Evaluating the Accuracy of the NRCS Lag Time Equation

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Abstract:

Lag time is a measure of the speed at which a watershed responds to a runoff-producing rain event; specifically, it represents the delay in time between the maximum rainfall and the peak discharge. Lag time is most commonly calculated using the National Resources Conservation Service's equation (NRCS), which is based on the physical characteristics of a specific watershed. This formula is shown in Equation (1):

$$T_l = \frac{L^{0.8}\left(\frac{1000}{CN} - 9\right)^{0.7}}{1900 S^{0.5}} \quad (1)$$

Where:
T_l = lag time (hrs)
L = longest hydraulic length of the watershed (ft)
CN = average watershed curve number
S = average watershed slope (%)

The goals of this study were to assess the prediction accuracy of this equation and to perform a statistical analysis to determine the presence of a relationship between lag time and some combination of watershed characteristics to develop a new lag time equation.

Process:

The first step in the process was to identify watersheds in the state of New Jersey with an area no greater than 50 square miles. This size limitation was implemented because Unit Hydrograph Theory, the method we used to back-calculate historical lag times, performs better with smaller watersheds and larger storm events. The coordinates, drainage areas, and flow data for each of these watersheds were then downloaded from the United States Geological Survey (USGS) website. Using these gage coordinates and the New Jersey StreamStats website, each watershed was delineated, and their shape files were downloaded for later analysis. Characteristics reports were run to obtain peak flow data, which was then combined with flow data from the USGS website to identify all storm flow data with peak flows in excess of 25 year storm events. Any storm flow graphs with significantly irregular shapes or inconclusive data were removed from the set.

Unit hydrographs were then derived for each of these hydrographs. To do this, flow data was plotted against time, and river baseflow was subtracted from the flow values to produce a direct runoff hydrograph. The volume of rain associated with each direct runoff hydrograph was divided over the watershed area to determine the depth of excess rainfall, which was used to convert the storm hydrograph into a unit hydrograph which produced one inch of runoff. Then, using the National Water Service (NWS) historical data website, the amount of rainfall from each of the storms for which hydrographs were developed was downloaded, and the Phi-Index Method was used to determine the duration of excess precipitation, or the duration of the unit hydrographs. Each unit hydrograph was then transformed into a one-hour unit hydrograph using the S-curve method, repeating and smoothing the curves until the final hydrograph made physical sense and had the desired duration. The lag time for each storm was back-calculated from the unit hydrographs using Equation (2):

$$T_l = T_p - 0.5 \quad (2)$$

Where:
T_l = lag time (hrs)
T_p = time to peak (hrs)

The next step was to predict lag times for each watershed using the NRCS equation. The downloaded shape files for each watershed were imported into the United States Department of Agriculture (USDA) Web Soil Survey to obtain soil data in the form of a soils map. These maps were used in combination with aerial photographs and land use tables to determine point-specific curve numbers and calculate an average curve number across each watershed. ArcGIS software was then used to determine the average watershed slope and longest hydraulic length for each watershed. The average curve numbers, longest hydraulic lengths, and average watershed slopes were then used in Equation (1) to calculate the predicted lag times.

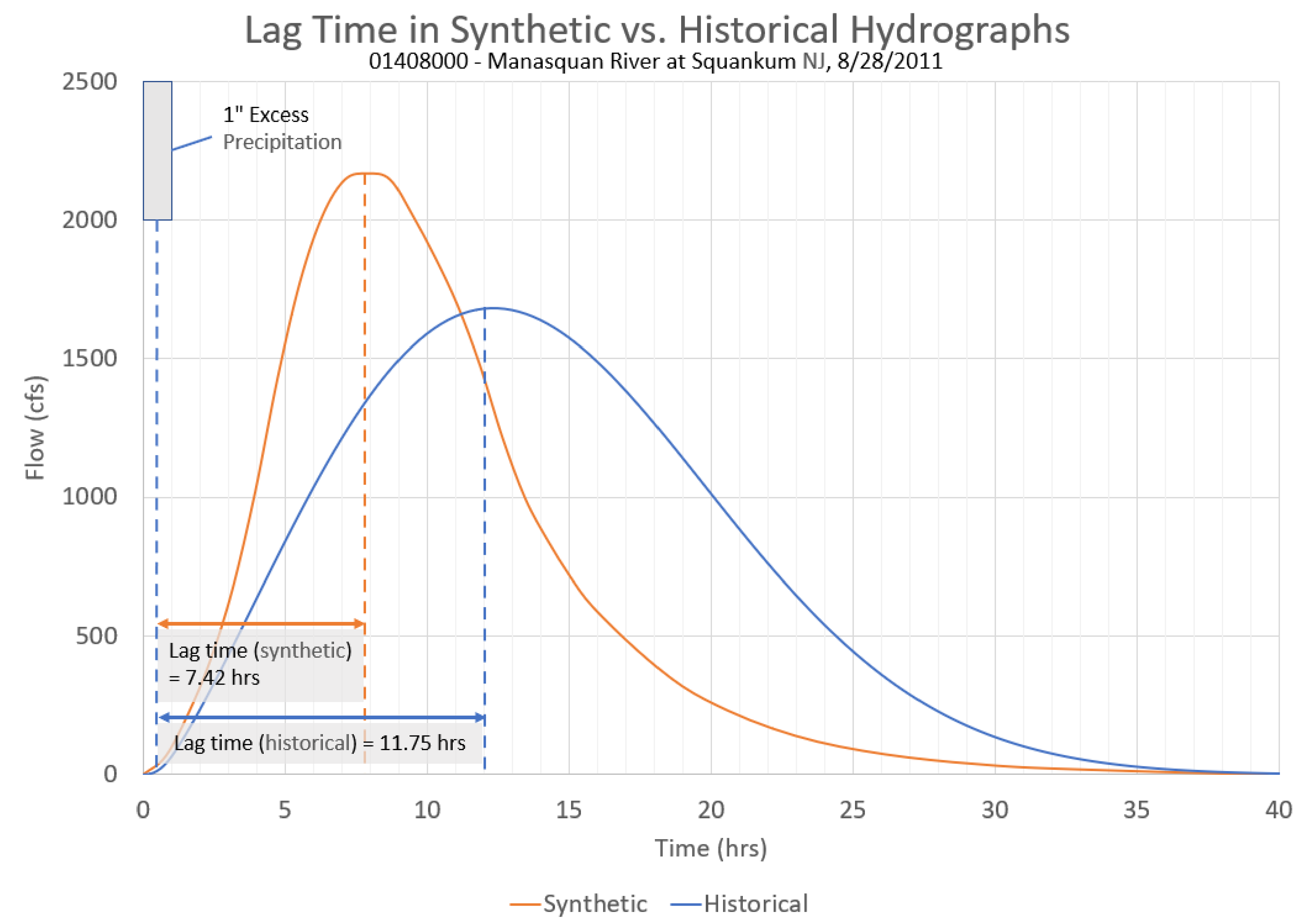

Figure 1 - Comparison of lag times for the same storm obtained using synthetic and historical methods

Table 1 - Lag times from each storm

Station #	Storm Date	Storm Lag Time from NRCS Equation (hrs)	Storm Lag Time from Historical Observations (hrs)	Station #	Storm Date	Storm Lag Time from NRCS Equation (hrs)	Storm Lag Time from Historical Observations (hrs)
01367800	8/28/2011	6.56	7.50	1408000	12/27/2012	11.70	13.00
01379699	8/28/2011	8.34	19.00		5/6/2017	8.03	12.25
01379780	8/28/2011	7.26	15.75		4/16/2018	8.80	15.75
01381400	8/28/2011	6.78	8.00		5/27/2018	15.19	12.50
01381500	8/28/2011	11.22	10.75		8/13/2018	22.27	4.75
01382170	3/11/2011	1.80	21.25		11/25/2018	8.76	11.75
01382210	8/28/2011	5.94	13.50	01408120	12/27/2009	12.12	30.25
01382270	8/28/2011	6.39	22.25		3/14/2010	19.31	37.00
01386000	8/28/2011	8.90	2.50		3/31/2010	22.86	39.00
01389550	9/6/2008	5.02	3.00		8/28/2011	31.30	13.25
	8/28/2011	5.74	5.00		5/1/2014	26.36	27.50
01391000	10/8/2005	7.55	22.00		8/13/2018	30.83	4.75
	3/2/2007	4.67	3.50	01410150	8/13/2000	6.01	10.75
	4/15/2007	6.19	12.75	01410784	8/28/2011	9.83	28.00
	8/28/2011	6.10	9.00	01410820	8/29/2011	16.12	28.75
01394500	8/28/2011	4.95	6.25	01411300	8/28/2011	30.27	10.50
01395000	8/28/2011	14.88	13.75	01411456	8/28/2011	7.23	13.00
01396190	8/28/2011	8.07	7.50	01412800	8/28/2011	13.90	11.00
01396800	8/28/2011	17.27	5.50	01439800	8/28/2011	9.10	5.75
01398000	8/28/2011	2.91	3.00	01443280	8/28/2011	4.82	22.00
01398500	8/28/2011	10.84	5.75	01445000	8/28/2011	8.27	29.00
01398900	8/28/2011	9.80	5.25	01446000	8/28/2011	8.11	26.00
01399500	8/28/2011	27.38	8.25	01455090	8/28/2011	9.09	8.25
	9/8/2011	20.26	3.50	01455500	8/28/2011	10.57	26.00
01403900	8/28/2011	9.04	11.50	01463740	8/28/2011	2.14	3.50
01405030	8/28/2011	12.04	11.25	01466500	8/28/2011	10.53	13.00
01406050	8/28/2011	8.21	8.00	01467081	8/28/2011	5.86	10.00
01407290	8/28/2011	4.72	9.50		8/28/2006	3.41	6.75
01407500	8/28/2011	10.97	13.25		4/15/2007	6.45	12.25
	12/27/2012	8.86	9.75	01467150	8/28/2011	10.77	1.50
	5/5/2017	5.65	8.25		4/30/2014	11.31	10.50
	5/27/2018	11.54	10.50		4/16/2007	8.52	15.00
	11/25/2018	6.93	7.00	01475001	8/28/2011	4.30	11.50
1408000	8/28/2011	7.42	11.75	01477120	8/28/2011	8.66	4.50

Results and Discussion:

The lag times for each storm were calculated using the NRCS equation and back-calculated from the historical data. The lag times from the NRCS equation were predictions of what would happen on a specific watershed in response to a given rain event, and the back-calculated values were based on historical data and show what actually happened when the rain event occurred in the past. The full set of lag times is shown in Table 1. Figure 2 shows a plot which compares the two datasets. The x-axis holds the lag times from the NRCS equation, and the y-axis holds the lag times from the historical back-calculation.

Drawn over the data on the plot is the function y = x. If the NRCS equation yielded a lag time equal to the known and historically accurate lag time for a specific storm, then the point representing that storm would fall on the line, denoting that the NRCS equation gave an accurate prediction. An analysis of the data shows almost no correlation between the lag times predicted with the NRCS equation and the historically accurate lag times, even when a different line of best fit other than the one which is theoretically best is used ($r^2 = 0.03$).

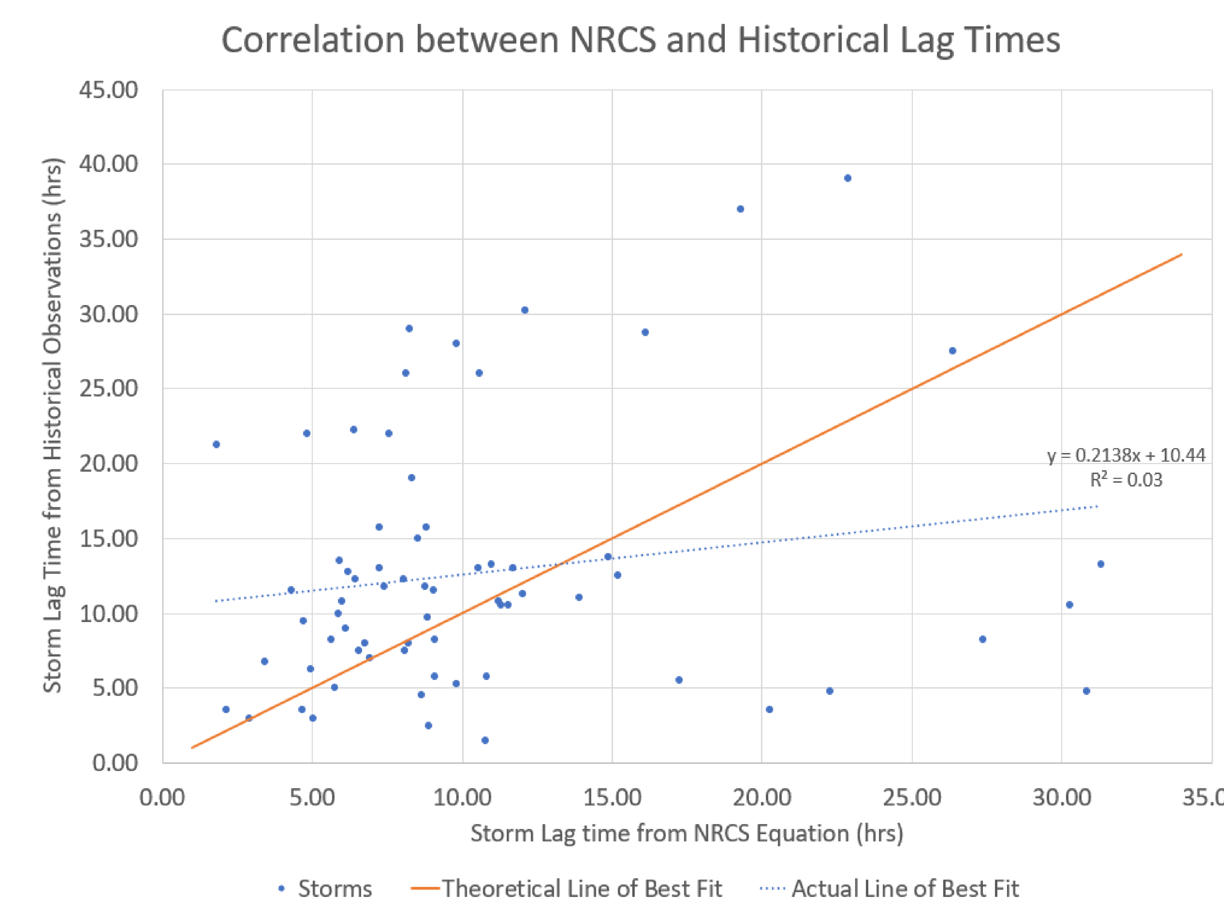

Figure 2 - Plot comparing the NRCS and historical lag times and theoretical vs. actual lines of best fit

Conclusions:

The lag times found using the National Resources Conservation Service (NRCS) lag time equation differed greatly from those back-calculated using Unit Hydrograph Theory and historical data, but there is no clear pattern in the differences. The evaluation of the NRCS equation shows that it is not accurate or precise in its predictions of storm lag time. A new equation for predicting storm lag time based on watershed characteristics was not developed in this study. The extremely low correlation ($r^2 = 0.03$) between the predicted and historically accurate lag times does not make the possibility of developing a replacement equation that accurately predicts lag time from watershed characteristics seem likely, but it remains possible that some combination of watershed characteristics may yield more accurate results than the existing equation.

Future Directions:

The authors intend to expand upon this research by performing a statistical analysis on the characteristics of the watersheds that were used in this analysis in an attempt to obtain an equation that yields more accurate predictions of lag time than the NRCS lag time equation currently does.

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