Rev. Fac. Agron. (UCV) 37(3): 116-128. 2011.

Application of a curve stream response function to Mount Hope river, Connecticut

Juan Stella[1]* y Glenn Warner[2]

[1] Department of Civil and Environmental Engineering, University of Connecticut. Storrs, CT. USA.
[2]Department of Natural Resources & Management Engineering Young Building, Unit 4087 University of Connecticut. Storrs, CT. USA.

ABSTRACT

This research is related to an alternative approach to runoff estimation. Several watershed response functions or models such the curve number or the rational method have been developed to estimate runoff and peak discharge for a given storm, often for design purposes. The S-shaped curve method, created by D.A. Hughes, use watershed functions response to predict the runoff, peak discharge, and recession curve. This method describes an isolated event flood model based upon the concept of expanding source areas using the S-curve function link with the proportion of precipitation that transforms in stream flow. The stream response function approach of Hughes has been tested in few places had a lack of testing in other areas besides South Africa. The Hughes method includes the application of a hyperbolic tangent function that link the initial and maximum water depth in the watershed with the amount of rainfall in percent of runoff that the system will deliver to the stream. The test of this approach to the northeast of Connecticut in this research involved the development of an alternative method to determine the stream response function including parameters such as the initial watershed storage and the maximum watershed storage using a daily watershed budget. This research tests the application of this concept to the Mount Hope river, Connecticut, a small New England stream, northern USA. Four events, three in 2004 and one in 2005 were tested and the parameters for the model calibrated for those events. The general S-Shaped response shows that individual observed hydrographs can be accurately predicted. However, some parameters such as the initial water storage and the time shift of the direct runoff hydrograph vary among individual events, requiring calibration.

Key words: S-curve, discharge, peak flow, Connecticut..

Aplicación de la función curva de respuesta de escorrentía en el río Mount Hope, Connecticut

RESUMEN

Esta investigación introduce un enfoque alternativo a la estimación de escorrentía y máxima descarga durante una tormenta a los métodos comúnmente usados como el de la curva y el racional. El método de la curva con forma-S, creado por D.A. Hughes, usa las funciones de respuesta de la cuenca para predecir escorrentía, máxima descarga y recesión durante una tormenta. Este método describe un evento aislado basado sobre el concepto de fuente de áreas expansivas que utiliza un vínculo entre la función con forma-S y la proporción de precipitación que se transforma en escorrentía. Este enfoque creado por Hughes no ha sido probado en otros lugares aparte de Sudáfrica. El método de Hughes incluye la aplicación de la función tangente hiperbólica que vincula la altura inicial y el máximo de agua subsuperficial en la cuenca con la escorrentía total que el sistema entrega al río. Este enfoque fue puesto a prueba en Connecticut e implicó el desarrollo de un método alternativo para determinar el cálculo de los parámetros altura

*Autor de correspondencia: Juan Stella

E-mail: juan.stella@yahoo.com

Recibido: marzo 03, 2011 Aceptado: septiembre 28, 2011

inicial y máximo de agua en la cuenca de la función con forma-S usando un balance hídrico diario. La aplicación de este concepto se puso a prueba en el rio Mount Hope, Connecticut, una pequeña corriente de agua en Nueva Inglaterra, Noreste de los Estados Unidos. Cuatro acontecimientos, tres en 2004 y uno en 2005, fueron probados y los parámetros del modelo calibrados. Las conclusiones generales de la aplicación de función con forma-S muestra que los hidrogramas de respuesta a una tormenta pueden ser predichos con alta exactitud, con variación en algunos parámetros como la altura inicial de agua subsuperficial y la traslación del tiempo del hidrograma de escorrentia entre eventos, requiriendo calibración.

Palabras clave: curva forma-S, caudales, máxima descarga, Connecticut

INTRODUCTION

Accurate estimation of the streamflow response to a rainfall event is still one of the most difficult aspects of hydrology in spite of a century or more of studies trying to relate runoff and rainfall (Dingman, 2002). The factors that influence the rate of runoff not only depends on the weather-related factors such as the amount and intensity of precipitation, but also on watershed characteristics such as geomorphology, vegetative cover, soils, land and channel slopes and human influences such as urban areas, crop fields, and roads (Monsalve, 1999).

Several watershed response functions or models have been developed to estimate event runoff volume and peak discharge for a given storm, often for design purposes. It is possible to classify the models in two ways: 1) models that use empirical relationships between runoff and rainfall, and 2) models that account for the physical processes resulting in runoff for a given rainfall (Todini, 1995). The underlying reason for developing process-based models is to represent the hydrologic cycle by linking together process components, which describe physical concepts, on the presumption that the model parameters would also bear physical meaning, so there could be assigned values without reference to the observed data (Todini, 1995). The process models often are distributed in time and space and attempt to mimic the variation of runoff based on observations of the stream characteristics such as channel geometry, and vegetative cover along the stream, or by using the energy and water balances in the stream (Monsalve, 1999).

A continuing problem of complex, integrative type rainfall-runoff models has been the large number of parameters required (Jakeman and Hornberger, 1993). However, application of empirical methods to create water simulation models is very difficult due the huge number of parameter involved in the process such as changes in vegetative cover, soil disturbance, and other watershed parameters (Monsalve, 1999). In addition, most runoff-rainfall relationships are non-linear and are affected by the antecedent moisture conditions at the beginning of the rainfall event.

One of the most common methods relating runoff and rainfall is the curve number (CN) approach (USDA-SCS, 1972), whereby the depth of rainfall is converted to a depth of runoff with use of a series of curves that are based on an empirical relationship (USDA-SCS, 1972). The CN method is not only still used in many hydrologic models, such as TR55, TR20, and HEC–1, but it is also used in many water quality models. The CN is based on soils, plant cover, amount of impervious area, interception, and surface storage. The relationships for the CN method are shown in Equations 1 and 2:

$$Q_{stormflow} = \frac{(P - 0.2^{*})\,(S^{1})^{2}}{(P+0.8^{*}S)} \qquad (1)$$

and,

$$S = \frac{25400}{CN} - 254 \qquad (2)$$

where:

$Q_{stormflow}$ Depth of runoff, mm

P Precipitation, mm

CN Curve number parameter

S Potential maximum retention after runoff begins, mm

Equation 1 is valid for P>0.2*S, where 0.2*S is usually taken as a constant initial abstraction of rainfall (Ia). The CN method provides a non-linear response of runoff to precipitation as shown by the curves provided in manuals (USDA, 1986). Its application is usually taken for an average or normal antecedent (wetness) condition (Class II), although the CN can be adjusted for dry (Class I) or wet conditions (Class III) when the 5-day precipitation before the start of the storm is known. Threshold values between classes, which may vary with season, of the 5-day rainfall are used to separate the classes. Many researchers have questioned into the theoretical basis and proper application of the CN (Kumar and Jain, 1982; Steenhuis *et al.*, 1995; Yu, 1998). Despite its wide use, the SCS equation is not taken in account for many hydrologists due to its lack of sound theoretical background (Steenhuis *et al.* 1995), besides the extreme simplicity of the SCS equation may well describe most of the observed variability in runoff for small watersheds (Yu, 1998), but the method continues to be used as the core equation in the runoff component of many runoff-erosion simulation models in many countries.

Another commonly used approach to the runoff-rainfall relationship is the "Rational Equation". The runoff coefficient in this relationship is the ratio (hence the term "rational") between the peak rate of runoff and the peak rate of rainfall (Dingman, 2002). The rational method remains in use, especially for small catchments, despite the advent of more sophisticated, albeit complicated approaches (NERC, 1975). The method is typically recommended for application to only small catchments, e.g. below an arbitrary limit of 1 km^2. In the USA and Australia this method is the most common method used for peak flow estimation in small-ungauged catchments (Cawley and Cunnane, 2003). The general form of the rational equation (Equation 3) is generally given in English units. Equation 3 is not dimensionally correct but the needed unit correction value of 1.008 is usually ignored (Maidment, 1992).

$$Q_{PeakFlow} = \frac{CR * ir * Area}{360} \quad (3)$$

where:

$Q_{PeakFlow}$ Peak flow, m^3/s

CR Runoff coefficient

ir Rainfall intensity, mm/h

Area Drainage area, ha

Monsalve (1999) has shown how the rational Equation can be applied incrementally during a steady-state rainfall event of infinite duration to produce an S shape curve that can be then used to generate an event hydrograph for surface runoff.

Although the run off coefficient (CR) value that is a relationship between runoff and precipitation linked to the slope and land use is typically given as a range in handbooks (e.g. Dunne and Leopold, 1978). Rantz (1971) provided a series of graphs of CR values for the San Francisco area where the impervious area as a function of percentage storm recurrence interval (RI) where CR is estimated from frequency analysis of observed floods and increases rapidly with RI. A probabilistic approach of the rational method (Equation 4) can be obtained with the intention that the calculation of the peak discharge for an RI of Y years is equal to the same RI, Y, of the rainfall intensity (ir) and concentration time (tc), as determined by a frequency analysis (Maidment, 1992).

$$Q(Y) = CR(Y) * ir(tc, Y) * Área \quad (4)$$

where:

Q Peak flow, m^3/s

CR Runoff coefficient

ir Rainfall intensity, mm/h

tc Concentration time, h

Area Drainage area, ha

A less well known method that also uses an S-shaped curve to predict peak stream flows and runoff was developed and used in South Africa by Hughes (1984). This approach was used to describe an isolated event using the stream response function that calculates the proportion of precipitation that is transformed into stream flow. The advantage of this S-shaped curve is the varying, non-linear relationship that is applied between a runoff/rainfall ratio and the relative soil water storage in the watershed, both at the start and during the duration of the storm. Hughes (1984) found good agreement between predicted and observed discharges when tested on several watersheds in South Africa.

The curve stream response function was inspired by the IEM4 model of the United Kingdom Flood Studies Report that use an exponential relationship between the initial soil moisture deficit of the catchment at the beginning of the storm and the runoff ratio of the gross rainfall which eventually becomes quick flow, the runoff ratio then remaining constant during any one event, but there it has not yet been tested in other areas besides South Africa.

The objective of this study was to test the applicability of the Hughes (1984) curve stream response function to predict a single storm event hydrograph for a stream in the northeast of Connecticut and apply the method of the relative water storage in a runoff-relative moisture relationship.

Response curve theory

The key to the curve stream response function is the relationship between the runoff-rainfall ratio (ROP) and the relative watershed water storage (RAT). The ROP is defined as the proportion of the catchment that is functioning as a source-area at any one time during the storm, therefore all the rainfall falling on this becomes direct runoff while the rainfall falling on the remainder of the watershed contributes to the increasing moisture level and consequently an increasing source-area. The RAT is defined as proportion of moisture ratio storage in the watershed over the maximum moisture storage in the watershed (Hughes, 1984); both ROP and RAT are undimensional values.

Hughes (1984) theorized that the non-linear relationship would have an S shape and tried various mathematical expressions to link the initial water storage in the watershed with amount of runoff created by a single storm that can be generalized to either symmetrical or non-symmetrical S-curves.

To obtain RAT, Hughes (1984) first obtained the moisture ratio storage (API) at the beginning of the storm by applying Equation 5, usually 20 days before the storm. The parameter recession constant (k) has been found by previous users to be between 0.85 and 0.98.

$$API = \sum_{i=0}^{n} DR * k^i \qquad (5)$$

where:

API Moisture ratio storage, mm

DR^i Daily rainfall total for i-th day before storm, mm

K Recession constant, $k < 1.0$

i of day before the storm, day

The value initial value of RAT is then obtained by Equation 6:

$$RAT = \frac{API}{Smax} \qquad (6)$$

where:

Smax Maximum moisture storage, mm

Smax was calculated using the methodology applied by Stella (2007).

Figure 1 shows examples of some possible relationships between ROP and RAT that follow a S shape curve. Although there are several mathematical functions that can fit a S shaped curve, the mathematical function choose by Hughes in his research was a hyperbolic tangent, with a general equation as given by Equation 7 (Hughes, 1984).

$$ROP = A^*\{Tanh[B^*(RAT\text{-}C)] + 1\} \qquad (7)$$

The parameter A controls the maximum ROP in the model, B controls the slope of the major part of the curve, and C controls the position of the curve in RAT axe. For his application, (Equation 7) Hughes divided the S-curve into two portions: one below a break point C and another above point C. The value of C is the RAT (X axis) value, while the ROP (Y axis) value of C as deduced from Hughes (1984) is the value of the parameter designated DA.

Hughes (1984) alters the equation 7 to confine the S-curve in the positive axes and to allow for a non-symmetrical shape. This was achieved by dividing the function in two sectors that permits a continuous curve that uses the parameters A, B, DA, and C, which results in Equations 8 and 9 as show in Figure 1.

For RAT< C

$$ROP = A1^*\{Tanh[B1^*(RAT\text{-}C)] + 1\} \qquad (8)$$

For RAT ³ > C

$$ROP = A2^*\{Tanh[B2^*(RAT\text{-}C)] + 1\} + D2 \qquad (9)$$

where:

A1 A*DA

A2 A*(1.0-DA)

B1 2,0/C

B2 2,0/(1.0-C)

D2 A – 2,0* A2

The runoff and water storage for each time i, are obtained by applying Equations 10 and 11, respectively:

$$E_i = ROP_i * R_i \qquad (10)$$

$$ST_{i+1} = ST_i + R_i - E_i \qquad (11)$$

where:

ST_i Water storage at hour i, mm

R_i Rainfall at hour i, mm

E_i Direct runoff in hour 1, mm

The discharge rate N(i) for a watershed with area (A) and time step (St) is calculated by Equation 12.

$$Ni = \frac{ROP_i * R_i * \text{Àrea}}{St} \qquad (12)$$

where:

Ni Discharge rate at time i, m^3/s

St Step time of the simulation, s

Área Area of the watershed, m^2

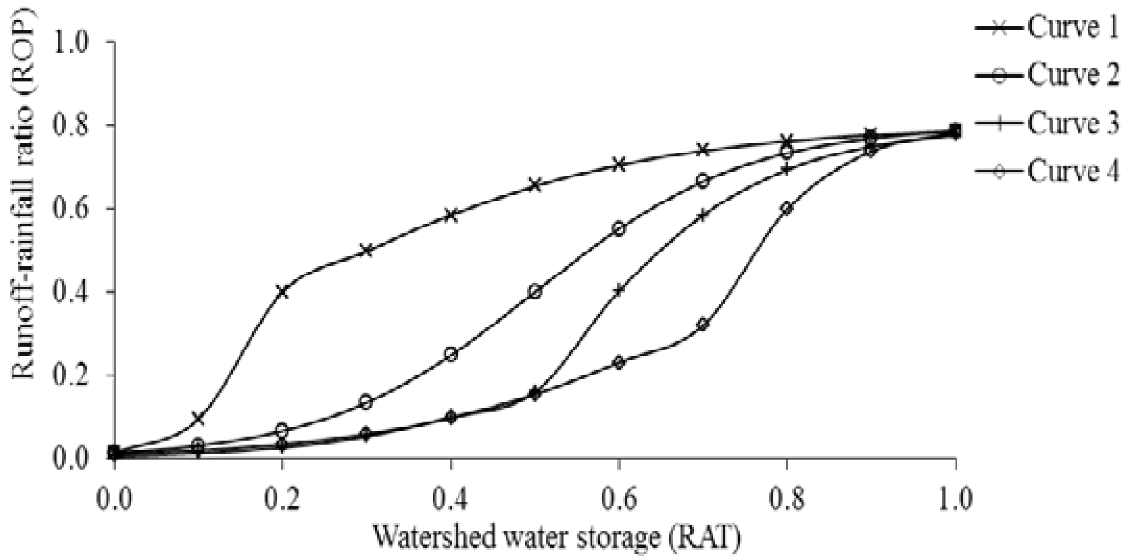

Figure 1. S shape curve relationship between watershed water storage (RAT) and runoff-rainfall ratio (ROP) both undimensionals for different values of A, C and DA given in Table 1. Adapted from Hughes (1984).

Table 1. Parameters A, DA and C for the curves in Figure 1.

	A	DA	C
Curve 1	0,8	0,5	0,2
Curve 2	0,8	0,5	0,5
Curve 3	0,8	0,2	0,5
Curve 4	0,8	0,4	0,7

The calculation of the discharge uses Equations 14, 15, and 16 as part of the model structure (NERC, 1975). These equations were originally deduced from Equation 13 (Hughes and Murrel, 1986).

$$S = AC^* W'' \tag{13}$$

where:

S Water storage, m/day

AC* Storage constant, $(mm/h)^{0.5}$

W'' Discharge, m^3/day

n Parameter, $0<n<1$

Equation 14 can only be resolved analytically for n = 0.5 (NERC, 1975).

If Ni = 0

$$q_{i+1} = \frac{q_i}{(1+\frac{q_i^{0.5}}{AC})^2} \tag{14}$$

where:

q_i Discharge at time i, m^3/s

q_{i+1} Discharge at time i +1, m^3/s

If Ni > 0

$$q_{i+1} = N_i * (\frac{q_i^{0.5} + N_i^{0.5} *H}{N_i^{0.5} + q_i^{0.5} *H})^2 \tag{15}$$

$$H = \tanh (\frac{N(i)^{0.5}}{AC}) \tag{16}$$

Finally, a linear interpolation given by Equation 17 (NERC, 1975) is used to solve for the discharge.

$$q_{1+i} = q_{i-1} *Del - q_i *(1 - Del) \tag{17}$$

where:

Del Time shift of the direct runoff hydrograph

MATERIALS AND METHODS

Study site and data used

The Mount Hope river is tributary of the Thames river (Figure 2) has a total length of 23 km, the drainage area at the USGS gage # 01121000 is 74,0 km^2 and is located at in the northeast of the state of Connecticut, New England Region, northeast of USA. The discharges gage datum is 102,3 masl National Geodetic Vertical Datum of 1929 (NG5D29) (USGS, 2005).

Table 2 shows the hydrologic and vegetative cover of the Mount Hope river basin, where the discharge

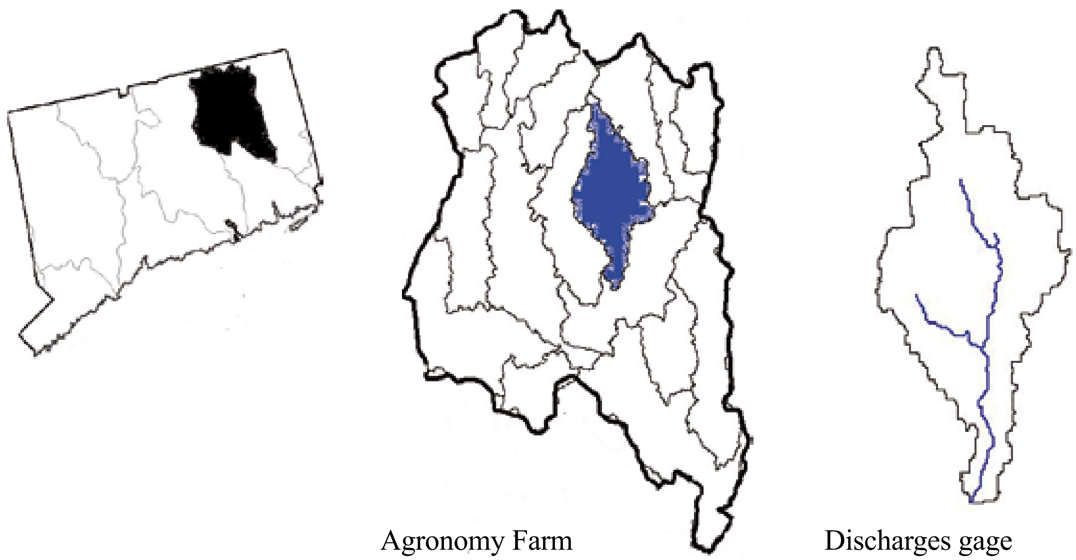

Figure 2. Left, the west branch of the Thames river watershed (Mount Hope river is tributary of Thames river) in black color in the state of Connecticut. Center, the east branch of the Thames river watershed with the Mount Hope river watershed in black color and the Agronomy Farm site (black star). Right: Mount Hope river watershed and the gage discharge site (black star).

attributes are based on WY 1941-2003 (USGS, 2005), the percentages of land use in the watershed are based on 1990 Land Use and Land Cover data compiled by MAGIC (2004), the Department of Natural Resources Management & Engineering (University of Connecticut) and calculated by Bighinatti (2005), the stratified drift from Apse (2000).

Flow and precipitation data for testing Hughes model were obtained for the years 2004 and 2005, flow data were obtained from the USGS gage # 01121000 for the Mount Hope river and precipitation data were obtained from the University of Connecticut, Agronomy Farm 41°47'42" N and 72°13'42" W, approximately 11,3 km from the Mount Hope gage (Figure 2).

Table 2. Attributes of Mount Hope river basin

Attribute	Value	Unit
Mean discharge	1,46	m^3/s
Median discharge	0,878	m^3/s
Median discharge		$m^3/s/km^2$
Modal discharge	0,368	m^3/s
Watershed area	74,1	km^2
Land use in the watershed		
Barren land	1,4	%
Forest	84,4	%
Non-forested vegetation	8,3	%
Open water	2,1	%
Urban	2,8	%
Wetland	1,0	%
Stratified drift	4,2	%

Source: Bighinatti, 2005.

The precipitation data were available for 30 min increments, while the stream discharge was in 15 min increments. Therefore, the 15 min stream flow data were combined into 30 min increments to directly compare rainfall and stream flow.

Application of Hughes (1984) approach

The application of the stream response functions model was tested for the following periods: 1) between july 12 and 20, 2004 during 185 h of simulation, 2) between september 17 and 26, 2004 with 225 h of simulation, 3) between september 25 and october 6, 2004 with 250 h of simulation and 4) between october 13 and 23, 2005 during 241 h of simulation. Those periods of time for simulations represent different scenarios for different storms, the first one during summer season and with a double peak and the other three during the fall with a single and higher peak.

To obtain RAT, an alternative method was developed to estimate the water storage (Si), at the start of a rainfall event to replace API. The result is Equation 18:

$$RAT = \frac{Si}{Smax} \tag{18}$$

where:

Si Water storage in time i, mm

To obtain Si and Smax, it was first necessary to estimate a water balance between the evapotranspiration, discharge and precipitation in the Mount Hope river basin. The depth of water storage in the Mount Hope watershed as show Figure 3 was calculated using the methodology applied by Stella (2007). The Smax is the maximum depth of water storage available from 1997 to 2006.

The Smax for the Mount Hope river basin between 1997 and 2006 was estimated to be 544 mm for every period of the simulation. Table 3 provides the estimated initial water storage (So) for each of the rainfall events selected for testing the Hughes (1989), S-shaped curves method to simulated a hydrograph for each storm.

The simulated and observed discharges for the four events were compared using square R and the Nash - Sutcliffe model of efficiency (Nash and Sutcliffe, 1970) given by Equation 19. The peak discharges values of simulated versus observed was compared via a linear regression developed within a spreadsheet.

$$NS = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2} \qquad (19)$$

Table 3. Initial water storage (So) in the Mount Hope watershed estimated for each period of the simulation.

from	to	So (mm)
12/7/2004	20/7/2004	118
17/9/2004	26/9/2004	329
25/9/2004	6/10/2004	377
13/10/2005	23/10/2005	258

where:

O_i Observed discharges
$\overline{O}$ Mean of observed discharges
S_i Simulated discharges
n Number of steps modeled

RESULTS AND DISCUSSION

Discharge and peak discharges simulation

Figures 4 and 5 show the ROP and the Mount Hope river discharges simulated and observed with a double peak from 12 July to 20 July of 2004 with 200 h in total. This simulation shows an event with two peak discharges and concentration times, the first peak with a value of 1,61 m^3/s at 82,5 h for the observed and 1,61 m^3/s at 80,5 h for simulated peak discharge, the second peak with a value of 1,77 m^3/s at 114,5 h for the observed and 2,01 m^3/s at 110,5 h for the simulated. The shape of the concentration curve of the simulated events follow the

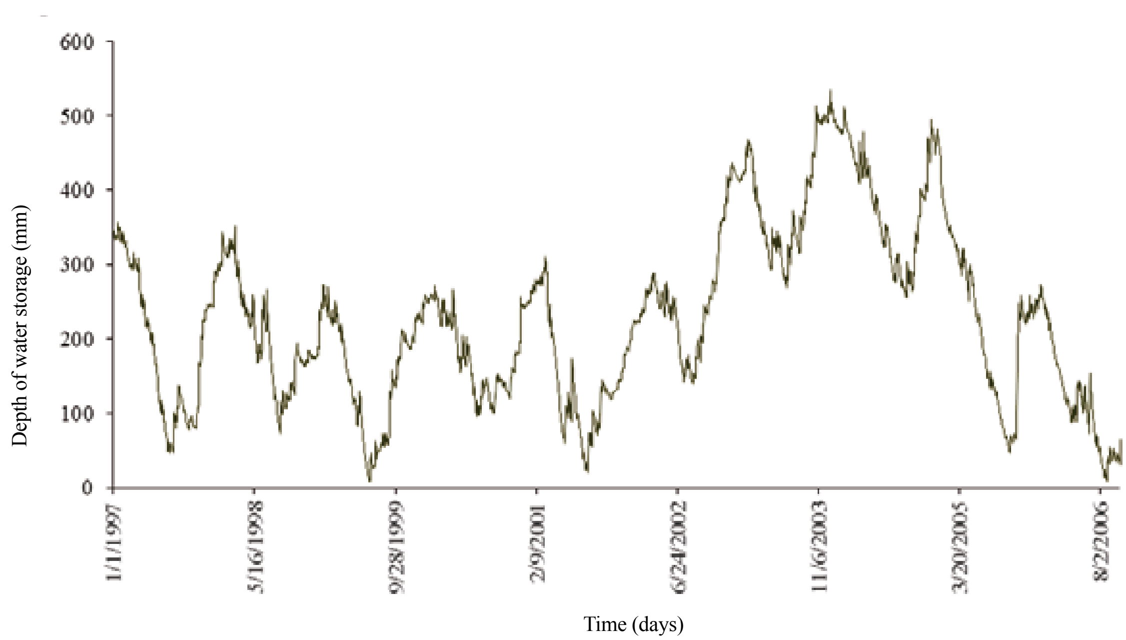

Figure 3. Depth of water storage in the Mount Hope river basin, from 01/01/1997 to 31/12/2006 (Stella, 2007).

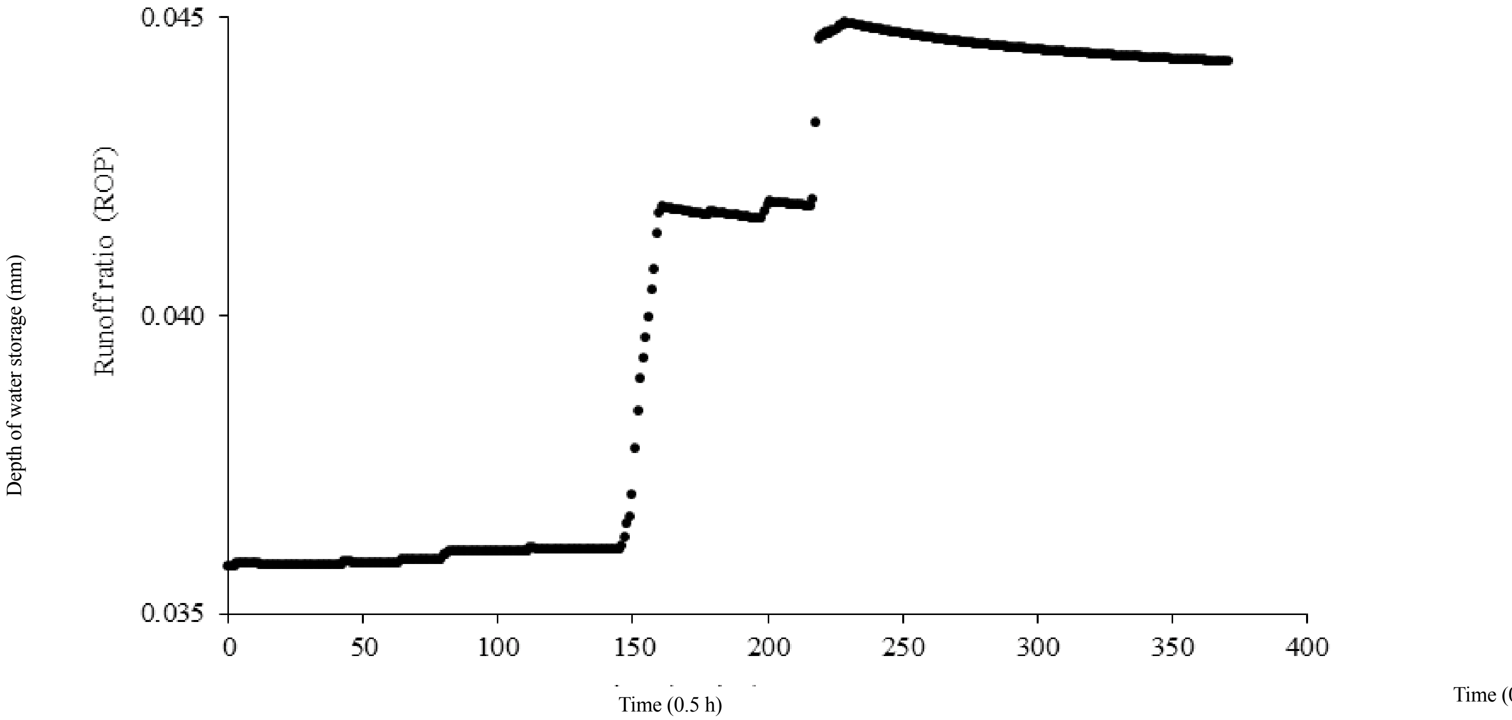

Figure 4. Runoff ratio (ROP) simulated in Mount Hope river, from 12 to 20 July of 2004.

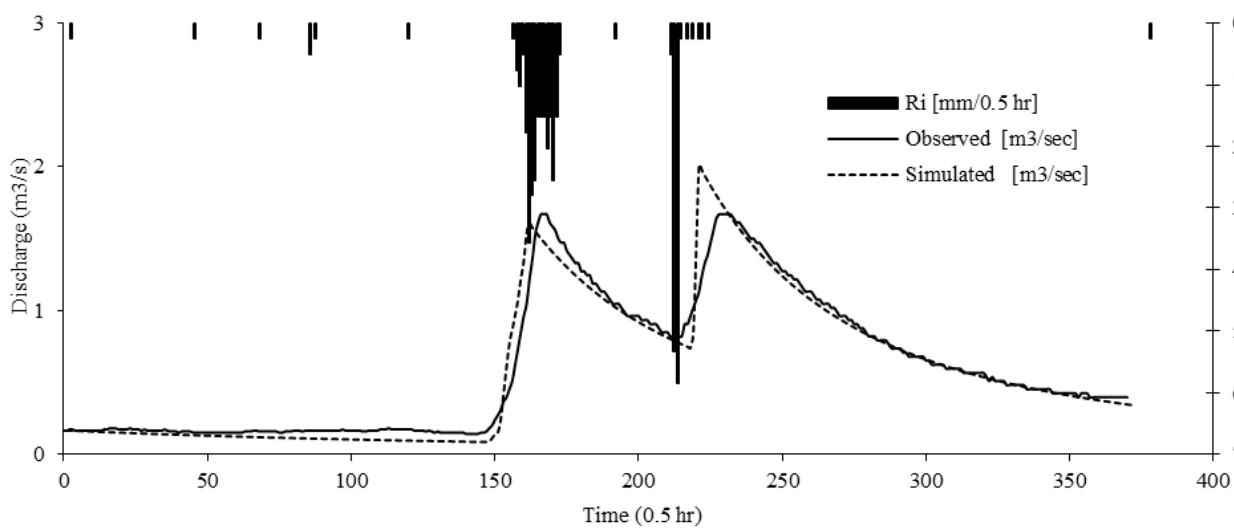

Figure 5. Observed and simulated discharge in Mount Hope river, from 12 to 20 July, 2004.

trend of the observed discharges for the first peak, but fail to follow the trend in the second event. The shape of the recession curves for the simulated events follow the trend in both of the observed discharges. The model showed a high sensitivity to the variations in the intensity of the rain in the first peak failing in the second peak.

Figure 6 shows ROP for 9 days of simulation for the 17 to 26 September, 2004 event. Figure 7 shows the Mount Hope river discharges simulated and observed during the summer between 17 and 26 september, 2004. This simulation shows an event with one peak discharge and concentration time, the peak with a value of 23,70 m^3/s at 35,5 h for the observed and 23,78 m^3/s at 34,5 h for simulated peak discharge. The shape of the concentration and recession curves of the simulated events follows the trend of the observed discharges. The model showed a high sensitivity to the variations in the intensity of the rain.

The simulation for 10 days between 25 september to 6 october, 2004, is shown for the ROP in Figure 8, and discharge simulated and observed in Figure 9. This simulation shows an event with one peak discharge and concentration time, the peak with a value of 14,24 m^3/s at 95 h for the observed and 14,24 m^3/s at 95 h for the simulated. The shape of the concentration and recession curves of the simulated events follows the trend of the observed discharges. The model showed a high sensitivity to the variations in the intensity of the rain in both peaks.

A simulation for the largest peak flow in the last century that occurred between 13 and 23 october, 2005 was also performed. The ROP is given in Figure 10, and discharge as simulated and observed in Figure 11. This simulation shows an event with one peak discharge and concentration time, the peak with a value of 144,70 m^3/s at 73,5 h for the observed and 119,70 m^3/s at 74,5 h for simulated peak discharge. The shape of the concentration and recession curves of the simulated events follows the trends of the observed discharges. The model showed a high sensitivity to the variations in the intensity of the rain but failed to achieve a close value of the observed peak.

Parameters and statistical analysis

Of interest to the application of the stream response function method, is whether the parameters have consistency across the events simulated. Table 4 provides the parameter values for the four storms used to test the general method. Some parameters, such as A are fairly uniform across all storms. The storm from 13/10/2005 to 23/10/2005 had values for some parameters such as DA and C that varied widely from the other storms. This storm was an extreme event that followed one of the driest periods on record (Warner *et al.*, 2006).

A summary of all the results obtained from the Nash – Sutcliffe (NS) and regression coefficient between the discharges simulated by the model and observed is

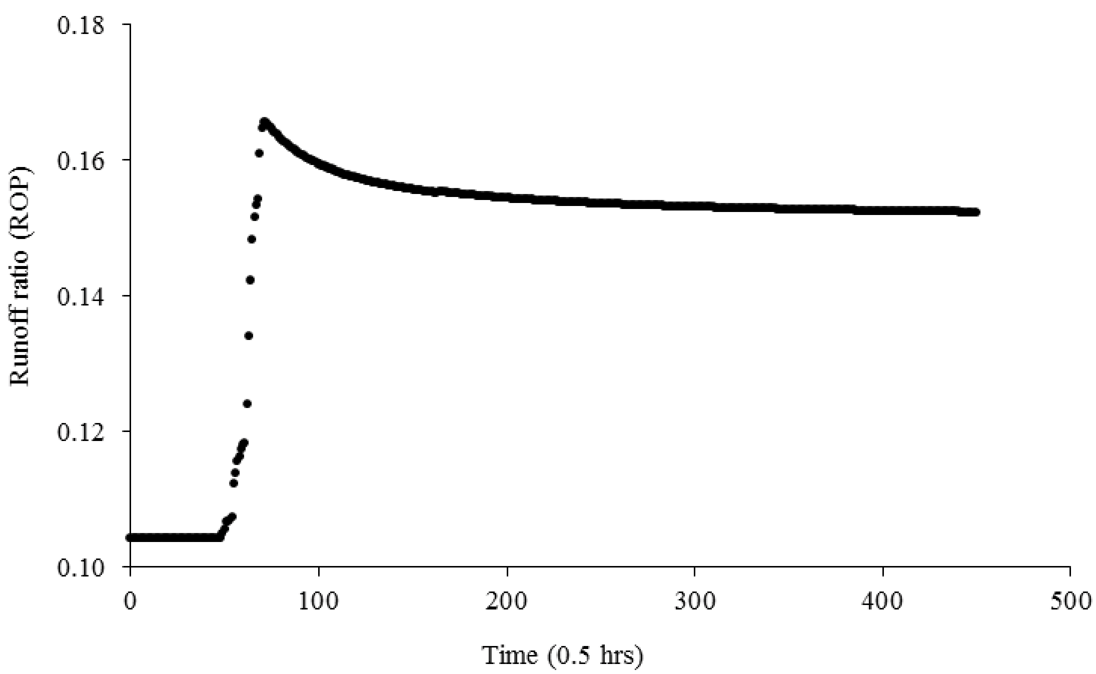

Figure 6. Runoff ratio (ROP) simulated in Mount Hope river, from 17 to 26 September, 2004.

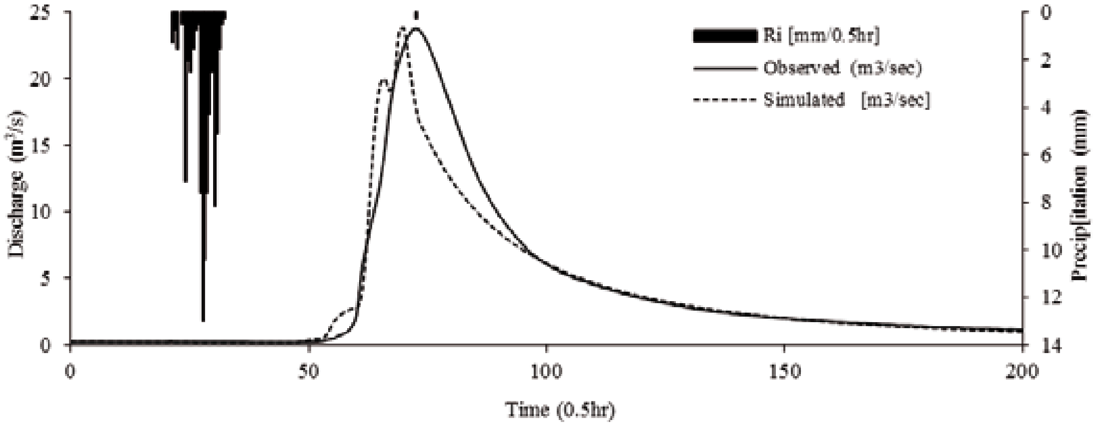

Figure 7. Observed and simulated discharge in Mount Hope river, from 17 to 26 september, 2004.

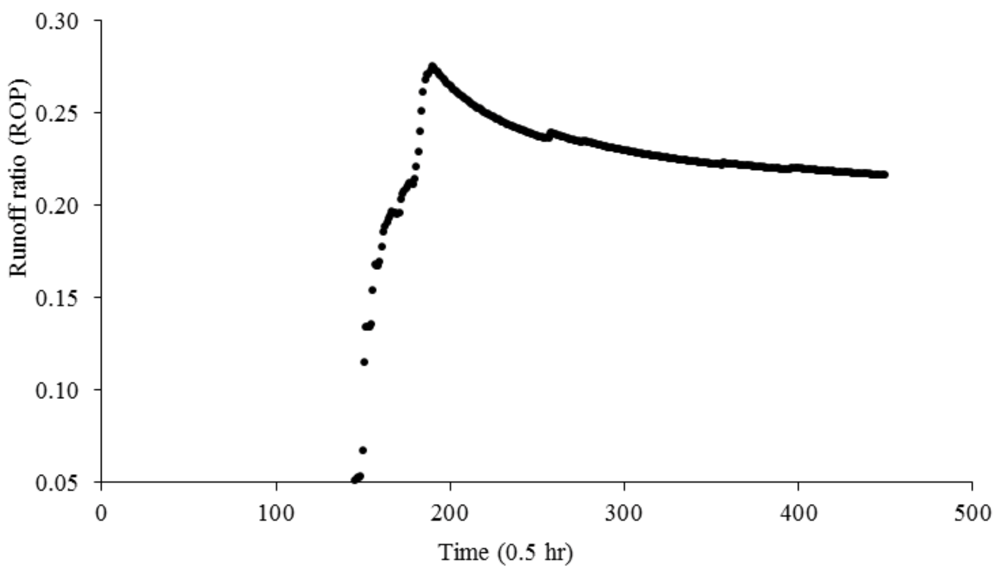

Figure 8. Runoff ratio (ROP) simulated in Mount Hope river, from 25 september to 6 october, 2004.

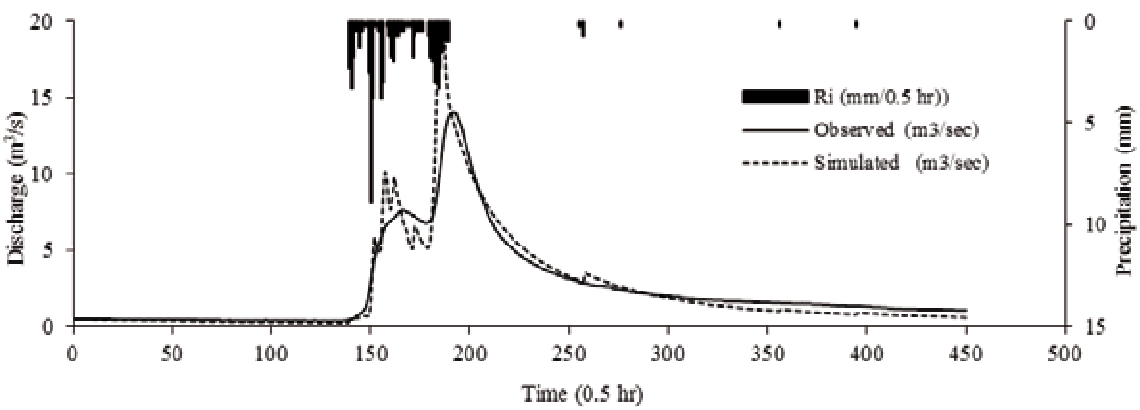

Figure 9. Observed and simulated discharge in Mount Hope river, from 25 september to 6 october, 2004.

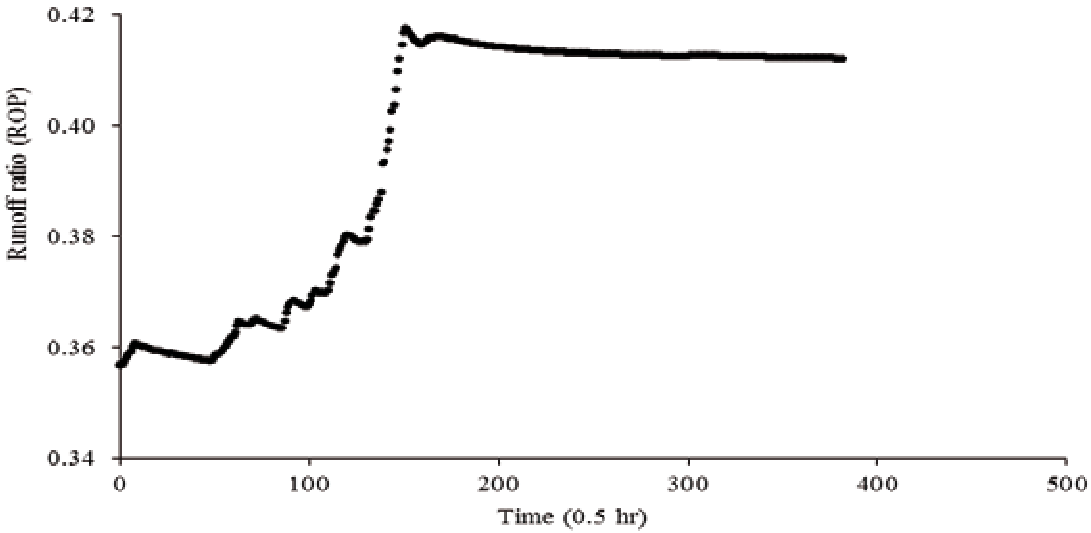

Figure 10. Runoff ratio (ROP) simulated in Mount Hope river, between 13 to 23 october, 2005.

shown in Table 5.

Figure 12 shows a comparison of the simulated and observed peak discharges for the four events analyzed using linear regression.

The application of the Si/Smax relationship along with the stream response function, reliably predicted the discharges, Nash – Sutcliffe coefficients with values over 0,75 and square R over 0,89 and peak discharges with square R equal to 0,99 and line slope 0,95, after the parameters So, A, DA, C, AC and Del were calibrated, leading to confidence that the method can predict discharges and peak discharge. However, the calibrated parameters among storms did not produce constant values for all parameters.

Figures 7, 9, and 11 show instability in the simulated discharge that could be due to two explanations. One is that the relative water storage calculated, with a daily step time, did not match exactly with the half hour step time for the storms simulated. The other source of instability could be that the solution (Equations 14 and 15) for the equation 13 for the simulation of the discharges, using the analytical value for n = 05, is not representative of the watershed. Further testing with use of the empirically derived values could improve the results.

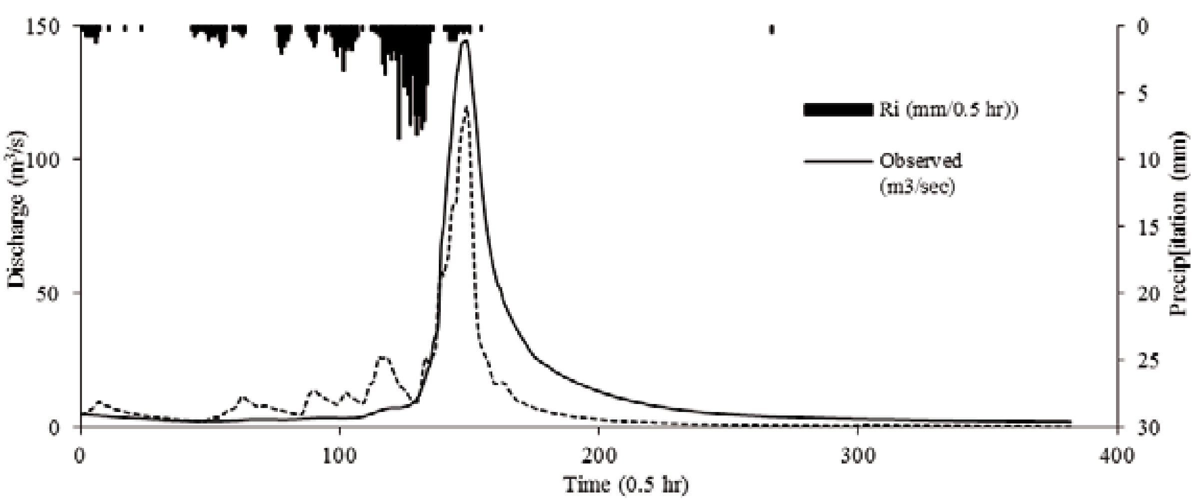

Figure 11. Observed and simulated discharge in Mount Hope river, between 13 to 23 october, 2005.

Table 4. Parameters So, A, DA, C, AC, and Del of the stream response function applied by Hughes (1984) calibrated for the four events tested in the Mount Hope river

From	To	So	A	DA	C	AC	Del
12/7/2004	20/7/2004	350	0,48	0,20	1,03	30	0,20
17/9/2004	26/9/2004	329	0,46	0,45	0,84	25	0,12
25/9/2004	6/10/2004	377	0,50	0,10	0,70	35	0,28
13/10/2005	23/10/2005	258	0,48	0,02	0,05	45	0,30

Table 5. Nash – Sutcliffe coefficient (NS) and R^2 for discharges in the four events.

From	To	NS	R^2
12/7/2004	20/7/2004	0,92	0,94
17/9/2004	26/9/2004	0,89	0,93
25/9/2004	6/10/2004	0,79	0,89
13/10/2005	23/10/2005	0,75	0,94

CONCLUSIONS

The stream response function applied by Hughes (1984) has much in common with methods of empirical origin such the Rational Equation and the CN. But one of the main problems that these methods have for the calculation of runoff and peak discharge is the lack of initial conditions related to the water storage and soil water content in the basin at the start of rainfall. The stream response function developed by Hughes (1984) provides an approach where the percentage of runoff changes as a non-linear function of the water in the watershed. His parameters include Smax related to maximum relative water storage in the basin and API, a parameter that describe the initial water storages including soil water as an initial condition. The API parameter was modified by using a daily, continuous water balance to estimate the initial relative water storage (Si), at the start of a given rainfall event. It is concluded that Hughes (1984) stream response function method as modified has potential in application to small rivers in Connecticut but that further research is needed to determine parameters. Research in the future should apply the model to more storms and other watersheds along with techniques to relate the geometric parameters such as A, C and DA to physical attributes of a watershed.

REFERENCES

Apse, C.D. 2000. Instream Flow Protection in New England: Status, Critique, and New Approaches to Standard-Setting. Masters of Environmental Management Thesis, Yale School of Forestry and Environmental Studies. New Haven, EUA.

Bighinatti, S.J. 2005. Investigations of flow-duration curves and application to estimating discharge on ungauged streams. Master Thesis. University of Connecticut, Storrs, EUA.

Cawley, A.M.; C. Cunnane. 2003. Comment on estimation of greenfield runoff rates. Proceedings National Hydrology Seminar, Tullamore. pp. 29-43.

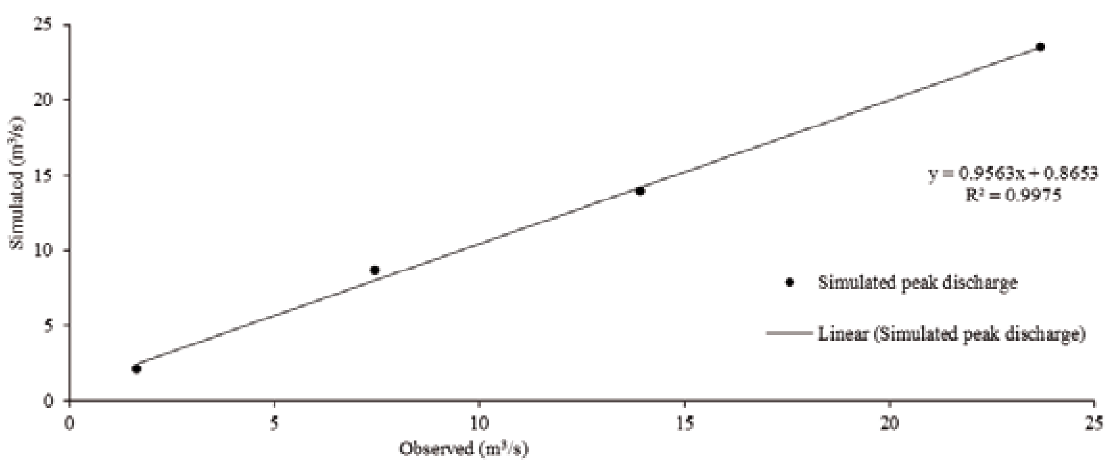

Figure 12. Linear regression between the observed and simulated peak discharge applying Hughes (1984) stream response function for the four events.

Dingman, S.L. 2002. Physical Hydrology. Prentice Hall Inc., Englewood Cliffs, USA.

Dunne, T.; L.B. Leopold. 1978. Water in environmental planning. W. H. Freeman Company, New York, EUA.

Hughes, D.A. 1984. An isolated event model based upon direct runoff calculations using an implicit source area concept. J. Hydrol. Sci. 29: 3-9.

Hughes D.A.; H.C. Murrell. 1986. Non-Linear runoff routing, a comparison of solution methods. J. Hydrol. 85: 339-347.

Jakeman, A.J.; G.M. Hornberger. 1993. How much complexity is warranted in a rainfall-runoff model? Water Res. Res. 29: 2637-2649.

Kumar, S.; S.C. Jain. 1982. Application of SCS infiltration model. Water Res. Bull. 18: 503-507.

MAGIC (Map and Geographic Information Center). 2004. Land use/land cover. Map and Geographic Information Center. University of Connecticut, Storrs, EUA. On line: http://magic.lib.uconn.edu/

Maidment, D.R. 1992. Handbook of Hydrology. Mc Graw-Hill. New York, USA.

Monsalve, G. 1999. Hidrologia en la Ingenieria. AlfaOmega Grupo Editor. Ciudad de México, México.

Nash, J.E.; J.V. Sutcliffe. 1970. River flow forecasting through conceptual models: Part 1 – a discussion of principles. J. Hydrol. 10: 282–290.

NERC (Natural Environment Research Council). 1975. Flood Studies Report, Vol. I-5. pp. 527-534. Natural Environment Research Council. London, England.

Rantz, S.E. 1971. Suggested criteria for hydrologic design of storm-drainage facilities in the San Francisco Bay Region, California. U.S. Geological Survey Open File Report. Menlo Park, USA.

Steenhuis, T.S.; M. Winchell; J. Rossing; J.A. Zollweg; M.F. Walter. 1995. SCS runoff equation revisited for variable-source runoff areas. J. Irrig. Drain. Eng. 121: 234-238.

Stella, J. M. 2007. Modeling temperature, recession curves and event response for two third-order eastern Connecticut streams. Doctoral Dissertation. University of Connecticut, Storrs, EUA.

Todini, E. 1995. The ARNO rainfall-runoff model. J. Hydrol. 175: 339-382.

USDA–SCS. 1972. National Engineering Handbook. Hydrology Section 4. Chapters 4-10. U.S. Dept. Agriculture, Soil Conservation Service. Washington, USA

USDA. 1986. Urban hydrology for small watersheds. Tech. Rel. 55. 210-VI-TR-55, 2nd ed. U.S. Dept. Agriculture. Washington, USA.

USGS. 2005. Daily streamflow for Connecticut. U.S. Geological Survey. On line: http://waterdata.usgs.gov/nwis/nwisman/?site_no=01121000&agency_cd=USGS

Warner, G.S.; F.L. Ogden; A.C. Bagtzoglou; P. Parasiewicz. 2006. Long term impact analysis of the University of Connecticut's Fenton river water supply wells on the habitat of the Fenton river. Final Report. Connecticut Institute of Water Resources. Special Report 39. Storrs, USA. 211 pp.

Yu, B. 1998. Theoretical justification of SCS method for runoff estimation. J. Irrig. Drain. Eng. 124: 306-309.