CHANGE IN STREAMFLOW TIMING IN THE NORTHEASTERN UNITED STATES

THESIS

Submitted in partial fulfillment of

the requirements for the degree

Master of Engineering (Civil)

at

The City College

of the

City University of New York

By

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January 2010

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1.0 Acknowledgments

The work described in this report was partially supported by the National Oceanic and Atmospheric Administration, Cooperative Remote Sensing Science and Technology Center (CREST) of the City College of New York under the supervision of CREST director, Dr. Reza Khanbilvardi. Special thanks to Cecilia Hernandez for her encouragement and help during all steps of the project and to my advisor, and professor in the Civil Engineering Department, Dr. Nir Krakauer. Also, thanks to my family for their support in this new step in my life.

2.0 Abstract

Climate models and historical trends demonstrate that warming of the world's temperature is taking place. These changes in temperature result in a shift in the timing of hydrological events, such as an increase in the winter streamflow and decrease in the spring and summer streamflow. Regions with persistent snow/ice during winter, located in latitudes greater than approximately 45 degrees North and South, could be particularly affected by these shifts and variations. The increase in winter streamflow is due to the change in precipitation patterns, with less precipitation as snowfall and more as rainfall, and earlier snowmelt. This leads to an earlier spring peak in runoff affecting areas such as the northeastern United States, which may also result in a reduction in the available water supply for the warm months. We used the Hydro-Climatic Data Network (HCDN) from the USGS, a data set that consists of daily streamflow records from basins relatively free from anthropogenic influences, to quantify the changes in streamflow timing in the northeast of the United States. A shift in average of approximately of 5.5day/ºC in the timing of peak streamflow is taking place as result of the warming in surface temperatures for the extreme northeast US; in the other hand low latitude areas have a lower magnitude in the shift in peak streamflow, consistent with the lesser importance of snow in the annual hydrologic cycle farther south. An increase of approximately 5% in the volume of water before the peak streamflow for the same region is observed. Understanding the magnitude of the shift in streamflow is extremely necessary for determining the effects on water availability and providing assessment for future improvement of water management.

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5.0 Hypothesis

It is believed that global warming has produced a change in climatological patterns around the world. This includes change in hydroclimatological parameters as temperatures, streamflow and precipitation. A change in magnitude of temperature and precipitation in specific locations can affect the surface hydrological conditions of the area, and even the water resource availability. A decrease in precipitation in certain seasons, together with an increase in temperature, would cause severe water scarcity and drought in many places, while in others increasing precipitation or more severe storms would cause extreme floods. In regions with extensive winter snow, such as the northeastern United States, warming will cause a shift of the peak streamflow towards the winter season. This shift in the timing of average peak streamflow is due to early melting of snow and ice and changes in precipitation patterns during winter and early spring, with more precipitation as rainfall and less as snowfall.

An early melting of the snow and ice, and an increase in precipitation as rainfall and a decrease as snowfall, has been documented around the world and in the western United States. The melted ice and snow then runs off earlier during the winter season and will affect river discharge; changes in those two parameters will produce a change in streamflow magnitude and timing. This can also be seen in interannual variability with earlier peak flow and lower spring and summer flows in warmer years.

6.0 Introduction

6.1 Scope of the question

The main objective of this research was to quantify the change in the timing of peak streamflow occurring in the northeast United States due to a change in surface temperature and its effect on precipitation and snow/ice melting patterns during winter and spring. This includes the analysis of a possible seasonal variation of the different variables involved due to climate change. We address the following key questions:

- What are the trends for hydro-climatic variables as streamflow, temperature and precipitation in the northeast United States in the last 60 years?
- What is the seasonal variation in streamflow and precipitation?
- What is the main contributor to the change in the timing of peak stream flow?
- What is the spatial pattern in the timing of peak streamflow?
- What is the magnitude of the change in timing of the peak streamflow due to the warming of earth?
- Is there any change in the precipitation seasonal pattern that contributes to the shift in the timing of the peak streamflow?

In addition to the implication that this research can have to the scientific community related to climate change, the result presented may have great importance to the future of the assessment and planning of water resources and engineering designs in the northeast United States. Other questions may be raised based on results, and the

possible effect of changes in timing to the existing water infrastructure for these snow dominated regions.

6.2 Literature Review

6.2.1 Hydrologic cycle and precipitation

In the hydrological cycle, which is the process where water continuously moves between the oceans, atmosphere and land, precipitation as rainfall or snowfall is the main driver of the land surface hydrologic processes (e.g. runoff, infiltration) but it is also one of the main components that closes the cycle. Therefore, of primary importance is understanding the changes in precipitation, the effect of temperature in its patterns and finally its hydrologic response in terms of streamflow and timing. Precipitation distribution around the world is highly dependent on the global general atmospheric and ocean circulation, and because of this it is unevenly distributed around different latitude zones. Precipitation has its maximum near the equator, where solar radiation, evaporation and moist convection are most intense. In midlatitudes, around 45° north and south, global precipitation has its second peak. This second peak is the one with more interest for us due to location of the study area, the northeast United States. This second peak is associated with the characteristic weather systems such as cyclonic disturbances and synoptic storm systems, with strong winds that drive vertical motion and release water. In the US, studies done in the northeast region have shown that the amount of precipitation is almost independent of the season. In this area frontal precipitation is replaced by summer convective precipitation. No obvious changes related to the seasons and the amount

of rainfall have been recorded in the northeast United Sates, but there is theoretical expectation that climate warming will result in increased evaporation and precipitation leading to the hypothesis that one of the major consequences will be an intensification or acceleration of the water cycle (DelGenio et al. 1991, Loaciga et al. 1996, Trenberth et al. 1999, Held and Soden 2000, Arnell et al. 2001, Huntington et al. 2005). This could mean an increase in precipitation due to the increase in moisture and water vapor in the atmosphere.

Furthermore an increase in an overall temperature, for a snow dominated area, as the northeast United States, will ultimately change the amount of precipitation reaching the surface as snowfall during the winter season. Since 1970, the northeast region of the United States has experienced an increase in temperature of about 0.25°C/decade (Hayhoe et al 2006). Huntington et al 2004 analyzed the snow to precipitation ratio (S/P) for the period of 1949 to 2000 in New England, and found a general decrease in the S/P ratio. This is one of the explanations for a decline in snow cover area, and the future projections of snow cover decline for the northeastern United States (see appendix, Figures 13 and 14). Regional trends in surface temperatures modify hydrology through changes in the volume, intensity, or type of precipitation (rain versus snow), and through shifts in seasonal timing of streamflow (Regonda et al. 2004).

6.2.2 Temperature and snow cover in high latitude areas

The northeast United States is located in the northern hemisphere between the latitudes 37°N to 45°N, where although there is an approximately the same amount of monthly precipitation during the whole year, the nature of the storm that produces the precipitation is not the same. During late fall, winter and spring seasons most of the precipitation is based in cold fronts, and especially during the winter season bringing precipitation in the form of snowfalls. Snow accumulation, cover and duration through the northeast varies, from the extreme northeast US with at least 2.5 cm on the ground for more than 100 days each year to southern region of the northeast US, Maryland, Delaware and Virginia, with less than 30 days of snow cover (Leathers et al. 2005). Changes in temperature could greatly affect the hydrological conditions of this mid latitude area, which is dominated by snow during part of the year. Northern Hemisphere higher latitude regions are expected to be particularly sensitive to climatic change in part because anthropogenic warming is expected to increase poleward (ACIA, 2005; IPCC 2007a).

The presence of a snow cover affects a myriad of environmental and societal systems through its modification of surface energy balance and its ultimate impact on near surface air temperatures (Leathers et al 1995). Winter season is the time of the year where potential evaporation is the lowest due to low incoming electromagnetic radiation and high albedo. With a warmer temperature, loss of snow pack earlier during the winter is expected, and this could lead to a reduced surface albedo and a positive feedback of evapotranspiration due to an increase in radiation (Adam et al

2008). This reduction in snow cover can be translated to an increase in stream flow for the same period of time because of the earlier snowmelt and more rainfall. The maximum extent of seasonally frozen ground has decreased by about 7% in the Northern Hemispheres from 1901 to 2002, with a decrease in spring of up to 15% (IPCC, 2007a); Figure 1. Many areas of the northeast US have had a decrease in snow cover of 20 to 30 days per year (Wake et al. 2005). Historically we have therefore seen a reduction in the amount and duration of snow covered area, but also an advance of the snow melt day. As mentioned, a decline of snow cover area could imply an increase in the runoff, therefore in streamflow during the same period of time, and because of that a shift of the peak streamflow towards the winter season.

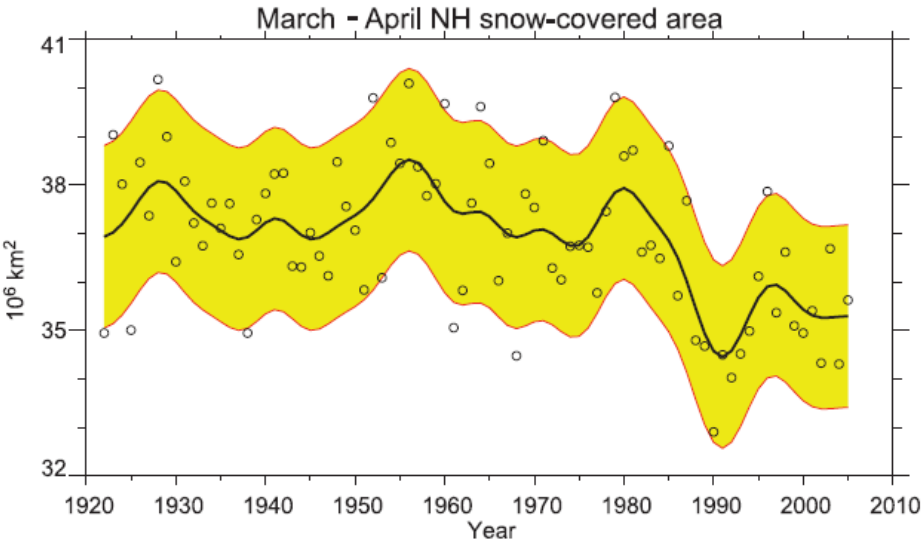

Figure 1: Northern Hemisphere March-April average snow-covered area (SCA) from Brown (2000). Graph was obtained from the IPCC 2007a. The snow covered area has shown a decreasing trend since about 1950, with large interannual and decadal variability.

7.0 Methodology

7.1 Location Characteristics

The selected area of study is the northeast United States; this includes 12 states, and extends from the most northern state of Maine to the most southern state of Virginia. Most of the states, excepting Vermont, have the Atlantic Ocean to the east and a range of mountains in the interior and west. The topography goes from the plain coast to the high-elevated areas with the individual mountains averaging around 1,000m in the Appalachian Mountains. Because of the geographical position and topography the northeastern states possess a wide range of climates, precipitation varies from over 50 inches (1.3 m) annually in some coastal areas, to 32 inches (810 mm) in the western part of Pennsylvania and New York (Figure 4). Snowfall can range from over 100 inches (2.5 m) per year in upstate New York to only trace amounts in the coastal areas of southern New Jersey. Generally, northern New England, the parts of New York north of the Mohawk River, highland areas in the Appalachians and some coastal areas possess a warm summer humid continental climate with warm, humid summers and snowy, often bitterly cold winters. Further south, much of the region (except for the higher elevations) has a hot summer humid continental climate with hot, humid summers and cold, snowy winters. Much of New England and the northern part of the Mid-Atlantic States have this climate.

Figure 2: Topographic representation of the northeast United States[4], showing the New England and Mid Atlantic Region.

7.2 Data Used

7.2.1 Stream Flow

Streamflow data was obtained from the Hydro Climatic Data Network (HCDN)[1] and the US Geological Survey (USGS). I used the HCDN data set, which consists of stream flow records for 1,659 sites throughout United States and its territories. Records cumulatively span the period 1874 through 1988. Only records of streamflow that are largely unaffected by artificial diversions, canalizations, storage, or any other anthropogenic action were used in this data set, which allows the study of natural weather variability in streamflow and its relation with precipitation and temperature changes throughout the period of record. No reconstructed record of "natural flow"

was permitted, nor was any record extended or had missing values "filled in" using computational algorithms (Slack and Maciunas, 1992).

We obtained daily stream flow (cfs) for 232 gage stations in the northeastern United States. This is the New England and Mid Atlantic regions, Region 01 and 02 of the USGS, including the states of Connecticut, Delaware, New Hampshire, New Jersey, New York, Main, Maryland, Massachusetts, Pennsylvania, Rhode Island, Vermont and Virginia. Our study period is from 1950 to 2008; the period of time from 1989 to 2008 was filled directly from the United States Geological Survey (USGS). The following figure contains the spatial location of the selected 232 stream gages, Region 01 and Region 02 (USGS), used in the analysis.

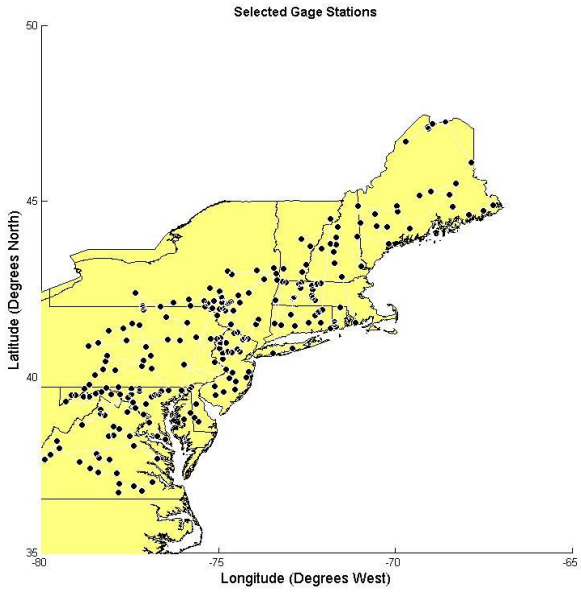

Figure 3: Location of streamflow gages used for the analysis.

7.2.2 Precipitation

Data for precipitation was obtained from the Global Precipitation Climatology Center (GPCC)[2], established in the year 1989 on request of the World Meteorological Organization (WMO). This is gage-based gridded monthly precipitation data sets for the global land surface, available in spatial resolutions of 1.0° x 1.0° and 2.5° x 2.5° geographical latitude by longitude. For our study the 1.0° x 1.0° global grid was use to obtain the precipitation (mm/month) for the northeast United States for the period of study.

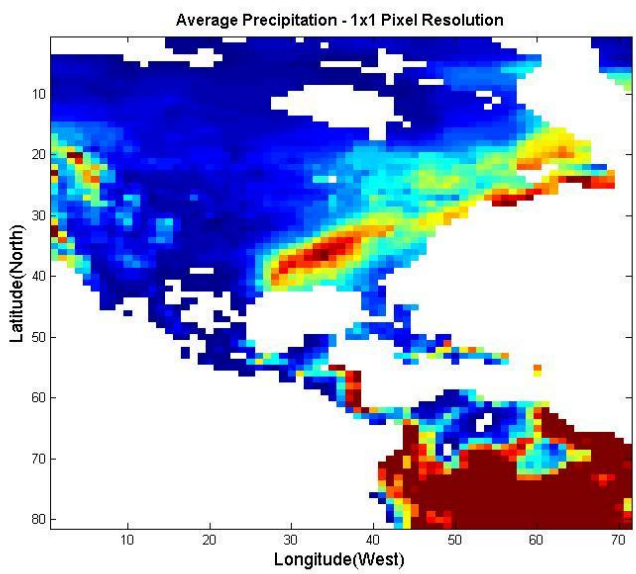

Figure 4: Average precipitation for the period February to April, for the water years: 1951-2008, from GPCC 1.0° x 1.0° global grid.

7.2.3 Temperature

Data was obtained from the National Climatic Data Center (NCDC)[3]. The major parameters in this data file are sequential statewide, regional, and national monthly precipitation and monthly "time bias corrected" average temperature. The period of record is 1895 through the latest month available, and we obtained the data for the

period of 1950 to 2008. This data set contains temperature in degrees Fahrenheit in a 2.5º x 2.5º global grid. The statewide values are available for the 48 contiguous States and are computed from the divisional values weighted by area, seen in Table 1. As previously mentioned in the streamflow sections, the northeast United States was selected as the study area, the following table includes the states in the study area, the state value or 'name' given by NCDC and the state area weights.

Table 1: Values representing each state in the NCDC database and the weight they represent for calculations.

State	State Value	State Weights
CT	6	0.02752
DE	7	0.0113
ME	17	0.18251
MD	18	0.05812
MA	19	0.04537
NH	27	0.05112
NJ	28	0.04306
NY	30	0.27242
PA	36	0.2491
RI	37	0.00667
VA	44	0.13900
VT	43	0.0528

7.3 Apparatus/Program

Average daily streamflow, monthly temperature and precipitation were collected for up to 58 water years for 232 gages. Because the amount and type of data collected, I required a computer program prepared to store, modify and manipulate data in such a way that would allow me to have the result in table and as in graphs. MATLAB R2008a was used as the main tool for that purpose. It allowed me to retrieve the data, make statistical analysis and show result geospatially.

7.4 Procedure and Assumptions

7.4.1 Assumptions

There are many complex relationships between the hydraulic, hydrologic and climatic variables involved in this study, because of that for this analysis we established some assumptions:

1. Changes in temperature are not limited to a specific basin or watershed. A change in temperature is going to have regional effect; therefore all the gage stations will likely experience similar change in temperature. In this case we presumed that a drastic change in temperature, as what occurs during the transition from winter to summer, will have the biggest impact on the average streamflow and will represent the highest extreme because the snow melting regime.
2. Temperature during the months of February, March and April are going to be the determining factors for the changes in streamflow and because of that the timing of peak streamflow. An average between the three monthly average temperatures is used for the regression analysis.
3. It is important to notice that the maximum daily average streamflow is not necessary the maximum flow for the day, since the USGS only records hourly streamflow values and determines the daily average. This will not represent a big difference or error in big watersheds where the stream have high flows, but for small watersheds and stream with small flows and high variability it could represent a source of error.

4. Interpolated precipitation data with a 1ºX1º resolution, with implicit regional characteristics and distribution, is assumed representative of the real precipitation for each watershed contained in the area. We only analyzed the time distribution or seasonal variation in precipitation.
5. Gage stations that contained the specification '*N*' by the USGS were eliminated from the analysis because there are not considered suitable or reliable information by the HCDN.

I collected average daily streamflow data from 1950 to 2008 (or 1951 to 2008 water years), and eliminated station with no reliable information according to USGS standards. All around the US there has been a tendency of a decline in the number of station recording data related to streamflow. The northeast United States is not the exception; there are gage stations that stopped recording daily average streamflow data between 1950 and 2008, which is the period of study. Because not all the stations have the complete set of data, I considered for the analysis gage stations with more than 12 years of consecutive streamflow data.

I created a complete series of 365 days of daily average streamflow for each year and gage station. Based on the complete series hydrograph, the day where the daily average peak streamflow peaks was determined. Because the hydroclimatic conditions of the regions, which causes a second peak of streamflow during the late fall and early winter months, I only looked for the peak streamflow created by the snow-ice regime, which occurs during or after winter (January –June). In Figure 5 a

diagram of values and parameters observed in each hydrograph is shown. I completely neglected the second peak which is caused or triggered by precipitation patterns during fall, only taking into consideration the peak streamflow caused by the change in temperature and the streamflow as the snow and ice melts. Also to minimize the effect of individual storms that could create a peak higher than the average peak streamflow caused by snow melting, a seven-day moving average was applied to the average daily streamflow. By doing so a reduction of peak streamflow related to specific events was obtained, providing a more consistent measure of spring peak streamflow. I analyzed the first six months of the year to find the time where the average daily streamflow peaks. I recorded for each year available and gage station the timing of average peak streamflow, the average peak streamflow, the total amount of flow from the beginning of the year to the peak, the change in total streamflow to the average peak for the station and monthly streamflow.

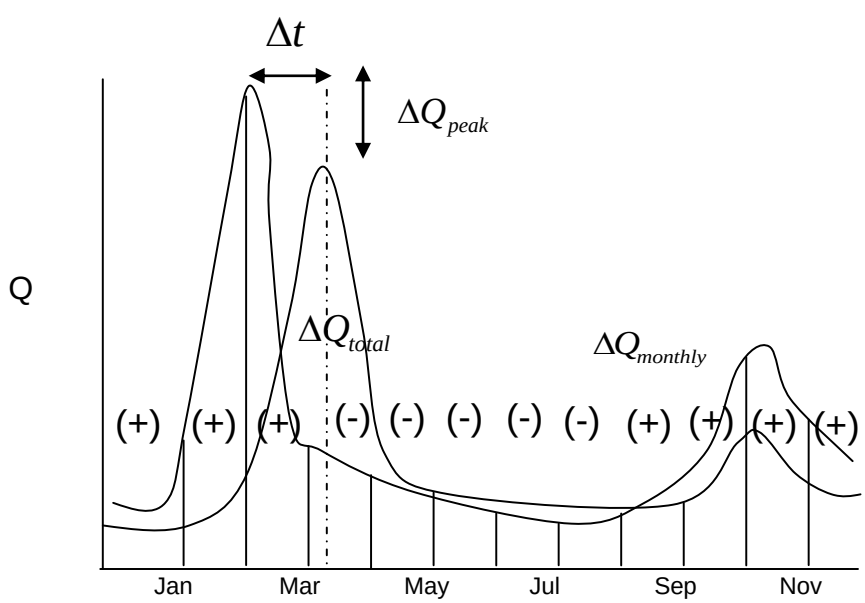

Figure 5: Schematic representing seasonal hydrograph and changes in its shape expected to result from warming.

7.4.2 Minimum temperature analysis

In order to better understand the spatial and temporal nature of the change in the timing of peak streamflow during the late winter and spring season, and its relationship with other variables, we divided for the analysis of the peak streamflow timing, the northeastern gages in four different groups. These groups are based on the average minimum temperature registered for each gage station for the period of the months of February, March and April from 1950 to 2007. Thus, we divided the stations into quartiles, from the "coldest" (Case I) to the "warmest" (Case IV) stations, using the average minimum temperature for the February to April period. After definition of the four groups, temperature, precipitation, streamflow, peak streamflow and timing of the average peak streamflow where obtained for each one of the cases.

We created linear regression for temperature, precipitation and streamflow as time series, or the trend that the parameter have had in the last 58 years. Using the following equation:

$$T = \alpha t \square \beta$$

Where:

T = parameters (temperature, precipitation or streamflow)

t = time in years

β = intercept

One possible concern in relation to obtaining the change in the day of the peak average streamflow, change in average monthly streamflow and other relationships is the presence of two or more causative mechanisms, as for example an increase in temperature along with precipitation during late winter. The combination of both factors will contribute to a possible shift in the peak streamflow timing. Based on various causative mechanisms that could be influencing the timing of peak streamflow we created multivariable linear regression following the next equation:

$$S = \alpha T \square \beta P \square \lambda$$

Where:

S = timing in days

α = regression coefficient for temperature (day/ ºC)

β = regression coefficient for precipitation (day/mm)

λ = intercept

8.0 Results and discussion

8.1 Temperature trends in the northeast United States

The research is concerned with the consequences of an increase in temperature in the northeast United States. Showing the trends that this variable has had is important and necessary to proceed with the next analysis.

Temperature in the northeast United States has a great variation from summer to winter. The coldest months are January and February. During March the average temperature is close to the melting point (Table 2). This is the period of time where

the late March – early April average streamflow peak starts to rise. In Tables 2 and 3 shows the mean temperature per state and month and the time series regression of temperature. For the most part is important to notice that the temperature has an increasing trend all over the northeast for almost every month over the 1950-2008 period with one exception. October, according to the result obtained with the data set, has shown a trend toward decreasing temperatures.

In general, the regression coefficient for every state shows that for the months of March and April the temperature has been increasing and values for the linear regression varies from -0.005 to 0.025 ºC/yr. An increase of 0.025 ºC/yr is approximately for our period of study is an increase of 1.45ºC in surface temperature. States as Maine, New York, New Hampshire and Vermont, which in average have had a temperature lower than the melting point for the month of March have had a rate of change in temperatures of -0.001, 0.013, 0.014 and 0.004 ºC/yr respectively, corresponding to a change of -0.06, 0.75, 0.81 and 0.23 ºC, respectively for the period of study. Although resolution for temperature data set is not high and great variability inside state borders exists, changes in temperatures typically span extended areas. States as New York and New Hampshire that have average temperature for the period of study close to the melting point, and have experienced an increase of almost 1ºC in average, are at risk to undergo the highest change in the timing of peak stream flow. It is important to recognize that regional variations could be significantly higher than those recorded by the state level temperature data, hydroclimatological conditions are not subject to political boundaries.

Table 2: Temperatures for the northeast United Sates.

	Monthly Average Temperature (ºC) for the Period 1950-2008											
States	January	February	March	April	May	June	July	August	September	October	November	December
Connecticut	-3.4	-2.2	2.3	8.4	14.0	19.0	21.8	20.9	16.6	10.7	5.3	-0.8
Delaware	14.4	15.5	18.1	20.9	24.2	26.6	27.5	27.5	26.3	22.7	18.5	15.3
Maine	-9.8	-8.5	-2.9	3.9	10.6	16.0	18.9	17.8	13.1	7.1	1.1	-6.3
Maryland	0.3	1.4	5.9	11.6	16.8	21.6	24.1	23.3	19.5	13.3	7.6	2.3
Massachusetts	-3.8	-2.7	1.6	7.6	13.3	18.4	21.3	20.4	16.1	10.2	5.0	-1.1
New Hampshire	-7.5	-6.2	-1.0	5.6	12.0	17.2	19.8	18.6	14.1	8.1	2.3	-4.5
New Jersey	-0.7	0.4	4.6	10.3	15.8	20.8	23.5	22.7	18.7	12.6	7.2	1.6
New York	-6.1	-5.2	-0.3	6.6	12.8	17.9	20.4	19.4	15.2	9.2	3.4	-3.2
Pennsylvania	-3.2	-2.2	2.4	8.8	14.3	19.1	21.5	20.6	16.6	10.5	4.9	-0.9
Rhode Island	-1.6	-0.7	3.0	8.2	13.4	18.5	21.7	21.1	17.2	11.6	6.6	0.9
Vermont	-8.6	-7.4	-1.9	5.3	12.0	17.1	19.6	18.4	14.0	7.8	1.9	-5.2

Table 3: Time series regression values for temperature for each month by state.

	Change in monthly temperature (ºC/yr) for the Period 1950-2008											
States	January	February	March	April	May	June	July	August	September	October	November	December
Connecticut	0.010	0.015	0.021	0.011	0.016	0.013	0.013	0.024	0.015	-0.012	0.009	0.028
Delaware	0.000	0.008	0.014	-0.002	0.000	0.005	0.011	0.006	0.004	0.011	0.027	0.019
Maine	-0.023	-0.009	-0.001	-0.002	0.000	0.003	-0.003	0.011	0.009	-0.014	-0.008	0.016
Maryland	0.007	0.010	0.025	0.012	0.004	0.012	0.012	0.018	0.010	0.000	0.025	0.026
Massachusetts	0.001	0.009	0.012	0.000	0.002	0.004	0.003	0.017	0.011	-0.016	0.001	0.022
New Hampshire	-0.001	0.005	0.014	0.006	0.007	0.008	0.007	0.022	0.016	-0.011	0.001	0.026
New Jersey	0.013	0.015	0.024	0.008	0.008	0.008	0.007	0.017	0.010	-0.008	0.017	0.030
New York	0.006	0.007	0.013	0.000	0.008	0.004	0.000	0.012	0.007	-0.017	0.008	0.024
Pennsylvania	0.005	0.006	0.018	0.004	0.001	0.002	0.001	0.011	0.001	-0.013	0.018	0.022
Rhode Island	-0.003	0.001	0.014	0.009	0.019	0.018	0.014	0.026	0.024	-0.001	0.002	0.021
Vermont	-0.001	0.000	0.004	-0.005	-0.001	-0.001	-0.003	0.009	0.004	-0.025	-0.007	0.020
Virginia	0.000	0.003	0.018	0.001	-0.013	0.001	0.003	0.008	-0.003	-0.010	0.020	0.017

8.2 Temperature, precipitation and streamflow magnitude and timing

The increase in temperatures (Table 3) of up to approximately 0.25°C per decade has triggered many hypotheses about a possible change or acceleration in the hydrologic cycle. Such acceleration or intensification of the water cycle would represent an increase in precipitation and therefore of the runoff and streamflow. To verify the potential effect of the increased temperature on the total annual precipitation and streamflow trends observed in the past 58 water years, we created regression of precipitation and streamflow as time series and as function of temperature.

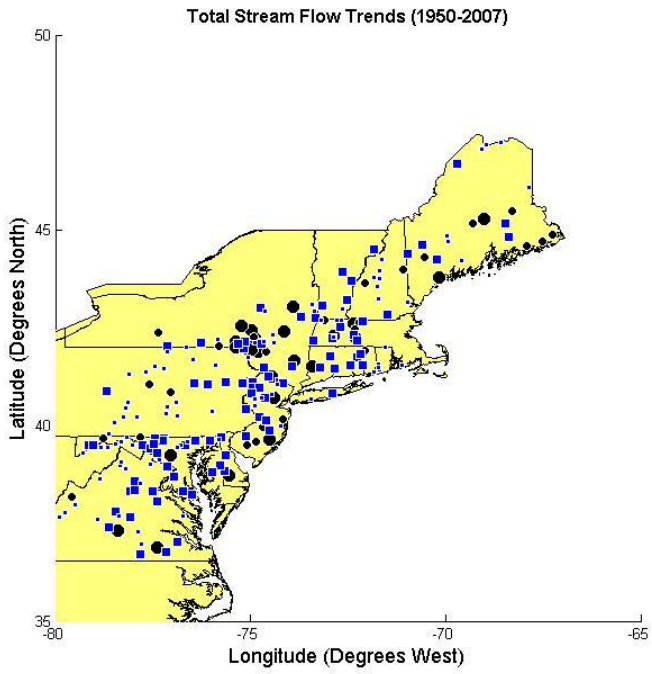

Figure 6: Total annual streamflow trends in the north east United States, in mm/year.

The results of total annual streamflow can be observed in Figure 6, where blue squares represent an increase in total annual streamflow, the bigger squares representing a larger increase in streamflow, and black circles a reduction, where bigger circles represent a bigger reduction. From this result we can say that an

increase in total annual streamflow has taken place for most of the streams analyzed. An increase in rainfall is implicit in Figure 6; the only ways an increase in annual streamflow can take place is by increasing the volume of water (precipitation) or with a decrease in evaporation.

The important factor of this increase in streamflow and therefore precipitation is its temporal distribution. Studies made in the past shows that the northeast United States precipitation is almost independent of the season although it is variable depending on the location. Areas close to the coast of New York, Connecticut, New Hampshire, Vermont, and Delaware receive more rain than mountainous regions of New York, New Jersey, Pennsylvania (i.e. Appalachian and Adirondack Mountains), this can be observed in Figure 4 and Table 4 showing the monthly average precipitation and for the February to April period in the northeast US.

Although we consider temperature as the main factor contributing to a change in the timing of the peak stream flow, a change in precipitation patterns can also affect the timing. Two possible effects can be occurring that can produce a shift in the timing of peak streamflow: (1) an increase in precipitation during winter and early spring and decrease during late spring and summer season, and (2) a decrease in precipitation as snowfall and an increase as rainfall. Seasonal changes in precipitation are noticed with changes in streamflow; on the other hand an increase in precipitation, because the extreme low temperatures during the winter season will not contribute to streamflow at that period as much as it does in later months. A change in precipitation

seasonal patterns, as an increase in precipitation in certain months and a decrease in others, will alter the timing of peak streamflow. Certainly this will contribute to the shift of the peak streamflow, but related to two possible causative mechanisms: direct effect of increase in temperatures on snowfall or the intensification of the hydrologic cycle.

Figure 7 shows the coefficients for regressions of monthly precipitation in function of temperature, where blue squares represent a trend of increase in precipitation as temperature increase, and black circles represents a decrease in precipitation. Winter and early spring months have experienced an increase in precipitation correlated with an increase in temperature specifically in the coldest regions, as we move to summer, a decrease in precipitation moving from south to north correlated with high temperatures occurs. This same trend happened with monthly streamflow when spatially distributed. Based on these results a change in precipitation seasonal pattern seems to be taking place.

Regression of monthly streamflow as a function of temperature demonstrates that a sudden reduction in streamflow during the months of spring is occurring as a trend in the northeast because an increase in surface temperature. This is specifically occurring for all the cases except Case I, where an increase in streamflow is still observed.

Table 4: Average monthly precipitation for the northeast United Sates.

	Monthly Average precipitation (mm) for the Period 1950-2008											
States	January	February	March	April	May	June	July	August	September	October	November	December
Connecticut	97.2	80.4	110.2	107.6	98.3	93.6	95.5	109.9	106.7	104.6	110.8	105.8
Delaware	85.6	78.1	104.1	86.8	88.5	93.4	106.8	119.9	95.7	87.1	86.4	89.7
Maine	84.3	71.6	83.1	87.5	90.2	92.2	93.8	91.6	92.9	100.3	109.0	97.8
Maryland	76.3	67.5	94.8	87.3	97.4	99.3	99.5	97.7	94.3	80.1	81.5	79.6
Massachusetts	88.6	72.3	96.9	99.3	99.6	98.8	96.3	104.6	100.4	99.7	103.9	97.5
New Hampshire	86.1	68.8	87.9	93.6	94.5	96.9	95.7	98.1	91.4	102.2	103.5	94.7
New Jersey	85.5	74.0	100.6	98.1	96.0	97.1	109.4	111.9	99.8	91.9	97.6	94.1
New York	76.5	64.8	86.1	91.9	95.7	101.2	100.8	98.6	99.0	91.5	94.2	83.7
Pennsylvania	73.2	63.1	87.8	89.7	95.4	100.7	101.7	95.7	96.4	80.4	87.4	77.2
Rhode Island	105.3	88.6	116.5	107.9	93.7	86.6	83.8	110.8	99.0	103.1	116.4	111.1
Vermont	84.5	71.4	90.8	88.5	94.5	94.9	101.1	107.0	96.2	92.9	93.2	89.7
Virginia	78.6	71.5	95.1	82.2	97.3	94.4	104.4	97.0	96.1	82.6	78.2	77.1

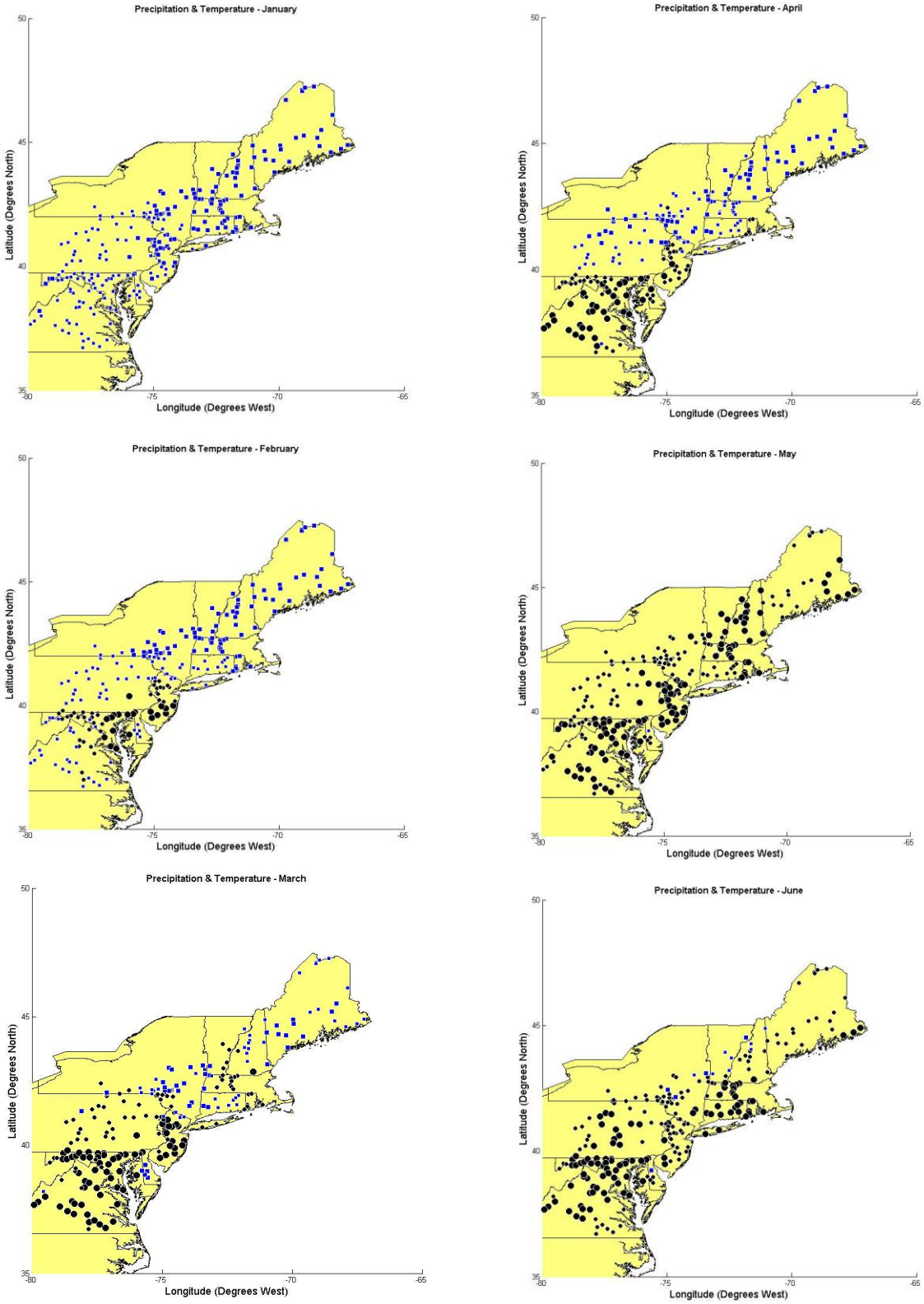

Figure 7: Monthly precipitation as a function of temperature.

Table 5: Time series regression for precipitation and streamflow (February to April).

Quartiles	Precipitation		Stream Flow	
	α (mm/acre-yr)	λ (mm/acre)	α (mm/acre-yr)	λ (mm)
Case I	-0.592	1414.376	-0.018	62.550
Case II	-1.091	2397.420	-0.116	255.230
Case III	-0.731	1897.326	-0.084	197.212
Case IV	-0.026	314.134	0.031	-45.162

Table 6: Streamflow in function of temperature and precipitation (February to April).

Temperature	Quartiles	α (mm/acre-ºC)	β (mm/mm)	λ (mm)	R^2	P-Value
Low	Case I	1.591	0.062	15.850	0.482	1.400E-05
↓	Case II	-0.436	0.087	6.099	0.555	4.615E-07
	Case III	-0.785	0.083	4.302	0.638	3.585E-10
High	Case IV	-0.417	0.067	0.931	0.581	3.807E-07

Results of monthly streamflow in function of temperature and precipitation can be observed in Table 7, where α is in (mm/ºC) and β is in (mm/ mm), for temperature and precipitation regressions respectively. It can be noticed that for January in Case I the increase in streamflow has a higher correlation with the increase in precipitation than with temperature. Areas with higher temperatures as Cases II and III, during this time of year, with temperatures close to the melting point (see Table 2), an increase in temperature could have a greater effect on stream flow than the changes in precipitation patterns. It is also very important to notice that precipitation is also dependent on temperature.

For the months of February and March an increase in streamflow is directly correlated to the increase in temperature. The explanation for this change between the months of January to February and March is that as the temperature starts to increase during this period of time, the snow accumulated during the same period and prior months starts to melt and create high volume of runoff. As the month of April begins

the amount of snow on the ground is less because the higher temperature, the effect that the precipitation has on the streamflow increases. For summer months, a negative relationship between temperature and streamflow generally prevails. A reduction in the streamflow can be noticed as the temperatures increase; this can be explained by a possible increase in evapotranspiration.

Table 7: Monthly streamflow regression coefficient in function of temperature and precipitation.

Quartiles	α (mm/ºC-acre)	β (mm/ mm-acre)	λ (mm-acre)	P-Value
	January			
Case I	0.800	0.100	9.750	1.961E-04
Case II	1.275	0.161	9.031	2.807E-07
Case III	0.832	0.190	3.212	9.419E-09
Case IV	0.079	0.152	2.680	3.664E-06
	February			
Case I	1.368	0.077	14.141	2.848E-04
Case II	2.104	0.090	18.015	5.072E-06
Case III	1.108	0.150	8.419	6.914E-06
Case IV	0.065	0.156	3.387	8.990E-06
	March			
Case I	3.744	0.143	13.645	9.678E-06
Case II	2.881	0.159	12.439	5.585E-04
Case III	0.269	0.184	8.788	9.153E-05
Case IV	0.036	0.158	3.655	8.990E-06
	April			
Case I	2.493	0.158	25.562	8.986E-03
Case II	-1.696	0.257	24.381	1.304E-03
Case III	0.147	0.216	2.801	1.602E-07
Case IV	0.197	0.156	2.203	4.297E-06
	May			
Case I	-1.733	0.149	38.357	1.844E-03
Case II	-0.776	0.167	13.903	5.542E-09
Case III	-0.286	0.144	8.172	3.069E-08
Case IV	0.212	0.103	-0.426	9.619E-05
	June			
Case I	0.840	0.129	-12.958	1.746E-05
Case II	-0.081	0.154	-1.934	2.454E-07
Case III	-0.797	0.147	14.113	8.160E-08
Case IV	-0.612	0.112	11.070	5.476E-06

From these results we can observe that the Case I, or area with the lower average temperature, has a higher variability than the rest of the cases. This tells us that the

streamflow or runoff in the extreme northeast US is especially sensitive to changes in temperatures during the late winter season and early spring. This sensitivity to temperature is essential to demonstrate that a change on the timing of peak streamflow is in fact taking place.

The p-values observed for all the cases and months were below 0.05 which makes the results statistically significant.

8.3 Shift in the time of peak streamflow

From the results observed in streamflow and precipitation, with an increasing trend during the winter and early spring season due to an increase in temperature, a multivariable regressions related to the timing of peak streamflow was create in order to observe a possible shift. Applying this regression in temperature, precipitation, timing of peak streamflow and time (water years 1951 to 2008), and dividing the station in quartiles base on minimum temperature we obtained the results presented in Table 8, where α and β are the regression coefficients for timing in function of temperature (day/ºC) and precipitation (day/mm) respectively.

Table 8: Timing regression coefficient in function of temperature and precipitation.

Temperature	Quartiles	α (day/ºC)	β (day/mm)	λ (mm)	R^2	P-Value
Low	Case I	-5.45	0.035	89.10	0.15	0.11
↓	Case II	-4.44	0.041	81.91	0.11	0.22
	Case III	-1.61	0.033	80.55	0.07	0.56
High	Case IV	-1.26	0.075	61.88	0.06	0.51

All the cases considered obtained as result in average a negative regression value for the timing of peak streamflow. Although there is high variability, most of the station had a result consistent with what we proposed; stations with the lowest average

minimum temperature during winter are more sensitive to changes in temperature than stations with higher average minimum temperatures. For Case I, with the lowest average minimum temperature gage stations and located in the farthest northeast US, the results shows that a movement of the average peak streamflow of approximately 5.5 days towards the winter is taking place per degree Celsius of increase in temperature. This result is for the states in the Region 01 of the USGS. As the minimum temperature increases in the observed stations (moving toward case IV), a decrease in the number of days per Celsius that the peak stream flow moves towards the winter takes place.

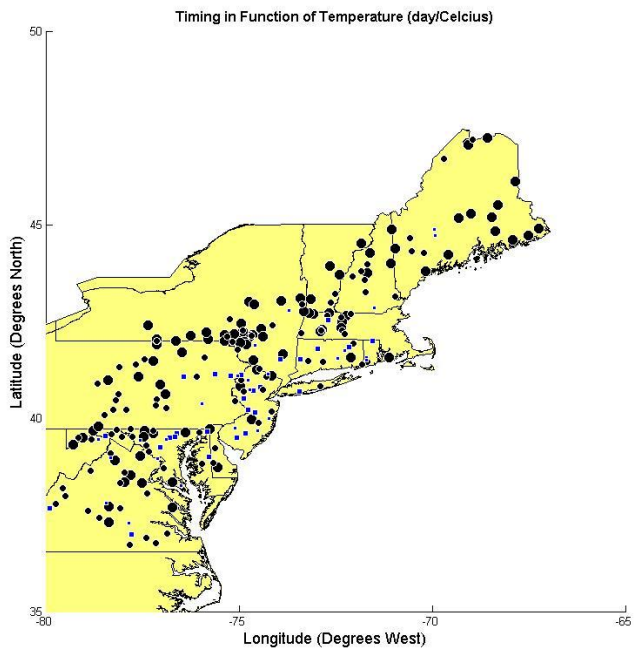

Figure 8: Timing of peak streamflow in function of temperature.

Observing the Figure 8, it is apparent that most stations have experienced a shift in the timing of peak streamflow due to temperature. It is important to notice that stations of Cases I and II have less variability in the timing than station in Cases III

and IV. For Cases I and II this is because high latitude regions have their peak during the period of February to April and it is mostly related to ground surface snow-ice melting, as temperature starts to increase during the change of season, accumulated snowfall from previous day starts the melting process. As a result, high quantities of runoff and discharges to streams are created. Therefore, it is the season and temperature, which dictates the temporal variability.

In the other hand, regions to the south of the area of study due to their warmer hydroclimatological characteristics, which induce a small accumulation of snow to the already small amount of snowfall received, peak streamflow is often due to particular storms, which have high variability from year to year. The mild reduction in days that the peak streamflow moves towards the winter compared with areas in higher latitude occurs because although they receive snowstorms during the winter season, in general those areas do not have an enough low temperature to accumulate and maintain high quantities of snow on the ground surface. The precipitation received in form of snowfall will be constantly melting and the timing of peak streamflow will not be only related to the ice and snow melting regime but caused by combinations of factors. Only regions located high enough in elevation or in latitudes more than approximately 40º north are going to be capable to maintain low temperatures for snow to get accumulated.

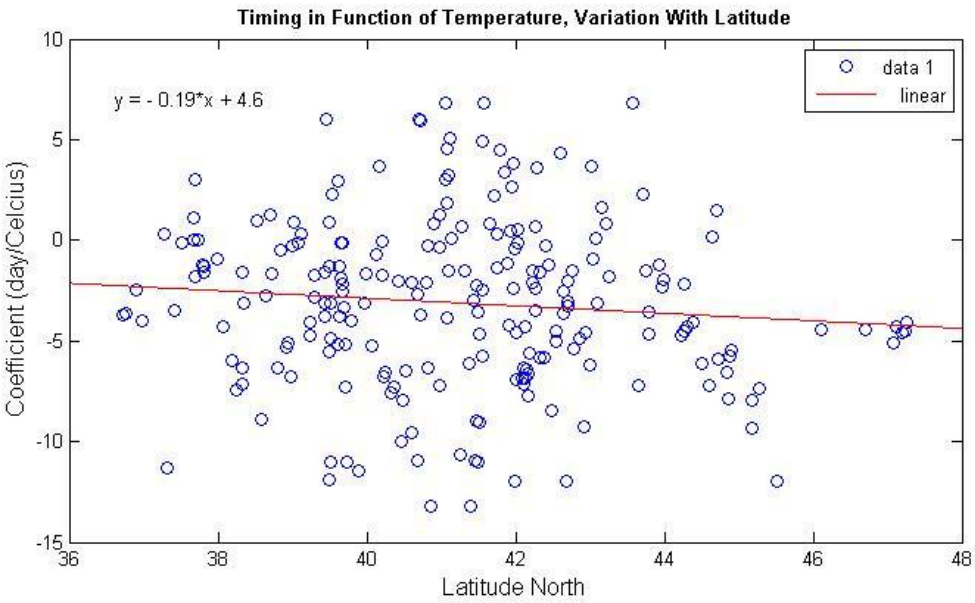

Figure 9: Scatter plot of the timing regression values as a function of temperature and distributed by latitude.

In Figure 9 is the relationship between the peak streamflow coefficient in function of temperature and its change with latitude. It can be seen that as the latitude increases there is a trend of an increase of the number of days that the peak streamflow moves towards the winter. Although there is high variability in the figure shown, together with Figure 8 and Figure 10 it demonstrates that high latitude and elevated areas show higher movement of the peak streamflow towards the winter.

Change in precipitation timing have also contributed to the shifting of the peak stream flow towards the winter. Although the regression coefficients are positive for timing of peak streamflow, the trends have shown a reduction of total precipitation during the months of February to April.

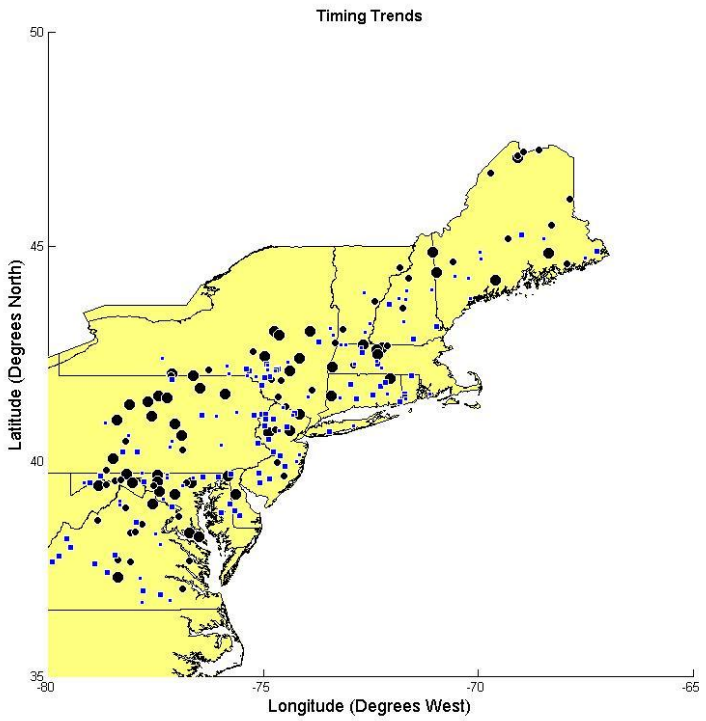

Figure 10: Trend in the timing of peak streamflow from 1950 to 2007.

8.4 Threshold Flow Ratio

A change in the peak streamflow could represent a decrease in the total amount or volume of water received during summer. The months of June, July and August, which are part of the summer season, is the time of the year where a high temperature is observed for the northern hemisphere. High temperatures, together with a trend of increasing temperatures as seen in Table 3, could increase the already high evaporation rates during the summer season. A reduction of water level in many reservoirs and water facilities could take place if these two factors, reduction of water volume due to a shift in peak streamflow towards the winter and higher evaporation rates, are true for the northeast US. Many areas could be facing water related

problems and challenges that would require a new set of policies and practices in water management.

In order to quantify the effect of a shift in the timing of peak streamflow on a possible decrease in water volume during the summer month, a basic relationship-ratio was created. This ratio derived from the time series hydrograph for each year and station, and I created a regression of this as a function of temperature. The ratio is between what is called the threshold volume which is the total volume from January to the day of peak streamflow, and the total volume from January to August for each year *i*. The ratio can be written as the following equation:

$$S_i = \frac{Q^i_{threshold}}{Q^i_{summer}}$$

Thinking that the amount of water passing through the threshold will be correlated with the temperatures during the February to April period and the time the peak occurs, we created the regression of this value in function of temperature for the same period. The result shows that indeed this value, or percent of streamflow from January to the peak streamflow from the total amount from January to August, is dependent on the temperature. As seen Table 9, the increase in temperature in cold regions has produces an increase in the ratio of the amount of streamflow passing through the average peak day compared to the total amount of stream flow for the January to August period. This is related to the trend observed by precipitation and streamflow, of an increase during the same period, but also implies that as temperatures increases the snow on the ground starts to melt earlier. In Figure 11 blue squares represent an increase in the ratio; big blue squares being the stations with

bigger increase in the volume of water before the average peak, and black circles represent a decrease in the ratio.

Table 9: Average regression coefficients for the stream flow to peak and stream flow to August ratio in function of temperature.

Temperature	Quartiles	α ($^oC^{-1}$)	β ($^oC^{-1}$)	λ	R^2	P-Value
Low	Case I	0.0490	-0.0003	0.6367	0.2652	0.004949
↓	Case II	0.0281	-0.0004	0.5778	0.1326	1.37E-01
	Case III	0.0060	-0.0002	0.5391	0.0763	0.425585
High	Case IV	0.0023	0.0754	0.5321	0.0896	0.415577

The results observed in the Table 8 shows that the volume of water is streams for the Cases I and II could be increasing approximately 5% and 3% per degree Celsius respectively. These are precisely the stations with the minimum average temperature. Based on the results an increase in total streamflow passing before the peak is directly related to the effect of temperature on the other hydroclimatological characteristics of the area.

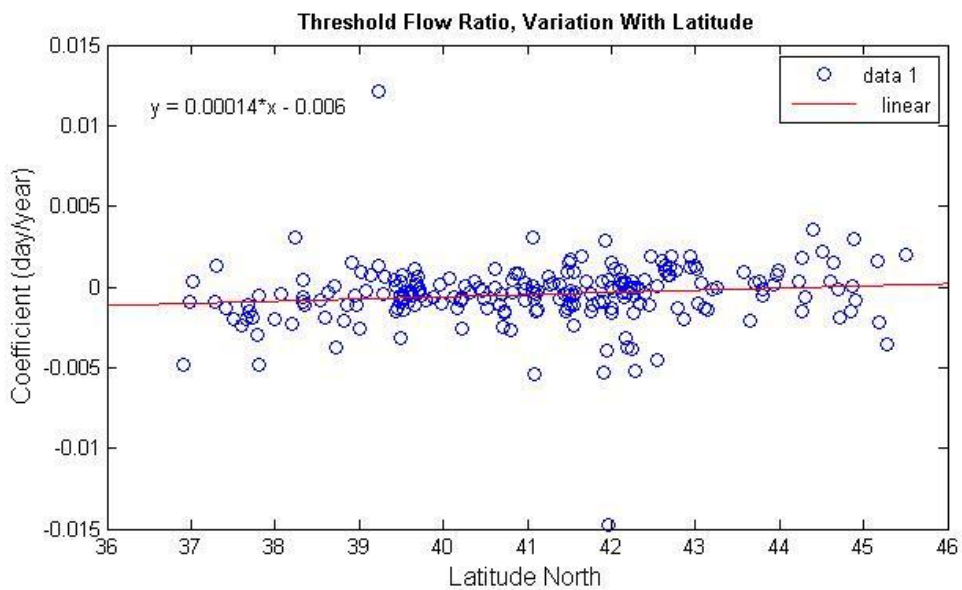

Figure 11: Ratio of threshold volume to total summer volume variation with latitude.

A result to be noticed is the P-value for the linear regressions. For most of the states in the extreme northeast region and for the most part Case I and II (including states as Connecticut, Maine, New Hampshire, New York and Vermont) when the median P-value is less that 0.05 (Table 9), which makes it statistically significant. The values obtained for the coefficient of determination are low, indicating that there is a high variability and other factors contributing to the change in volume received before the peak. Figure 12 shows how areas become more susceptible to have a positive change in the ratio as they become snow dominated.

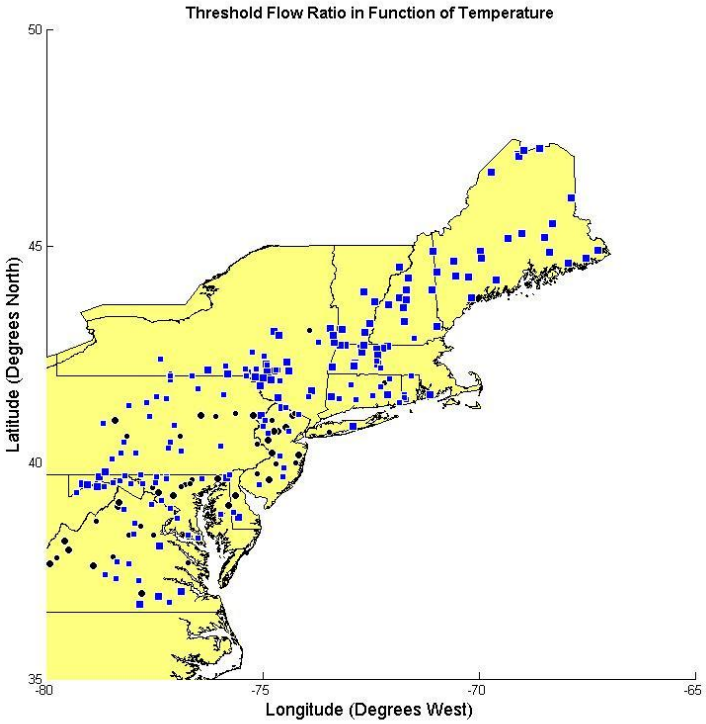

Figure 12: Station with an increase ratio

9.0 Conclusion

Climate models and historical trends demonstrate that warming of the world's temperature is taking place, possibly leading to an acceleration or intensification of the hydrological cycle. Based on the obtained data and analysis, these changes in temperature resulted in a shift of seasonal patterns and variations in the timing of hydrological events, such as increase in the winter streamflow and decrease in the spring and summer streamflow. In the northeast United Sates changes in the surface temperature go as high as an increase of 0.25ºC/decade, and although we have seen an increase in annual precipitation, which would support the theory about the intensification of the hydrological cycle, this cannot be attributed to the local increase in temperature but to a world event. In the other hand the increase in surface temperature and feedback has resulted in the change and redistribution of the amount of streamflow or water volume received in certain seasons. Specifically, an increase is observed in the amount of stream flow received earlier during the winter season and early spring. The effect that the increase in temperature have had in snow dominated regions is a faster melting of the snow and ice on the ground surface and a reduction of the amount of precipitation received as snowfall. There has also been a positive correlation between the increase in temperatures and an increase in precipitation during winter and early spring season, resulting in the change and redistribution of the amount of streamflow or water volume received at this time of year.

These can be demonstrated by the change in the timing of peak streamflow, where the areas with lowest average minimum temperature around the year and during the

winter season have had the biggest change in the timing of peak streamflow. Areas with low average minimum temperature receive more snow and have the capacity to maintain and accumulate the snow. The observed change in temperatures is affecting directly these areas, usually high elevation and high latitude, in contrast to areas with higher lower average minimum temperature, where the timing of peak streamflow and the amount of water received before the peak occurs have had only a mild change. For these areas changes in the amount of water and timing of peak streamflow will be related to more regional seasonal variations or the effects of a possible intensification of the hydrological cycle.

10.0 References

Adams, J.C. (2008). Implications of global climate change for snowmelt hydrology in the twenty-first century, Hydrological Process, *(12-29-2008), 962-972*

Barnett, T.P & Adam, J.C. (2005). Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature , 438/17 (11-2005), 303-309*

Brown, Ross D. (1999). Northern Hemisphere Snow Cover Variability and Change, 1915-97. *Journal of Climate, 2000 American Meteorological Society, (7-1-2000), 2339-2355*

Chow, V.T., D.R. Maidment, and L.W. Mays (1988). *Applied Hydrology*, McGraw-Hill, Boston, Massachusetts.

C. Wake and Clean Air – Cool Planet (2005). Indicators of Climate Change in the Northeast. *Climate Change Research Center, University of New Hampshire. (2005)I8-I15*

Easterling, David R. (1998). Long-Term in Extreme Precipitation Events over the coterminous United States and Canada. *Journal of Climate, 1999 American Meteorological Society, (8-1999), 2515-2527*

Hartman, Dennis L. *Global Physical Climatology*, Chapter 5: The Hydrologic Cycle, Page 115. Vol 56, International Geophysics Series.

Huntington, T.G. (2006). Evidence for intensification of the global water cycle: Review and synthesis. *Journal of Hydrology, 319(2006), 83-95*

Intergovernmental Panel on Climate Change (2007a). *Climate Change 2007 - The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Cambridge: Cambridge University Press.*

K. Hayhoe (2006). Past and future changes in climate and hydrological indictors in the US Northeast. *Climatic Change, Springer-Verlag, (11-16-2006), 381-404*

Leathers, D.J. (1996). Characteristics of snow cover duration across the northeast United States of America, *International Journal of Climatology, Vol. 17(1996), 1435-1547*

[4] **National Atlas of the United States (2006).** Color Conterminous United States Shaded Relief – 200-Meter. National Atlas of the United States, Reston, VA. Map. Available on-line[ttp://nationalatlas.gov/atlasftp.html?openChapters=chpgeol#chpGeol]

[3] **National climatic Data Center**, US Department of Commerce. National Environmental Satellite, Data, and Information Services (NESDIS). Data set. Available on-line [ftp://ftp.ncdc.noaa.gov/pub/data/cirs]

Oki, Taikan (2006). Global Hydrological Cycles and Water resources, Freshwater Resources, *Vol.313 (09-25-2006), 1068-1072*

Regonda, S.K. & Rjagopalan, B. (2003). Seasonal Cycle Shifts in Hydroclimatology over the Western United States. *Journal of Climate, 18(2004), 372-384*

[1] **Slack, JR and Maciunas, J. (2005).** Hydro-Climatic Data Network: U.S. Geological Survey stream flow data set for the United States for the study of climate variations, 1874 - 1988. Data set. Available on-line [http://pubs.usgs.gov/wri/wri934076/1st_page.html] USGS Open-File Report 92-129

[2] **U. Schneider, T. Fuchs, A. Meyer-Christoffer, B. Rudolf (2008).** Global Precipitation Analysis Products of The GPCC, Global Precipitation Climatology Center. Deutscher Wetterdienst, Offenbach a. M., Germany, Nov. 2008. Data set. Available on-line [ftp://ftp-anon.dwd.de/pub/data/gpcc/html/fulldata_download.html]

11.0 Appendix

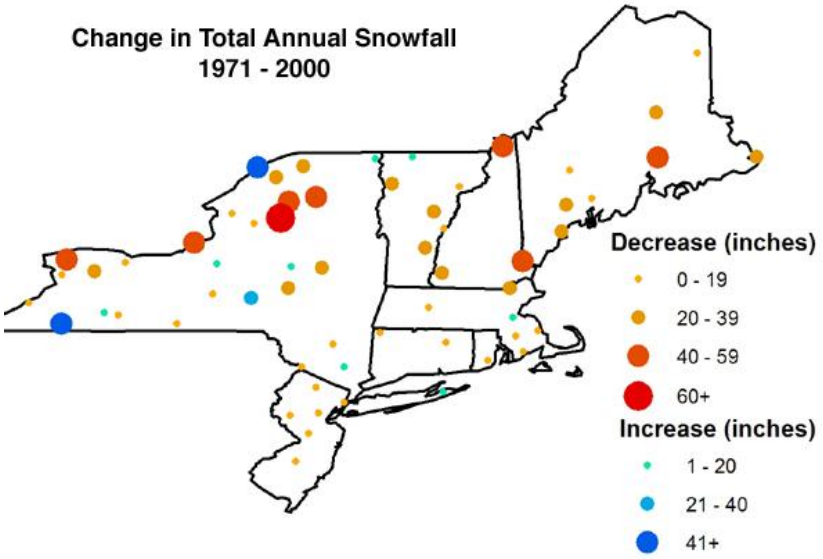

Figure 13: Map illustrating change (from linear regression) in total annual snowfall for stations 1971 to 2001. (Wake et al. 2005)

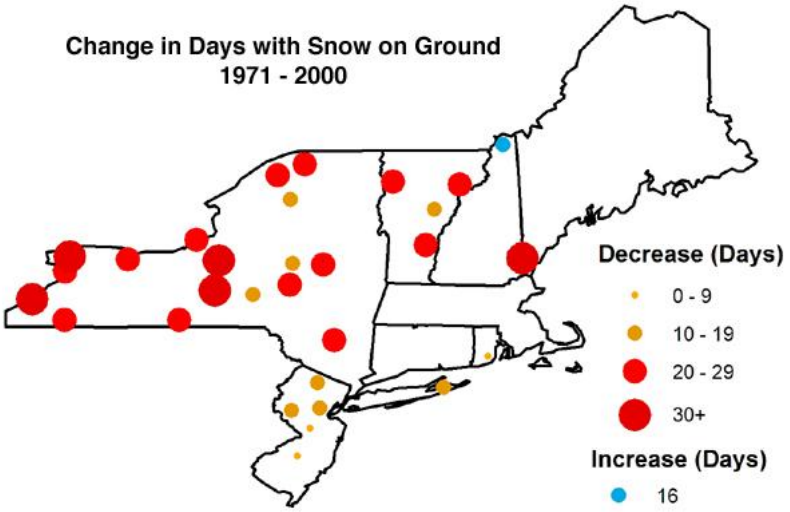

Figure 14: Map illustrating change (from linear regression) of days with snow on the ground from 1971-2000. (Wake et al. 2005)

Table 10: Regression coefficients for timing of peak stream flow in function of temperature and precipitation for each gage station, Case I.

Case I					
Station	α (day/acre-ºC)	β (day/acre-mm)	λ (mm)	R^2	P-Value
1010000	-4.0653	0.0153	102.5619	0.2445	0.001195
1010500	-4.4974	0.0407	97.0891	0.2901	0.000135
1011000	-4.6105	0.0053	105.8765	0.2393	0.001073
1011500	-4.3071	-0.0061	111.2708	0.2416	0.001142
1013500	-5.0922	0.0256	104.0836	0.4107	1.39E-06
1014000	-4.4363	0.0099	104.4793	0.2630	0.000418
1018000	-4.4614	-0.0207	103.7156	0.2159	0.042356
1021200	-11.9940	0.0200	59.6819	0.1806	0.020548
1021500	-7.3944	0.0401	71.1670	0.0922	0.313085
1022500	-7.9634	0.0592	53.7576	0.1148	0.077265
1023000	-9.3631	-0.0049	73.4328	0.1488	0.156748
1030500	-5.4827	0.0248	91.8913	0.2171	0.002812
1031500	-5.7321	0.0553	81.7977	0.1832	0.017471
1033500	-7.8778	-0.0027	98.3998	0.3776	0.008726
1035000	-6.5611	0.0332	87.5750	0.2165	0.087149
1047000	1.4917	-0.0224	120.5988	0.0108	0.791748
1048000	0.1480	-0.0628	126.7115	0.0416	0.465042
1052500	-7.2247	0.0621	94.4644	0.2170	0.001728
1054200	-6.1176	0.0727	73.8491	0.0941	0.227172
1055000	-4.0422	0.0362	93.2024	0.0534	0.299248
1055500	-4.2601	-0.0574	102.4004	0.1410	0.060161
1057000	-2.1361	-0.0231	102.9520	0.0311	0.50732
1064500	-4.7235	-0.0172	115.5551	0.0631	0.254596
1075000	-2.3219	-0.0318	123.7801	0.0364	0.606033
1076000	-1.2064	-0.0124	109.9563	0.0072	0.907102
1076500	-4.6687	0.0192	102.3154	0.0833	0.141459
1078000	-3.5711	0.0333	93.3343	0.0457	0.30321
1134500	-4.6112	0.0465	91.3623	0.1089	0.07467
1137500	-9.2764	0.0153	103.6773	0.2630	0.001413
1142500	-4.8988	0.1000	71.4310	0.1039	0.060985
1144000	-5.3793	0.0817	76.5045	0.1064	0.04795
1145000	-1.5199	-0.0182	109.9241	0.0155	0.822745
1153500	-3.0631	0.0387	88.3895	0.0237	0.689502
1156000	-3.2560	0.0777	78.6661	0.0481	0.465656
1169000	-2.5568	0.0237	100.2180	0.0198	0.618513
1169900	4.3523	0.0904	62.2261	0.0406	0.515025
1170100	-4.4745	0.1104	80.2103	0.0855	0.239176
1174000	-5.0118	0.0078	89.3201	0.0613	0.468161
1174900	-8.4326	0.0915	73.6552	0.0895	0.35631
4296000	-2.0746	0.0384	90.0667	0.0301	0.487528
1321000	-5.6296	0.0437	96.4671	0.1587	0.012181
1329000	-7.7040	0.1320	63.1471	0.1847	0.063455
1329500	-6.6140	0.4377	-6.0114	0.4596	0.00289

1332000	-14.5181	0.1461	91.1416	0.4252	0.000247
1348000	-7.1674	0.0842	79.5145	0.3088	0.000515
1349000	-6.8287	0.1015	62.3404	0.1161	0.115247
1413500	-2.4525	0.0437	74.3998	0.0084	0.851122
1414000	-19.4349	-0.2266	153.2745	0.3494	0.039782
1414500	-4.6773	0.1576	48.0021	0.0550	0.322427
1415500	-19.5193	-0.0543	103.1862	0.5773	0.116186
1422000	-8.9836	0.0553	66.3646	0.1534	0.311745
1422500	-10.9580	-0.1179	111.0142	0.1865	0.093179
1423000	-2.9751	0.0293	71.0072	0.0114	0.799242
1498500	-2.0831	0.0988	56.9084	0.0511	0.640526
4274000	-4.0288	0.0870	86.8559	0.1860	0.236753
4276500	-2.4303	-0.0091	104.5142	0.0609	0.427971
4287000	-3.6273	0.0702	80.3978	0.1468	0.014888
4293500	-3.7084	-0.0314	103.7980	0.0887	0.093718

Table 11: Regression coefficients for timing of peak stream flow in function of temperature and precipitation for each gage station, Case II.

Case II					
Station	α (day/acre-ºC)	β (day/acre-mm)	λ (mm)	R^2	P-Value
1038000	-5.9208	0.1039	46.2051	0.106698	0.078969
1060000	-4.5055	0.1149	43.8714	0.072898	0.237368
1073000	-1.9253	0.0385	79.4141	0.011937	0.745119
1086000	-1.5060	-0.0099	102.7765	0.024828	0.685832
1094000	2.3148	-0.0927	115.1102	0.039829	0.626629
1162500	-2.0009	0.0325	87.0779	0.009586	0.816863
1165000	-11.9595	0.2488	52.4621	0.307155	0.000375
1165500	-3.6216	0.1764	46.0687	0.114093	0.219964
1175500	-1.2376	0.0027	127.7913	0.001389	0.983462
1176000	-0.2420	0.1780	36.7823	0.105984	0.100597
1180000	-5.8326	0.0577	88.9958	0.304936	0.054475
1180500	-1.5523	0.1395	63.8326	0.1039	0.071872
1181000	-5.8424	0.2217	37.7888	0.168618	0.015686
1188000	3.6190	0.0388	70.6621	0.026938	0.579177
1198000	-2.3959	-0.0340	99.4455	0.01804	0.872373
1330500	-6.4411	0.1007	66.2595	0.181051	0.020348
1333000	-6.8443	0.2167	51.5676	0.169149	0.014094
1333500	-4.2933	0.1354	49.3007	0.09734	0.158283
1334500	-6.3396	0.2116	36.2001	0.124459	0.03605
1350000	0.5584	0.0990	71.6497	0.021973	0.662967
1361000	-0.1159	0.1327	50.9737	0.11573	0.47809
1361500	-6.8992	-0.0796	109.3123	0.274451	0.055719
1365000	-4.6067	-0.0370	109.7606	0.035839	0.473221
1418500	-9.0570	0.2018	36.3332	0.463231	0.009406
1419500	-11.0027	0.1424	54.2138	0.633045	0.001479

1420500	-3.5243	-0.0009	90.6564	0.01756	0.677219
1421000	-2.2800	0.1467	59.5778	0.031212	0.513815
1424500	-13.1873	-0.1217	117.6756	0.321494	0.257299
1425500	-6.1241	-0.0014	90.5670	0.206151	0.177024
1426500	-1.5112	-0.0156	96.3560	0.005523	0.900121
1427500	0.7137	-0.0583	95.9162	0.012768	0.86818
1435000	-10.6438	-0.0017	95.8766	0.173102	0.020312
1437000	0.0825	0.0886	82.3702	0.014357	0.910286
1439500	5.0786	-0.0513	90.7921	0.030647	0.536589
1440400	-1.5107	-0.0562	108.2115	0.012729	0.804306
1447500	-3.8808	-0.1317	138.5889	0.051096	0.332407
1463500	2.9839	0.0018	78.6574	0.006783	0.860927
1502000	-9.5184	-0.0442	92.6714	0.303099	0.001255
1503000	-6.4503	-0.0740	100.6654	0.117479	0.043967
1512500	-7.9761	-0.0840	101.7773	0.116202	0.048489
1514000	-10.0102	0.1526	51.9771	0.252039	0.047394
1518000	-1.9944	0.0910	66.4223	0.01814	0.674623
1520000	-7.2936	0.0063	100.7735	0.051505	0.312445
1520500	-7.5718	0.0480	76.5424	0.092602	0.173923
1528000	-6.5230	0.0198	81.6667	0.095988	0.154606
1531000	-6.7690	0.0368	77.3618	0.070787	0.171699
1532000	-1.7067	0.0966	61.7197	0.023086	0.612324
1534000	-0.0686	-0.1789	124.7243	0.074525	0.181981
1541000	-5.2048	0.1063	62.2761	0.045149	0.337669
1543500	-3.1157	0.0024	85.2512	0.009947	0.794591
1545600	-11.4871	-0.0292	128.2679	0.146207	0.079733
1548500	-10.9820	-0.1067	143.9945	0.176729	0.013866
1549500	-7.2959	-0.0244	105.7778	0.067202	0.216434

Table 12: Regression coefficients for timing of peak stream flow in function of temperature and precipitation for each gage station, Case III.

Case III					
Station	α (day/acre-ºC)	β (day/acre-mm)	λ (mm)	R^2	P-Value
1106000	-7.1812	0.2588	21.32726	0.207161	0.07781
1111500	6.8005	0.1196	24.5617	0.111336	0.088945
1117500	-1.8178	0.2585	10.62875	0.289057	0.000774
1117800	0.8332	0.2206	6.882858	0.23343	0.014218
1118000	1.6532	0.1521	29.12039	0.110928	0.079826
1118500	-3.0907	0.1609	43.91083	0.127517	0.057003
1119500	0.1065	0.1041	48.81291	0.040149	0.431692
1120500	-0.9606	0.0814	33.1432	0.034165	0.682234
1121000	3.6501	0.0655	49.14814	0.034811	0.450586
1127500	-6.2193	0.1647	45.10731	0.11409	0.069595
1193500	0.6544	0.1078	42.65443	0.051757	0.286819
1196500	-3.4576	0.0469	73.18829	0.017825	0.685429
1201500	18.3547	-0.0167	32.88077	0.216736	0.29481

1204000	-1.5378	0.1501	40.96859	0.066907	0.217945
1368000	-0.4345	0.0808	61.73547	0.017988	0.804266
1369000	-11.9866	0.1502	44.21598	0.115877	0.351041
1372500	3.8366	0.1259	44.82257	0.063386	0.269906
1373500	-2.4265	0.1334	34.23475	0.133816	0.453792
1379500	2.6474	0.0279	67.10813	0.005996	0.897401
1381500	0.4940	0.0740	69.60696	0.01976	0.677611
1384500	-4.2039	-0.0202	108.6424	0.014648	0.766736
1386000	-13.7955	0.1547	101.2295	0.162995	0.168764
1387500	-1.1203	0.1362	46.72729	0.057248	0.346064
1396500	3.4169	-0.0383	81.20345	0.015493	0.726086
1398500	0.3205	0.0376	80.59338	0.005957	0.892677
1399500	-1.4011	0.0521	79.85541	0.012262	0.786168
1408000	2.2338	0.2650	-18.7871	0.317565	0.002679
1440000	3.2506	-0.0259	81.75867	0.008456	0.833127
1443500	1.8139	0.0505	65.20039	0.009107	0.828997
1445000	-22.0404	0.0405	190.7325	0.242859	0.216507
1445500	4.5349	0.0605	48.70399	0.029163	0.561509
1471000	0.8439	0.1575	39.05093	0.049844	0.341737
1475000	-13.2379	0.0501	135.2366	0.079454	0.583841
1538000	3.6970	-0.0949	91.87345	0.024883	0.581729
1539000	-0.7374	-0.1750	128.799	0.059759	0.291598
1541500	-1.6839	0.0623	70.82131	0.005399	0.880543
1547700	-4.0306	-0.0291	95.28366	0.01746	0.684749
1555000	-5.1561	-0.0630	114.1067	0.045332	0.386345
1555500	-3.3116	-0.1507	124.6389	0.052642	0.348358
1556000	-2.5507	-0.0245	101.9085	0.006449	0.85065
1558000	-0.0903	0.0289	81.00294	0.001902	0.955333
1560000	-2.1694	-0.0649	110.3319	0.012375	0.732485
1562000	-1.8536	0.0145	92.45608	0.003115	0.929307
1564500	-0.1047	0.0386	78.8017	0.004838	0.905371
1567000	-3.7613	0.0483	84.16166	0.020878	0.596353
1568000	-1.2976	-0.0199	92.71878	0.002889	0.942407
1595000	-3.1330	-0.1628	140.9194	0.089999	0.166645
1597000	-11.0161	-0.0067	133.9446	0.151557	0.118057
1599000	-5.5306	-0.1861	172.3477	0.135532	0.028207
1601500	-11.8628	-0.0734	177.3882	0.1117	0.058268
1603500	-1.2986	0.0207	96.75384	0.001647	0.982028
1604500	0.8833	0.0352	71.64458	0.004647	0.894232
1608500	6.0084	-0.0739	72.7442	0.06526	0.21178
1610000	-1.5843	-0.0326	106.4052	0.005761	0.870515
1611500	-3.7865	-0.0348	124.9974	0.01965	0.679103
1613000	-3.1327	0.0079	108.7787	0.009074	0.803514
1614500	-2.8328	0.0209	96.76329	0.007676	0.853875
1632000	0.3019	-0.1878	142.9185	0.126021	0.067612
1634500	0.9061	-0.1547	141.2119	0.076294	0.181541
2013000	-1.5561	0.0613	66.30456	0.012503	0.739373
2015700	-1.2219	-0.0441	88.95625	0.009538	0.837523

2016000	0.0199	0.0190	80.85206	0.00063	0.98529
2020500	-0.0089	-0.1130	120.8599	0.034394	0.463017

Table 13: Regression coefficients for timing of peak stream flow in function of temperature and precipitation for each gage station, Case IV.

Case IV					
Station	α (day/acre-ºC)	β (day/acre-mm)	λ (mm)	R^2	P-Value
1305000	8.3528	0.128647	60.35677	0.136398	0.061654
1398000	4.4458	0.079374	31.32283	0.028081	0.607474
1408500	0.8109	0.131306	42.71478	0.061572	0.385492
1410000	6.8182	0.133106	16.77224	0.105704	0.176996
1411000	4.8961	0.201001	3.237371	0.162711	0.063763
1411500	-5.7220	0.271217	42.73622	0.148719	0.096841
1459500	6.7870	0.122343	25.20798	0.05972	0.385023
1464500	-0.3689	0.169795	31.25337	0.086537	0.257256
1466500	-7.1998	0.134531	83.91937	0.097197	0.175824
1467000	1.2951	0.160476	34.87898	0.094117	0.227031
1478500	-0.2685	0.172583	15.8706	0.067921	0.59006
1484000	-6.3589	0.100111	167.7164	0.062424	0.616666
1487000	-2.0773	-0.0048	117.334	0.002091	0.958995
1488500	5.9229	0.079585	-54.9051	0.036627	0.560806
1491000	-3.7265	-0.01034	110.219	0.008725	0.842916
1492000	5.9940	0.116901	17.1115	0.037125	0.767344
1495000	-2.6627	0.061124	69.61119	0.01798	0.708413
1496200	-10.9299	0.14746	100.1807	0.082306	0.54813
1574000	-5.2004	0.095515	66.33686	0.046307	0.352363
1580000	2.9256	0.076828	30.64636	0.013765	0.790068
1582000	8.1973	0.23144	-48.3668	0.172606	0.018705
1583000	8.1895	0.282163	-56.3328	0.14682	0.221252
1583500	2.2577	0.184037	-2.6479	0.089241	0.185894
1590000	11.8587	0.197118	-35.3112	0.136724	0.357312
1591000	-4.8709	0.113915	73.07953	0.038968	0.508795
1614000	-1.7255	0.253957	28.24668	0.115093	0.312987
1617800	-4.7282	0.092503	88.55291	0.040119	0.508845
1631000	-4.0775	-0.07854	103.4439	0.037798	0.480908
1634000	-0.1021	-0.13302	125.6971	0.04559	0.366693
1637500	-0.2391	0.090769	60.19122	0.020497	0.640653
1639000	-6.7852	-0.04179	129.58	0.029009	0.523283
1639500	-5.0603	0.125706	68.00614	0.075854	0.190787
1640500	-5.3124	-0.06521	138.7386	0.046088	0.581224
1641500	-0.4641	-0.03431	112.393	0.004763	0.939825
1643500	-6.3167	0.147752	87.63376	0.100052	0.185131
1644000	-1.6347	0.051435	59.49312	0.009774	0.82569
1645000	1.2769	0.034317	71.32298	0.003833	0.935001
1646502	-2.7480	0.023618	101.3394	0.009477	0.80714
1653600	-8.9056	0.153215	86.03872	0.135748	0.173654

1661050	0.9931	0.174211	19.19996	0.063648	0.485099
1661500	-3.1180	-0.01371	104.4226	0.007002	0.887399
1663500	-7.1417	0.144976	38.661	0.101773	0.210912
1664000	-1.5625	-0.05466	93.7361	0.012824	0.802992
1666500	-6.3261	-0.00904	79.14639	0.038669	0.542668
1667500	-7.4413	0.011597	72.28585	0.049698	0.431235
1668000	-5.9830	-0.00647	75.6576	0.032237	0.572889
1669500	-4.3214	0.053992	53.65736	0.024369	0.800885
1674000	-0.9158	0.045136	61.05949	0.005381	0.897701
2014000	-1.2732	-0.12922	123.4599	0.02808	0.582081
2017500	3.0542	0.026938	84.83678	0.009216	0.797052
2018000	-1.8080	-0.01901	90.89958	0.003156	0.928408
2027800	1.1085	-0.06537	113.263	0.012377	0.861178
2030000	-13.7873	0.105308	28.11385	0.177329	0.039924
2030500	-0.1357	0.142402	36.34316	0.076366	0.356038
2035000	-3.4887	-0.08108	99.9346	0.031195	0.46738
2038850	-11.3217	-0.03207	75.07146	0.104247	0.281945
2039500	0.2964	0.005437	75.87635	0.000169	0.996709
2041000	7.8263	0.076803	59.52711	0.084418	0.195613

Table 14: Regression coefficients for the threshold flow ratio in function of temperature and precipitation for each gage station, Case I.

Case I					
Station	α ($^{o}C^{-1}$)	β (mm^{-1})	λ (mm)	R^2	P-Value
1010000	0.0758	-0.0003	0.6781	0.3124	0.000125
1010500	0.0655	-0.0002	0.5980	0.2700	0.00028
1011000	0.0668	-0.0003	0.6463	0.3131	8.36E-05
1011500	0.0697	-0.0001	0.6226	0.3587	1.87E-05
1013500	0.0636	-0.0004	0.6677	0.3574	1.27E-05
1014000	0.0659	-0.0002	0.6189	0.3088	8.12E-05
1018000	0.0792	-0.0007	0.8387	0.3950	0.001454
1021200	0.0482	-0.0002	0.6249	0.2169	0.008491
1021500	0.0464	0.0003	0.5573	0.2299	0.043504
1022500	0.0577	-0.0001	0.6345	0.3893	3.18E-05
1023000	0.0723	-0.0007	0.9395	0.4926	0.000409
1030500	0.0774	-0.0005	0.8333	0.4131	2.79E-06
1031500	0.0769	-0.0004	0.8013	0.3642	0.000117
1033500	0.0970	-0.0006	0.8707	0.5444	0.000385
1035000	0.0579	-0.0005	0.7650	0.3105	0.024282
1047000	0.0390	-0.0001	0.6256	0.1752	0.015887
1048000	0.0452	0.0001	0.6056	0.2857	0.002341
1052500	0.0745	-0.0005	0.6174	0.4462	2.13E-07
1054200	0.0574	-0.0002	0.7616	0.2847	0.006567
1055000	0.0488	-0.0002	0.6626	0.2023	0.006933
1055500	0.0443	-0.0001	0.7199	0.2290	0.008139
1057000	0.0457	-0.0001	0.7172	0.2153	0.005449

1064500	0.0496	0.0000	0.5319	0.3047	0.000484
1075000	0.0542	0.0000	0.4331	0.3606	0.002388
1076000	0.0560	0.0000	0.5371	0.3353	0.004031
1076500	0.0425	-0.0002	0.5728	0.2604	0.001127
1078000	0.0587	-0.0001	0.4457	0.3789	5.31E-06
1134500	0.0635	-0.0005	0.7028	0.4454	1.73E-06
1137500	0.0562	-0.0002	0.5283	0.3752	4.06E-05
1142500	0.0369	-0.0008	0.7759	0.2252	0.001495
1144000	0.0312	-0.0006	0.7461	0.1817	0.004449
1145000	0.0564	-0.0003	0.6427	0.2864	0.014719
1153500	0.0550	-0.0009	0.8658	0.2637	0.008696
1156000	0.0564	-0.0005	0.7666	0.2744	0.006936
1169000	0.0690	-0.0003	0.3572	0.3728	1.37E-05
1169900	0.0384	-0.0005	0.4951	0.2230	0.017659
1170100	0.0615	-0.0004	0.4074	0.3533	0.000936
1174000	0.0397	-0.0005	0.5708	0.1961	0.072834
1174900	0.0218	-0.0007	0.6954	0.2603	0.03629
4296000	0.0427	-0.0002	0.6764	0.2893	0.000327
1321000	0.0478	-0.0007	0.7203	0.2967	0.000127
1329000	0.0410	-0.0007	0.7750	0.2118	0.040255
1329500	-0.0056	-0.0003	0.5102	0.0226	0.804885
1332000	0.0765	-0.0007	0.4168	0.2859	0.006401
1348000	0.0430	-0.0007	0.7713	0.2211	0.005969
1349000	0.0341	-0.0008	0.7486	0.1725	0.036405
1413500	0.0170	0.0000	0.4619	0.0403	0.458059
1414000	0.0256	-0.0004	0.5755	0.0875	0.503359
1414500	0.0331	-0.0001	0.4890	0.1614	0.029556
1415500	0.0879	-0.0006	0.6497	0.4482	0.226218
1422000	0.0141	0.0001	0.5082	0.0231	0.848854
1422500	0.0124	0.0000	0.5236	0.0164	0.826675
1423000	0.0099	-0.0004	0.6091	0.0280	0.574589
1498500	0.0216	0.0001	0.5154	0.0439	0.682758
4274000	0.0502	-0.0005	0.5901	0.3772	0.036326
4276500	0.0021	0.0001	0.5741	0.0037	0.95114
4287000	0.0298	-0.0004	0.6891	0.2161	0.001577
4293500	0.0385	-0.0001	0.6457	0.2264	0.001437

Table 15: Regression coefficients for the threshold flow ratio in function of temperature and precipitation for each gage station, Case II.

Case II					
Station	α ($^{o}C^{-1}$)	β (mm^{-1})	λ (mm)	R^2	P-Value
1038000	0.0719	-0.0006	0.8051	0.4252	3.89E-06
1060000	0.0576	-0.0005	0.7806	0.3189	0.000677
1073000	0.0344	-0.0003	0.6281	0.1265	0.036425
1086000	0.0375	0.0001	0.4139	0.2155	0.026234
1094000	0.0171	-0.0001	0.5248	0.0356	0.659209

1162500	0.0493	-0.0004	0.4928	0.2427	0.002918
1165000	0.0493	-0.0007	0.5876	0.2675	0.001242
1165500	0.0443	-0.0005	0.5592	0.1970	0.064424
1175500	0.0262	-0.0009	0.6404	0.1972	0.071638
1176000	0.0234	-0.0006	0.6411	0.2326	0.004399
1180000	0.0874	-0.0004	0.4223	0.4000	0.016805
1180500	0.0468	-0.0003	0.4773	0.2039	0.004197
1181000	0.0442	-0.0003	0.4591	0.1888	0.009028
1188000	0.0172	-0.0002	0.5287	0.0723	0.223073
1198000	0.0949	-0.0014	0.6872	0.3902	0.024478
1330500	0.0384	-0.0008	0.6640	0.2247	0.006985
1333000	0.0399	-0.0007	0.5631	0.2136	0.003975
1333500	0.0343	-0.0007	0.6894	0.1900	0.022513
1334500	0.0306	-0.0004	0.5654	0.1347	0.026881
1350000	0.0162	-0.0005	0.5883	0.0644	0.291836
1361000	0.0242	-0.0003	0.5764	0.0631	0.676537
1361500	0.0427	0.0001	0.4382	0.1574	0.214053
1365000	0.0356	-0.0001	0.4752	0.1567	0.030377
1418500	0.0470	-0.0004	0.5531	0.1662	0.255857
1419500	0.0531	-0.0005	0.5959	0.2764	0.12212
1420500	0.0329	0.0000	0.4738	0.1425	0.033964
1421000	0.0263	-0.0003	0.5121	0.0903	0.137154
1424500	0.0075	-0.0005	0.6607	0.0644	0.79221
1425500	0.0110	-0.0001	0.5453	0.0121	0.91277
1426500	0.0326	-0.0008	0.6166	0.1432	0.053055
1427500	0.0108	0.0001	0.5263	0.0261	0.747581
1435000	0.0410	-0.0001	0.4685	0.2201	0.006121
1437000	0.0354	-0.0005	0.5496	0.1148	0.452794
1439500	-0.0068	0.0000	0.5513	0.0058	0.890189
1440400	0.0080	-0.0002	0.5644	0.0269	0.628947
1447500	-0.0034	-0.0001	0.5441	0.0074	0.854688
1463500	0.0001	-0.0002	0.5803	0.0354	0.452972
1502000	0.0403	-0.0007	0.6875	0.1772	0.027123
1503000	0.0207	-0.0003	0.6048	0.0819	0.118013
1512500	0.0358	-0.0006	0.6536	0.2202	0.002258
1514000	0.0198	-0.0007	0.6902	0.1117	0.288463
1518000	0.0076	-0.0004	0.6303	0.0218	0.622302
1520000	-0.0085	-0.0003	0.6226	0.0105	0.792937
1520500	0.0191	-0.0006	0.6462	0.0454	0.43367
1528000	0.0227	-0.0008	0.7328	0.1209	0.092129
1531000	0.0105	-0.0003	0.5828	0.0274	0.512817
1532000	0.0170	-0.0002	0.5563	0.0315	0.510774
1534000	-0.0016	-0.0003	0.6044	0.0159	0.702129
1541000	-0.0081	-0.0001	0.6179	0.0119	0.754126
1543500	0.0105	-0.0003	0.5742	0.0231	0.584137
1545600	0.0176	0.0000	0.4431	0.0350	0.565514
1548500	0.0131	-0.0002	0.5129	0.0186	0.661542
1549500	0.0131	-0.0001	0.5163	0.0242	0.583258

Table 16: Regression coefficients for the threshold flow ratio in function of temperature and precipitation for each gage station, Case III.

Case III					
Station	α ($^{o}C^{-1}$)	β (mm^{-1})	λ (mm)	R^2	P-Value
1106000	0.0480	-0.0006	0.6408	0.4491	0.00142
1111500	0.0024	-0.0004	0.6728	0.0964	0.125072
1117500	0.0161	-0.0004	0.5860	0.1726	0.018697
1117800	0.0097	-0.0004	0.6248	0.1859	0.037222
1118000	0.0051	-0.0002	0.6015	0.0715	0.202699
1118500	0.0022	-0.0003	0.6227	0.0759	0.190585
1119500	0.0081	-0.0003	0.5881	0.0426	0.409833
1120500	0.0230	-0.0005	0.7395	0.1768	0.117594
1121000	-0.0013	-0.0003	0.6726	0.0437	0.366318
1127500	0.0319	-0.0005	0.5515	0.1760	0.014128
1193500	0.0047	-0.0003	0.6537	0.0522	0.283784
1196500	0.0055	-0.0003	0.6001	0.0779	0.182218
1201500	0.0330	-0.0003	0.6178	0.1810	0.368424
1204000	0.0048	-0.0002	0.6039	0.0276	0.540367
1368000	0.0040	-0.0005	0.7267	0.1137	0.235021
1369000	0.0327	-0.0008	0.8328	0.2168	0.125345
1372500	0.0145	-0.0005	0.6041	0.1343	0.055901
1373500	0.0142	-0.0003	0.6945	0.0565	0.726245
1379500	-0.0130	-0.0002	0.5986	0.0293	0.585503
1381500	-0.0004	-0.0002	0.5295	0.0192	0.685593
1384500	-0.0150	0.0000	0.6541	0.0203	0.691334
1386000	0.0030	-0.0004	0.6704	0.1079	0.319311
1387500	0.0020	-0.0003	0.6377	0.0473	0.417716
1396500	-0.0159	-0.0002	0.6591	0.0836	0.16692
1398500	-0.0221	0.0000	0.6113	0.0708	0.247725
1399500	-0.0149	-0.0003	0.6775	0.0758	0.214979
1408000	-0.0033	-0.0003	0.6238	0.0846	0.254267
1440000	-0.0124	-0.0002	0.6342	0.0290	0.531397
1443500	-0.0056	-0.0004	0.7085	0.1197	0.073202
1445000	0.0148	-0.0004	0.5932	0.2114	0.270817
1445500	-0.0021	-0.0006	0.6897	0.1384	0.05477
1471000	-0.0039	-0.0005	0.6256	0.0892	0.140628
1475000	0.0003	-0.0003	0.5687	0.2242	0.19205
1538000	-0.0156	0.0000	0.5746	0.0256	0.572264
1539000	0.0066	0.0000	0.5173	0.0043	0.916972
1541500	0.0022	-0.0002	0.5902	0.0078	0.831228
1547700	0.0061	-0.0006	0.6422	0.0557	0.291942
1555000	-0.0006	0.0001	0.4785	0.0022	0.955224
1555500	0.0212	0.0001	0.3997	0.0420	0.433453
1556000	-0.0013	-0.0001	0.5542	0.0018	0.956746
1558000	0.0036	-0.0001	0.5384	0.0114	0.75986

1560000	0.0120	-0.0002	0.4992	0.0267	0.508586
1562000	0.0055	-0.0003	0.5113	0.0212	0.604475
1564500	0.0011	0.0000	0.4701	0.0001	0.998016
1567000	0.0066	-0.0002	0.4863	0.0213	0.589884
1568000	0.0149	-0.0001	0.4505	0.0220	0.633135
1595000	0.0299	-0.0001	0.1998	0.1314	0.068749
1597000	0.0488	-0.0001	0.0827	0.2536	0.022325
1599000	0.0322	-0.0001	0.2627	0.0869	0.107764
1601500	0.0282	-0.0001	0.3131	0.0768	0.146912
1603500	0.0290	-0.0003	0.2716	0.1094	0.279435
1604500	0.0041	0.0000	0.4593	0.0013	0.969694
1608500	0.0045	0.0002	0.4031	0.0084	0.823595
1610000	0.0098	0.0001	0.3777	0.0118	0.753012
1611500	0.0106	0.0001	0.3562	0.0104	0.815814
1613000	0.0079	0.0001	0.3932	0.0070	0.844942
1614500	0.0170	-0.0001	0.3918	0.0376	0.455706
1632000	-0.0235	0.0003	0.3386	0.0441	0.4054
1634500	-0.0018	0.0001	0.4285	0.0012	0.974488
2013000	-0.0161	0.0001	0.4260	0.0332	0.44491
2015700	-0.0054	-0.0001	0.4746	0.0104	0.823943
2016000	-0.0124	0.0000	0.4613	0.0156	0.690803
2020500	-0.0159	-0.0002	0.4978	0.0219	0.614608

Table 17: Regression coefficients for the threshold flow ratio in function of temperature and precipitation for each gage station, Case IV.

Case IV					
Station	α ($^{o}C^{-1}$)	β (mm^{-1})	λ (mm)	R^2	P-Value
1305000	-0.0047	0.1286	0.6100	0.2855	0.001685
1398000	-0.0126	0.0794	0.7524	0.0838	0.216334
1408500	0.0005	0.1313	0.5916	0.1802	0.050729
1410000	-0.0149	0.1331	0.6607	0.1284	0.118756
1411000	0.0039	0.2010	0.5139	0.1446	0.088902
1411500	0.0132	0.2712	0.4766	0.1238	0.147161
1459500	-0.0189	0.1223	0.7679	0.1641	0.06213
1464500	0.0011	0.1698	0.6325	0.0487	0.473086
1466500	-0.0033	0.1345	0.6398	0.1542	0.057988
1467000	0.0003	0.1605	0.6315	0.1815	0.049576
1478500	-0.0193	0.1726	0.6187	0.0071	0.947769
1484000	0.0455	0.1001	-0.3738	0.1778	0.230389
1487000	0.0075	-0.0048	0.3789	0.0250	0.603091
1488500	-0.0262	0.0796	1.0971	0.0609	0.377491
1491000	0.0054	-0.0103	0.5617	0.0409	0.442937
1492000	0.0308	0.1169	0.1916	0.1089	0.446044
1495000	-0.0128	0.0611	0.6931	0.1655	0.032142
1496200	0.0075	0.1475	0.5976	0.0702	0.600719
1574000	0.0051	0.0955	0.6470	0.0706	0.199592

1580000	-0.0065	0.0768	0.6534	0.2339	0.010775
1582000	-0.0047	0.2314	0.6747	0.2194	0.005507
1583000	-0.0014	0.2822	0.4715	0.2375	0.076078
1583500	-0.0039	0.1840	0.6468	0.2589	0.004547
1590000	-0.0078	0.1971	0.5687	0.1770	0.255789
1591000	0.0136	0.1139	0.3638	0.0241	0.660284
1614000	0.0086	0.2540	0.5993	0.0548	0.585329
1617800	0.0144	0.0925	0.4539	0.0954	0.191244
1631000	-0.0008	-0.0785	0.4488	0.0001	0.997915
1634000	-0.0078	-0.1330	0.3619	0.0211	0.632838
1637500	0.0044	0.0908	0.5248	0.0249	0.581819
1639000	0.0142	-0.0418	0.5376	0.0370	0.436506
1639500	0.0061	0.1257	0.6127	0.1362	0.046236
1640500	0.0189	-0.0652	0.3460	0.0517	0.543079
1641500	-0.0176	-0.0343	0.5828	0.0422	0.57064
1643500	0.0180	0.1478	0.4103	0.1008	0.182669
1644000	0.0085	0.0514	0.5615	0.0306	0.545379
1645000	0.0014	0.0343	0.4710	0.0135	0.787964
1646502	0.0146	0.0236	0.4403	0.0614	0.24005
1653600	0.0104	0.1532	0.5845	0.0746	0.394648
1661050	0.0197	0.1742	0.4613	0.0492	0.574148
1661500	0.0028	-0.0137	0.4423	0.0021	0.964732
1663500	-0.0005	0.1450	0.6440	0.2122	0.031455
1664000	-0.0019	-0.0547	0.4471	0.0008	0.986123
1666500	0.0024	-0.0090	0.4550	0.0018	0.973133
1667500	-0.0047	0.0116	0.4613	0.0057	0.909928
1668000	-0.0051	-0.0065	0.5655	0.0639	0.325234
1669500	0.0287	0.0540	0.6835	0.2611	0.065618
1674000	-0.0009	0.0451	0.5928	0.0276	0.571434
2014000	-0.0141	-0.1292	0.4289	0.0366	0.492177
2017500	-0.0113	0.0269	0.4663	0.0145	0.699879
2018000	-0.0099	-0.0190	0.5002	0.0156	0.691469
2027800	-0.0038	-0.0654	0.5517	0.0464	0.565269
2030000	0.0152	0.1053	0.5542	0.0820	0.243546
2030500	0.0152	0.1424	0.5079	0.1445	0.131415
2035000	0.0010	-0.0811	0.5121	0.0114	0.758669
2038850	0.0090	-0.0321	0.4410	0.0173	0.818251
2039500	0.0058	0.0054	0.5372	0.0215	0.654185
2041000	-0.0075	0.0768	0.6085	0.0645	0.291138