CHANGES IN THE HYDROLOGY OF THE MOHAWK WATERSHED AND IMPLICATIONS FOR WATERSHED MANAGEMENT

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The Mohawk Watershed in upstate New York is a unique and distinctive basin that is the main tributary to the Hudson River. The drainage basin is 8961 km^2 with principal tributaries reaching far south into the Catskill Mountains (Schoharie Creek) and tributaries reaching into the Adirondacks to the north (West Canada Creek). The main trunk of the Mohawk River and the Mohawk Valley itself has played a key role in the early settlement of the North America, and the westward expansion in the United States because it is one of the few natural avenues through the Appalachian Mountains.

Of interest throughout the basin is how changes in global climate, especially in the Northeast (Hayhoe et al., 2006; Frumhoff et al., 2007), may impact the temporal and spatial distribution of precipitation across the Mohawk watershed. It may well be that change has occurred and is ongoing: it would appear that we are seeing more precipitation and that that precipitation is not distributed evenly over the basin (Burns et al., 2007; Kern, 2008; Cockburn et al., 2009). By all accounts we have entered a wet phase in this history of the basin, by some metrics, the wettest in recorded history (Figure 1). This wet phase is demonstrated by an increase in precipitation and discharge in the basin, and this has resulted in an increase in slope instability, bank erosion, and sediment transport in the main channels and their tributaries. This part of the Northeastern United States appears to be difficult to model for future climate change, and this is likely a function of the difference in the way in which storms track through eastern NY (Frei et al., 2002). Climate models for the Catskills, show that projected changes in mean annual precipitation range from an increase of ~10% to a decrease of 30% by the latter part of this century (Frei et al., 2002): thus modeling may not be helpful for guiding management decisions.

The geography of the basin is uniquely positioned to reveal important changes in the hydrologic regime in this part of the Northeast US. The Mohawk Valley itself allows for subtle west-to-east atmospheric transfer, and the low-lying Hudson Valley commonly serves as a funnel for Atlantic storms. But the positions of the two principal tributaries provide a unique natural laboratory to study how climate change and precipitation patterns are affecting this part of the Northeast. The basin is essentially partitioned to sample Atlantic tracking storms (south and east) and to sample continental systems (north and west).

The long-term average annual precipitation recorded by NOAA since 1925 is 0.93 m or 36.5 inches near the confluence with the Hudson (37.0 inches/yr since 1825; NOAA, Albany NY). Integrated over the entire basin, this would imply that a total of about 8.3 km^3 of precipitation falls in the basin annually. The annual discharge records from Cohoes Falls (U.S. Geological Survey station) would suggest that the average annual discharge of the Mohawk is 5.2 km^3, thus there is a difference of about 3.1 km^3 or about 37% loss annually. This difference is almost certainly lost through evaporation and transpiration (or evapotranspiration). If we iterate to solve for the amount of precipitation lost through this process, we estimate that this accounts for approximately 13.5 inches annually. This value is reasonable, but lower than what is traditionally assumed for this region (15 -25 inches per year - see Hansen, 1991). Thus there might be other mechanisms to consider for loss of water in the basin, but give the imprecision in our numbers we have used to make these estimates, these sorts of exercises are probably not warranted. Recall that a primary assumption here is that the annual total precipitation measured by NOAA at Albany applies evenly across the basin: this is certainly not the case. Nonetheless, these numbers serve as a useful first approximation of the volume of water in the system. Note that the only significant out-of-basin transfer of water is from the Schoharie Reservoir through the Ashoken tunnel to the Esopus Creek and eventually on to the New

York City water supply. If we assume that that water is pumped continuously, all year, at 300 cfs, this transfer would result in a net loss in the basin of 0.27 km^3. While this is not significant on a regional scale, this is potentially a significant number for the Schoharie Creek, where the mean annual discharge is about 1.0 km^2. Also note that we assume here that the amount of water lost through groundwater recharge is in dynamic equilibrium. There is a possibility that regionally groundwater tables are rising with increased precipitation, but we are unaware of data to support this, but it is a reasonable hypothesis worth consideration because precipitation has increased in the last decade (Figure 1).

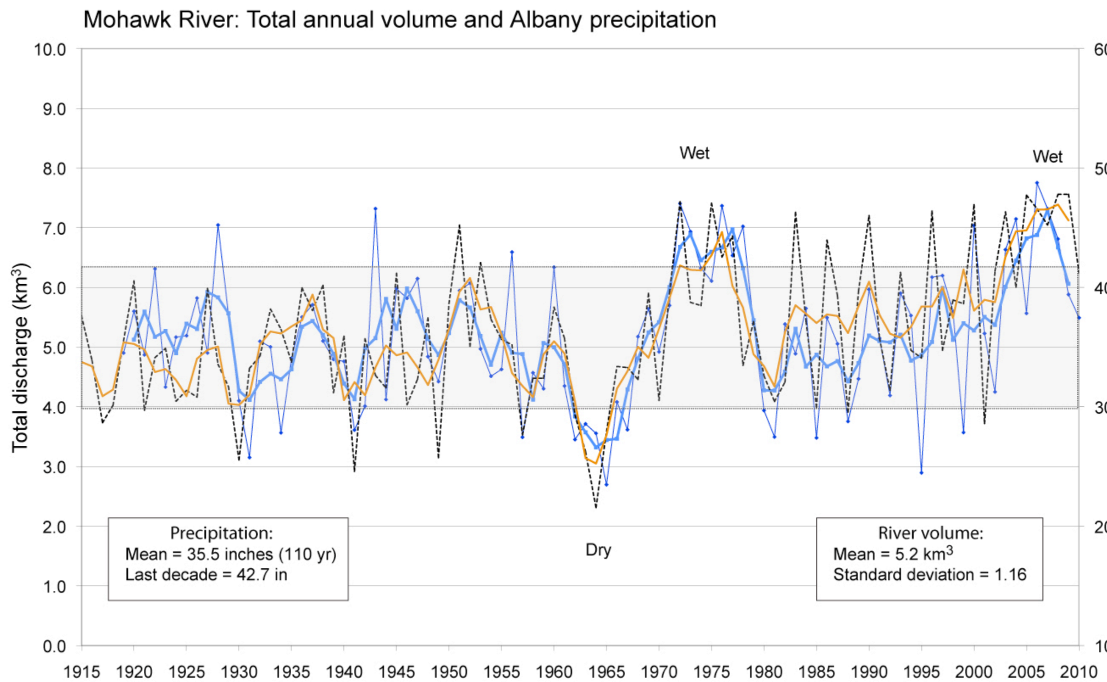

Figure 1. Annual discharge in km^3 of the Mohawk River from the USGS gage at Cohoes Falls. The total cumulative volume of water is given for each water year, which is 1 Oct to 30 Sept. The thin blue line is the annual totals, and the heavy blue line is an equal-weighted 3-point moving average. The orange line is 3 yr moving average of annual precipitation and the dotted black line is annual values (from NOAA Climate archives, Albany). For precipitation, a mean of 35.5 inches is the calculated annual totals from 1900 to 2010, and the "last decade" is eleven-year period from 2000 to 2010. The long-term mean precipitation annual total (1825-2010) is 37.0 inches (NOAA, NWS data; Stephen Dirienzo, personal comm., 2011).

To evaluate the total discharge, we take mean daily discharge records for every day of every year on record and calculate the volume of water for each day and then sum them for each water year, which is 1 October to 30 September. This means that the 2010 water year started on 1 October 2009, and ended in September of 2010 (it also means that the October 2010 floods are not considered in this analysis). The precipitation records considered are based on NOAA data that correspond to calendar years (i.e. January to December): so there is a slight difference in these records. The plot of the average annual discharge on the Mohawk River shows us that the mean flow is about 5.2 km^3 per year. The plot very closely corresponds to the average annual precipitation as recorded by NOAA, and thus we feel satisfied that the globally recognized relation between correlation between precipitation and river discharge applies here as well.

There are several significant excursions of discharge on the Mohawk (Figure 1) that are significant from a planning and management perspective. The first is the drought in the early 1960's, which was the most significant negative excursion the basin has seen in recorded history. The second is a period of abnormal precipitation that followed this in the early 1970's. It is not clear from the literature what external factors may have driven either of these excursions, and studies suggest that there is no clear link to the North Atlantic Oscillation (NAO), nor El Nino-La Nina (Hurrell et al., 2003; Kern, 2008). Finally, we note that we are in a period of very high discharge that apparently peaked in 2006, and has fallen slightly since. We note that this recent period of high discharge on the Mohawk corresponds to the wettest decade on record at Albany (NOAA), where records extend back to the early nineteenth century.

There are lessons in these long-term discharge records for watershed management, especially if a management plan involves understanding and optimizing water flow and availability as a resource. Consider the change in the basin hydrology going into the drought in the early 1960's, discharge dropped more than half in the five-year period from 1960 to 1965. Rapidly increasing annual flows can also be problematic due to flooding: between 1965 (2.7 km^3) and 1972 (7.4 km^3) discharge increased by a factor of 2.75 in less than a decade. Our current situation is not much different in that we appear to have an abundance of water, but we have entered this wet period gradually. Since 2003 the annual discharge has been above the historic mean, and in a few of these years it has been over the historic mean by more than 2 km^3. The highest total annual discharge in recent recorded history was in 2006, which coincides with the devastating June floods in the upper part of the watershed (Suro et al., 2009). These periods of high average discharge have important management implications, which are discussed briefly below.

To explore the significance of changing discharge in the basin, we look to variations within the basin to help us understand the regional implications for the patterns we are seeing. For simplicity we partition the Mohawk watershed into three manageable units that allow for us to explore differences in the basin. Actually these subdivisions are the two main tributaries – the West Canada Creek (WCC) to the NW and the Schoharie Creek (SCH) to the SE, and by default we then isolate the rest of the basin, which is largely the Mohawk Lowlands between these two sub-basins. This is a nice natural division by surface area: the Schoharie (26% surface area) and West Canada (16% surface area) together account for 42% of the entire basin while the reminder that is dominated by the Mohawk lowlands accounts for is 58% of the surface area in the basin. The strategic advantage here is that the hydrologic records for WCC at Kast Bridge (Figure 2), and SCH at Burtonsville (Figure 3) are relatively long (at least 50 yr), and therefore are useful in understanding annual and decadal trends in discharge. We have calculated the average annual discharge for the Mohawk (Cohoes Falls), and these two main tributaries: Schoharie Creek (Burtonsville, data since 1940) and West Canada Creek (Kast Bridge, data since 1925). Our analysis shows that the on average the WCC supplies 23% of the water to the basin while the SCH contributes 18%. Because the WCC drainage basin is slightly smaller, it is easy to conclude that the WCC historically has greater annual precipitation than the Schoharie. This of course assumes that there is no significant external reason for this difference, which seems like a reasonable assumption. Although the WCC has a significant reservoir as part of the system (Hinckley), that reservoir has existed since these hydrologic records begin, and there is currently no significant out-of basin transfer that we need to worry about. There are two significant reservoirs on the SCH, Gilboa and Schoharie. The Gilboa pump storage project is water neutral, but the Schoharie Reservoir does lose water through out-of-basin transfer through the Shandaken tunnel.

When the annual contribution to the watershed of each of these main tributaries is plotted, we see an interesting trend. While the long-term record suggests that the slightly smaller WCC basin contributes about 23% of the water to the Mohawk, the percentages are changing and have changed most significantly since 1996 (Figure 4). Since this time, the annual contribution of the WCC has decreased and the annual contribution of the SCC has increased to a point that 8 of the last 15 years (53%) the contribution of the SCH has been greater than the WCC. Prior to that in the 56 prior years, the SCH topped the annual contribution only 16% of the time. Thus we conclude that the relative flow from the SCH has increased relative to the WCC since 1996. This change could reflect greater precipitation in the southern part of the basin, decrease precipitation in the northern part of the basin, or both.

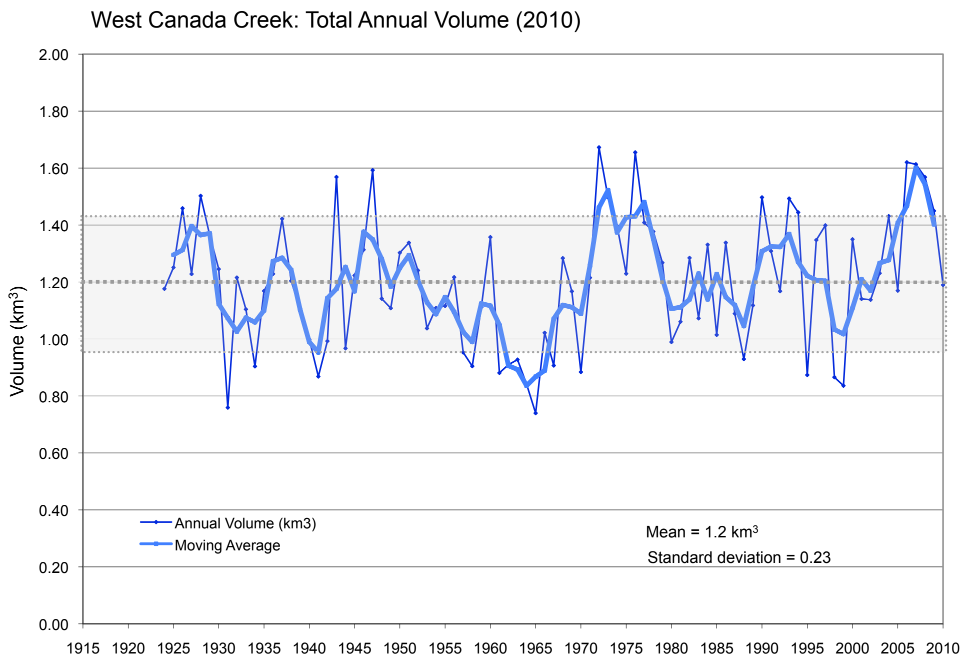

Figure 2. Annual discharge in km^3 of the West Canada Creek from the USGS gage at Kast Bridge.

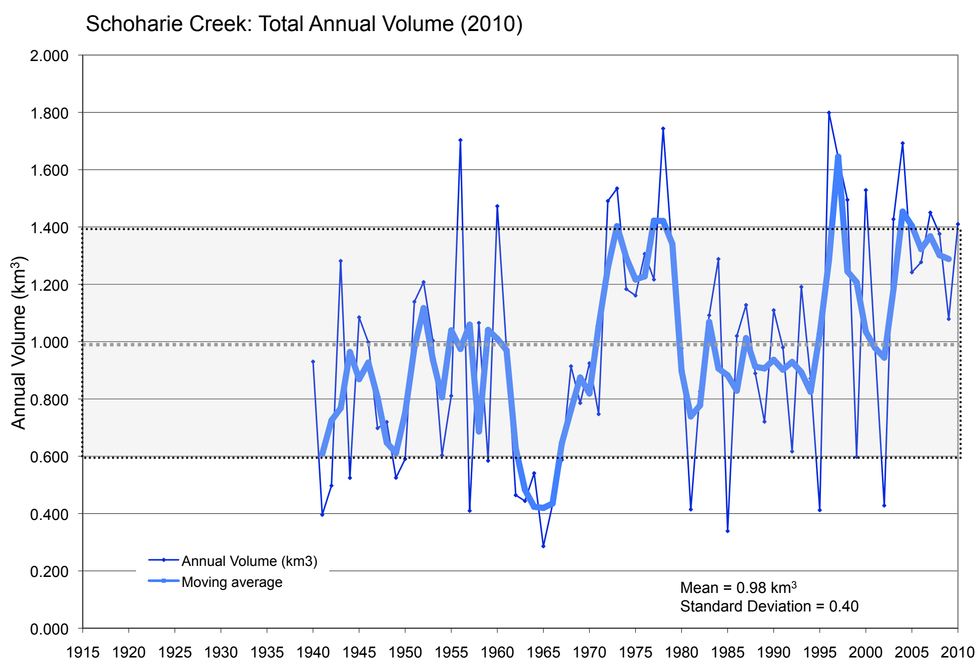

Figure 3. Annual discharge in km^3 of the Schoharie Creek from the USGS gage at Burtonsville.

Next we turn to the calculated annual discharge in the West Canada and in the Schoharie creeks (Figure 2 and 3). The West Canada Creek has a mean annual discharge of 1.2 ± 0.23 km^3 (standard deviation about the mean) and it does not appear to have significant variation from year to year (Figure 2): the flow is constant and consistent, certainly relative to the Schoharie.

The Schoharie Creek has a highly variable discharge with a mean of 0.98 ±0.40 km^3 and the record shows dramatic and wild inter-annual swings (Figure 3). For example compare 2002 (0.43 km^3) to 2003 (1.43 km^3). One of the hallmarks of the Schoharie Creek is the highly variable nature of its annual discharge. The mean discharge for the last eight years (2003 to

2010) has exceeded the long-term mean of 0.98 km^3 (Figure 5). The abundance of water in the Schoharie Creek presents highly significant management challenge partly because much of this water appears to be associated with high discharge events, many of which have caused significant and damaging flooding that is locally chronic.

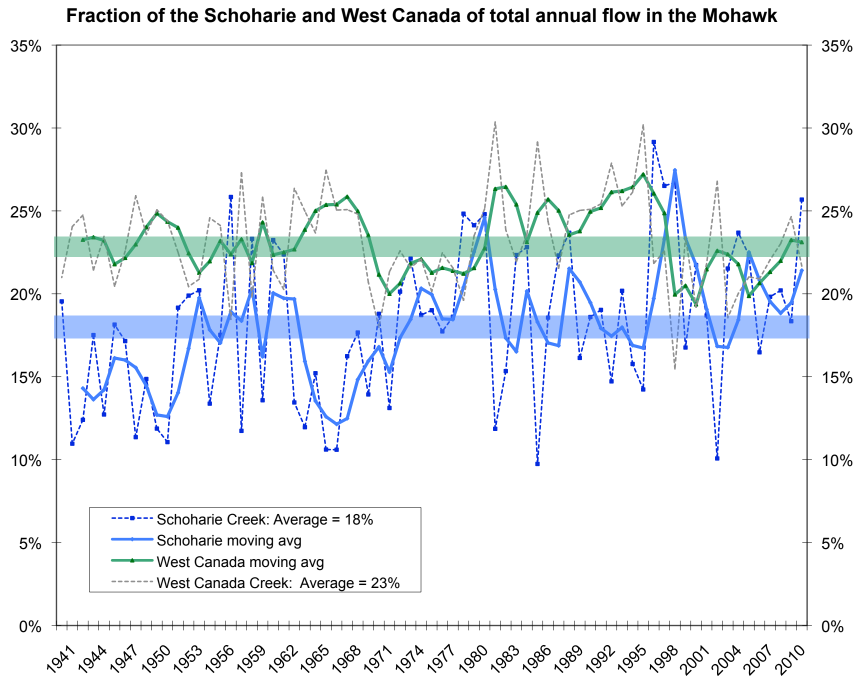

Figure 4. Relationship between the percentage of the annual flow from the two main tributaries of the Mohawk Watershed.

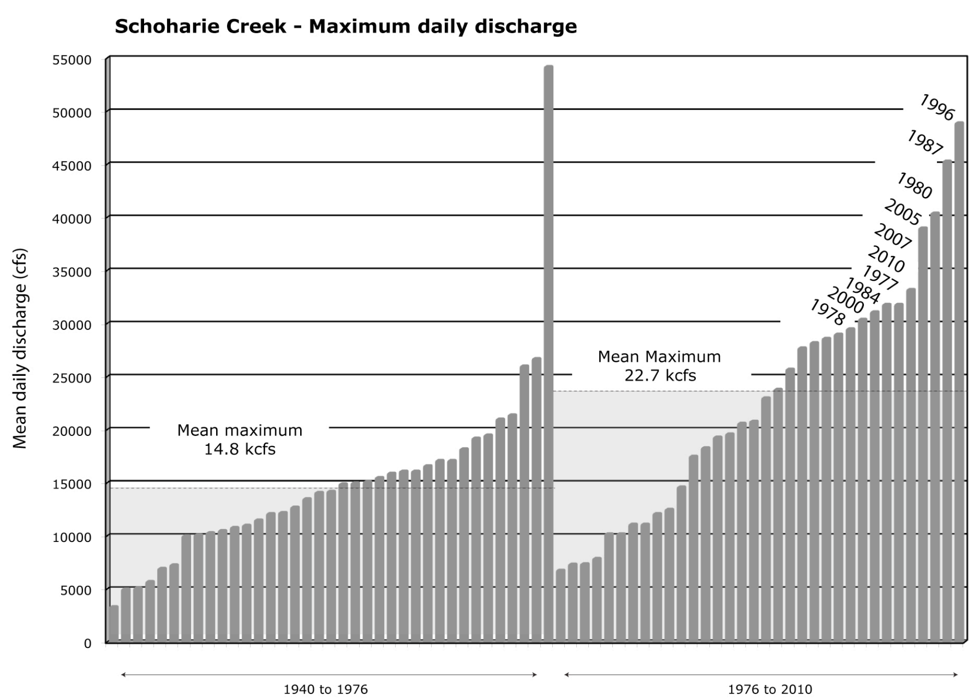

Figure 5. Maximum mean discharge of the Schoharie Creek spilt into pre-1976 and post 1976 intervals. Data are the ordered from maximum to minimum. The top ten floods in the recent interval are labeled.

A remarkable outcome of this analysis is that the Schoharie basin appears to have such a dramatically different and changed hydrology compared to other areas in the basin. It is clear that many of the floods are Atlantic-tracking storms that occur almost any time of the year. Recent work has shown that regionally there has been an increase in the number of heavy and very heavy precipitation events (Groisman et al., 2004), and the number of cyclonic systems in the East has increased over the last 30 yr (Briggs, 2007). In fact the number of Atlantic hurricanes peaked between 1984-2006, and many of these moved north and affected NY State (Vermette, 2007; Changnon, 2008). Notable storms are Nor'easters that dump snow that thaws quickly (Jan 1996), extratropical storms (hurricane Floyd, Sept 1999; Frances, Sept. 2004), and other coast-tracking systems. The importance of these events is that they can result in locally very high precipitation in the headwaters of the Schoharie (up to 10 inches or more in a few recent events), and very little precipitation elsewhere in the basin. Thus we hypothesize that the most dramatic and significant change in the hydrology in the Mohawk watershed is related to Atlantic-tracking storms, which have had a significant effect on flooding in the southernmost part of the watershed. We suggest that future studies focus on the meteorological and climatological implications of this hypothesis.

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