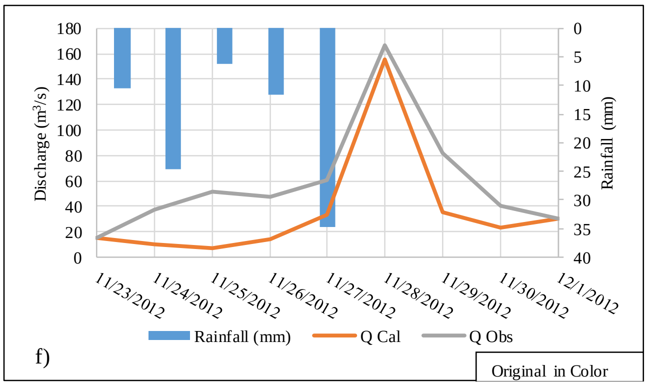


Event No.	E24	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	264.40	111.63	0.578
T_p (day)	2	2	0.000
T_b (day)	5	5	0.000
Vol (MCM)	34.91	16.74	0.520
Event MRAE		0.27	
Event RAME		0.52	

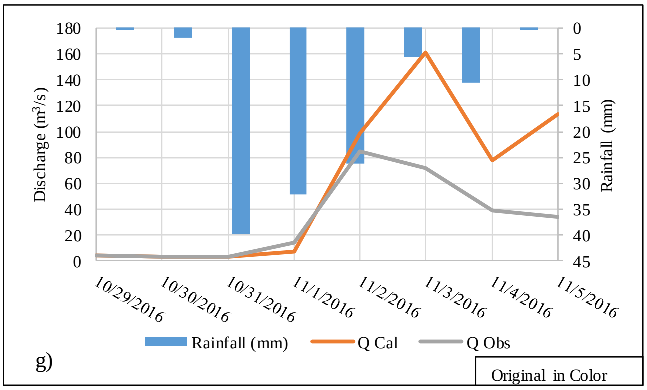
Figure N-1 (a-d): Calculated and observed streamflow graphs of events: E1-E4



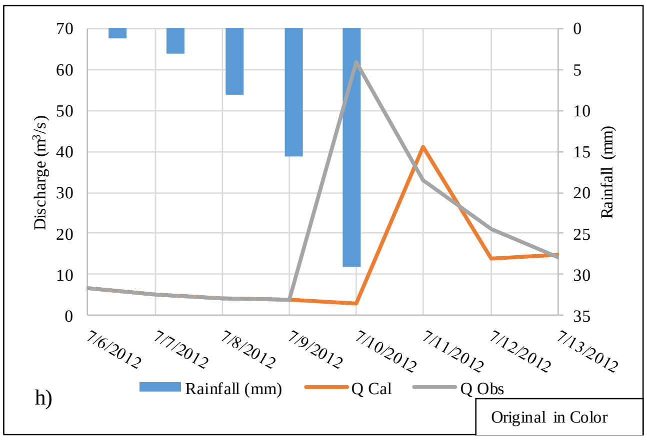
Event No.	E25	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	185.08	213.94	0.156
T_p (day)	6	6	0.000
T_b (day)	5	5	0.000
Vol (MCM)	35.83	32.27	0.099
Event MRAE		0.36	
Event RAME		0.33	



Event No.	E26	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	166.83	155.41	0.068
T_p (day)	5	5	0.000
T_b (day)	5	5	0.000
Vol (MCM)	45.76	27.93	0.390
Event MRAE		0.42	
Event RAME		0.39	

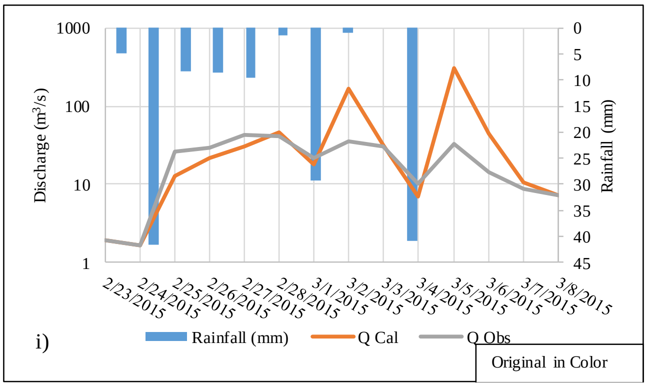


Event No.	E27	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	85.20	161.59	0.897
T_p (day)	5	4	0.200
T_b (day)	4	5	0.250
Vol (MCM)	22.07	40.65	0.842
Event MRAE		0.65	
Event RAME		0.89	

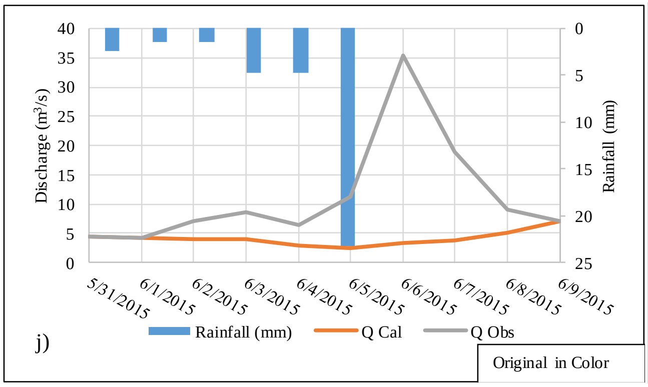


Event No.	E28	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	61.66	41.08	0.334
T_p (day)	5	4	0.200
T_b (day)	4	5	0.250
Vol (MCM)	12.94	8.00	0.381
Event MRAE		0.20	
Event RAME		0.50	

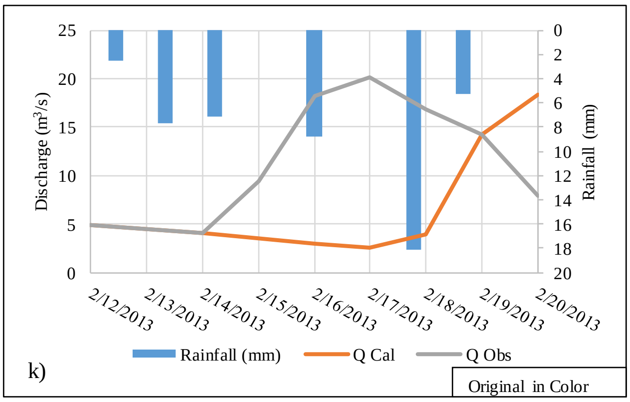
Figure N-2 (e-h): Calculated and observed streamflow graphs of events: E5-E8



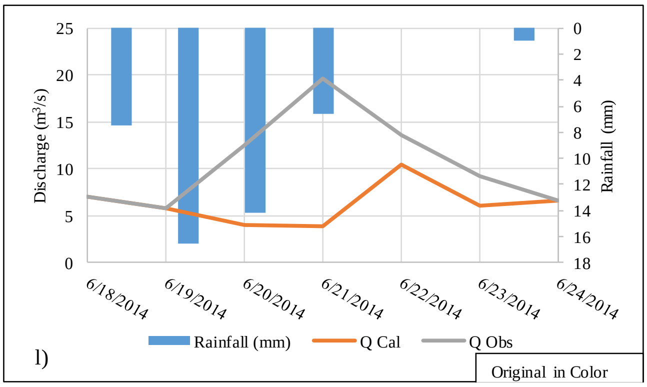
Event No.	E29	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	42.37	306.19	6.227
T_p (day)	10	4	0.600
T_b (day)	5	11	1.200
Vol (MCM)	26.30	61.37	1.333
Event MRAE		1.14	
Event RAME		1.59	



Event No.	E30	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	35.44	6.97	0.803
T_p (day)	9	6	0.333
T_b (day)	2	5	1.500
Vol (MCM)	9.70	3.54	0.635
Event MRAE		0.44	
Event RAME		0.63	

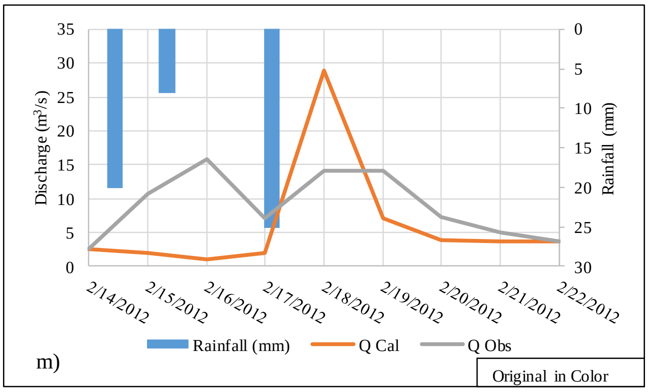


Event No.	E31	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	20.17	18.32	0.101
T_p (day)	8	5	0.375
T_b (day)	2	5	1.500
Vol (MCM)	8.66	5.091455	0.412
Event MRAE		0.49	
Event RAME		0.62	

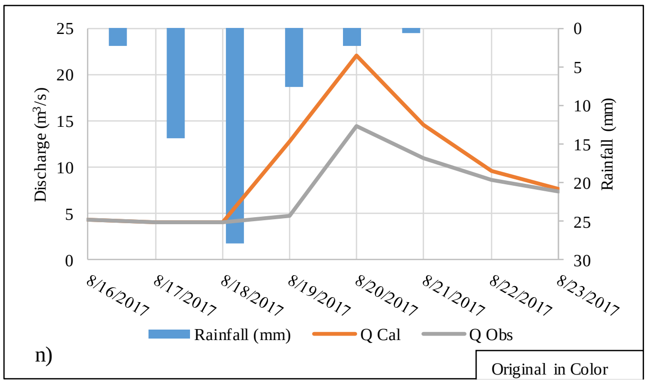


Event No.	E32	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	19.68	10.41	0.471
T_p (day)	1	3	2.000
T_b (day)	7	5	0.286
Vol (MCM)	6.44	3.79	0.410
Event MRAE		0.30	
Event RAME		0.41	

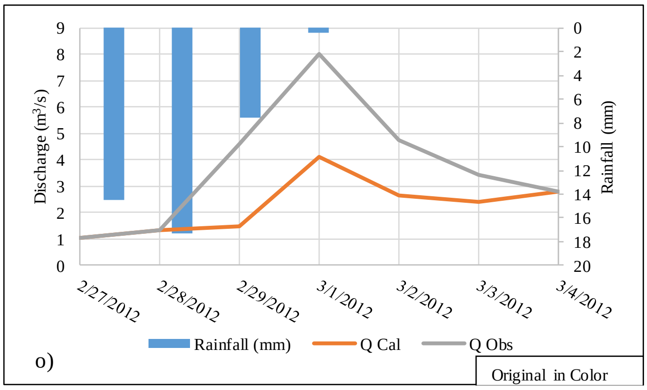
Figure N-3 (i-l): Calculated and observed streamflow graphs of events: E9-E12



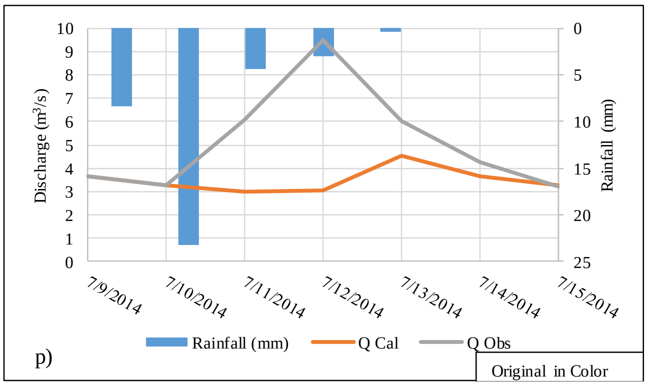
Event No.	E33	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.76	28.92	0.834
T_p (day)	4	2	0.500
T_b (day)	6	8	0.333
Vol (MCM)	6.95	4.75	0.317
Event MRAE		0.53	
Event RAME		0.68	



Event No.	E34	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	14.42	22.00	0.525
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
Vol (MCM)	5.07	6.85	0.350
Event MRAE		0.34	
Event RAME		0.35	

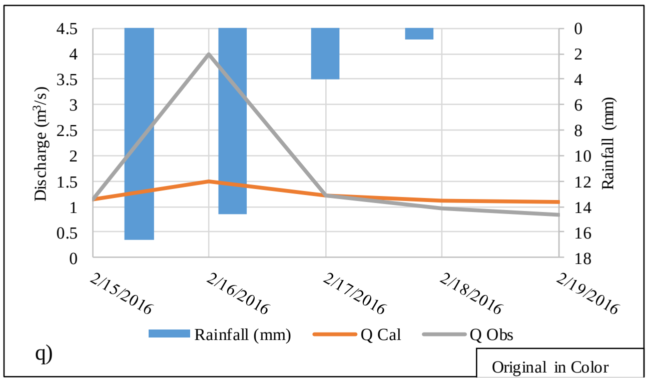


Event No.	E35	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	8.01	4.09	0.489
T_p (day)	6	3	0.500
T_b (day)	2	5	1.500
Vol (MCM)	2.24	1.36	0.391
Event MRAE		0.27	
Event RAME		0.39	

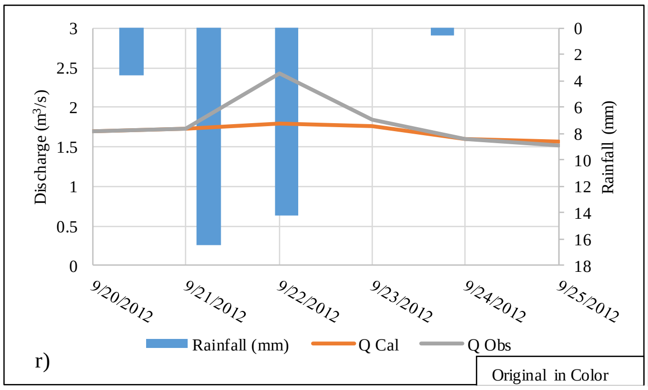


Event No.	E36	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	9.48	4.54	0.521
T_p (day)	1	3	2.000
T_b (day)	7	5	0.286
Vol (MCM)	3.11	2.11	0.321
Event MRAE		0.23	
Event RAME		0.33	

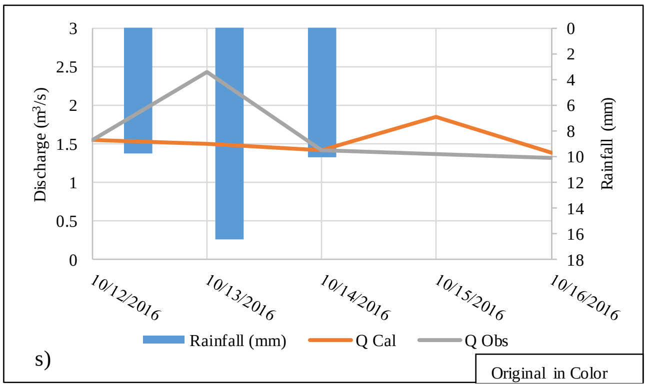
Figure N-4 (m-p): Calculated and observed streamflow graphs of events: E13-E16



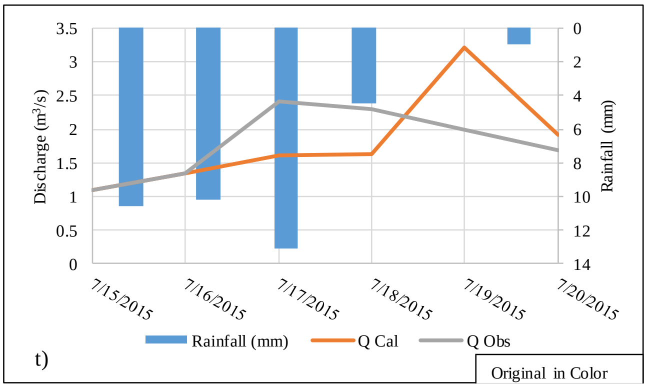
Event No.	E37	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	4.00	1.50	0.625
T_p (day)	1	1	0.000
T_b (day)	5	5	0.000
Vol (MCM)	0.70	0.52	0.256
Event MRAE		0.22	
Event RAME		0.36	



Event No.	E38	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.43	1.80	0.259
T_p (day)	2	2	0.000
T_b (day)	5	5	0.000
Vol (MCM)	0.93	0.88	0.059
Event MRAE		0.06	
Event RAME		0.07	



Event No.	E39	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.43	1.84	0.241
T_p (day)	1	1	0.000
T_b (day)	5	5	0.000
Vol (MCM)	0.70	0.67	0.047
Event MRAE		0.16	
Event RAME		0.18	



Event No.	E40	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.42	3.22	0.330
T_p (day)	5	2	0.600
T_b (day)	2	5	1.500
Vol (MCM)	0.94	0.93	0.004
Event MRAE		0.23	
Event RAME		0.27	

Figure N-5 (q-t): Calculated and observed streamflow graphs of events: E17-E20

Appendix O: Sorted verification and calibration Results

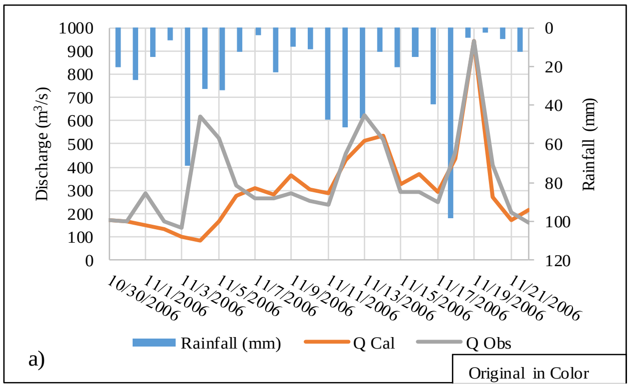
Table O-1: Sorted verification results

Event ID	From	To	Total RF (mm)	CN	Qp (m3/s)		Tp (day)		Tb (day)		Vol (MMC)		Error (RAE)				Event MRAE	Event RAEM
					Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Qp	Tp	Tb	Vol		
E38	9/20/2012	9/25/2012	24.2	60.04	1.8	2.4	2	2	5	5	0.9	0.9	0.26	0.00	0.00	0.07	0.05	0.07
E39	10/12/2016	10/16/2016	31.8	60.04	1.5	2.4	1	1	5	5	0.6	0.7	0.36	0.00	0.00	0.12	0.08	0.12
E37	2/15/2016	2/19/2016	26.0	60.04	1.5	4.0	1	1	5	5	0.5	0.7	0.63	0.00	0.00	0.31	0.13	0.31
E40	7/15/2015	7/20/2015	25.7	60.04	1.7	2.4	5	2	2	5	0.8	0.9	0.30	0.60	1.50	0.17	0.13	0.17
E28	7/6/2012	7/13/2012	56.9	60.04	41.1	61.7	5	4	4	5	8.0	12.9	0.33	0.20	0.25	0.38	0.20	0.50
E23	11/29/2015	12/12/2015	206.7	60.04	398.5	361.9	10	10	5	5	159.7	155.5	0.10	0.00	0.00	0.03	0.26	0.31
E24	5/12/2013	5/17/2013	74.6	60.04	111.6	264.4	2	2	5	5	16.7	34.9	0.58	0.00	0.00	0.52	0.27	0.52
E32	6/18/2014	6/24/2014	29.5	60.04	7.1	19.7	1	3	7	5	2.9	6.4	0.64	2.00	0.29	0.54	0.28	0.38
E36	7/9/2014	7/15/2014	22.5	60.04	3.6	9.5	1	3	7	5	1.9	3.1	0.62	2.00	0.29	0.39	0.29	0.39
E35	2/27/2012	3/4/2012	19.2	60.04	2.8	8.0	6	3	2	5	1.1	2.2	0.65	0.50	1.50	0.51	0.34	0.51
E34	8/16/2017	8/23/2017	54.9	60.04	22.0	14.4	4	4	5	5	6.8	5.1	0.53	0.00	0.00	0.35	0.34	0.35
E21	10/15/2014	11/3/2014	434.6	60.04	952.8	567.4	16	16	5	5	423.8	312.3	0.68	0.00	0.00	0.36	0.35	0.38
E25	4/8/2013	4/17/2013	102.5	60.04	213.9	185.1	6	6	5	5	32.3	35.8	0.16	0.00	0.00	0.10	0.36	0.33
E26	11/23/2012	12/1/2012	87.6	60.04	155.4	166.8	5	5	5	5	27.9	45.8	0.07	0.00	0.00	0.39	0.42	0.39
E30	5/31/2015	6/9/2015	38.1	60.04	7.0	35.4	9	6	2	5	3.5	9.7	0.80	0.33	1.50	0.63	0.44	0.63
E31	2/12/2013	2/20/2013	49.4	60.04	18.3	20.2	8	5	2	5	5.1	8.7	0.10	0.38	1.50	0.41	0.49	0.62
E33	2/14/2012	2/22/2012	53.4	60.04	28.9	15.8	4	2	6	8	4.7	7.0	0.83	0.50	0.33	0.32	0.53	0.68
E27	10/29/2016	11/5/2016	116.8	60.04	161.6	85.2	5	4	4	5	40.6	22.1	0.90	0.20	0.25	0.84	0.65	0.89
E22	9/4/2013	9/21/2013	308.7	60.04	1040.0	544.2	9	9	10	10	239.2	142.5	0.91	0.00	0.00	0.68	0.76	0.75
E29	2/23/2015	3/8/2015	145.2	60.04	306.2	42.4	10	4	5	11	61.4	26.3	6.23	0.60	1.20	1.33	1.14	1.59
												Max	***6.23***	***2.00***	***1.50***	***1.33***	***1.14***	***1.59***
												Min	***0.07***	***0.00***	***0.00***	***0.03***	***0.05***	***0.07***
												Average	***0.78***	***0.37***	***0.43***	***0.42***	***0.37***	***0.49***

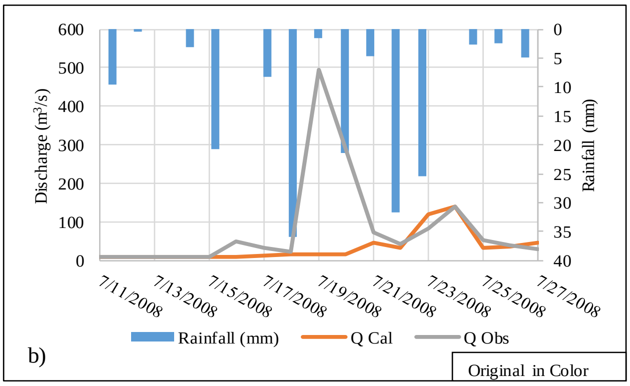
Table O-2: Sorted Calibration results

Event ID	From	To	Total RF (mm)	CN	Qp (m3/s)		Tp (day)		Tb (day)		Vol (MMC)		Error (RAE)				Event MRAE	Event RAEM
					Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Qp	Tp	Tb	Vol		
E6	12/16/2006	12/23/2006	32.5	89.61	188.3	188.3	4	4	5	5	34.4	35.5	0.00	0.00	0.00	0.03	0.05	0.04
E9	1/29/2005	2/5/2005	96.5	54.74	135.2	117.7	4	4	5	5	21.5	20.6	0.13	0.00	0.00	0.04	0.06	0.11
E17	7/31/2007	8/7/2007	14.7	85.16	15.8	15.8	4	4	5	5	6.0	6.6	0.00	0.00	0.00	0.09	0.08	0.09
E11	11/19/2007	11/26/2007	39.6	79.01	91.0	70.9	4	4	5	5	22.5	21.5	0.22	0.00	0.00	0.05	0.11	0.15
E20	3/20/2011	3/26/2011	24.0	87.29	28.7	20.8	4	3	4	5	8.9	7.9	0.28	0.25	0.25	0.13	0.14	0.19
E14	3/3/2011	3/9/2011	48.0	65.74	41.8	41.8	3	3	5	5	10.7	11.6	0.00	0.00	0.00	0.08	0.15	0.19
E16	12/15/2008	12/19/2008	35.0	65.15	23.5	26.5	3	1	3	4	8.0	9.6	0.13	0.67	0.33	0.16	0.16	0.18
E5	4/24/2008	5/2/2008	115.9	56.52	220.3	233.0	4	5	6	5	58.3	77.6	0.06	0.20	0.20	0.25	0.17	0.25
E12	8/20/2010	8/25/2010	40.6	72.48	35.3	54.5	2	2	5	5	8.7	12.1	0.54	0.00	0.00	0.28	0.20	0.29
E15	3/29/2006	4/4/2006	36.6	66.75	20.3	25.9	4	3	4	5	6.8	9.5	0.27	0.25	0.25	0.29	0.22	0.29
E1	10/30/2006	11/22/2006	621.6	28.50	944.6	944.6	20	20	5	5	629.3	717.8	0.00	0.00	0.00	0.12	0.22	0.23
E8	6/19/2006	6/27/2006	195.0	45.63	305.8	156.9	4	5	6	5	74.5	65.3	0.49	0.25	0.17	0.14	0.23	0.32
E18	8/15/2011	8/20/2011	13.6	81.87	4.9	15.3	4	2	3	5	1.8	3.2	2.10	0.50	0.67	0.43	0.23	0.44
E10	6/5/2010	6/15/2010	108.7	50.42	107.2	96.7	7	7	5	5	30.2	35.1	0.10	0.00	0.00	0.14	0.26	0.23
E3	5/22/2011	6/5/2011	209.0	42.03	236.8	422.4	11	5	5	11	96.6	150.1	0.78	0.55	1.20	0.36	0.26	0.45
E2	7/11/2008	7/27/2008	172.6	41.84	138.5	494.3	12	8	6	10	48.4	119.8	2.57	0.50	0.40	0.60	0.32	0.67
E19	3/12/2007	3/20/2007	61.9	50.99	11.1	11.1	5	5	5	5	2.4	4.0	0.00	0.00	0.00	0.39	0.35	0.39
E7	1/4/2006	1/17/2006	84.3	50.20	57.5	158.7	10	10	5	5	24.8	48.3	1.76	0.00	0.00	0.49	0.36	0.49
E4	9/27/2010	10/10/2010	251.9	39.55	206.8	312.0	12	5	3	10	122.0	142.8	0.51	0.58	2.33	0.15	0.42	0.40
E13	4/15/2006	4/23/2006	85.7	47.26	32.3	53.0	4	2	6	8	10.2	22.4	0.64	0.50	0.33	0.54	0.43	0.56
												Max	***2.57***	***0.67***	***2.33***	***0.60***	***0.43***	***0.67***
												Min	***0.00***	***0.00***	***0.00***	***0.03***	***0.05***	***0.04***
												Average	***0.53***	***0.21***	***0.31***	***0.24***	***0.22***	***0.30***

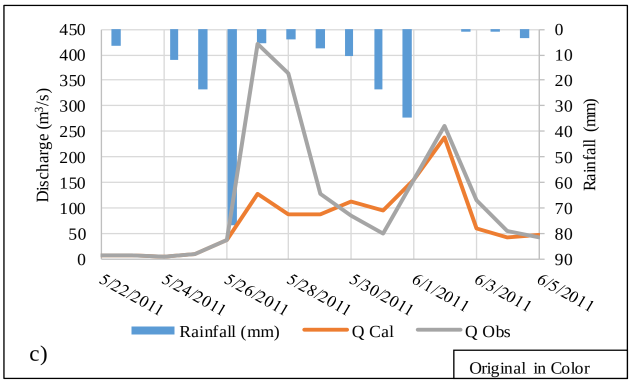
Appendix P: Calibration graphs for 20 events (E1-E20)



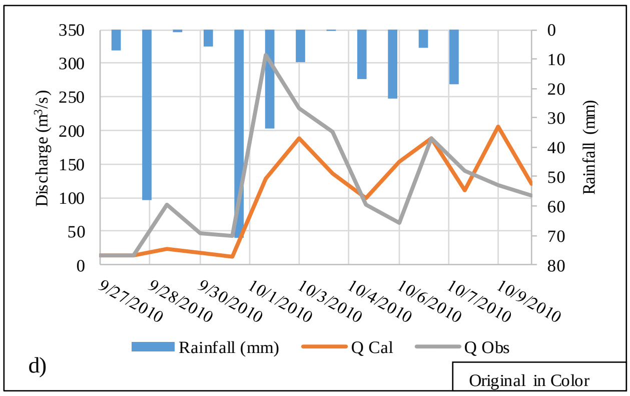
Event No.	E1	CN=	28.50
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	944.58	944.58	0.000
T_p (day)	20	20	0.000
T_b (day)	5	5	0.000
Vol (MCM)	717.75	629.32	0.123
Event MRAE		0.22	
Event RAME		0.23	



Event No.	E2	CN=	41.84
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	494.26	138.50	2.569
T_p (day)	8	12	0.500
T_b (day)	10	6	0.400
SF Vol (MCM)	119.8	48.4	0.596
Event MRAE		0.32	
Event RAME		0.67	

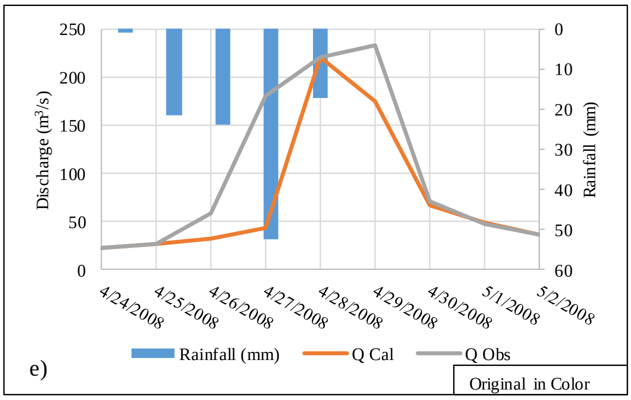


Event No.	E3	CN=	42.03
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	422.39	236.80	0.784
T_p (day)	11	5	0.545
T_b (day)	5	11	1.200
Vol (MCM)	150.09	96.58	0.357
Event MRAE		0.26	
Event RAME		0.45	

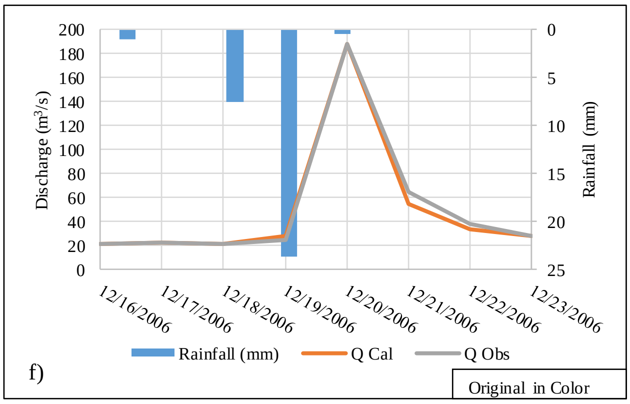


Event No.	E4	CN=	39.55
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	312.05	206.79	0.509
T_p (day)	12	5	0.583
T_b (day)	3	10	2.333
SF Vol (MCM)	142.81	121.96	0.146
Event MRAE		0.42	
Event RAME		0.40	

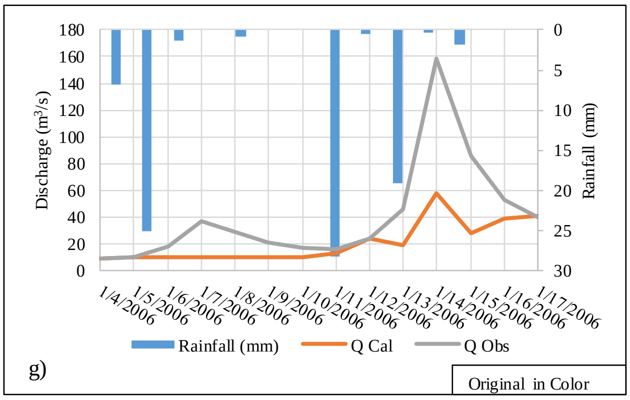
Figure P-1 (a-d): Calculated and observed streamflow graphs of events: E1-E4



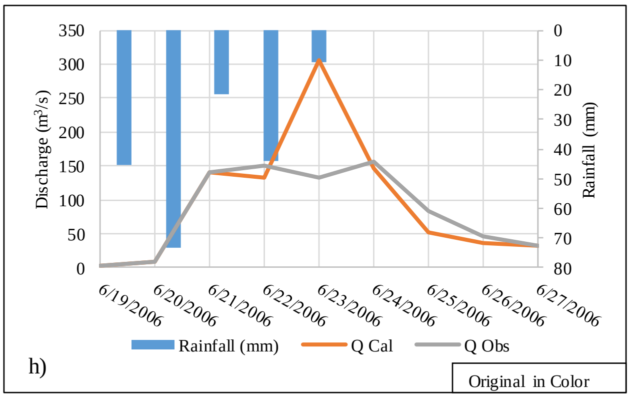
Event No.	E5	CN=	56.52
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	232.99	220.30	0.058
T_p (day)	5	4	0.200
T_b (day)	5	6	0.200
SF Vol (MCM)	77.60	58.32789	0.248
Event MRAE		0.17	
Event RAME		0.25	



Event No.	E6	CN=	89.61
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	188.29	188.29	0.000
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	35.47	34.44	0.029
Event MRAE		0.05	
Event RAME		0.04	

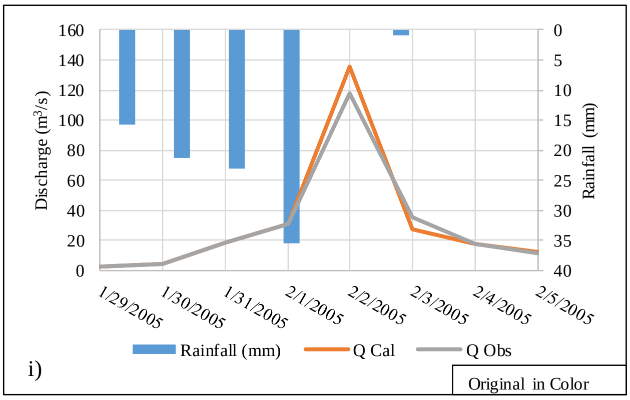


Event No.	E7	CN=	50.20
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	158.68	57.50	1.760
T_p (day)	10	10	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	48.29	24.80	0.487
Event MRAE		0.36	
Event RAME		0.49	

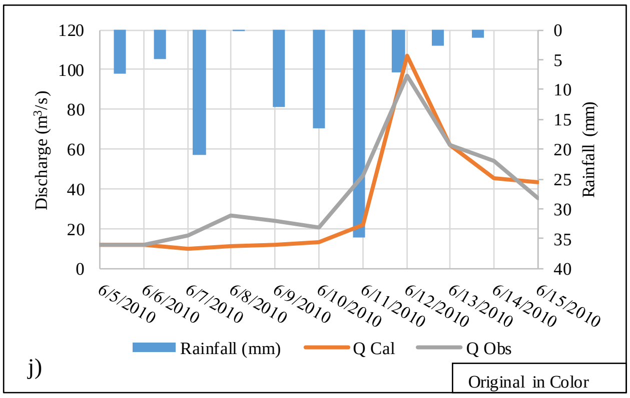


Event No.	E8	CN=	45.63
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	156.88	305.80	0.487
T_p (day)	4	5	0.250
T_b (day)	6	5	0.167
SF Vol (MCM)	65.34	74.48	0.140
Event MRAE		0.23	
Event RAME		0.32	

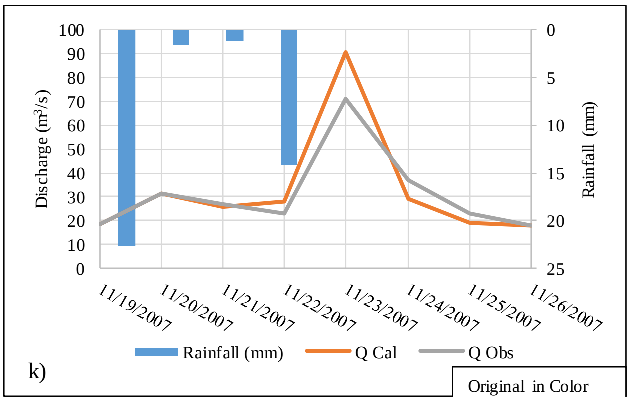
Figure P-2 (e-h): Calculated and observed streamflow graphs of events: E5-E8



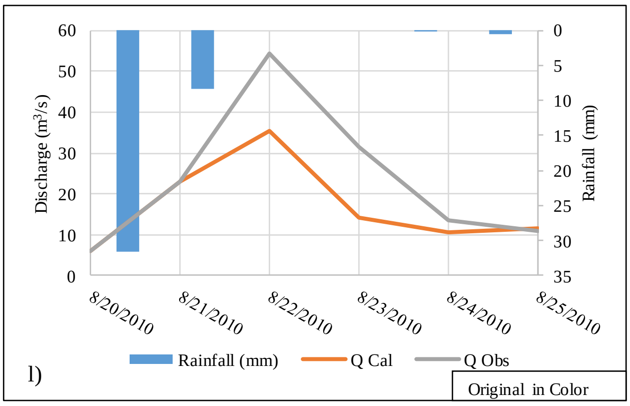
Event No.	E9	CN=	54.74
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	117.69	135.17	0.129
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
Vol (MCM)	20.59	21.49	0.044
Event MRAE		0.06	
Event RAME		0.11	



Event No.	E10	CN=	50.42
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	96.73	107.17	0.097
T_p (day)	7	7	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	35.08	30.20	0.139
Event MRAE		0.26	
Event RAME		0.23	

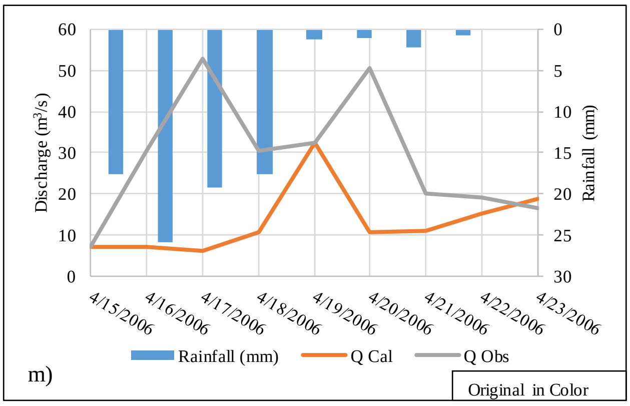


Event No.	E11	CN=	79.01
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	70.93	91.00	0.221
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
Vol (MCM)	21.50	22.53	0.048
Event MRAE		0.11	
Event RAME		0.15	

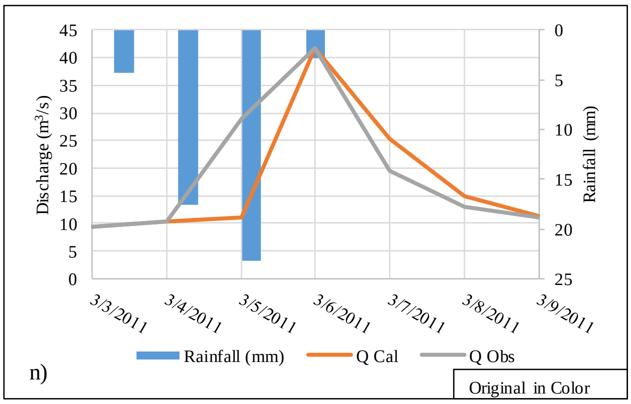


Event No.	E12	CN=	72.48
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	54.47	35.32	0.542
T_p (day)	2	2	0.000
T_b (day)	5	5	0.000
Vol (MCM)	12.06	8.72	0.277
Event MRAE		0.20	
Event RAME		0.29	

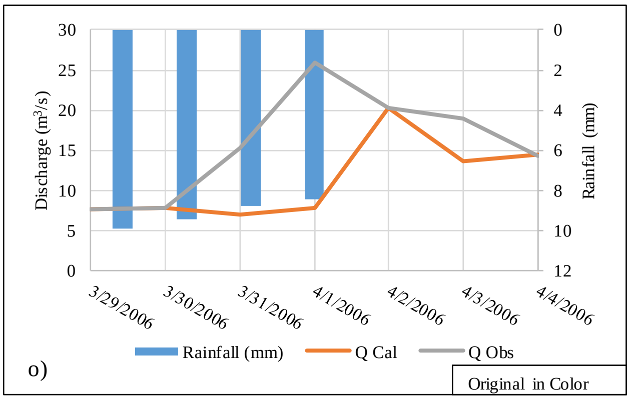
Figure P-3 (i-l): Calculated and observed streamflow graphs of events: E9-E12



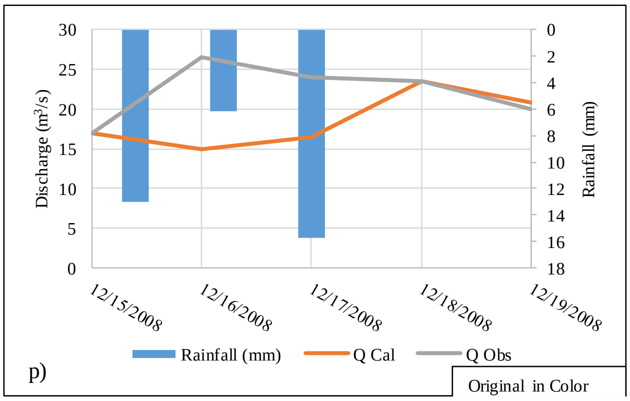
Event No.	E13	CN=	47.26
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	53.00	32.29	0.641
T_p (day)	4	2	0.500
T_b (day)	6	8	0.333
SF Vol (MCM)	22.43	10.25	0.543
Event MRAE		0.43	
Event RAME		0.56	



Event No.	E14	CN=	65.74
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	41.81	41.81	0.000
T_p (day)	3	3	0.000
T_b (day)	5	5	0.000
Vol (MCM)	11.59	10.70	0.077
Event MRAE		0.15	
Event RAME		0.19	

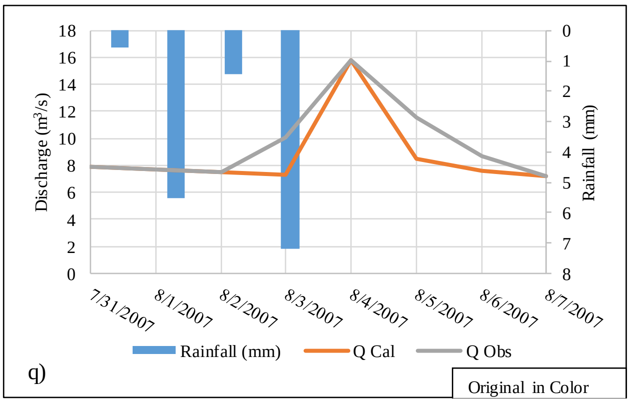


Event No.	E15	CN=	66.75
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	25.87	20.30	0.274
T_p (day)	4	3	0.250
T_b (day)	4	5	0.250
SF Vol (MCM)	9.50	6.77	0.288
Event MRAE		0.22	
Event RAME		0.29	

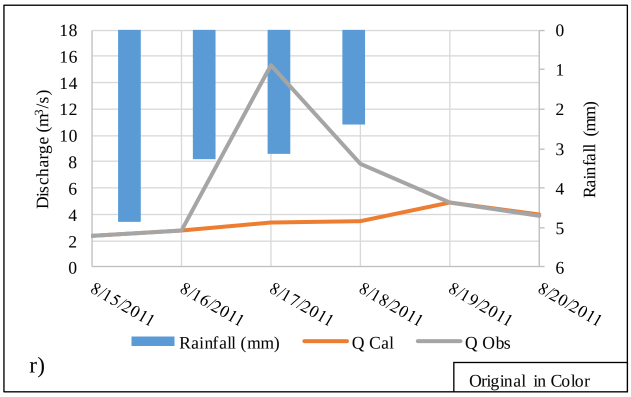


Event No.	E16	CN=	65.15
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	26.50	23.50	0.128
T_p (day)	3	1	0.667
T_b (day)	3	4	0.333
SF Vol (MCM)	9.582	8.006	0.164
Event MRAE		0.16	
Event RAME		0.18	

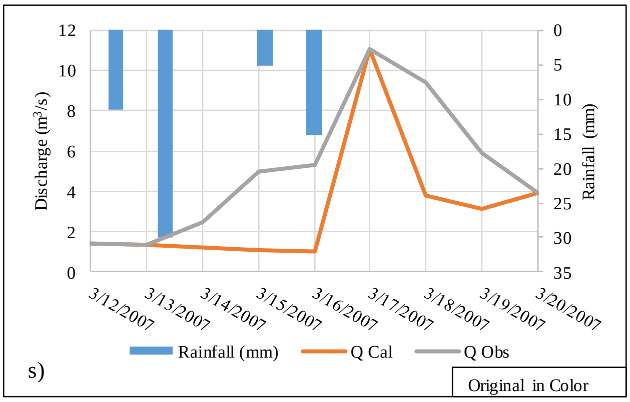
Figure P-4 (m-p): Calculated and observed streamflow graphs of events: E13-E16



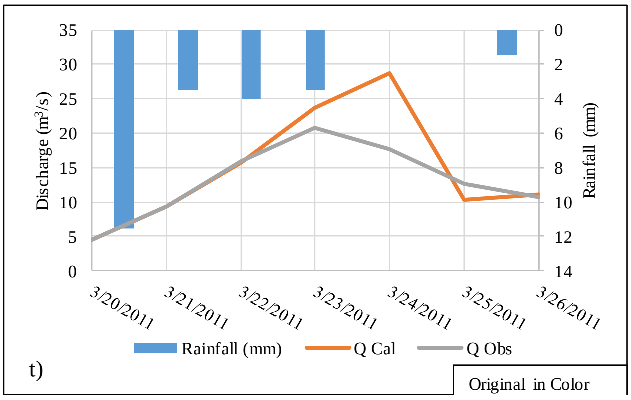
Event No.	E17	CN=	85.16
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.76	15.76	0.000
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	6.61	6.00	0.092
Event MRAE		0.08	
Event RAME		0.09	



Event No.	E18	CN=	81.87
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.32	4.94	2.100
T_p (day)	4	2	0.500
T_b (day)	3	5	0.667
SF Vol (MCM)	3.21	1.82	0.434
Event MRAE		0.23	
Event RAME		0.44	



Event No.	E19	CN=	50.99
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	11.07	11.07	0.000
T_p (day)	5	5	0.000
T_b (day)	5	5	0.000
Vol (MCM)	3.96	2.42	0.389
Event MRAE		0.35	
Event RAME		0.39	



Event No.	E20	CN=	87.29
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	20.81	28.74	0.276
T_p (day)	4	3	0.250
T_b (day)	4	5	0.250
Vol (MCM)	7.93	8.94	0.127
Event MRAE		0.14	
Event RAME		0.19	

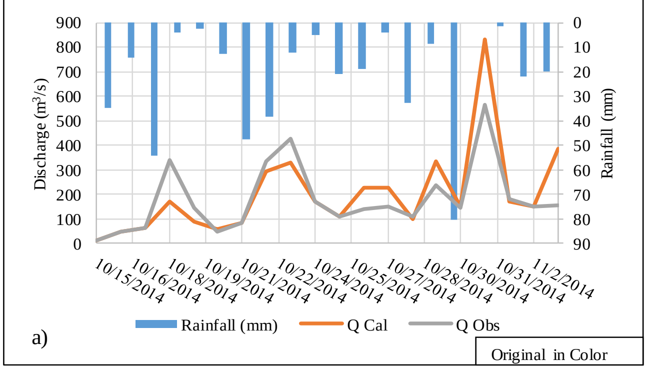
Figure P-5 (q-t): Calculated and observed streamflow graphs of events: E17-E20

Appendix Q: Evaluation of streamflow estimation on verification data (E21-E40) with optimized CN

Table Q-1: Details of streamflow estimation on verification data (E21-E40) with optimized CN

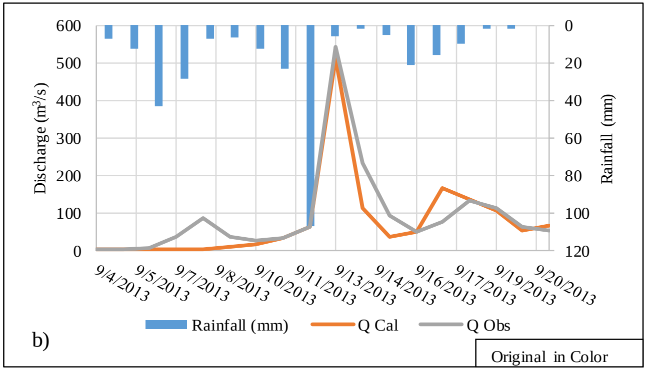
Event ID	From	To	Total RF (mm)	CN	Qp (m3/s)		Tp (day)		Tb (day)		Vol (MMC)		Error (RAE)				Event MRAE	Event RAEM
					Cal	**Obs**	**Cal**	**Obs**	**Cal**	**Obs**	**Cal**	**Obs**	**Qp**	**Tp**	**Tb**	**Vol**		
E21	10/15/2014	11/3/2014	434.6	47.99	833.2	567.4	16	16	5	5	346.4	312.3	0.47	0.00	0.00	0.11	0.26	0.32
E22	9/4/2013	9/21/2013	308.7	37.47	511.4	544.2	9	9	10	10	119.0	142.5	0.06	0.00	0.00	0.16	0.36	0.30
E23	11/29/2015	12/12/2015	206.7	50.48	296.1	361.9	10	10	5	5	129.9	155.5	0.18	0.00	0.00	0.16	0.20	0.28
E24	5/12/2013	5/17/2013	74.6	72.11	264.4	264.4	2	2	5	5	32.0	34.9	0.00	0.00	0.00	0.08	0.11	0.08
E25	4/8/2013	4/17/2013	102.5	56.09	171.5	185.1	6	6	5	5	26.0	35.8	0.07	0.00	0.00	0.27	0.29	0.28
E26	11/23/2012	12/1/2012	87.6	75.50	302.4	166.8	5	5	5	5	53.8	45.8	0.81	0.00	0.00	0.18	0.30	0.44
E27	10/29/2016	11/5/2016	116.8	43.15	66.6	85.2	7	4	2	5	14.4	22.1	0.22	0.43	1.50	0.35	0.39	0.60
E28	7/6/2012	7/13/2012	56.9	58.49	33.1	61.7	5	4	4	5	7.2	12.9	0.46	0.20	0.25	0.44	0.17	0.45
E29	2/23/2015	3/8/2015	145.2	32.06	32.8	42.4	10	4	5	11	7.2	26.3	0.23	0.60	1.20	0.73	0.55	0.73
E30	5/31/2015	6/9/2015	38.1	71.26	35.4	35.4	6	6	5	5	6.7	9.7	0.00	0.00	0.00	0.30	0.32	0.30
E31	2/12/2013	2/20/2013	49.4	60.04	18.3	20.2	8	5	2	5	5.1	8.7	0.10	0.38	1.50	0.41	0.49	0.62
E32	6/18/2014	6/24/2014	29.5	74.00	14.7	19.7	4	3	4	5	4.4	6.4	0.25	0.25	0.25	0.32	0.25	0.35
E33	2/14/2012	2/22/2012	53.4	56.18	14.1	15.8	4	2	6	8	3.3	7.0	0.10	0.50	0.33	0.53	0.43	0.53
E34	8/16/2017	8/23/2017	54.9	55.73	13.4	14.4	4	4	5	5	5.1	5.1	0.07	0.00	0.00	0.00	0.04	0.04
E35	2/27/2012	3/4/2012	19.2	78.00	4.9	8.0	2	3	6	5	1.5	2.2	0.39	0.50	0.17	0.33	0.22	0.35
E36	7/9/2014	7/15/2014	22.5	74.00	5.5	9.5	2	3	6	5	2.2	3.1	0.42	0.50	0.17	0.30	0.21	0.30
E37	2/15/2016	2/19/2016	26.0	67.00	1.5	4.0	1	1	5	5	0.5	0.7	0.63	0.00	0.00	0.29	0.15	0.32
E38	9/20/2012	9/25/2012	24.2	70.00	2.0	2.43	4	2	3	5	0.9	0.9	0.16	0.50	0.67	0.00	0.13	0.14
E39	10/12/2016	10/16/2016	31.8	62.50	1.5	2.43	1	1	5	5	0.6	0.7	0.36	0.00	0.00	0.09	0.10	0.14
E40	7/15/2015	7/20/2015	25.7	69.00	2.1	2.42	5	2	2	5	0.8	0.9	0.13	0.60	1.50	0.13	0.18	0.21
			Average CN	**60.55**								**Max**	***0.81***	***0.60***	***1.50***	***0.73***	***0.55***	***0.73***
												Min	***0.00***	***0.00***	***0.00***	***0.00***	***0.04***	***0.04***
												Average	***0.26***	***0.22***	***0.38***	***0.26***	***0.26***	***0.34***

Appendix R: Verification graphs with optimized CN values (E21-E40)



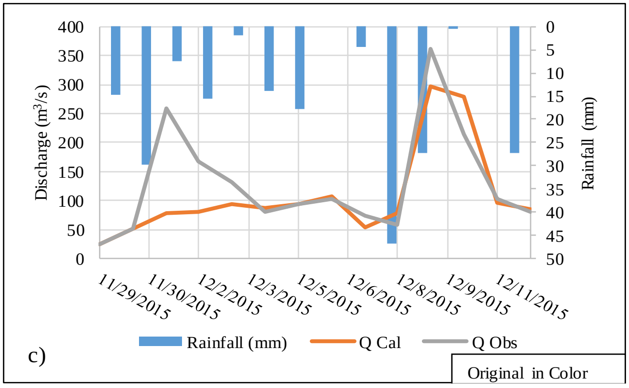
a)

Event No.	E21	CN=	47.99
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	567.4	833.2	0.469
T_p (day)	16	16	0.000
T_b (day)	5	5	0.000
Vol (MCM)	312.3	346.4	0.109
Event MRAE		0.26	
Event RAME		0.32	



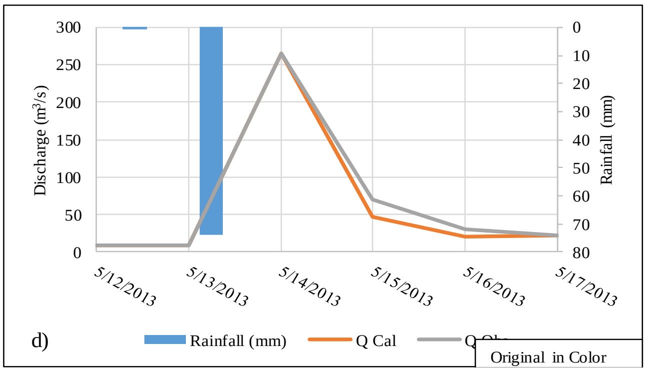
b)

Event No.	E22	CN=	37.47
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	544.2	511.4	0.060
T_p (day)	9	9	0.000
T_b (day)	10	10	0.000
Vol (MCM)	142.5	119.0	0.165
Event MRAE		0.36	
Event RAME		0.30	



c)

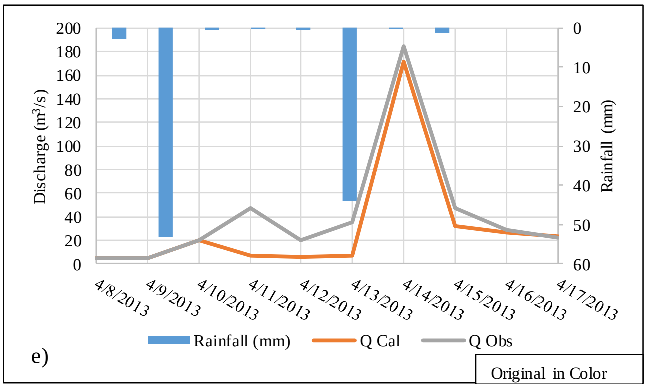
Event No.	E23	CN=	50.48
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	361.92	296.13	0.182
T_p (day)	10	10	0.000
T_b (day)	5	5	0.000
SF Vol (MCM)	155.49	129.85	0.165
Event MRAE		0.20	
Event RAME		0.28	



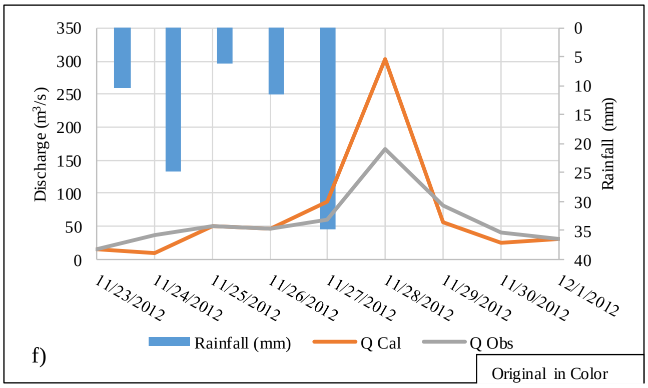
d)

Event No.	E24	CN=	72.11
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	264.40	264.40	0.000
T_p (day)	2	2	0.000
T_b (day)	5	5	0.000
Vol (MCM)	34.91	32.00	0.083
Event MRAE		0.11	
Event RAME		0.08	

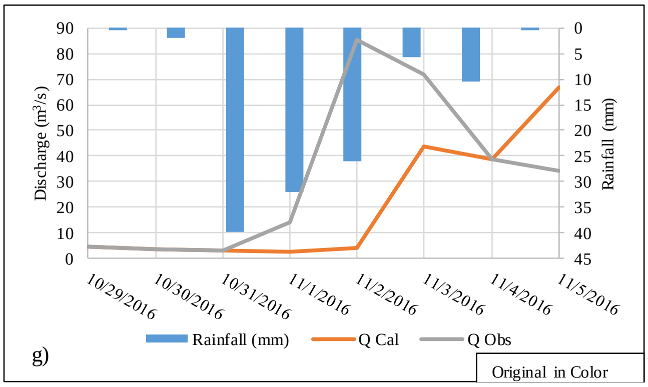
Figure R-1 (a-d): Calculated and observed streamflow graphs of events: E1-E4



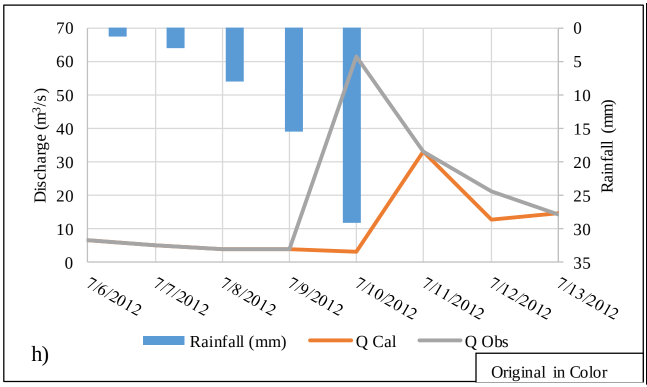
Event No.	E25	CN=	56.09
Description	Observed	Calculated	RAE
Q_p (m^3/s)	185.08	171.47	0.074
T_p (day)	6	6	0.000
T_b (day)	5	5	0.000
Vol (MCM)	35.83	26.04	0.273
Event MRAE		0.29	
Event RAME		0.28	



Event No.	E26	CN=	75.50
Description	Observed	Calculated	RAE
Q_p (m^3/s)	166.83	302.42	0.813
T_p (day)	5	5	0.000
T_b (day)	5	5	0.000
Vol (MCM)	45.76	53.77	0.175
Event MRAE		0.30	
Event RAME		0.44	

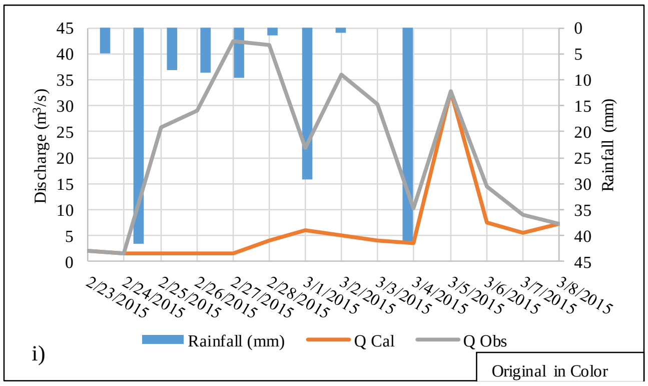


Event No.	E27	CN=	43.15
Description	Observed	Calculated	RAE
Q_p (m^3/s)	85.20	66.62	0.218
T_p (day)	7	4	0.429
T_b (day)	2	5	1.500
Vol (MCM)	22.07	14.39	0.348
Event MRAE		0.39	
Event RAME		0.60	

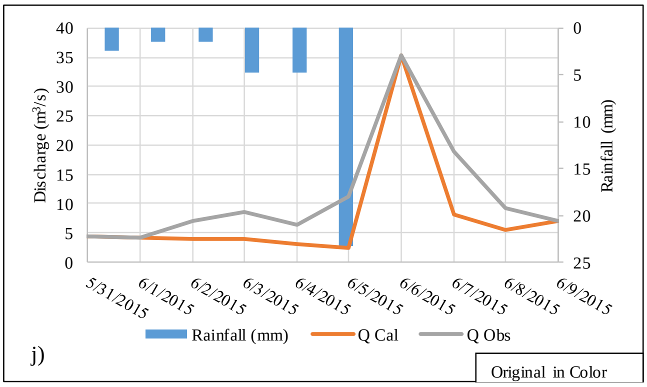


Event No.	E28	CN=	58.49
Description	Observed	Calculated	RAE
Q_p (m^3/s)	61.66	33.11	0.463
T_p (day)	5	4	0.200
T_b (day)	4	5	0.250
Vol (MCM)	12.94	7.21	0.443
Event MRAE		0.17	
Event RAME		0.45	

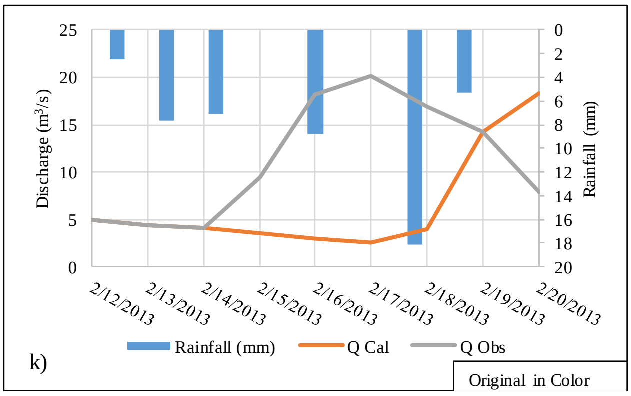
Figure R-2 (e-h): Calculated and observed streamflow graphs of events: E5-E8



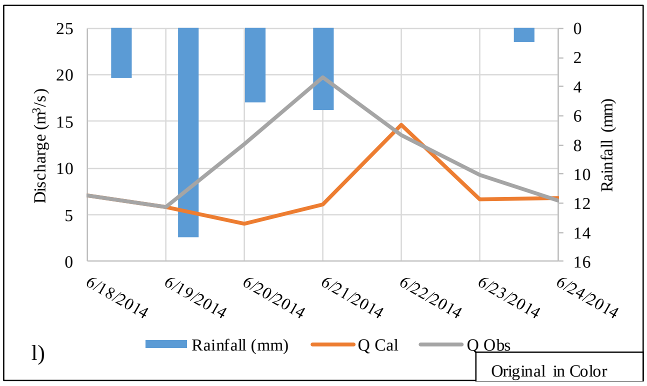
Event No.	E29	CN=	32.06
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	42.37	32.78	0.226
T_p (day)	10	4	0.600
T_b (day)	5	11	1.200
Vol (MCM)	26.30	7.22	0.726
Event MRAE		0.55	
Event RAME		0.73	



Event No.	E30	CN=	71.26
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	35.44	35.44	0.000
T_p (day)	6	6	0.000
T_b (day)	5	5	0.000
Vol (MCM)	9.70	6.75	0.304
Event MRAE		0.32	
Event RAME		0.30	

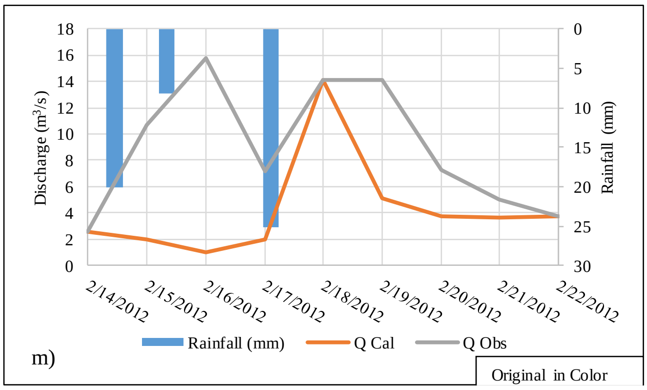


Event No.	31	CN=	60.04
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	20.17	18.32	0.101
T_p (day)	8	5	0.375
T_b (day)	2	5	1.500
Vol (MCM)	8.66	5.091455	0.412
Event MRAE		0.49	
Event RAME		0.62	

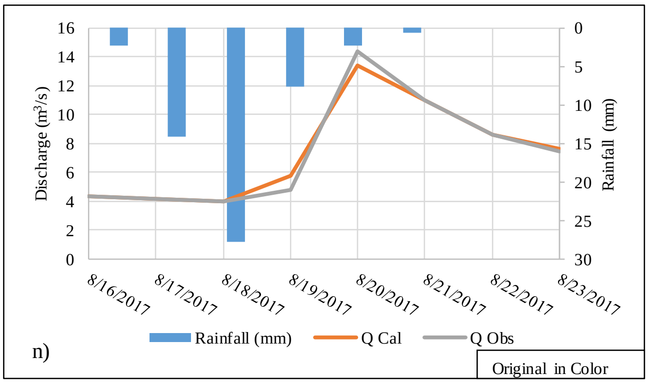


Event No.	E32	CN=	74.00
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	19.68	14.67	0.255
T_p (day)	4	3	0.250
T_b (day)	4	5	0.250
Vol (MCM)	6.44	4.40	0.316
Event MRAE		0.25	
Event RAME		0.35	

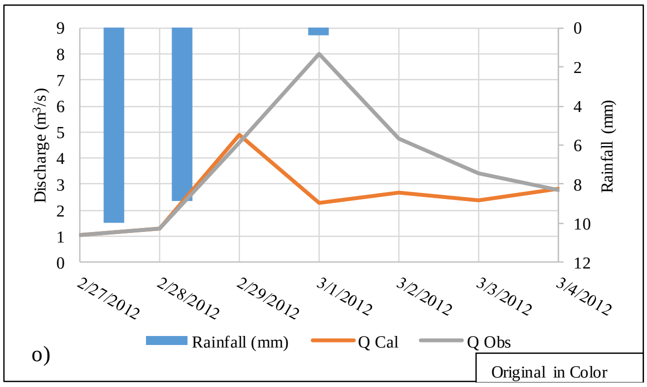
Figure R-3 (i-l): Calculated and observed streamflow graphs of events: E9-E12



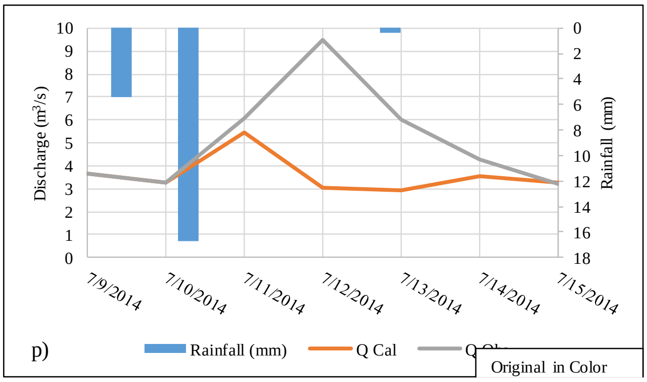
Event No.	E33	CN=	56.18
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	15.76	14.14	0.103
T_p (day)	4	2	0.500
T_b (day)	6	8	0.333
Vol (MCM)	6.95	3.27	0.530
Event MRAE		0.43	
Event RAME		0.53	



Event No.	E34	CN=	55.73
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	14.42	13.37	0.073
T_p (day)	4	4	0.000
T_b (day)	5	5	0.000
Vol (MCM)	5.07	5.08	0.002
Event MRAE		0.04	
Event RAME		0.04	

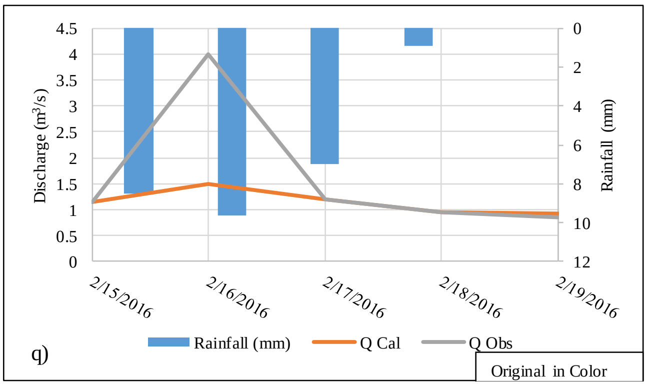


Event No.	E35	CN=	78.00
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	8.01	4.91	0.387
T_p (day)	2	3	0.500
T_b (day)	6	5	0.167
Vol (MCM)	2.24	1.50	0.329
Event MRAE		0.22	
Event RAME		0.35	

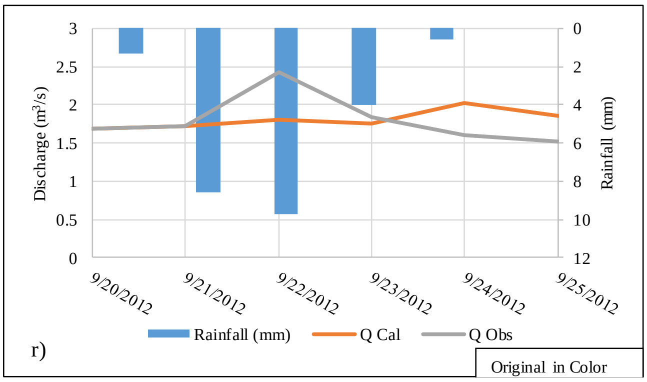


Event No.	E36	CN=	74.00
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	9.48	5.47	0.423
T_p (day)	2	3	0.500
T_b (day)	6	5	0.167
Vol (MCM)	3.11	2.18	0.298
Event MRAE		0.21	
Event RAME		0.30	

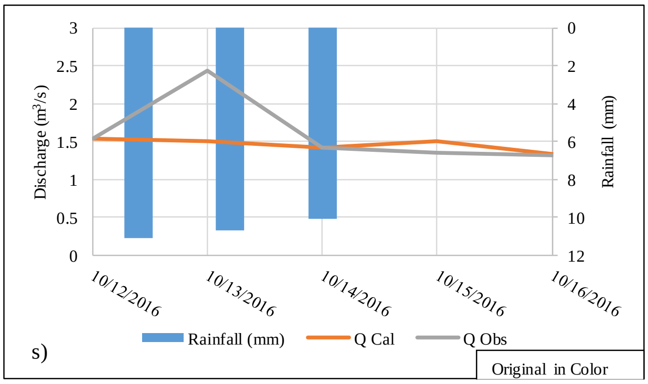
Figure R-4 (m-p): Calculated and observed streamflow graphs of events: E13-E16



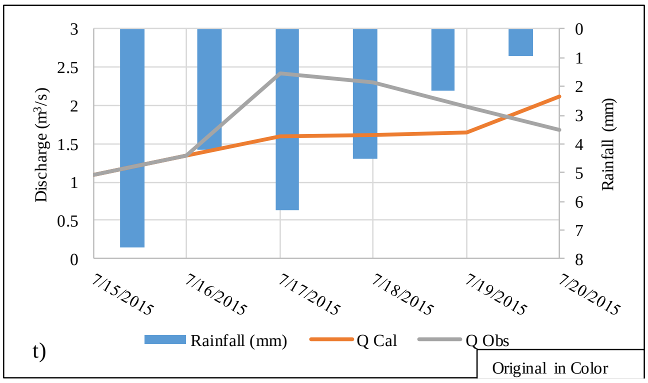
Event No.	E37	CN=	67.00
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	4.00	1.50	0.625
T_p (day)	1	1	0.000
T_b (day)	5	5	0.000
Vol (MCM)	0.70	0.50	0.295
Event MRAE		0.15	
Event RAME		0.32	



Event No.	E38	CN=	70.00
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.43	2.03	0.165
T_p (day)	4	2	0.500
T_b (day)	3	5	0.667
Vol (MCM)	0.93	0.94	0.005
Event MRAE		0.13	
Event RAME		0.14	



Event No.	E39	CN=	62.50
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.43	1.55	0.363
T_p (day)	1	1	0.000
T_b (day)	5	5	0.000
Vol (MCM)	0.70	0.63	0.094
Event MRAE		0.10	
Event RAME		0.14	



Event No.	E40	CN=	69.00
Description	**Observed**	**Calculated**	RAE
Q_p (m^3/s)	2.42	2.11	0.127
T_p (day)	5	2	0.600
T_b (day)	2	5	1.500
Vol (MCM)	0.94	0.81	0.130
Event MRAE		0.18	
Event RAME		0.21	

Figure R-5 (q-t): Calculated and observed streamflow graphs of events: E17-E20