STUDY OF 20TH CENTURY TRENDS IN STREAM FLOW FOR WEST CANADA AND SCHOHARIE CREEKS OF THE MOHAWK-HUDSON RIVERS WATERSHED

By

Amanda Lindsay Kern

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ABSTRACT

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In order to assess the effect of global climate change on the hydrologic regime in upstate New York, a study of 20th century trends in stream flow for West Canada and Schoharie Creeks of the Mohawk-Hudson Rivers watershed was conducted. Climate impact assessments suggest that climate change in the Northeast has been changing noticeably since 1970. Using USGS discharge data, this study compared historic and recent decade stream flow on West Canada and Schoharie Creeks to determine if the affects of regional climate change are altering the hydrologic regime in upstate New York. Both rivers show changes in discharge trends during the recent decade which consistent with regional climate change predictions. Overall discharge on West Canada Creek has remained consistent throughout the data record (1921-2007), however during the recent decade discharge levels have increased during the months of October and November and spring melt discharge levels have decreased compared to the historic norms. This shift in discharge levels may be due to an increase in winter melt events because of warming temperatures causing a decrease in spring melt discharge levels because of reduced snow pack. Schoharie Creek has experienced a 31% increase in yearly average discharge during the recent decade compared to the historic norm (1940-2007). This excess water is discharging through the system over the entire year and is not concentrated during one season. High discharge levels and variable discharge on Schoharie Creek will result in increased flooding and bank erosion and sediment transport. The increased sediment transport may stress aquatic ecosystems.

ACKNOWLEDGEMENTS

I would like to thank and acknowledge a number of people. First my parents who have always been behind me with love and encouragement ever willing to lend a listening ear and best of all pay Union's ever increasing tuition. Professor John Garver for his energy and entertainment and most importantly his guidance throughout my time at Union not only in academics but in all of the challenges college affords. Professor Cockburn for having the answer to every random question and with unmatched knowledge concerning Microsoft Excel. Lastly, every Geology major who kept me sane during endless hours spent in room 332.

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INTRODUCTION

Global climate change is a worldwide phenomenon actively changing earth systems in ways not seen in the last 650,000 years (Frumhoff et al., 2007). Global surface temperatures are increasing with eleven of the last twelve years (1995-2006) the warmest since 1850 (Bernstein, et al., 2007). It is unequivocal that Earth's climate is warming and this is evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (Bernstein, et al., 2007). Most scientists agree that the majority of warming in this past century is due to human influence and that temperatures will continue to rise until there is a sharp reduction in carbon loading to the atmosphere, much of this loading is due to current burning of fossil fuels. However, global scale changes cannot be simply applied to local ecosystems because of local differences in atmospheric circulation, topography, land use and other physiographical features that modify global changes to produce unique patterns of change at the regional scale (Hayhoe et al., 2006).

The Northeast United States is an area that includes the states of Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey and Pennsylvania. The "Northeast Climate Impact Assessment: Confronting Climate Change in the U.S. Northeast", states that since 1970, the Northeast has been heating up at a rate of 0.5° F (0.3° C) per decade (Frumhoff et al., 2007). Temperature alone will have important effects on Northeast watersheds. A few of the other changes over the past few decades include: (A) less precipitation falling as snow and more as rain; (B) earlier breakup of winter ice on lakes and rivers; and (C) earlier spring snowmelt resulting in earlier peak spring stream flow. These latter points are especially relevant to watershed dynamics. Projections of the future suggest that over the next several decades, the Northeast will see an additional 2.5° to 4° F (1.4° to 2.2° C) rise in winter temperatures and 1.5° to 3.5° F (0.83° to 1.9° C) in summer temperatures (Frumhoff et al., 2007). If these projections come to fruition, the Northeast hydrologic regime is likely to see an enhancement of the changes that have already occurred.

Future temperature rise is speculative because it is based on models with certain assumptions. However, temperature changes over the past century have been directly measured. Since 1970 the Northeast has been warming at a rate of nearly 0.5° F (0.3° C) per decade. Temperature increases will likely alter ecosystems in the Northeast and in some cases this change is becoming increasingly apparent. A good example of change is the northward shift in hardiness zones from 1990 to 2006 as determined by the Arbor Day Foundation. Since 1990 there has been an increase in the area of the United States where warmer weather trees can be planted and thrive (Arbor Day Foundation, 2008). The length and severity of winter weather is beginning to decrease and the duration of hot, dry summer conditions are becoming slightly longer (Frei, 2002). Since 1850, the date of spring ice-out on lakes has shifted nine days earlier in the northern part of the region and 16 days earlier in the southern part (Hodgkins, et al., 2002). This ice-out shift shows the significant changes being made to watershed hydrology, and temperature is not the only variable altering Northeast waterways. Annual average precipitation has been gradually increasing 5-10% across the region since 1900 and less winter precipitation is falling as snow and more as rain (New England Regional Assessment Group, 2001). These and other variables are actively changing the hydrology of watersheds in the

Northeast and a key question is how dramatic is this change and what are the implications.

The Hudson River flows 315 miles (507 km) from its headwaters in the Northern Adirondacks to Lower New York Bay draining 14,000 square miles (22531 km^2) before discharging at an average 21,400 ft^3/sec (6,523 m^3/sec). The Mohawk River, constituting 25% of the Hudson watershed (by area), flows from the eastern edge of the Tug Hill Plateau 140 miles across central New York where it joins with the Hudson near Albany. Schoharie and West Canada Creeks are the largest tributaries to the Mohawk, joining near the cities of Herkimer and Fort Hunter respectively, constituting over 40% of the Mohawk drainage basin miles (Figure 1). Stream flow in these rivers is derived from the hydrological balance of their watersheds but modified by dams in the drainage. The dominate processes that determine the hydrology of a watershed include precipitation, evapotranspiration, surface runoff, infiltration and baseflow (Black, 1996). The overall hydrologic budgets for these two rivers are dependent upon precipitation from weather systems affected by regional weather systems in the overall context of global climate changes. The hydrological budget is also affected by land use and infrastructure within each watershed and the size of each river's drainage basin.

In addition to the infrastructure within the West Canada and Schoharie Creeks drainage basins, both rivers have been dammed creating reservoirs for water supply and hydro power. West Canada Creek has a number of dams though only a few of which greatly alter the flow of the river. Most notably is the Hinckley Dam which holds behind it the Hinckley Reservoir which serves as the drinking water source for the greater Utica area (Hinckley Reservoir Working Group, 2007). Farther downstream from the Hinckley

Dam is the Trenton Falls Power Dam which holds back water used to run the Trenton Falls Electric Generating Plant. Schoharie Creek flows into the Schoharie Reservoir near Gilboa, New York and is contained by the Gilboa Dam, which also operates as the Blenheim-Gilboa Pumped Storage Power Project.

By studying and comparing the discharge of each river over the twentieth century, this study intends to ascertain whether changes in the hydrologic regime are having a significant effect on the main tributaries of the Mohawk and what this will mean for the State's hydrologic budget into the future.

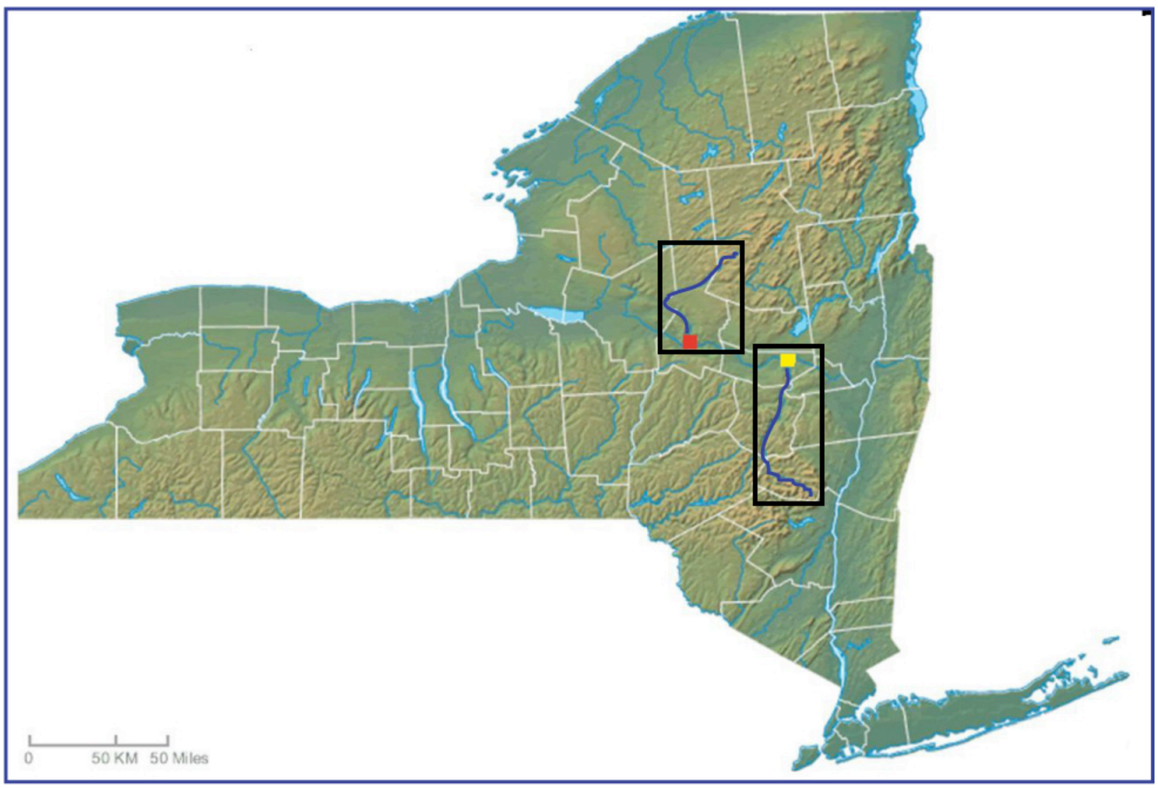


Figure 1: New York State with prominent rivers in blue. West Canada and Schoharie Creeks general drainage basin area is outlined in black and the confluence with the Mohawk River is marked in red and yellow respectively (modified from geology.com, 2008).

The people of New York are reliant on water supplied naturally through the hydrologic regime of the state. Because of this, it is important to know how and why water resources are being impacted by regional climate change so appropriate measures can be taken to ensure reliable sources of water into the future. Citizens rely on the State to provide safe drinking water year round. Agriculture is dependent on a consistent water supply for irrigating crops. And finally, sportsmen trust that water will be properly managed so the rivers, lakes and streams remain suitable for fishing and recreation. This study focuses on determining past trends in stream flow in hopes that it will show what can be expected for the future as the State experiences changes in its hydrologic regime.

BACKGROUND

New York State is notorious for having extreme, well-defined seasons. Winter is cold with snow and ice typically from December to March, whereas summer is hot and humid beginning in June through August. The flora and fauna are well adapted to these seasonal variations and this can be seen in the beautiful fall foliage when trees drop their leaves in preparation for the coming cold and during the spring when animals shed their winter coats. The variation in New York weather is due to multiple factors including latitude, position of the Jet Stream and movement of frontal systems.

Just as the plants and animals have adapted to life in New York, humans have also modeled their lifestyles around the weather and seasons. This includes human infrastructure which has been made to withstand cold winters and endure warm summers, the diversity in clothing worn throughout the year and the various forms of recreation specific to certain seasons (i.e. snow skiing versus water skiing). Though humans have become acclimated to fluctuations in New York weather, a sense of dominion over nature is also seen and felt. Air conditioners and snow makers are two examples where humans determine their own temperature and weather patterns regardless of the natural cycles. As global climate change sets in, weather fluctuations, both great and small, are going to have a considerable effect on the landscape and humans are going to have difficulty controlling a constantly changing system that already proves difficult to predict.

New York waterways are a good example of a natural system that New York residents constantly battle. In the past, New Yorkers have been able to plan and prepare for events such as flooding or ice jamming, but as global climate changes, it may become more difficult to predict fluctuations in weather because these changes may fall outside the norm. New York waterways are very sensitive to changes in the hydrologic regime. Temperate and precipitation changes can quickly alter the amount of water entering river systems. Small variances in temperature can determine the difference between snow and rain which have greater consequences than a discussion about which jacket to wear, down or Gore-Tex®. In the near future New York residents are going to be forced to confront issues surrounding water availability so gaining a better understanding of the natural system is imperative to prepare for the future. In terms of waterways, one key question is if the past can be used as a proxy for the future. Studying past extreme events such as the drought, which occurred during the 1960's, will provide scientists with a comparison for present day happenings. This may be helpful in determining if present changes are indicators or warning signs of what can be expected into the future in terms of extreme events. Extreme events are becoming more and more frequent and increasingly considered less of an extreme and more of a norm. If this trend continues it will be important to know the cause and effect of each event to better prepare for the future.

The physiography of New York plays an important role in the hydrological regime. The varied topography defines watersheds, direction of flow and creates a temperature gradient establishing a snow line during fall and winter months. The Adirondack and Catskill mountain ranges contain the headwaters to the majority of rivers in New York, including West Canada and Schoharie Creeks flowing from the southern Adirondacks and eastern Catskills respectively. The steep terrain of these two mountainous regions decreases the time delay between a precipitation event and increased levels of discharge in the rivers because runoff flows quickly downhill. West

Canada and Schoharie Creeks drain the southern Adirondack and northern Catskill regions and they are the two largest tributaries to the Mohawk River. The Mohawk River flows through the Mohawk Valley, between these two mountainous regions before converging with the Hudson River. The Mohawk Valley is a natural passageway connecting middle American to the Atlantic Coast channeling not only the river, but also wind and other weather patterns.

Western New York has been nicknamed the lakes region due to the Great Lakes that border the state and also the presence of Finger Lakes. The Finger Lakes are warmed to depths by the summer sun and then freeze completely over by mid winter. The Great Lakes have a much stronger affect, and the variability in lake surface temperature has an effect on weather systems moving through the region (Sousounis, 2000). The 'lake effect' is a key variable in the hydrological regime for New York State. During the winter, cold arctic winds move across long expanses of warmer lake water of the Great Lakes region in western New York. Provided the lakes have not iced over, warm surface water provides energy and water vapor that is precipitated on the lee margins, most often as snow but also sometimes as rain. The lake effect is most prominent in the early winter before the lakes have had time to freeze and historically has the potential to drop huge amounts of snow over a very short period of time (Heidorn, 1998). Precipitation due to the Lake Effect is commonly transferred as far east as Albany and increases the runoff into the Mohawk-Hudson River watershed. The Lake Effect is very pronounced in the Tug Hill Plateau and western Adirondacks but less so in the middle Mohawk and Catskills region. The Lake Effect is one example of how weather systems and precipitation patterns tend to move from west to east across the northern United States and especially across New York State.

Most weather systems are driven across New York State by the Jet Stream. The Jet Stream is a strong flow in the upper atmosphere that consistently blows across the US from west to east throughout the year. It exists because cold polar air collides with warmer southerly air and as a result, a front is created. The Jet Stream is continuous around the globe though stronger during winter months compared to summer months due to a greater temperature contrast between the polar and southerly air (National Weather Service, 2007). The Jet Stream defines how weather systems move across New York State. Depending on the exact location and speed of the Jet Stream, the effects of different weather fronts can be greatly altered.

The Jet Stream fundamentally drives weather systems and moves them west to east across the Northeast, but the extreme systems such as Nor'easters, Alberta Clippers and even hurricanes are attributed to more complicated atmospheric movements (Ewing, 1954). Nor'easters are ill-famed for bringing large amounts of precipitation, high winds, large waves and storm surges from the Northeast seaboard up the coast to Atlantic Canada (Davis et al., 1993). Nor'easters are a type of extra-tropical cyclone and are connected with fronts and horizontal gradients in temperature and dew point otherwise known as "baroclinic zones" (Davis et al., 1993). They combine strong northeasterly Gulf Stream low-pressure systems with Arctic high-pressure systems. Though they can occur anytime year round, Nor'easters are most prominent between the months of October and April because late fall through early spring weather provides the greatest temperature difference between the warm southerly formed Gulf Stream and freezing arctic air (Davis et al., 1993). In addition to heavy precipitation, Nor'easters are notorious for their destruction, most notably the "Blizzard of '93", Halloween 1991, President's Day 1979 and Ash Wednesday 1962.

Alberta Clippers are also a winter frontal phenomenon that affects the Northeast. These systems spread west to east moving cold winds and precipitation (Williams, 1997). Alberta Clippers receive their name from the Canadian province from which they originate, Alberta, and the clipper ships of the 19th century, one of the fastest ships of that time (Williams, 1997). Clippers are generally moisture deprived and therefore do not drop huge amounts of snow or rain, but bring frigid winds traveling at high speeds. They originate from warm, moist Pacific Ocean winds that travel east of the Canadian Rockies to Alberta's high plains where the storms are born. From Alberta, winds travel south to the Dakotas and Minnesota before crossing the Great Lakes and creating blizzard conditions for the lakes region of New York. Some of the most notable Alberta Clippers in New York history include, the New England Blizzard of 1978 and the Blizzard of 1996 which both dropped record snowfall across the northeast (Seacoast SAD, 1978 and Janofsky, 1996).

West Canada and Schoharie Creeks are notable New York waterways because they serve as the two largest tributaries to the Mohawk River which in turn is the largest tributary to the Hudson River. It is important to understand the individual hydrologic regimes for West Canada and Schoharie Creeks because of the greater implications the flow of these two rivers has for the southern half of the state. Because of this, major flooding events are often attributed to the Mohawk and Hudson Rivers as opposed to their smaller tributaries. Major flooding on the Mohawk River includes "break-up" events following winter freezing and “free-water” events from longer than normal precipitation events (Johnson and Garver, 2001). Break-up events are caused by rising temperatures, melting snow and/or heavy rains in the winter and early spring and they are typically accompanied by ice jams. Free-water flood events commonly occur in late summer and early fall, during peak hurricane season and are associated with significant precipitation (Johnson and Garver, 2001).

Being the two largest tributaries of the Mohawk River, flood events on West Canada and Schoharie Creeks are often discussed as they pertain to Mohawk River discharge increases though each individual river has experienced considerable flooding in the past. Two notable flood years on West Canada Creek include 1932 and 2006. Schoharie Creek has also flooded numerous times with the most notable floods taking place in 1987 and 1996.

METHODS

The United States Geologic Survey (USGS) maintains river monitoring sites across the country with the mission to provide water information that will benefit the Nation's citizens. These sites collect data on a variety of river characteristics including real-time conditions, surface and ground water data, water use and quality information, flood frequency, etc. For this project, surface water data for West Canada and Schoharie Creeks was downloaded from the USGS website from the Kast Bridge (West Canada) and Burtonsville (Schoharie) monitoring stations. Both sites are the farthest downstream gaging stations and capture the discharge of virtually the entire respective watershed.

The USGS stream-gaging data collection process involves numerous instruments and measurements (Figure 2). The two most basic pieces of data obtained for a river are stage and discharge. Stage is defined as the height of the water surface above a reference elevation and is measured through the use of a stilling well or bubbler system. The most notable difference between these two systems is stilling wells are located on the bank of a stream or on a bridge pier whereas a bubbler station can be located hundreds of feet from the edge of the water. The most practical method for measuring the discharge of a stream is the velocity-area method. Discharge is determined as the product of the area times the velocity. The cross-sectional area of a stream requires physical measurement whereas velocity is measured using a current meter. A current meter must be lowered from a bridge spanning the river or if wading is possible, in the river (Figure 3). Numerous velocity and corresponding river depth measurements are taken across the river at predetermined increments. The product of the width, depth and velocity for each section is the discharge through that increment of the river cross section. The total incremental section discharges equals the discharge of the river (Wahl et al., 1995).

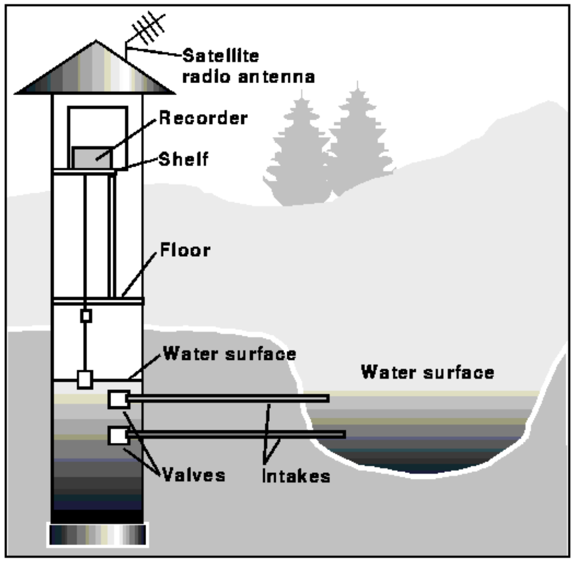


Figure 2: Schematic of a stilling well and shelter (Wahl et al., 1995).

Figure 3: Current meter and weight suspended from a bridge crane (USGS, 2008).

Kast Bridge Monitoring Station

The West Canada Creek Kast Bridge monitoring station is located in Herkimer County, latitude 43°04'08", longitude 74°59'19, on the right bank of the creek 600 ft downstream from the bridge on old State Highway 28, 1.2 miles downstream from North Creek, 2.2 miles north of Herkimer and 4.0 miles upstream from the confluence with the Mohawk River. Data collection at Kast Bridge began in January 1907 but has been continuous only since 1921. Records are good except those for estimated daily discharges, which are poor and diurnal fluctuation at low and medium flow is caused by power plants upstream from the station. Since March 1914, flow has been regulated by the Hinckley and Prospect Reservoirs, approximately 31 miles upstream from the gauging station (USGS, 2008). Hinckley Reservoir is a 2,800-acre drinking water reservoir averaging about 7 feet deep and has a maximum depth of 20 feet. Prospect Reservoir starts directly below the Hinckley Reservoir Dam and stretches for about 1 mile to the Power Dam (Figure 4).

Figure 4: Dammed Hinckley Reservoir in the background and Prospect Reservoir below the dam in the foreground (Ram-Air Skyways, 2006).

Burtonsville Monitoring Station

The Burtonsville monitoring station on Schoharie Creek is located in Schenectady County, latitude 42°48'00", longitude 74°15'48, on the right bank of the creek, 0.4 mi south Burtonsville, 2.7 mi north of Esperance, and 14.9 mi upstream from the confluence with the Mohawk River. Data collection has been continuous since October 1939. Records are fair except for those estimated daily discharges, which are poor (USGS, 2008). Flow is affected by the New York Department of Environmental Protection (DEP) which diverts water from the Schoharie Reservoir through the Shandaken Tunnel into Esopus Creek (upstream from Ashokan Reservoir) as part of the water supply for New York City. The Schoharie Reservoir consists of a single 6-mile basin and holds 17.6 billion gallons of water at full capacity (USGS, 2008). Slightly downstream flow on Schoharie Creek is partly regulated by the Blenheim-Gilboa Pump Storage Project.

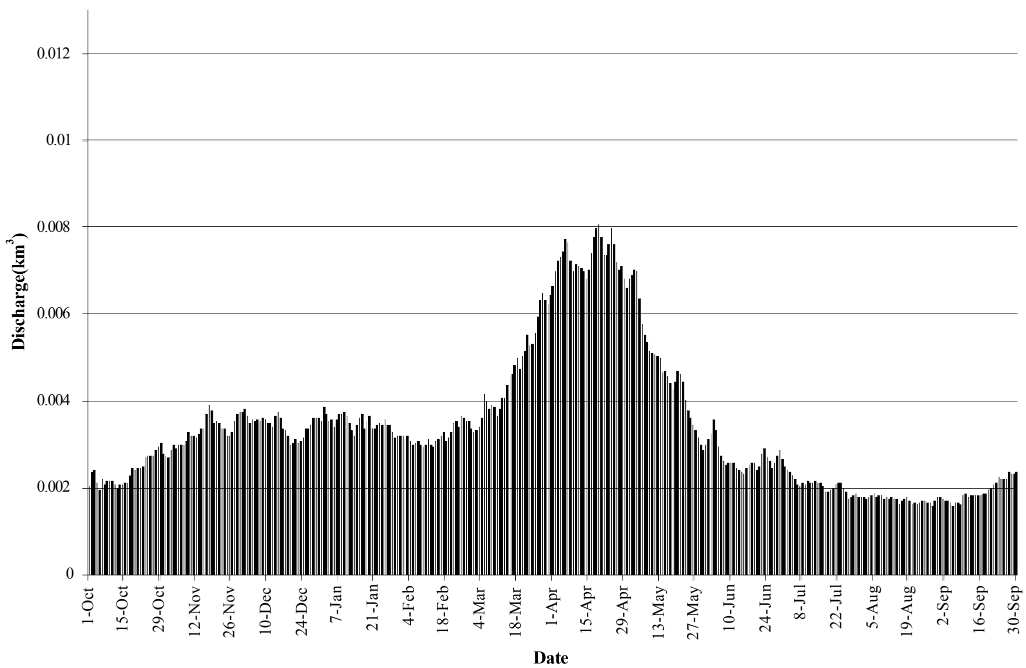
USGS collects and publishes water data online daily, constantly updating their nationwide database. In New York State alone, the network of monitoring includes 374 surface water sites. Every major river in New York is monitored, some with multiple gaging station locations along the river length. West Canada has two gaging stations, Schoharie Creek has seven, and the data from these stations is easily accessible via the USGS website, http://ny.water.usgs.gov/htmls/pub/data.html. For this study, discharge (ft^3/sec.) was the focus parameter downloaded from the USGS database into Microsoft Excel. After reorganizing the data into water years beginning October 1st and ending September 30th of the following year, discharge was converted from ft^3/second into km^3/second. Leap years were accounted for by being ignored where each water year consists of 365 days.

The focus of this study is to isolate trends in discharge for West Canada and Schoharie Creeks. In order to analyze discharge, extensive data manipulation was conducted in Microsoft Excel in an attempt to isolate trends, then illustrate and explain them in an easily understood manner.

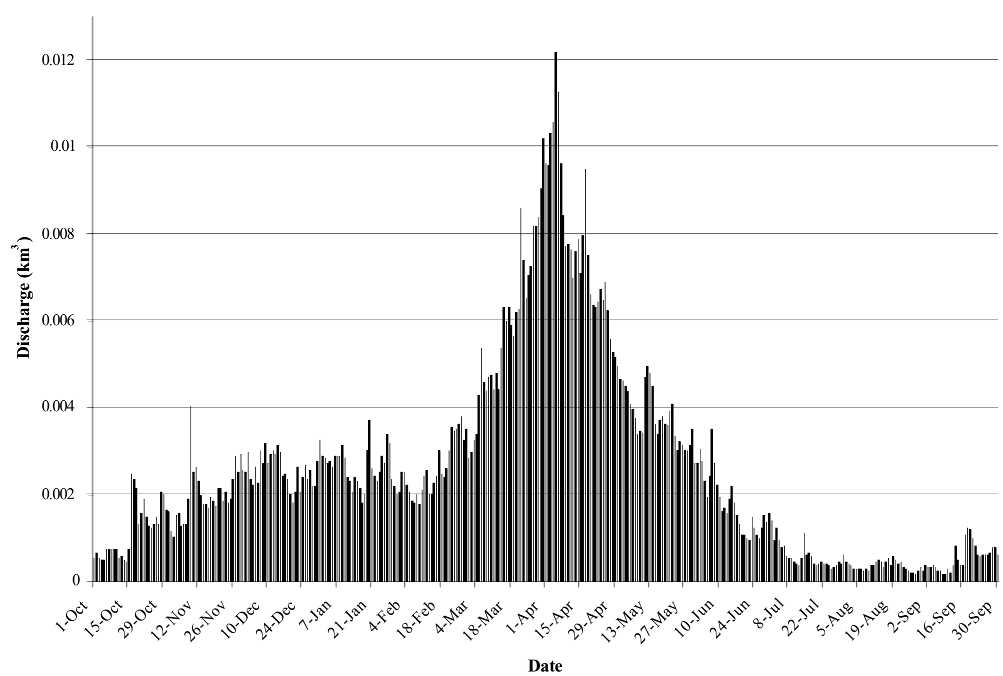
RESULTS

Total average daily discharge encompassing the entire data range was calculated and graphed for West Canada and Schoharie Creeks (Figures 5A and 5B). Both rivers show similar yearly flow trends, though Schoharie Creek is more variable, with average daily discharge levels during the fall and winter, reaching the yearly peak flow during the spring melt followed by the lowest discharge levels during the summer months. The daily discharge for both rivers during the months of October through February is consistently between 0.002-0.003 km^3. Following winter, is a spring melt period when discharge increases dramatically on both rivers with daily discharge rates reaching 0.008 km^3 and above historically between April 1^{st}-May 1^{st}. Summer tends to be dryer on the Schoharie than the West Canada with daily discharge remaining consistent around 0.002 km^3 for the West Canada and dropping below 0.001 km^3 for Schoharie. The lowest discharge rates take place beginning in mid-August through mid-September. While the overall annual discharge in each river is about the same for both rivers, the low flow on Schoharie Creek during the summer months is notable. Typical low daily flows of 0-0.002 km^3 on the Schoharie Creek must stress the aquatic ecosystem much more than is seen on the West Canada Creek.

[A] West Canada Creek



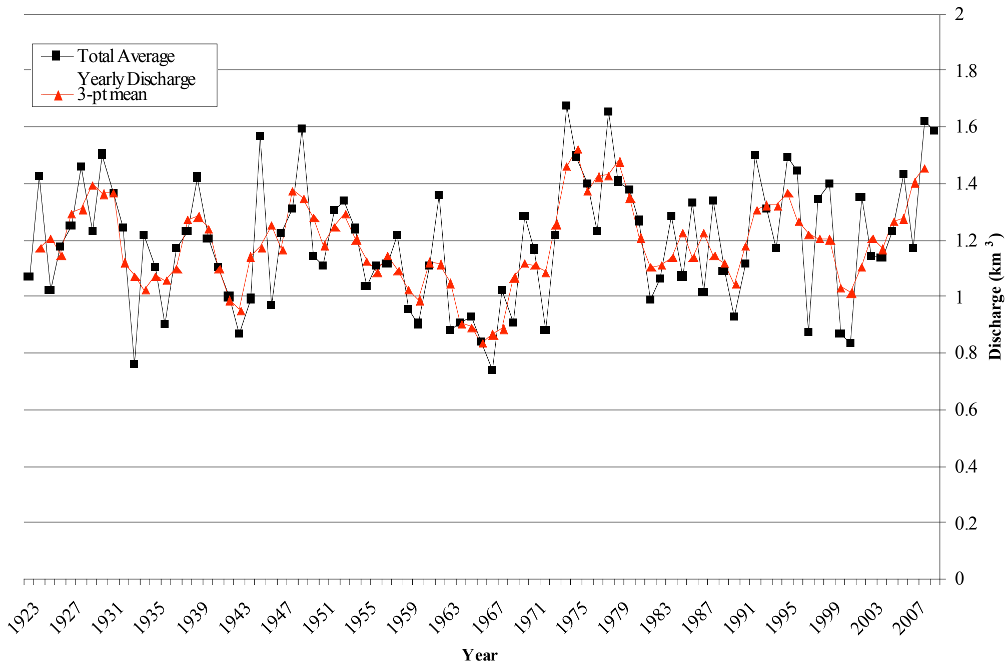
[B] Schoharie Creek



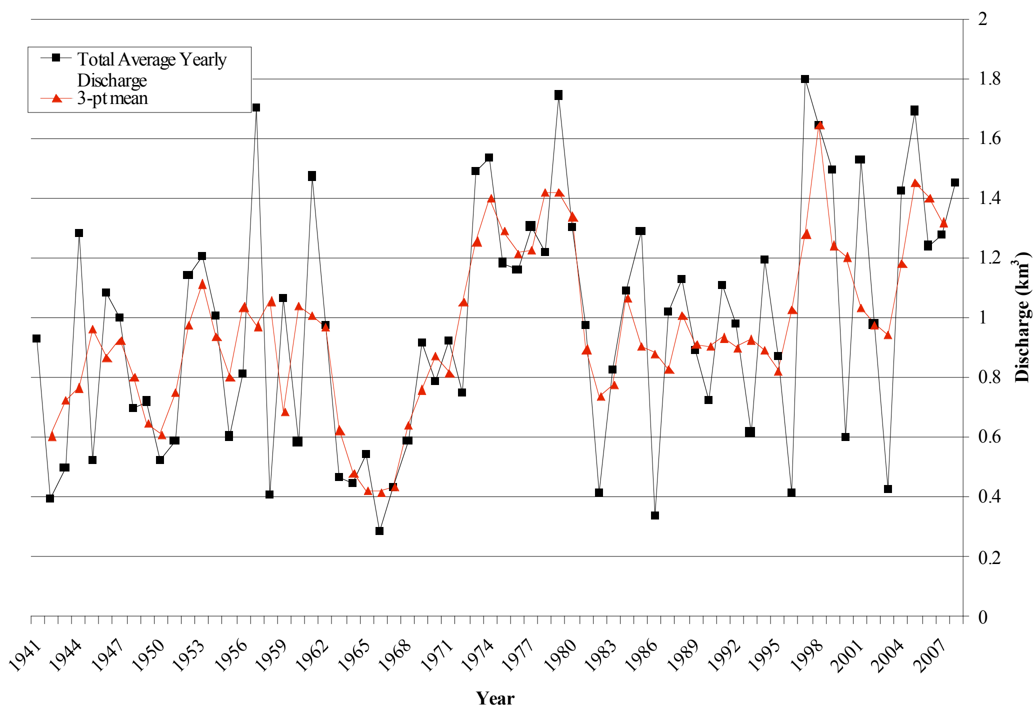
Figures 5A and 5B: West Canada (A) and Schoharie (B) Creeks average daily discharge (km^3), 1921-2007 and 1940-2007, respectively.

West Canada and Schoharie Creeks historically display similar trends in discharge, though the recent decade discharge trends for each river is very much different. West Canada Creek has had much more consistent discharge levels where Schoharie Creek has been highly variable. The discharge trends for both rivers display a clear similarity in the 1960s drought period and the 1970s wet period. Other years of well above or below average flow is consistently exhibited for both rivers. During the most recent decade (1998-2007), flow on West Canada Creek has remained relatively consistent whereas the discharge for Schoharie Creek has increased 31% overall but also shows two years of low flow, showing how flow on Schoharie Creek has been much more variable (Figures 6A and 6B).

[A] West Canada Creek



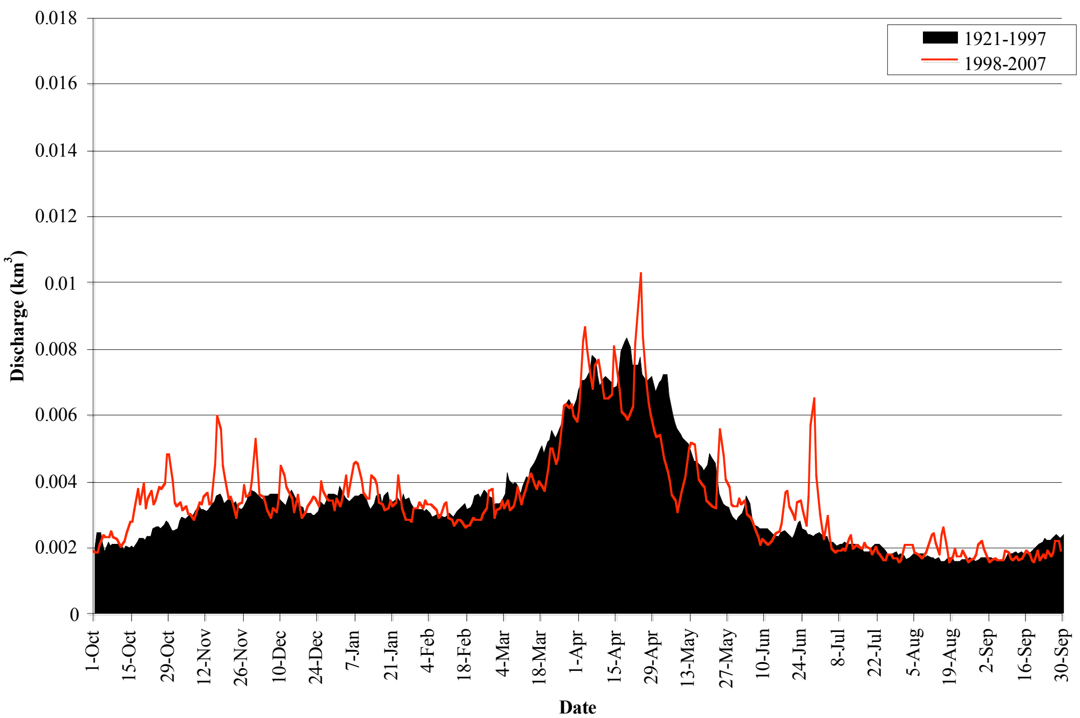
[B] Schoharie Creek



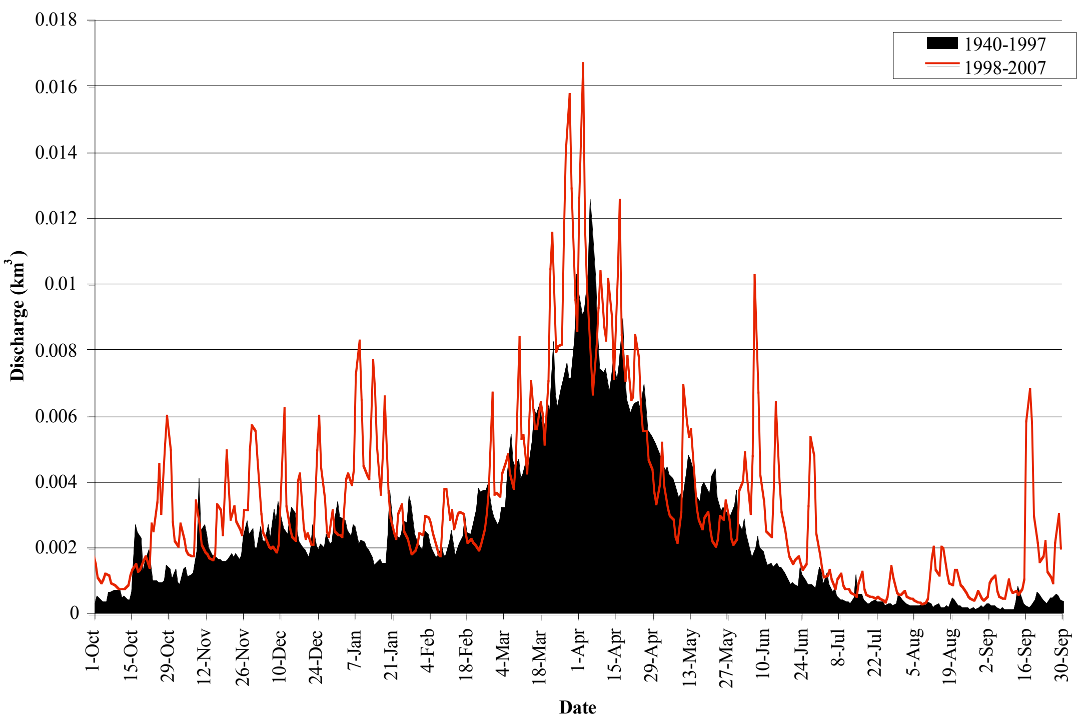
Figures 6A and 6B: West Canada (A) and Schoharie (B) Creeks total average yearly discharge, 1921-2007 and 1940-2007 respectively, represented in black, with three-point running mean represented in red.

Daily average discharge for the historic period was graphed with the daily average discharge for the recent decade, to compare the flow regime of the two time intervals on both rivers (Figures 7A and 7B). The variation in flow for West Canada Creek is minimal and difficult to see considering overall flow has not changed. The total discharge for the recent decade on West Canada Creek is 1.24 km^3 which is identical to a historic value of 1.25 km^3. However the flow regime has changed noticeably for Schoharie Creek with a total daily discharge value of 0.92 km^3 for the historic period compared to an increased flow of 1.21 km^3 for the recent decade, a 31% increase.

[A] West Canada Creek



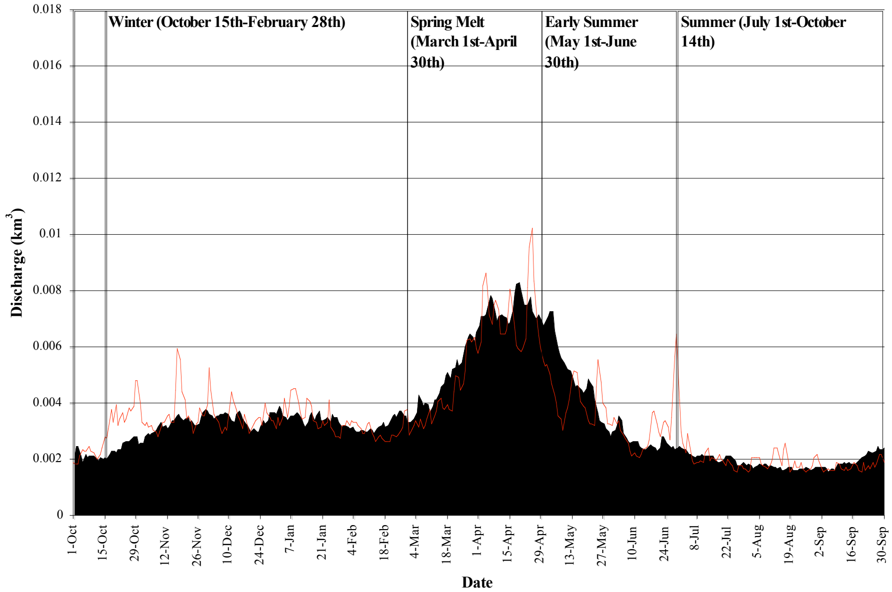
[B] Schoharie Creek



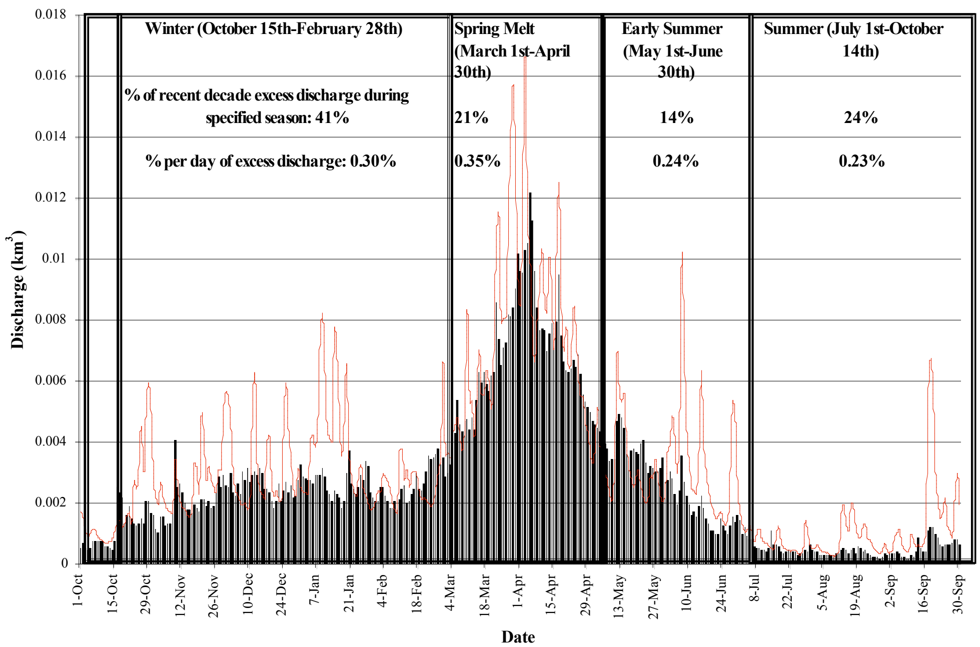
Figures 7A and 7B: West Canada (A) and Schoharie (B) Creeks total average daily discharge for the historic period 1921-2007 and 1940-1997 respectively, represented in black compared to the recent decade 1998-2007 represented in red.

To isolate trends in discharge and determine how the flow regime has changed on each river, the water year was divided into four seasons: 'Summer' (July 1-October 15), 'Winter' (October 15-February 28) 'Spring Melt' (March 1-April 30) and 'Early Summer' (May 1-June 30) (Figures 8A and 8B). Seasons were determined by separating patterns of discharge through the year in an attempt to isolate divisions in flow. Overall the yearly trends in discharge are similar for both rivers with average daily discharge levels during the fall and winter, reaching yearly peak flow during the spring melt followed by early summer storms causing isolated instances of above average discharge and ending with the lowest levels during the late summer months. The Winter (Oct 16th-February 18th) has historically had consistent, moderate discharge levels. However, on Schoharie Creek the recent decade shows multiple winter events of increased discharge from the historic average 0.002-0.004 km^3 up to as high as 0.008 km^3. During the Spring Melt (March 1st-April 30th) the snow pack melts from the Adirondack and Catskill Mountain regions causing discharge levels to reach the yearly peak. The recent decade discharge for the Early Summer (May 1st-June 30th) is dominated by isolated extreme flow events not seen during the historic period. Though both rivers June discharge display these isolated events, it is most notable on Schoharie Creek. Following Early Summer is Summer (July 1st-October 14th) with historically low flow. With the exception of a couple of high flow events in early September on Schoharie Creek, this remains a period of low flow for both rivers. West Canada Creek average daily flow for the summer period is 0.0020 km^3 and 0.0019 km^3 for the historic and present periods respectively. Schoharie Creek average daily flow for the summer period is 0.0005 km^3 and 0.0012 km^3 for the historic and present periods respectively.

[A] West Canada Creek



[B] Schoharie Creek

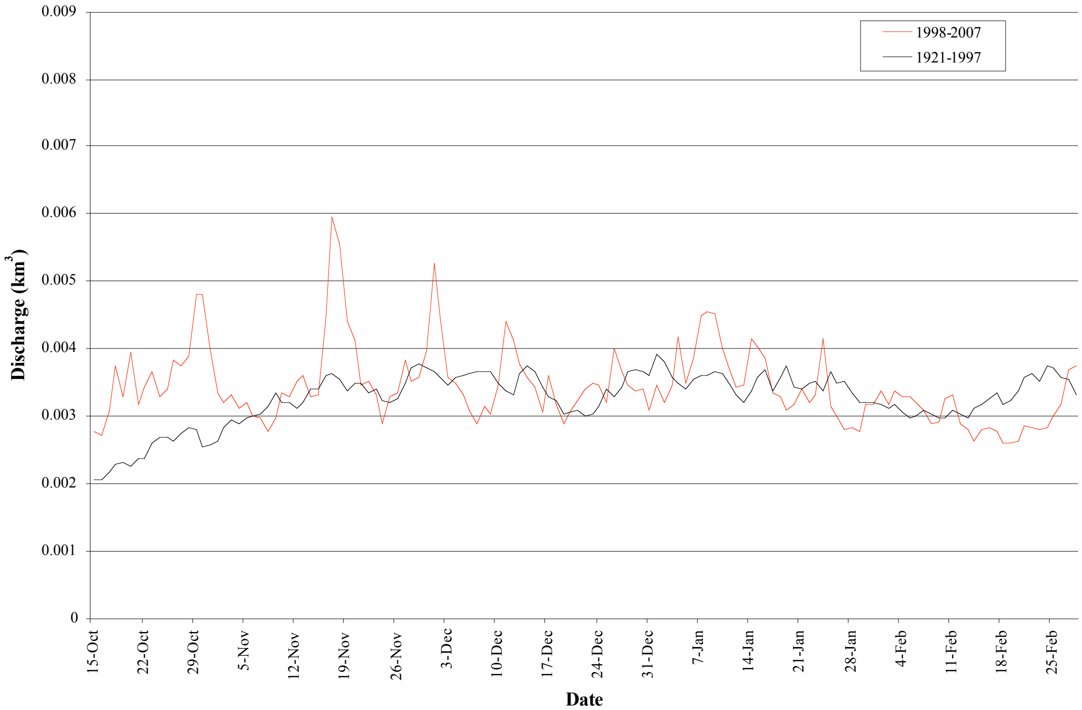


Figures 8A and 8B: West Canada (A) and Schoharie (B) Creeks seasonal division of total daily average discharge for the historic period (1940-1997 and 1921-1997, respectively) represented in black compared to the recent decade (1998-2007) represented in red. For Schoharie Creek (B) percent of excess discharge flowing through during each season is included in addition to the percent excess discharge flowing through on a daily basis. This shows when throughout the year excess water is discharging from the river.

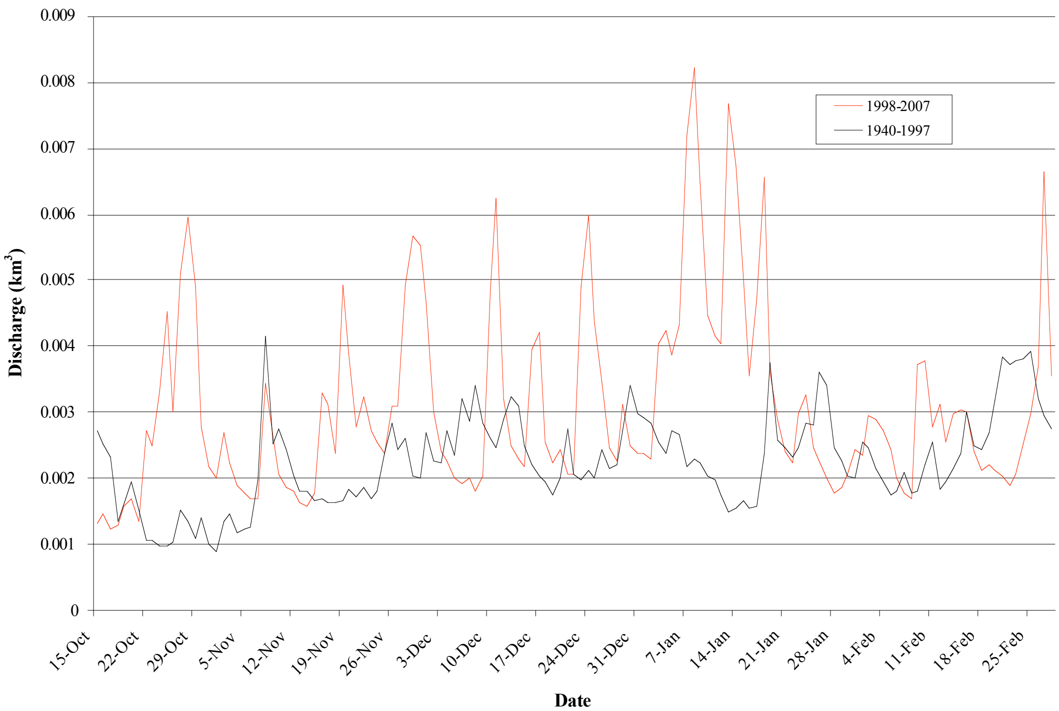
Separating the water year into seasons allows a determination of when throughout the year water is flowing through the river systems. This is especially relevant for Schoharie Creek, which has excess discharge for the recent decade whereas discharge for the recent decade on West Canada Creek has remained more or less constant. On Schoharie Creek graphically it appears that the majority of excess water flows during the winter months, but note that this is the longest of the seasonal periods. To normalize these data, the percent excess discharge for each season was calculated by dividing the total daily average discharge for each recent decade season by the total residual in the recent decade. Excess Winter discharge accounts for 41% of the overall recent decade discharge, Spring Melt 21%, Early Summer 14% and Summer 24% (Figure 8B). To normalize the overall seasonal percentages of increased discharge, the percent change per day of excess discharge was calculated for Schoharie Creek. These percentage values are less variable between the seasonal periods: Winter 0.30%, Spring Melt 0.35%, Early Summer 0.24% and Summer 0.23% showing that discharge is increasing throughout the entire year and is not isolated to one season. However, the largest change is in the winter and spring, 0.30-0.35%, compared to early summer and summer, 0.24 and 0.23% respectively.

Where historically there has been one large spring snow melt event increasing discharge during the months of March and April, the data from the recent decade show multiple isolated events beginning in October and continuing through until the classic spring melt period. This trend is more noticeable on Schoharie Creek though still discernable on West Canada Creek (Figures 9A and 9B).

[A] West Canada Creek – Winter Period Discharge



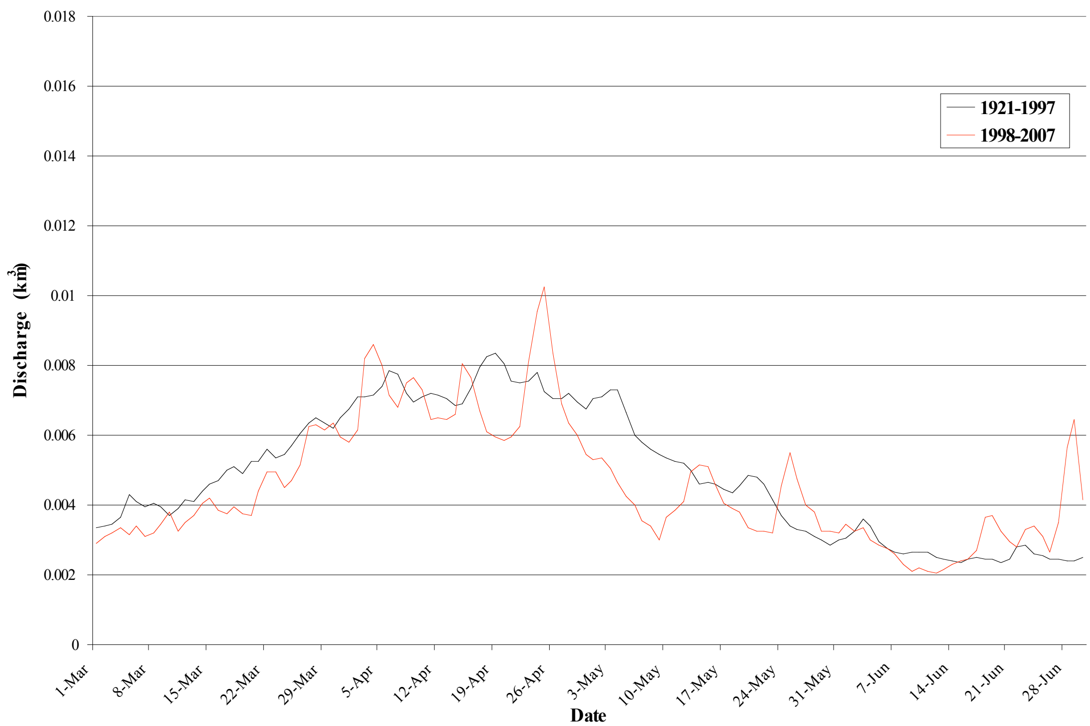
[B] Schoharie Creek – Winter Period Discharge



Figures 9A and 9B: West Canada (A) and Schoharie (B) Creeks winter discharge recent and historic period comparison represented in red and black respectively.

An important implication of the Northeast Climate Impact Assessment study is reduced snow pack and earlier snowmelt. For this reason the spring melt and early summer period for both creeks was graphed to determine whether or not the spring melt period is happening earlier in the year (Figures 10A and 10B).

[A] West Canada Creek – Spring Melt and Early Summer Periods



[B] Schoharie Creek – Spring Melt and Early Summer Periods

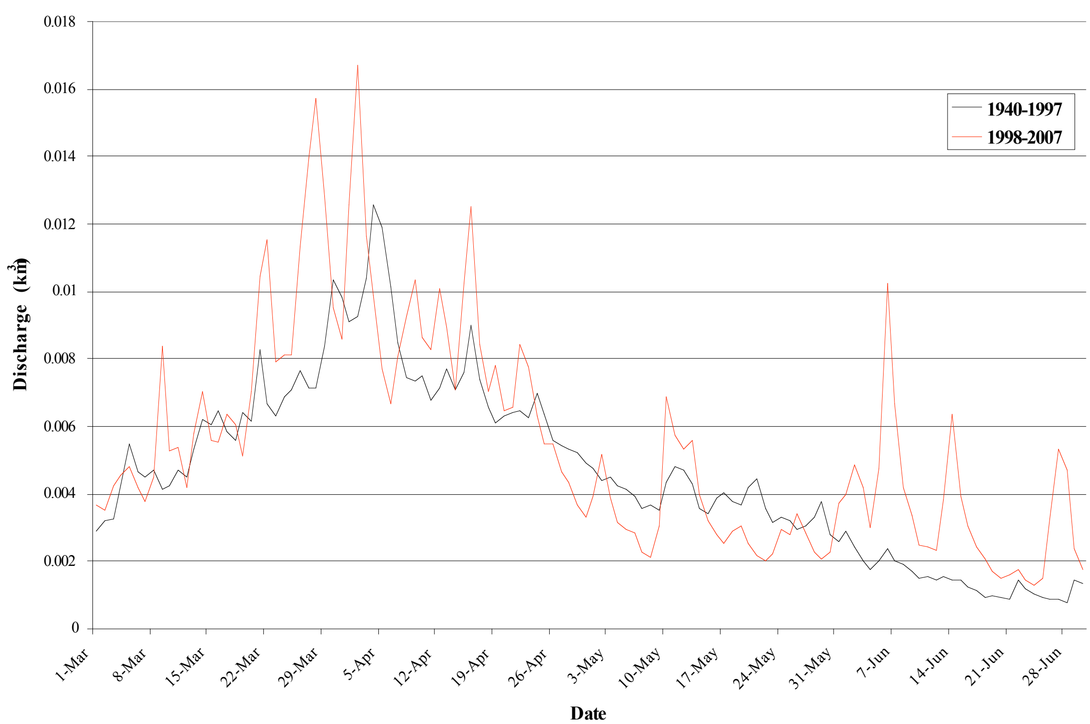
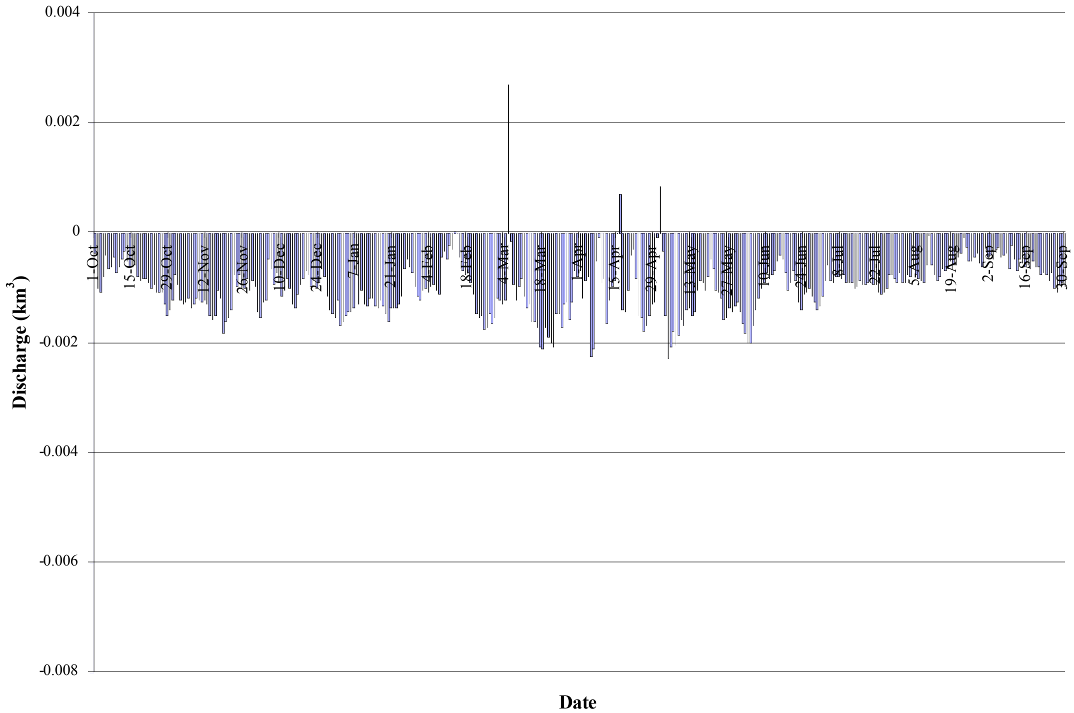


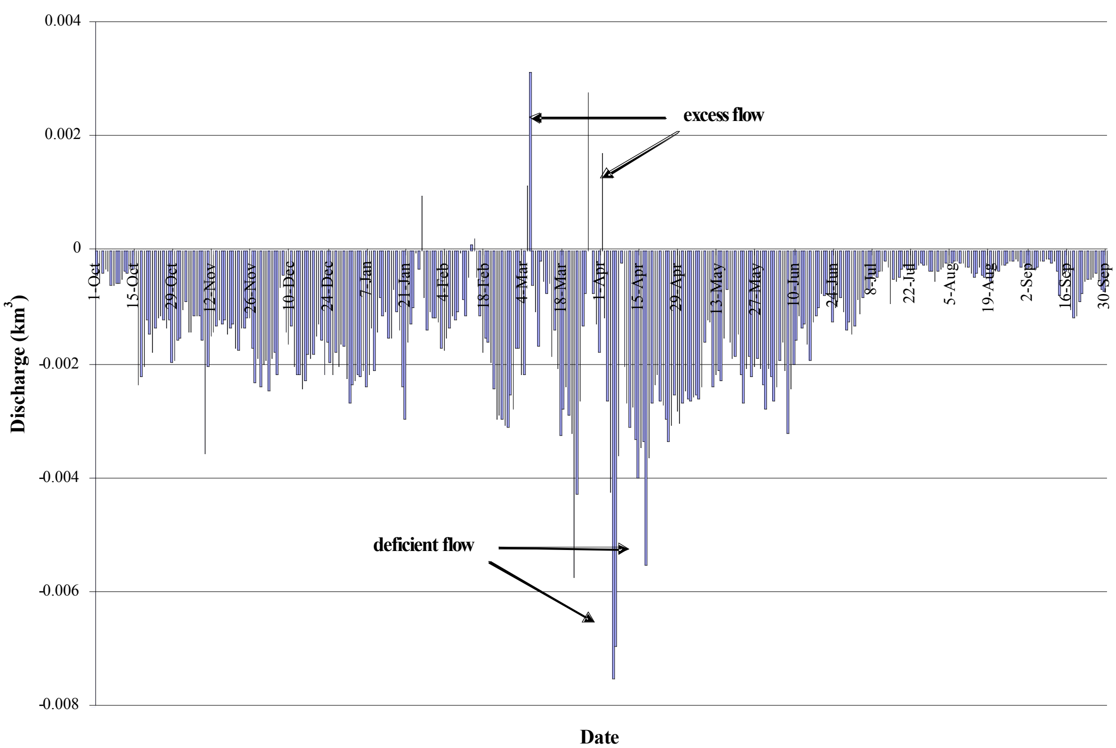
Figure 20A and 10B: West Canada (A) and Schoharie (B) Creeks Spring Melt and Early Summer (March 1-June 30) average discharge with the historic period in black and recent decade represented in red.

During the 1960s the Northeast experienced an extreme period of drought followed in the 1970s by a period of above average wetness (Namias, 1966, Diaz, 1983 and Burns et al., 2007). To illustrate this phenomenon, the residuals were calculated for each period by subtracting the daily average for the historic period, 1921-1997 and 1940-1997 for West Canada and Schoharie Creeks respectively, from the recent decade, 1998-2007. Figures 11A, 11B, 12A and 12B demonstrate the severity of these two periods graphically with the residuals graphed against the historic daily average normalized to zero.

[A] West Canada Creek – 1962-1967

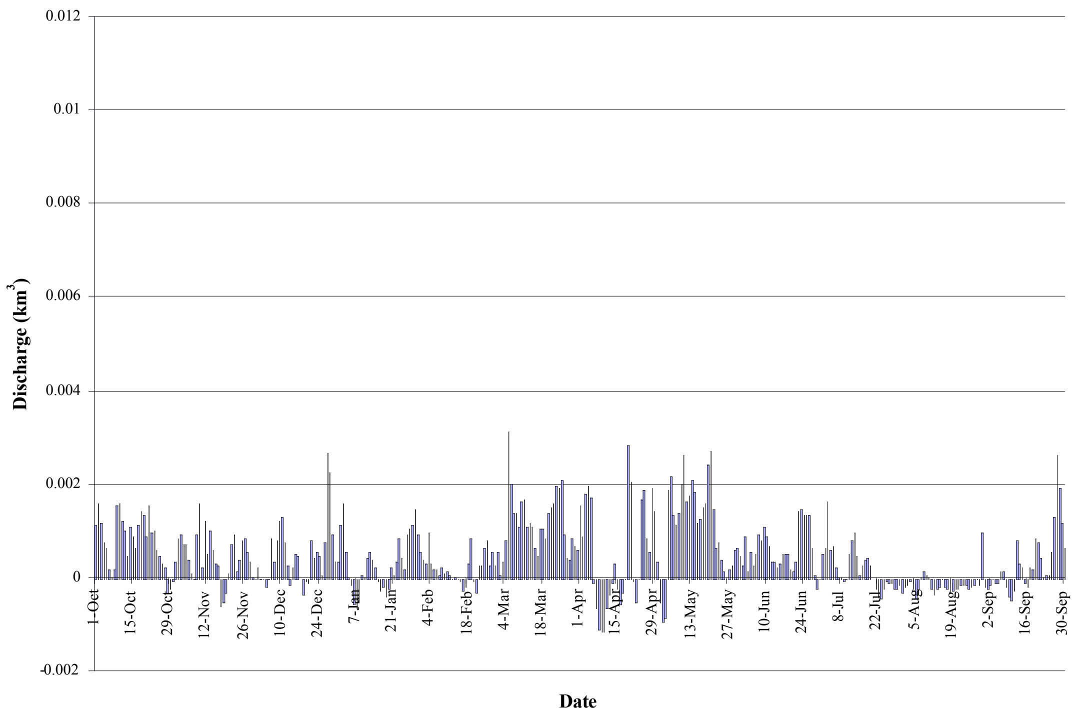


[B] Schoharie Creek – 1962-1967

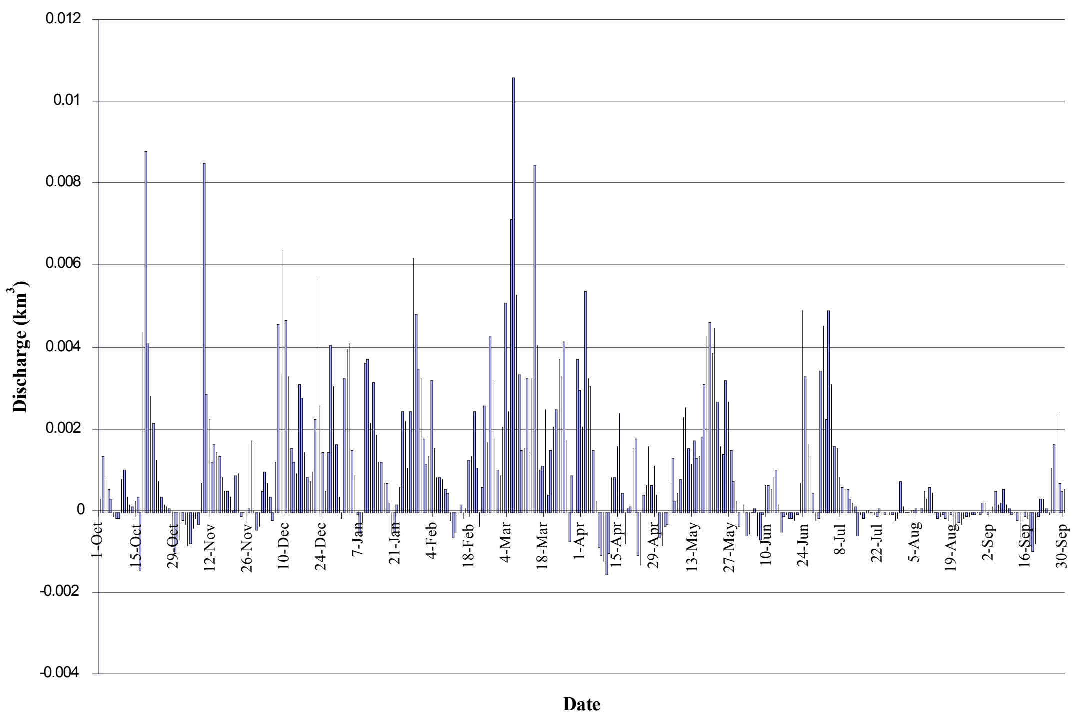


Figures 11A and 11B: West Canada (A) and Schoharie (B) Creeks 1962-1967 drought period residuals.

[A] West Canada Creek – 1972-1979 wet period



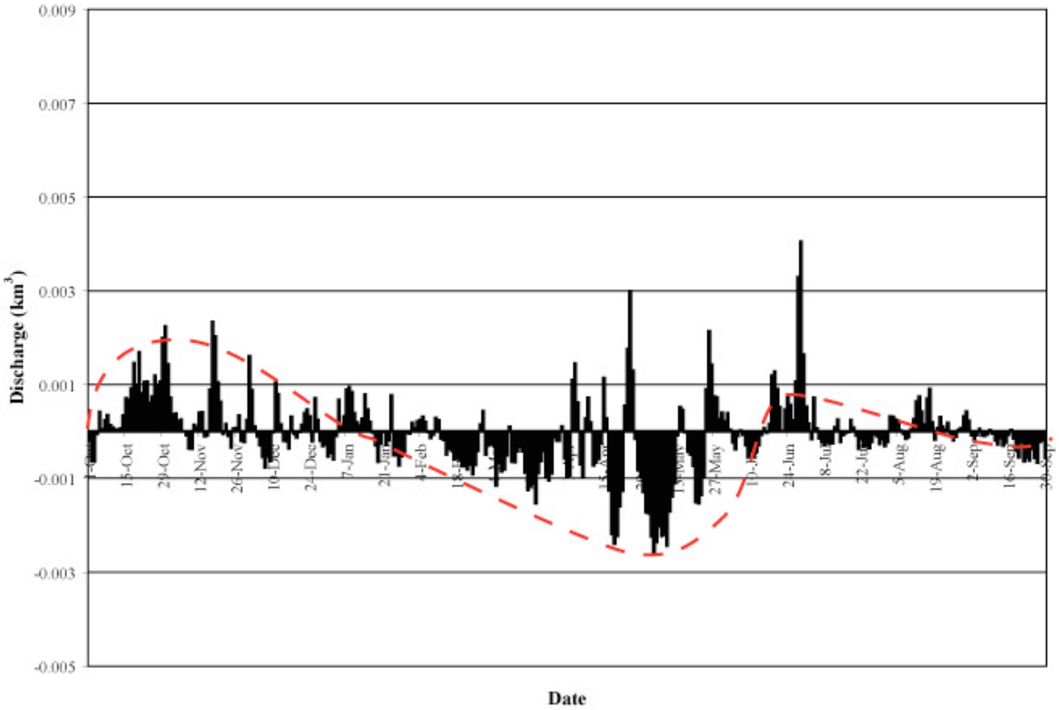
[B] Schoharie Creek – 1972-1979 wet period



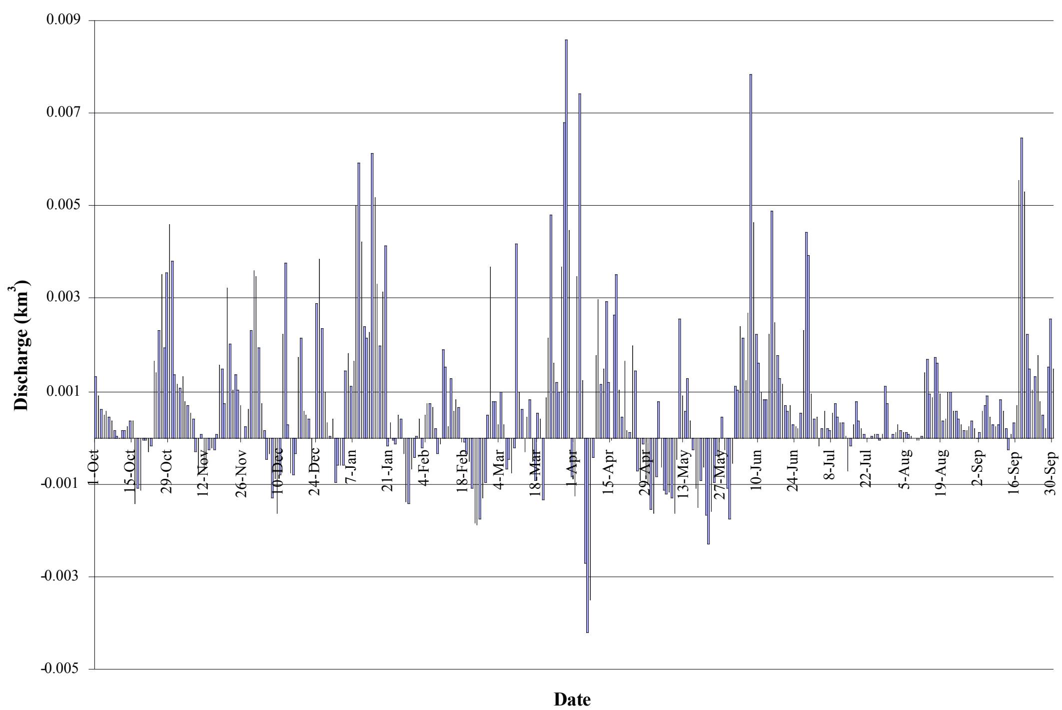
Figures 12A and 12B: West Canada (A) and Schoharie (B) Creeks 1972-1979 wet period residuals.

Using the same graphing method, the residuals for the most recent decade, 1998-2007 were plotted for both rivers (Figure 13A and 13B). For West Canada Creek recent decade discharge residuals fluctuate little from the historic norm. There are a few isolated events beginning in April and continuing until August. However, though discharge residuals are fluctuating very little from the historic norm, there is some increase in discharge during October and early November and decrease in the spring melt during April and May which may be correlated. The residuals for Schoharie Creek are highly variable with little similarity with the historic norm.

[A] West Canada Creek – 1998-2007 residual from norm.



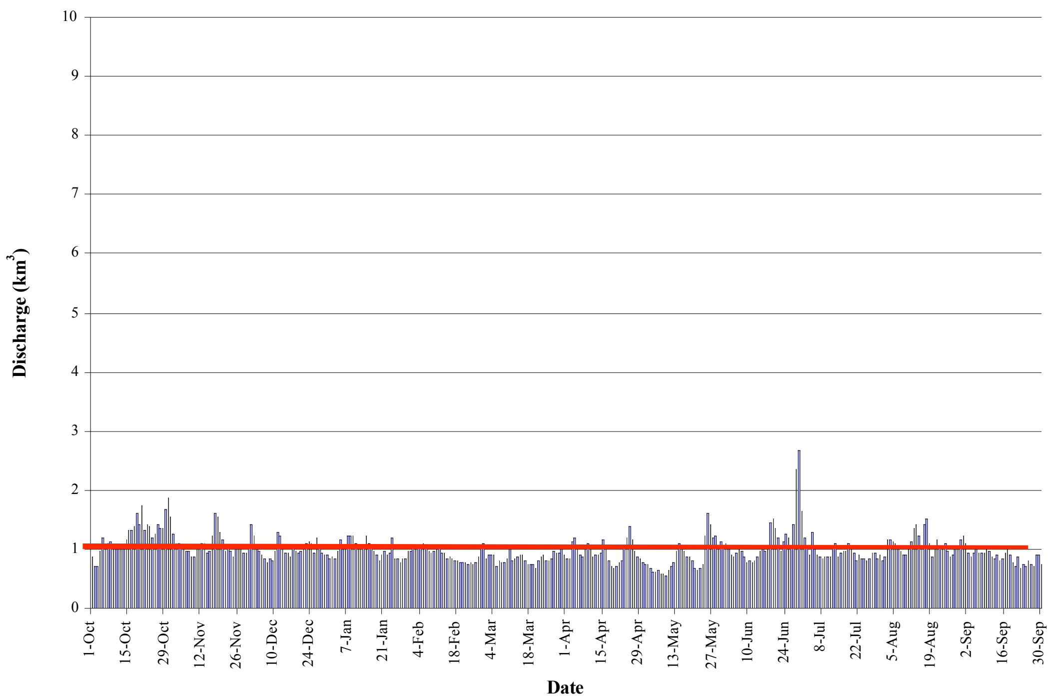
[B] Schoharie Creek – 1998-2007 residual from norm



Figures 13A and 13B: West Canada (A) Schoharie (B) Creeks recent decade, 1998-2007, residual variations from the historic norm, 1921-1997 and 1940-1997, respectively. Red line on 13A, West Canada Creek, represents increased winter melt events causing decreased peak spring melt.

The percent mean was calculated for the recent decade and graphed to illustrate what percent of historic norm discharge was flowing through each river system throughout the recent decade (Figures 14A and 14B). Percent mean was calculated by dividing the recent decade daily averages by the historic period daily averages. A discharge at 1 on the y-axis is equivalent to 100% or an identical discharge value for the recent and historic periods and is represented on the following graphs by the red line.

[A] West Canada Creek – Recent Decade (1998-2007)



[B] Schoharie Creek – Recent Decade (1998-2007)

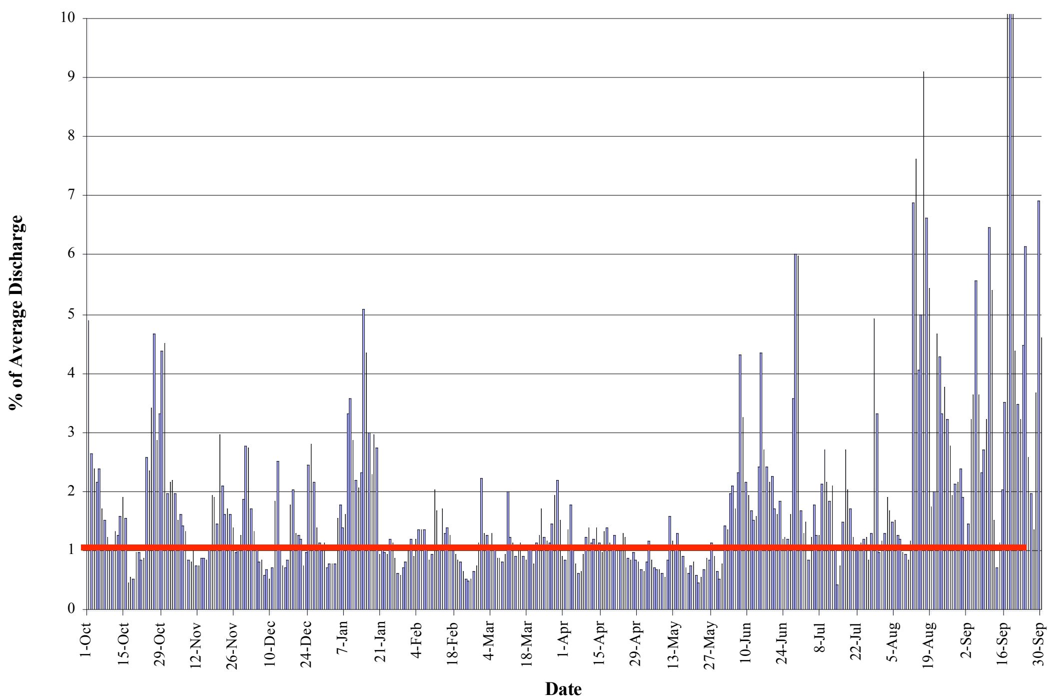


Figure 14A and 14B: West Canada (A) and Schoharie (B) Creeks percent mean discharge for the recent decade (1998-2007) compared to the historic mean 1921-1997 and 1940-1997, respectively. Red line represents percent flow equal to historic norm or 100% of historic normal flow.

Though average daily flow has increased on Schoharie Creek during the recent decade, there have also been multiple years of very low flow. The years 1999 and 2002 have average discharge values as low as the 1960s drought period. Figure 15 illustrates this extreme variability during the recent decade on Schoharie Creek.

Figure 15: Schoharie Creek recent decade (1998-2007) total yearly discharge. Further displays that high annual variability during the recent decade on Schoharie Creek.

DISCUSSION

Regional climate change predictions for the US Northeast suggest that as temperatures continue to increase, river discharge is projected to become more variable (Frumhoff et al., 2007). The purpose of this study is to ascertain whether global climate change has already begun to have an effect on New York State rivers and what this might mean for the state's hydrologic budget now and into the future as regional climate change makes a more profound effect on the hydrology of the state.

Water flow on West Canada and Schoharie Creeks has always been variable across decades. The best examples of this variance being the two periods of most extreme, persistent streamflow, the early to mid-1960s deficit and the wet years of the mid-1970's (Figures 11A, 11B, 12A and 12B). These two periods of significant swings in river discharge were caused by complex interactions between the atmosphere and sea-surface temperatures that dictate weather patterns across the Northeast and throughout the world. The 1960s and 1970s are commonly thought to represent a major climatic aberration in the US precipitation regime (Namias, 1966, Diaz and Namias, 1983 and Burns et al., 2007). Though historically considered abnormalities, the levels of discharge recorded during these two periods occur back to back during the most recent decade on Schoharie Creek.

Overall since 1998 Schoharie Creek has experienced a 31% increase in average yearly discharge compared to the historic norm. The average level of yearly discharge on West Canada Creek has remained more or less constant since the start of data collection. Therefore this difference, seen in these two tributaries to the Mohawk River must reflect local precipitation patterns. Weather patterns that affect the Schoharie Creek drainage basin and Catskill Mountain region are apparently not occurring farther north and therefore do not affect the Adirondack Mountain region and West Canada Creek drainage basin since total discharge has not been altered during the recent decade on West Canada Creek. According to Burns et al. (2006), precipitation in the Catskill Region has been increasing over the past 50 years. The Northeast regional climate change report also states that annual average precipitation has been gradually increasing across the region since 1900 (Frumhoff et al., 2007). On a multi-month basis, increases in precipitation amounts were greatest during June through October and the sharpest increase in precipitation amount in the past 25 years occurred most recently from the late 1990s through 2005 (Burns et al., 2006). Because Schoharie Creek is located in the Catskill Region, it is not surprising that the discharge data show identical trends with isolated high flow events throughout June assumed to be due to increased storminess and numerous high flow events throughout September and October (Figure 7B).

The Northeast regional climate change report suggest that precipitation events should become heavier and more intense as temperatures increase (Frumhoff et al., 2007). What this suggests is that regional precipitation has not begun to significantly affect the southern Adirondacks but is altering the precipitation regime or precipitation pattern of the Catskills. During the past decade average discharge levels have increased on Schoharie Creek. To account for this increase, the drainage basin must be receiving an increase in the number of precipitation events, heavier precipitation events or a combination of the two. The pattern cannot just be explained by earlier or sporadic snow melt: there is 31% more water, on average being transported through the system during the recent decade compared to historic norms. That said, 1999 and 2002 are two years during the recent decade with average daily discharge levels at extremely low flow. Considering these low-flow and high-flow years, Schoharie Creek appears to be experiencing an increase in discharge variability and not simply an increase in overall discharge.

A recent study of climate trends and water resources in the Catskill Mountains determined that annual mean air temperature and annual precipitation show increasing trends at the majority of sites studied (Burns et al., 2006). Schoharie Creek is not an isolated case. Regional climate change is altering the hydrologic regime for rivers across the northeast. Mean stream flows are increasing significantly and spring snowmelt is occurring earlier each year in New England (Hodgkins and Dudley, 2005). As discharge levels continue to rise, it will become increasingly important to know when throughout the year the excess water is moving through the system. The excess water from the increase in discharge over the last decade for Schoharie Creek is not concentrated in one season but rather discharging at similar increased rates throughout the year. The percent per day of excess discharge is flowing through during the winter, spring melt, early summer and summer periods at 0.30%, 0.35%, 0.24% and 0.23%, respectively.

On Schoharie Creek, the spring melt takes place during late March and early April and historically an above average melt would be attributed to a greater winter snowpack. Recall that regional climate change forecasts suggest that there will be reduced snowpack and increased snow density due to rising global temperatures (Frumhoff, et al., 2007). This report also discusses a shift in spring ice-out on lakes and peak stream flow to earlier in the season (i.e. mid-March and late February) (Frumhoff et al., 2007). The amount of water discharging during the spring melt has increased on Schoharie Creek but there is no clear indication as to whether the melt date has shifted to earlier in the year. West Canada Creek spring melt discharge has not increased during the recent decade and is with Schoharie Creek, the shift in melt date is not significant.

By the end of the century, the winter season is forecasted to receive increased amounts of precipitation, falling not as snow, but as rain in high intensity, more frequent events (Frumhoff et al., 2007). The current situation on the Schoharie Creek (winter discharge data) seen to suggest that this possible future scenario is already here. Average discharge has increased during the recent decade and that increase is accounted for by multiple, isolated extreme flow events (Figure 8B). However, the lack of such a discharge pattern on West Canada Creek supports that Atlantic systems are currently making a big difference. These include Nor'easters and extra-tropical systems. An implication of this is that normal frontal systems, Lake Effect and Alberta Clippers are significantly different or if they are, this cannot by seen in the data.

During the early summer and early fall, recent decade discharge increases for Schoharie Creek can also be attributed to extreme events lasting only a couple of days. Atlantic hurricane season generally begins in June and continues into the late fall and sometimes early winter. Hurricanes are not a new phenomenon in the northeast but changing atmospheric and sea-surface temperatures is causing an increase in the number and the intensity category of hurricanes weathered during one season (NOAA, 2006). The 2005 Atlantic Hurricane season is listed as the worst on record and extends the active hurricane season that began in 1995 (NOAA, 2006). Hurricanes and lesser storms such as Nor'easters, cause millions of dollars in damage and are a threat to human life. Though coastal areas are the worst hit, severe amounts of precipitation over a short interval greatly increases the flood potential for any river basin, Schoharie and West Canada Creeks included. Hurricane Floyd is a good example happening September 1999 and seen clearly in Figure 7B with the peak in discharge for Schoharie Creek on 18 an d19 September 1999. The Hurricane Floyd event is not as easily seen on West Canada Creek though the discharge doubled on 17 September 1999 (Appendix A).

The overall discharge on West Canada Creek has not increased over the past century and though not significant, there might be evidence of increased winter melt events causing a reduction in peak spring melt (Figure 13A). The Northeast regional climate change report predicts that as winter temperatures continue to rise, snow will melt faster and earlier increasing runoff during the winter (Frumhoff et al., 2007). This could explain the recent decade discharge for West Canada Creek, though the trend is subtle (see Figure 13A). The same temperature changes could be affecting the Schoharie Creek basin but the flow is too variable to discern such a subtle change.

Regional temperature changes may not be discernable from the Schoharie Creek discharge data, but the increase in average discharge during the recent decade is obvious and deserving of attention. There are many concerns with increasing river discharge. The three most important implications are increased flooding, stress to aquatic ecosystems and back erosion and sediment transport. Every year there are high discharge events which cause flooding, though some years are more severe than others. These floods are a risk to human life and cause millions of dollars in damage to people's property. Most recently on 28-29 June 2006 there was extensive flooding on West Canada Creek, the Mohawk River and elsewhere in New York damaging homes, businesses and public infrastructure including bridges, roads and dams (Figure 16 and 17).

Figure 16: West Canada Creek June 28-29, 2006 flood event.

Figure 17: West Canada Creek June 28-29, 2006 flood event.

Stress to aquatic ecosystems is a concern on Schoharie Creek during times of below and above average discharge. Northeast climate change reports predict little change in summer rainfall which is good for aquatic ecosystems because the summer months are generally the times of lowest flow (Frumhoff, 2007). However, if current summer discharge levels decrease in the future, aquatic animals will suffer. In terms of increased levels of discharge, there are multiple concerns. Excess flow and flooding can cause a loss of protected areas and spawning grounds. A loss of banks and sediment washed away by excess discharge will negatively impact aquatic ecosystems. Also, increased flow during spawning season has the potential to wash away fertilized eggs hurting the annual brood stock.

Increased flow during the last decade on Schoharie Creek is causing noticeable bank erosion and assumed downstream sediment transport. Schoharie Creek is reaching levels not seen in recent history as evidenced by river banks eroding into mature forests (Figures 18 and 19). In addition to the above mentioned concern for aquatic ecosystems, bank erosion will also have a detrimental affect on human infrastructure built on the banks of the Schoharie River and also recreation such as fishing, picnicking, etc. And once erosion occurs, the sediment from the eroded banks will be transported causing sedimentation problems downstream. The greatest concern in terms of sediment transport on Schoharie Creek is the infilling of reservoirs and build up of sediments behind Gilboa Dam.

Figure 18: Schoharie Creek bank erosion, 2008 (J.I. Garver, 2008).

Figure 19: Schoharie Creek bank erosion into mature forest, 2008 (J.I. Garver, 2008).

CONCLUSION

Regional climate change is now and will continue to become an increasing concern for society as global temperatures increase. As this study indicates, isolated regions of the Northeast are already being altered by regional changes due to climate change. Understanding regional variations in climate change prediction will help society and individuals cope with the impending changes caused by global warming.

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