# MATHEMATICAL MODEL FOR THE PREDICTION OF RECESSION CURVES

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## ABSTRACT

Prediction of recession curves remains an important task for management of diversions or reservoirs that affect flow in streams during low-flow periods. There have been many approaches to baseflow recession applying either power or exponential equations, but there has not been any successful approach to link the parameters of these exponential and power equations such as the turnover time of the groundwater storage with hydrological parameters, and the initial peak discharge before the recession and the recession time. The Fenton and Mount Hope Rivers basin are neighbors, located in Northeast of the State of Connecticut. This research developed and tested a mathematical model in exponential form to simulate discharges during recession with coefficients related with the initial peak discharge before recession and time of recession. The recession model was applied and calibrated in the Mount Hope and Fenton Rivers. The results found that the recession model showed good approximation for the representation of the recession phenomenon, to predict the recession discharge for low flows in the Mount Hope and Fenton Rivers.

**Keywords**: *Recession, model, prediction, Connecticut*

## RESUMEN

*Modelo matemático para la predicción de curvas de recesión.*
La predicción de curvas de recesión es una tarea importante para la gestión y diseño de obras hidráulicas y depósitos de agua subterránea por el efecto que el bajo flujo de agua tiene durante períodos de bajos caudales. Ha habido muchos enfoques para poder relacionar la recesión con ecuaciones exponenciales u otras funciones, pero no ha habido ningún enfoque de éxito para ligar los parámetros de estas funciones exponenciales con el tiempo de recesión, parámetros hidrológicos, y con la descarga máxima inicial antes que comience la recesión. Las cuencas de los ríos Fenton y Mount Hope son vecinas, situadas en noreste del Estado de Connecticut, USA. Esta investigación desarrolló y probó un modelo matemático en forma exponencial para simular descargas durante periodos de recesión, con coeficientes relacionados con la descarga inicial máxima antes de recesión y el tiempo de duración de la recesión. El modelo de recesión fue aplicado en las cuencas de los ríos Mount Hope y Fenton. Los resultados encontrados muestran que el modelo de recesión empleado es representativo de las recesiones observadas y que es una buena aproximación para predecir recesiones durante periodos de bajos caudales en los ríos Mount Hope y Fenton.

**Palabras clave:** *Recesión, modelo, predicción, Connecticut*

## INTRODUCCION

Prediction of flow during non-rainfall periods is often needed for management of water resources. Management of water supply reservoirs during drought periods, estimation of water availability for competing users, and water available for dilution of wastewater discharges and for instream biological needs are a few classical examples. The baseflow in streams is typically maintained by drainage into channels from saturated zones in the subsurface strata which varies with the geology of particular watersheds. The gradual depletion of streamflow during non-runoff periods is usually characterized by a baseflow recession, which is a hydrological property of every watershed (Boughton 1986).

The recession for a streamflow in a general way is conditioned by meteorological factors, both present and precedent to the recession period, and by the water retention capacity of the watershed (Coutagne 1948). During drought periods, an accurate forecast of the future streamflow is important for management purposes and in particular for fish and animal life in the river (Rivera-Ramirez *et al.* 2002).

The basic theoretical approach to baseflow recession is attributed to Boussinesq (1877) who developed an exponential expression (Equation 1) for the flow from aquifers. Here, $q_0$ and $q_t$ are the flows at the initial time 0 and at time t, and $\tau$ is the turnover time of groundwater storage (Chapman 1999).

$$q_t = q_0 * e^{-\frac{t}{\tau}} \quad [1]$$

Where:

| | |
|---|---|
| qt | Discharge at time t |
| $q_0$ | Initial discharge at time t = 0 |
| $\tau$ | Turnover time of groundwater storage |
| t | Time |

The first application of Equation 1 to streamflow data is usually credited to Maillet (1905) in "Fontaine du Defends" (Coutagne 1948). In 1921 D. Halton showed that Equation 1 accurately represents the recession in Chalk regions of West Sussex (Horton 1933). The use of the storage turnover time ($\tau$), given in Equation 1 requires further analysis for direct application.

A second Equation (2) was popularized by Barnes (1939), where a recession constant (k) was used for the selected time periods (Chapman 1999).

$$q_t = q_0 k^t \quad [2]$$

Where: k Storage delay factor

The simplest application of Equation 2 for baseflow recession is given in the form of Equation 3 which assumes a linear relationship given as a storage delay factor k between $q_{t+1}$ and $q_t$ (Chapman 1999).

$$q_{t+1} = k^* q_t \quad [3]$$

Where: qt+1 Discharge at time t+1

Coutagne (1948) deduced Equation 4, where to obtain the recession curve as a function of a groundwater storage parameter S. Chapman (1999) used Equation 4 and the relationship, with n = 0.5, in his research to compare various algorithms for streamflow recession and baseflow separation.

Chapman developed Equation 6 as a more general expression of Equation 4, with the parameter a = $1/\tau_0$ (Equation 5), where $\tau_0$ is the turnover time of the groundwater storage at time = 0, $\tau_0 = \frac{S_0}{q_0}$ , and n is a parameter representative of the basin conditions (Chapman 1999).

$$q_t = aS^n \quad [4]$$

$$a = \frac{1}{\tau_o} \quad [5]$$

$$q_t = q_0 * [1+(n-1)\frac{t}{\tau_o}]^{\frac{-n}{n-1}} \quad [6]$$

Where:

| | |
|---|---|
| S | Groundwater storage |
| τo | Turnover time of the groundwater storage at time = 0 |
| n | Empirical parameter of the groundwater storage |

Chapman (1999) applied Equation 6 at different streams during periods of no recharge. For recessions lasting up to about 10 days, he found that the linear model remains a good approximation, using a biased value of the groundwater turnover time, but that there is great variability in the parameters of turnover time in the recession model from one recession to another, attributable to spatial variability in groundwater recharge (Chapman 1999).

Hughes and Murrell (1986) applied four different methods to solve the non-linear input storage discharge Equation 4 and found that the acceptability of different methods depended upon the time step over which the equations are solved as well as the value of parameters involved.

Another general equation that has been used for estimation of soil moisture drainage is a power form equation (Equation 7). This equation represents the recession period, where $\alpha$ and $\beta$ are empirical parameters (Richards *et al.* 1956).

$$q_t = \alpha * t^\beta \quad [7]$$

Where:

| | |
|---|---|
| $\alpha$ | Empirical parameter |
| $\beta$ | Empirical parameter |

Most widely used hydrology books such as those by Viessman *et al.* (1972), Hornberger *et al.* (1998), Maidment (1993) and Dingman (1994), give equations for recessions similar to the equations above. Another possible way to obtain the master recession curve of one stream is searching for mathematical functions that can fit the recession period of the discharge created during one period of time.

The University of Connecticut (UConn) obtains part of its water supply from four high capacity wells located in the alluvial deposits along the Fenton River approximately 6.8 kilometers upstream of its discharge point to the Mansfield Hollow Lake. During low-flow periods that normally occurs in mid to late summer and early fall, there are potentials for damage to fish and wildlife in the Fenton River resulting from the reduction in streamflow due to the pumping of water supply wells. The Fenton River study (Warner *et al.* 2006) was conducted to determine the water balance in the Fenton River, the streamflow variations, especially during the low-flow period of the summer, and the amount of induced infiltration caused by the wells. As part of this study, recession curves or constants were needed to predict the future baseflow level in the River based on given current flows in order to manage the well field and minimize the potential impacts. The recession's constants can be used to predict how quickly the flow will reach a certain critical minimum discharge under non-rainfall conditions to allow a shift in pumping rates.

The specific objectives of the study reported here were:

1) Develop and test in the Mount Hope River a mathematical model to simulate recession curves, and 2) apply this model to Fenton River to test hydrologic conditions under which this equation represent the recession cycle.

## METHODS

**Description of the study site**

The Fenton and Mount Hope Rivers, (Fig. 1), are two of three major streams that discharge into the Mansfield Hollow Lake. The other stream is the Natchaug River. The Fenton River has a total length of 23 km and drainage area of 89 km$^2$ (Warner *et al.* 2006) as it enters Mansfield Hollow Lake, while the Mount Hope River has a total length of 23 km and a drainage area of 74 km$^2$ at the USGS gage # 01121000 located at Latitude 41°50'37" and Longitude 72°10'10" North American Datum 1927 (NAD27) (USGS 2005).

The Fenton River water-supply wells are located in the floodplain of the Fenton River. The dominant unconsolidated materials in the Fenton River valley are coarse-grained stratified glacial deposits. Prior investigations by Giddings (1966), Rahn (1968) and LBG (2001) along the Fenton River Valley clearly indicate the presence of low-permeability layers of silt and fine sand (glacial lacustrine deposits) in the areas of Well B and Well C. These deposits vary from a few meters to more than ten meters thick. Uplands in the Fenton River watershed consist primarily of glacial till deposits. Hilltops and hillsides along Horsebarn Hill extend down toward the stratified drift and consist of thick glacial (drumlin) till. The till deposits generally vary in thickness from a few meters in shallow bedrock areas to ten meters, but can be greater in drumlin areas. Bedrock under the unconsolidated deposits consists of metamorphosed rock of Devonian or an earlier age. Three types of bedrock units have been identified in the area that was investigated in the project (LBG 2001), Hebron Gneiss, Brimfield Schist and the upper member of the Bigelow Brook Formation (Warner *et al.* 2006).

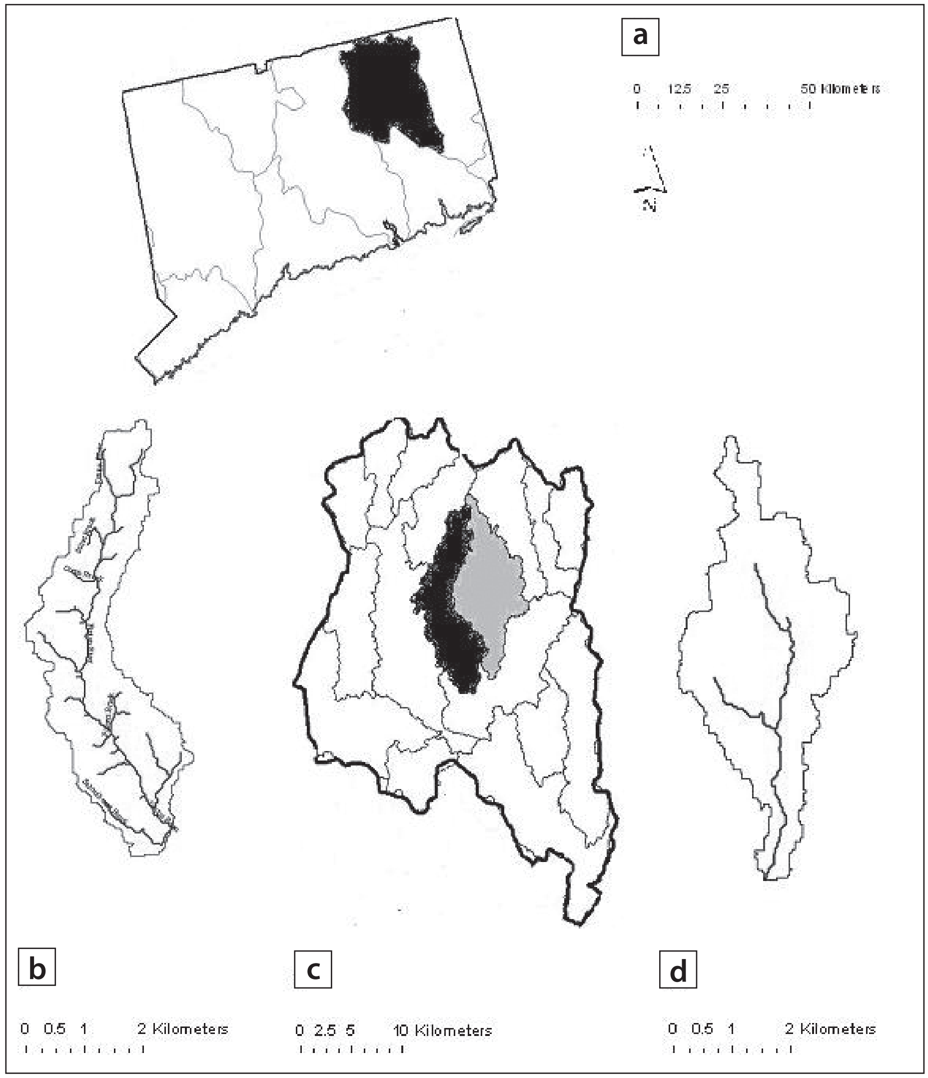


**Figure 1:** a) the State of Connecticut with the west branch of the Thames River watershed, b) Fenton river watershed, c) west branch of the Thames River watershed with the Fenton and Mount Hope Rivers watersheds and d) Mount Hope River watershed.

Prior to the UConn study in 2001 funded by the Willimantic Water Works, there had been no continuous stream gauges installed on the Fenton River, (Warner *et al.* 2006). The nearest long term stream gage is the USGS gage #01121000 on the Mount Hope River approximately 11 km from the Fenton River study area. The lowest recorded 7Q10 in the Mount Hope River at Warrenville was 0.011 $m^3/s$ on August 8, 1957. The USGS made same-day measurements at 10 sites along the Fenton River during 1963, one of the worst drought years in Connecticut history (Warner *et al.* 2006).

In August 1966, Rahn (1968) conducted a study on the effects of water withdrawals from the UConn well field on the flow in the Fenton River. Pump tests conducted using UConn's water supply Well B during a low-flow period in August 1966 resulted in the loss of surface water flow in segments of the Fenton River in the vicinity of the well field area extending approximately 2500 meters downstream. During this time surface flow in the Fenton River, approximately 304.8 m upstream from Well B was between 0.011864 $m^3/s$ and 0.012742 $m^3/s$. Portions of this work were also documented by Giddings (1966) in an UConn Master thesis. Giddings additionally reported that there was no surface water flow past the UConn water supply wells in the Fenton River in August 1965 (Warner *et al.* 2006).

**Field methods**

The daily streamflow records of the Mount Hope and Fenton Rivers during the summer season of 2005 were compared to check if both rivers had the same discharge trends and responses (peak flow, recession and baseflow). Figure 2 represents the streamflows observed in the Fenton and Mount Hope Rivers from 06/01/2005 to 09/17/2005.

Figure 3, shows the relationship between the streamflows observed in Mount Hope and the Fenton River from 06/01/2005 to 09/17/2005, the line of regression and the coefficient of regression.

The coefficient of regression between the Mount Hope and the Fenton Rivers streamflow obtained for a linear regression is 0.726, this is not a perfect regression

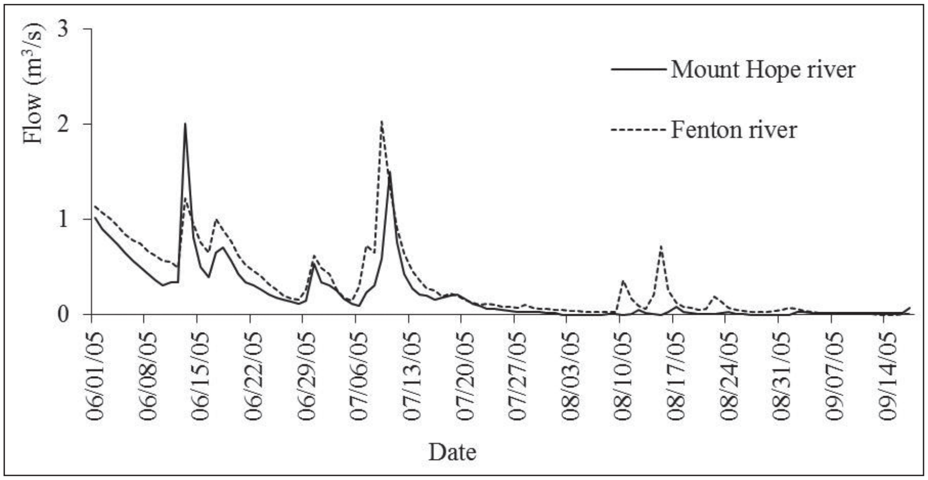


**Figure 2:** Fenton River and the Mount Hope River daily streamflows at Old Turnpike Bridge and Warrenville stations from 06/01/2005 to 09/17/2005.

due the scattered of streamflow measurements over 1.5 $m^3/s$, assuming as hypothesis that the model is for non-rainfall periods, under 1.5 $m^3/s$ for the Fenton and Mount Hope Rivers, it can be concluded that there is a strong linear relationship between the streamflows of the Mount Hope and the Fenton Rivers for non-rainfall periods.

Daily streamflow measurements from 1941 to 2007 for the Mount Hope River at the USGS station, (01121000) near Warrenville in Connecticut were used to compare the discharges in both watersheds. Recession curves were extracted from the daily record for all periods where there was a continuous decrease or constant average daily flow for 9 days or longer. The selected recessions were divided into four seasons; winter (January-March), spring (April-June), summer (July-September) and fall (October-December) for analysis. Since the critical baseflow period is the summer period, data analyses were focused on the July-September months.

A generalization of Equation 7 represented by the exponential Equation 8 was applied to find a relationship between the parameters $\alpha$ and $\beta$ for the exponential equation with the initial flow ($q_0$) at the start of the recession and the relative time of the recession (T).

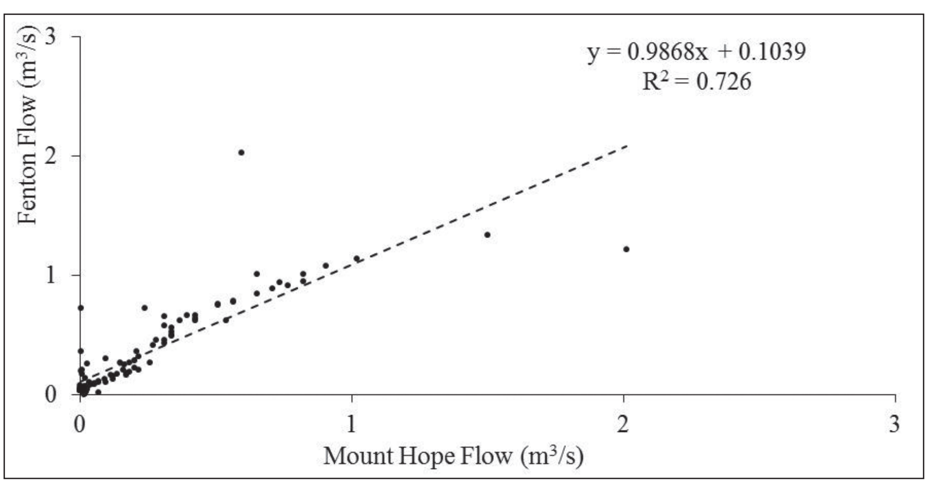


**Figure 3:** the daily Streamflows observed in Mount Hope and the Fenton River, the line of regression and the coefficient of regression from 06/01/2005 to 09/17/2005.

$$q_t = \alpha * e^{\beta * T} \qquad [8]$$

To determine the values that link the initial streamflow ($q_o$) and the parameters $\alpha$ and $\beta$ in Equation 8, a regression was performed between the parameters and the initial flow ($q_o$) for selected recessions from observed flow records during recession periods on 07/10/1997, 08/29/1997, 07/9/1998, 07/03/1/1998, 07/14/1999, 07/05/2000, 07/21/2000, 08/22/2001, 08/03/2002 and 08/14/2003.

A correlation analysis was then performed between the parameters a and b with qo and T to determine the best fit of the general exponential Equation (8). Results for the streamflows observed in Mount Hope and the Fenton River from 06/01/2005 to 09/17/2005 are shown in figures 4 and 5.

The coefficient of regression between the peak flows and parameter $\beta$ in Mount Hope River during recession periods obtained for a logarithm regression is 0.70, the logarithm function was the best fit between many functions tested, and therefore it was the function selected for the application.

The resulting regressions were inserted into Equation 8 to obtain Equation 9. The parameters $q_0$ and $q_t$ are the flows at T = 0 and at time T = t, while $ae_1$, $be_1$, $ae_2$, $be_2$ are parameters to be calculated and T is the time of recession in days.

$$q_t = (ae_1 q_0 + be_1)e^{(ae_1 Lq_0 + be_2)*T} \qquad [9]$$

Where:

| | |
|---|---|
| $q_0$ | Peak discharge before recession |
| $ae_1$ | Recession parameter |
| $ae_2$ | Recession parameter |
| $be_1$ | Recession parameter |
| $be_2$ | Recession parameter |

The simulated and observed discharges during recession for three events in the Mount Hope river and three events in the Fenton river were compared using the Nash - Sutcliffe model of efficiency (Nash and Sutcliffe 1970) given by Equation 10 and a linear regression developed within a spreadsheet.

$$NS = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O}_i)^2} \qquad [10]$$

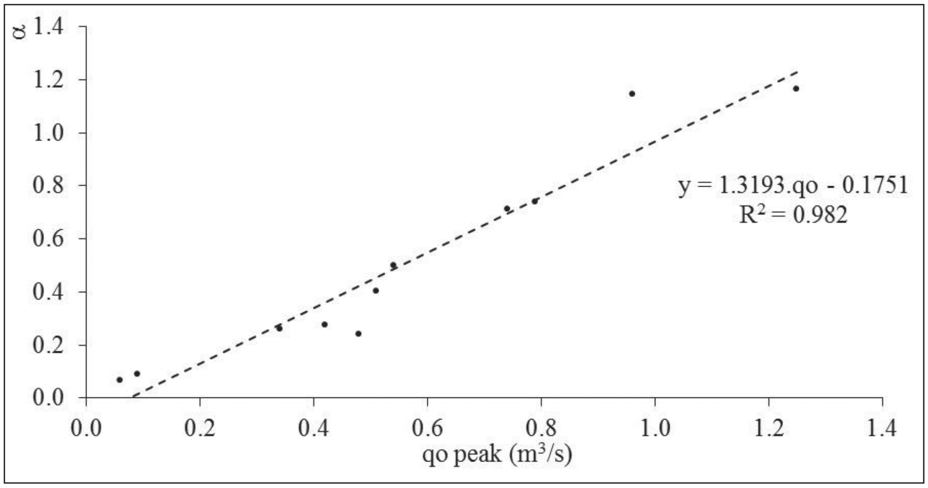


**Figure 4:** linear relationship between peak flows and parameter α in Mount Hope River during recession periods for exponential functions.

Where:

| | |
|---|---|
| $O_i$ | Observed discharges |
| $\bar{O}$ | Mean of observed discharges |
| $S_i$ | Simulated discharges |
| N | Number of steps modeled |

## RESULTS AND DISCUSSION

Table 1 shows the calibrated parameters for the Mount Hope streamflow for use in the exponential (Equation 9) equation from 6/01/2005 to 9/17/2005.

Figure 6 shows the application of the recession curve model in the Mount Hope River during eleven days of recession from 06/18/2005 to 06/28/2005 for a streamflow under 1.0 $m^3/s$ with no precipitation during the interval.

Another application of the simulation of baseflow recession as shown in figure 7 was conducted in the Mount Hope River from 07/13/2005 to 08/02/2005 for a streamflow under 0.3 $m^3/s$ with no precipitation during the interval of 21 days.

Figure 8 shows the application for the simulation of baseflow recession conducted in the Mount Hope River from 08/17/2005 to 09/07/2005 for a streamflow under 0.24 $m^3/s$ with no precipitation during the interval of 20 days.

Figure 9 shows the observed and simulated recession curves in the Fenton River during twelve days of recession from 06/18/2005 to 06/28/2005 for a streamflow under 1.0 $m^3/s$ with no precipitation during the interval of 11 days.

**TABLE 1:** calibrated parameters for the exponential recession curves for Mount Hope from 6/01/2005 to 9/17/2005.

| | Initial Flow ($m^3/s$) | | |
|---|---|---|---|
| Parameters | 0.71 | 0.28 | 0.22 |
| ae1 | 1.29 | 1.00 | 1.29 |
| be1 | -0.08 | 0.00 | -0.10 |
| ae2 | 0.01 | 0.02 | 0.01 |
| be2 | -0.18 | -0.12 | -0.18 |

The calibrated parameters for the Fenton River streamflow for use in the exponential (Equation 9) equation from 06/01/2005 to 09/17/2005 are summarized in the Table 2.

Another application for the simulation of baseflow recession as shown in figure 10 was conducted in the Fenton River from 07/13/2005 to 08/02/2005 for a streamflow under 0.5 $m^3/s$ with no precipitation during the interval of 21 days.

Another application for the simulation of baseflow recession shown in figure 11 was conducted in the Fenton River from 19/08/2005 to 09/09/2005 for a streamflow under 0.20 $m^3/s$ with no precipitation during the interval of 20 days.

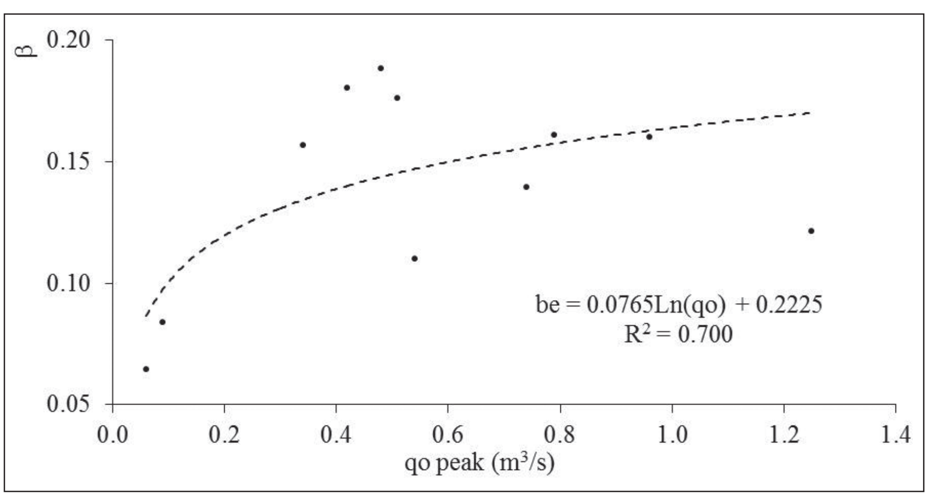


**Figure 5:** logarithm relationship between peak flows and parameter β in Mount Hope River during recession periods, for exponential functions.

### Parameters and statistical analysis

The statistical results of the simulated and observed discharges during recession in the Mount Hope River for the three events with the calculation of regression, correlation, Nash-Sutcliffe coefficients (Equation 10) and the slope of the regression line are summarized in the Table 3. For the three cases of the recession discharge simulation for low streamflow in the Mount Hope River, the coefficient of regression is greater than 0.86, the coefficient of correlation is greater than 0.92, the coefficient of Nash-Sutcliffe was close to 1.0 and the slope is close to 1.0 for each of the exponential functions. A coefficient of Nash-Sutcliffe of 1.0 corresponds to a perfect match of simulated to the observed recession data, therefore

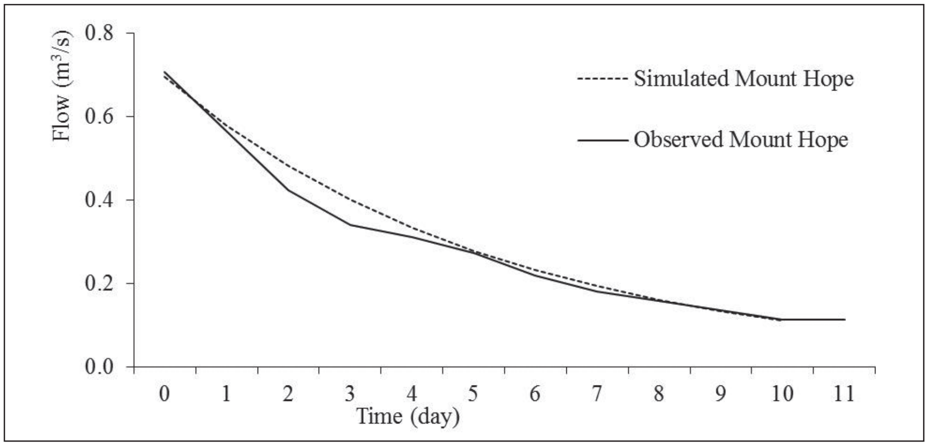


**Figure 6:** observed and simulated recession curves in Mount Hope River for streamflows under 0.71 m3/s from 06/18/2005 to 06/28/2005.

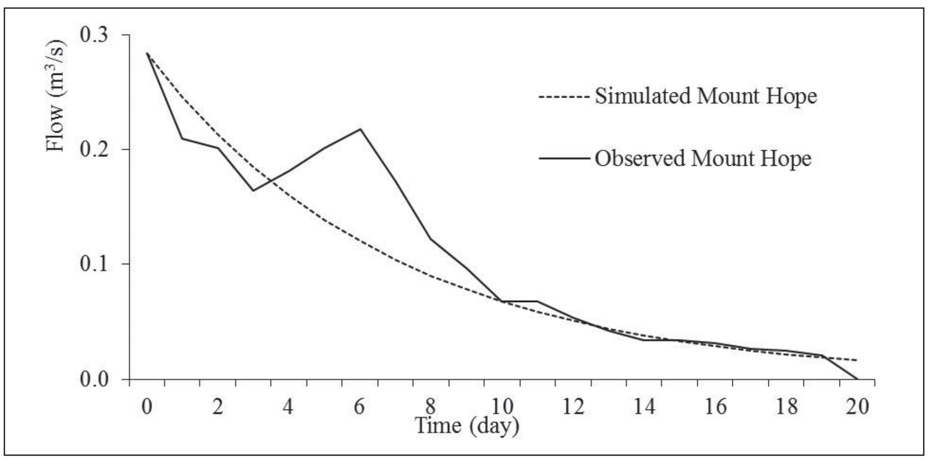


**Figure 7:** observed and simulated recession curves in Mount Hope River for streamflows under 0.28 m3/s from 07/13/2005 to 08/02/2005.

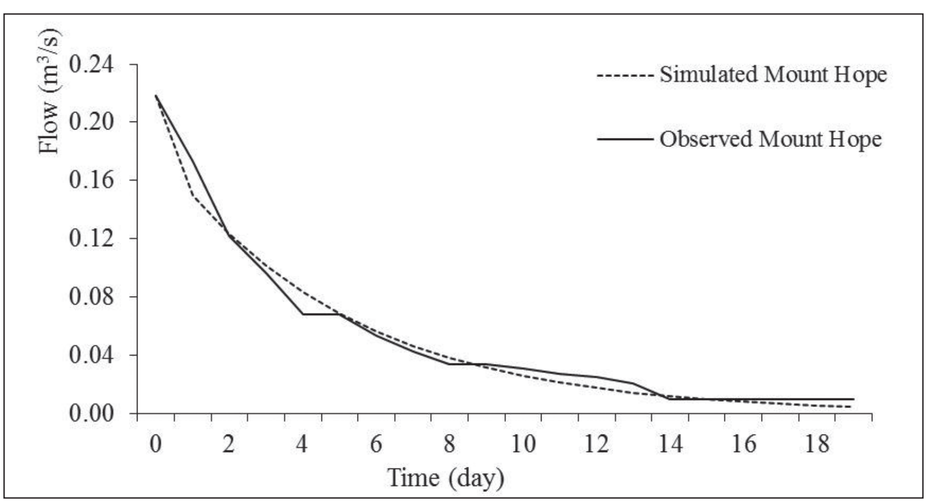


**Figure 8:** observed and simulated recession curves in Mount Hope for streamflows under 0.22 m3/s from 08/17/2005 to 09/07/2005.

**TABLE 2:** calibrated parameters for the Fenton River streamflow from 06/01/2005 to 09/17/2005 used in the equation 9.

| | Initial Flow ($m^3/s$) | | |
|---|---|---|---|
| **Parameters** | 1.01 | 0.46 | 0.21 |
| ae1 | 11.10 | 1.00 | 1.00 |
| be1 | -0.04 | -0.04 | 0.00 |
| ae2 | 0.23 | 0.35 | 0.30 |
| be2 | -0.18 | 0.15 | 0.37 |

the simulated recession shows a high correlation with the observed recession in the Mount Hope River.

The statistical results of the simulated and observed discharges during recession in the Fenton River for the three events with the calculation of regression, correlation, Nash-Sutcliffe coefficients and the slope of the regression line are summarized in the Table 4.

For the three cases of the recession discharge simulation for low streamflow in the Mount Hope River, the coefficient of regression is greater than 0.91, the coefficient of correlation is greater than 0.95, the coefficient of Nash-Sutcliffe was close to 0.0 and the slope of the line of the regression line is close to 1.0 for each of the exponential functions. A coefficient of Nash-Sutcliffe of 0.0 indicates that the model simulations are as accurate as the mean of the observed recession data, a coefficient of Nash-Sutcliffe less than zero means that the observed mean is a better predictor than the simulated values. Therefore the simulated recession shows a high correlation with the observed recession in the Fenton River.

Mean and Standard Deviation for the parameters ae1, be1, ae2 and be2 of the exponential function in the Mount Hope and the Fenton rivers for each of the three events simulated in each basin were calculated, Tables 5 and 6 summarize the values.

The values calculated for the standard deviation shows that shows that the variation of the parameters ae1, be1, ae2 and be2 calculated from the average is smaller in the verification of the exponential function in the Fenton river that in the application in the Mount Hope river.

The exponential model created use four empirical parameters, more than the expressions used by Boussinesq, (turnover time of groundwater storage), Barnes (storage delay factor), Coutagne, (groundwater storage, turnover time of groundwater storage and empirical parameter) and Chapman (turnover time of the groundwater storage at initial time of the simulation), all those equations are good fit under the conditions that correspond unconfined aquifer, however the exponential equation tested in the Mount Hope and Fenton Rivers with positive results is a new contribution for the study of the recessions in a streamflow.

These positive results can be explained by the complexity of the exponential equation applied, the exponential equation includes a linear and logarithm relationship, both empirically obtained, between the initial peak flow and empirical parameters. The linear function applied showed a strong relationship between the initial peak flow and parameter $\alpha$ in Mount Hope River, with a coefficient of regression greater than 0.98. The logarithm function used showed a weaker relationship between peak flows and parameter $\beta$ in Mount Hope River with a coefficient of regression of just 0.70. Even though this weak coefficient of regression, is strong enough to assume that the logarithm function is a first positive step to find a relationship between peak flows and parameter $\beta$, future research can focused on finding a better relationship between peak flows and parameter $\beta$.

In three opportunities there is a small increase of flow in the rivers without precipitations measured in the watershed, in the Mount Hope River from 07/13/2005 to 08/02/2005, and in the Fenton River from 07/13/2005 to 08/02/2005, and from 19/08/2005 to 09/09/2005. Those increases of flow can be attributed to a change in the trend of the groundwater contribution or more likely to a precipitation fall in a spot of the watershed not recorded by the rainfall stations, however this water contribution that increases the flow measured in the Fenton and Mount Hope Rivers for a short period of time,

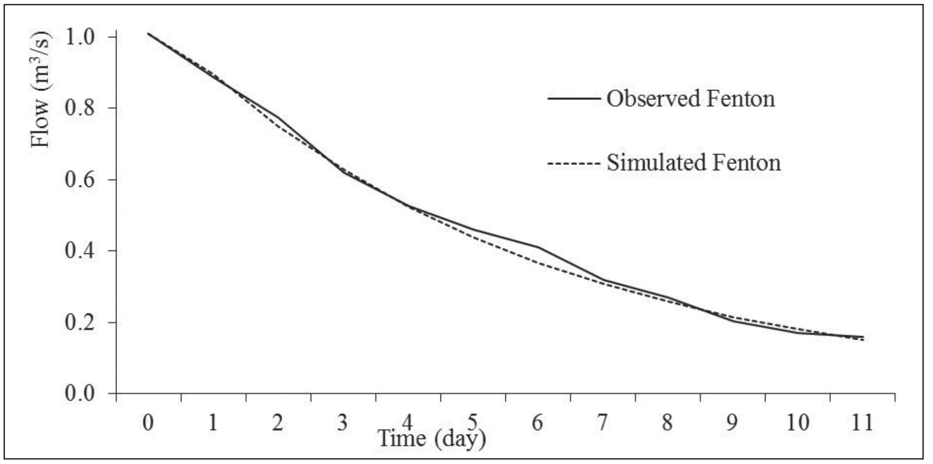


**Figure 9:** observed and simulated recession curves in Fenton River for stream flows under 1.01 $m^3/s$ from 06/18/2005 to 06/28/2005.

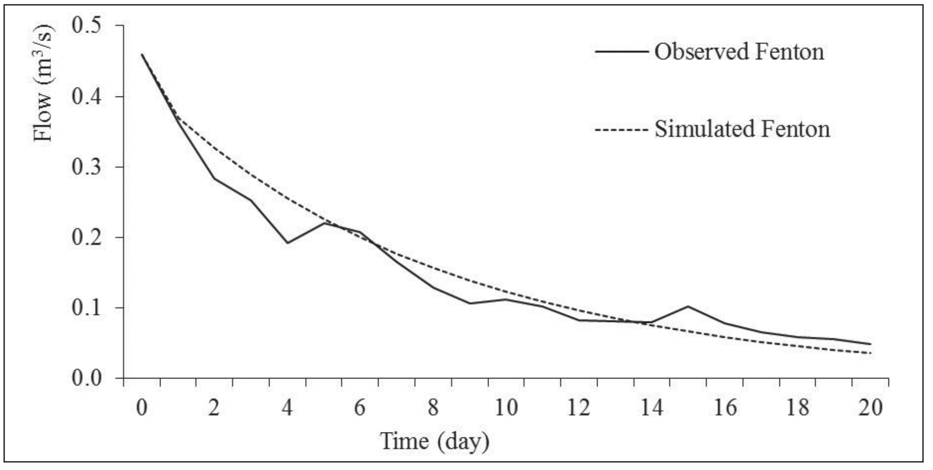


**Figure 10:** observed and simulated recession curves in Fenton River for streamflows under 0.46 m3/s 07/13/2005 to 08/02/2005.

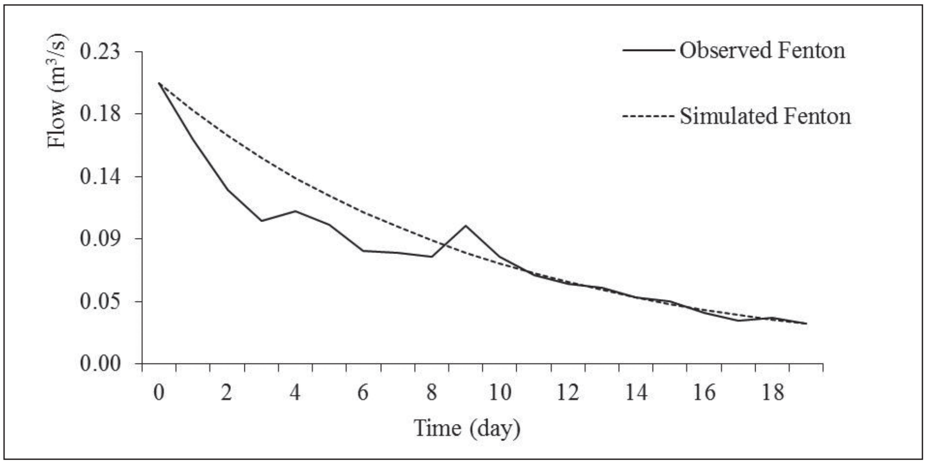


**Figure 11:** observed and simulated recession curves in Fenton River for streamflows under 0.21 m3/s from 19/08/2005 to 09/09/2005.

**TABLE 3:** regression, correlation, Nash-Sutcliffe coefficients and the slope of the regression line for the recession simulated in the Mount Hoper river.

| Events | Initial flow | $R^2$† | r | N-S | s |
|---|---|---|---|---|---|
| 06/18/2005 to 06/28/2005 | 0.71 | 0.98 | 0.99 | 0.79 | 1.01 |
| 07/13/2005 to 08/02/2005 | 0.28 | 0.86 | 0.92 | 0.85 | 0.87 |
| 08/17/2005 to 09/07/2005 | 0.22 | 0.98 | 0.99 | 0.98 | 0.98 |

†$R^2$ = coefficient of regression, r = coefficient of correlation, s = slope of the regression line, N-S = Nash-Sutcliffe coefficient.

**TABLE 4:** regression, correlation, Nash-Sutcliffe coefficients and the slope of the regression line for the recession simulated in the Fenton river.

| Events | Initial flow | $R^2$† | r | N-S | s |
|---|---|---|---|---|---|
| 06/18/2005 to 06/28/2005 | 1.01 | 0.99 | 0.99 | -0.33 | 1.00 |
| 07/13/2005 to 08/02/2005 | 0.46 | 0.96 | 0.98 | 0.22 | 1.07 |
| 19/08/2005 to 09/09/2005 | 0.21 | 0.91 | 0.95 | 0.00 | 1.12 |

†$R^2$ = coefficient of regression, r = coefficient of correlation, s = slope of the regression line, N-S = Nash-Sutcliffe coefficient.

don't change the main trend simulated for the recession model.

From the statistical results can be conclude that the exponential function created for the simulation of the streamflow recession curves of the Fenton and Mount Hope Rivers are representative of the discharges during recession periods simulated.

## CONCLUSION

Coefficients related with initial peak discharge before recession and time of recession using discharge records of two streams in eastern Connecticut (Mount Hope and Fenton Rivers) in exponential form of recession equations was estimated and applied.

The exponential function showed good approximation for the representation of the recession phenomenon, therefore it is possible to use an exponential function to predict the recession discharge for low flows in the Mount Hope and Fenton Rivers.

One of the main problems with using a recession equation in the past has been finding a relationship between the parameters included in the exponential equation for recession with the relative time of recession and the initial discharge before the recession. This goal was achieved by finding a linear and logarithmic relationship between parameters of the exponential equation with the initial peak flow before the recession**.**

The exponential function has empirical origins and for general applications in any basin and under any situation (low and high flows) analytical recession curves are needed. Future studies should focus on finding the relationship between the parameters of the exponential function and physical parameters of the stream basin.

**TABLE 5:** mean and standard deviation for the parameters ae1, be1, ae2 and be2 of the exponential function in the Mount Hope River for the three events simulated.

| | Parameters | | | |
|---|---|---|---|---|
| Mount Hope river | ae1 | be1 | ae2 | be2 |
| Mean | 1.19 | -0.06 | 0.01 | -0.16 |
| Standard Deviation | 0.14 | 0.04 | 0.00 | 0.03 |

**TABLE 6:** mean and standard deviation for the parameters ae1, be1, ae2 and be2 of the exponential function in the Fenton River for the three events simulated.

| | Parameters | | | |
|---|---|---|---|---|
| Fenton river | ae1 | be1 | ae2 | be2 |
| Mean | 1.03 | -0.03 | 0.29 | 0.11 |
| Standard Deviation | 0.05 | 0.02 | 0.05 | 0.23 |

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