9.4 CHANGES IN UPLAND WATERSHED RESPONSE TO RAINFALL EVENTS DURING AUTUMN SEASON TRANSITION

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1. INTRODUCTION

During the autumn season transition from the growing season to the dormant season, there is a marked decrease in evapotranspiration (ET) in the forested upland watersheds in the northeastern United States. This region is largely covered by deciduous forests (U. S. Forest Inventory and Analysis; http://fia.fs.fed.us), so that the autumn season decrease in ET represents a widespread land cover change. As ET decreases, a smaller amount of groundwater is withdrawn, allowing more groundwater to feed into streams and result in higher streamflows. Following leaf drop in autumn, streamflow has been observed to increase even in the absence of precipitation (Doyle 1991). The spring season increase in ET is detectable in the analysis of streamflow data in the northeastern United States (Czikowsky and Fitzjarrald 2004). The autumn season ET decrease should likewise be detectable in streamflow records, although there have been no studies of this type to date for a network of stations in the northeastern United States. We examine two streamflow characteristics over a dense network of upland watersheds in the Hudson Valley / Catskill Mountain region of New York State during the autumn transition period in 2003, which was the time period the intensive portion of the Hudson Valley Ambient Meteorological Study (HVAMS) was conducted. The streamflow characteristics examined are stormflow recession (the decline in streamflow following a rainfall event; hereafter referred to as streamflow recession), and an ET-modulated diurnal streamflow cycle observed in some smaller watersheds during dry periods between rainfall events.

2. LOCATION AND DATA

The study area encompasses the mid-Hudson Valley between Albany and Poughkeepsie, New York, and extending westward into the Catskill Mountain region (Figure 1). The approximate latitude and longitude bounds for the study region are 41.6°N to 42.8°N, and 73.5°W to 75.0°W respectively. The peak elevation in the Catskill Mountains exceeds 1000m. There were 46 streamflow stations (dots on Figure 1) operated by United States Geological Survey that recorded streamflow data at 15-minute intervals. Three of the stations are located in the Hudson Valley, with the remainder in the Catskill Mountain region. The valley station elevations ranged between 10 m and 56 m with the valley station drainage areas ranging between 463 and 1779 km^2. The mountain stations range in elevation from 189 m and 628 m. Although upland station drainage areas range from 2 to 1100 km^2, over 30 watersheds have drainage areas under 200 km^2. We obtained data from these stations from day of year 232 (August 20) to day of year 319 (November 15) in 2003. Four additional streamflow stations located in the study region were excluded because of excessive flow regulation.

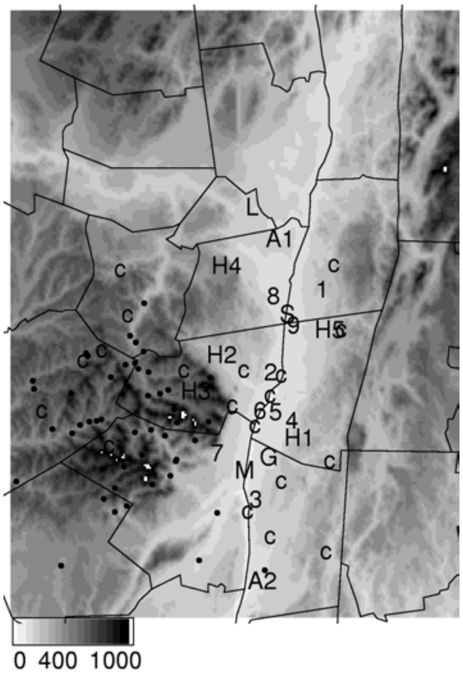

Figure 1: Topography and data stations for the study area of the Hudson Valley and Catskill Mountains. Streamflow stations are the black dots. Precipitation sites include the NCAR-PAM sites (1-9), Hobo weather stations (H1-H5), MIPS station (M), ASOS stations (A1 and A2), and the Cooperative observer network (c). Units for the elevation on the legend are in meters.

Precipitation data recorded at one-minute intervals were obtained from nine NCAR Portable Automated Mesonet (PAM) stations (1 through 9 on Figure 1) deployed along the Hudson Valley during the HVAMS intensive period of September through October, 2003. One-minute precipitation data were

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also available for the same time period from the Univerisity of Alabama-Huntsville Mobile Integrated Profiling System (MIPS) station (M on Figure 1), five Onset Hobo weather stations in the uplands surrounding the Hudson Valley (H1 through H5 on Figure 1), and the Albany and Poughkeepsie Automated Surface Observing Stations (ASOS; A1 and A2 on Figure 1). Daily precipitation data were obtained from the Cooperative weather observers network (c on Figure 1).

3. METHODS

3.1 Diurnal streamflow amplitude

A well-defined diurnal streamflow signal is observed in some small watersheds during dry periods in the growing season. During the day, transpiring vegetation draws upon the groundwater supply that feeds the baseflow of a gaining stream, thereby reducing the stream inflow and total streamflow. Transpiration is at a minimum at night, resulting in increased stream inflow and total streamflow. The signal is slightly asymmetric; a gradual nighttime to morning rise is followed by a more abrupt afternoon to evening decline in streamflow (Lundquist and Cayan 2002). Approximating the diurnal streamflow signal using a simple, symmetric sine curve has been found to be adequate for determining the presence and amplitude of the diurnal streamflow signal (Czikowsky and Fitzjarrald 2004).

A station was deemed to exhibit the diurnal streamflow signal using the following objective procedure, which identified the same cases as did a subjective review of the data. First, three-day windows of streamflow data were least-squares fitted using a simple sine curve, with the trend, amplitude, and phase statistics kept. Next, precipitation or recession periods were removed by only keeping the data for which the sum of the residuals normalized by streamflow was less than one. Streamflows with diurnal variations greater than or equal to two percent of the total streamflow were considered to have the diurnal streamflow signal.

A review of the precipitation and streamflow data resulted in the selection of four periods to examine the presence of the diurnal streamflow signal. Each period was in at least a four-day span where no appreciable rainfall was observed in the network. The time periods examined were day of year 234-236 (August 22-24); day of year 252-254 (September 9-11); day of year 281-283 (October 8-10); and day of year 296-298 (October 23-25).

3.2 Streamflow recession

Streamflow recession, the decline in streamflow following a precipitation event, was reported by Federer (1973) to proceed more quickly with the onset of transpiration in the spring and slow with the leaf drop in autumn, using several years of data from the 42-ha Hubbard Brook, New Hampshire watershed. Streamflow recessions were found to proceed more quickly in the spring in a large network of U.S. east-coast stations (Czikowsky and Fitzjarrald 2004). In that study, the streamflow recession time was defined as the time required for the streamflow to reach *1/e* of the value of the streamflow peak. This limited the number of analyzed recession events per year, but many years of data were used. In this study, we examine a dense station network for only one season. In order to build a series of recession events for analysis, a higher threshold runoff value from the streamflow peak must be taken.

We chose 60% of the streamflow peak as the streamflow recession value. Choosing a lower threshold resulted in too few recession events, and choosing a higher threshold resulted in very short recession events. Three rainfall events were chosen for analysis; day of year 245 (September 2); day of year 270 (September 27); and day of year 302 (October 29). These were events with precipitation throughout the network and with no precipitation in the days immediately following the event. For these events, network-wide averages of streamflow recessions using the 60% of streamflow peak threshold were complied.

4. RESULTS

4.1 Diurnal streamflow amplitude

The presence of the diurnal streamflow signal in the network watersheds during the growing to dormant season transition is seen in Figure 2. The first period selected (August 22-24) falls well within the growing season. Half of the stations in the network observed a diurnal streamflow signal during this period (Figure 2a). One of the large valley stations (area > 1000 km^2) observed the signal during this period. All of the remaining stations observing the diurnal streamflow signal have drainage areas less than 200 km^2, and the mean and standard deviation of the drainage area of these stations are 48.2 km^2 and 39.7 km^2 respectively.

The second period chosen (September 9-11) still falls within the growing season. Little change is noted as 48% of the stations in the network observed a diurnal streamflow signal for this period (Figure 2b). No valley stations reported a diurnal streamflow signal during this period, and all of the stations observing the diurnal streamflow signal have drainage areas less than 200 km^2. The mean and standard deviation of the drainage area of these stations are 51.7 km^2 and 45.3 km^2 respectively.

During the third period selected (October 8-10), a much lower percentage (11%) of network stations observe a diurnal streamflow signal (Figure 2c). This period occurs during the transition from the growing season to the dormant season in this region, and is concurrent with ET decreasing to near dormant season values at Harvard Forest, a long-term flux

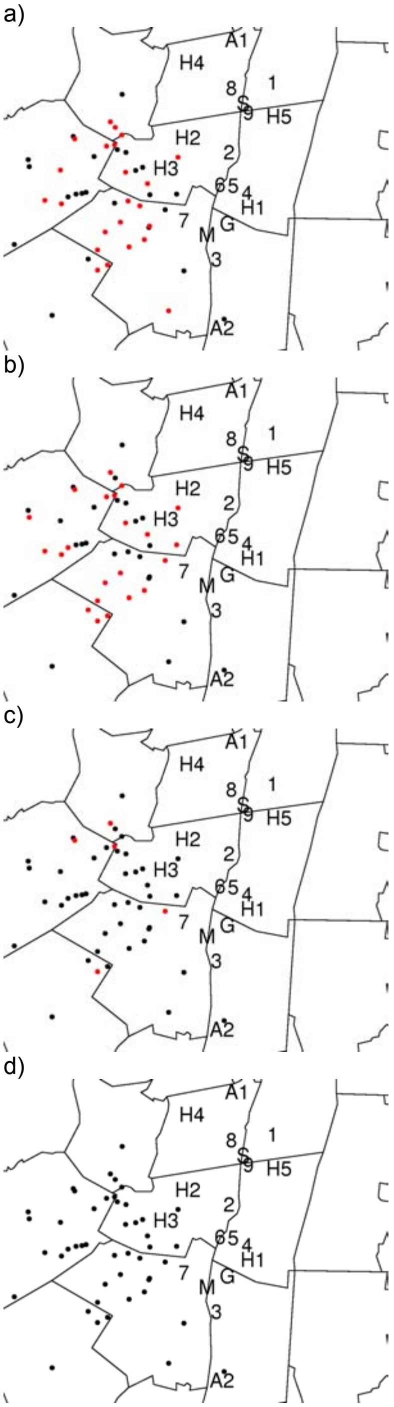

Figure 2: (a): Streamflow stations with an observed diurnal streamflow signal (red dots), and stations with no observed diurnal streamflow signal (black dots), day of year 234-236 (August 22-24). (b): same as in (a), but for day of year 252-254 (September 9-11). (c): same as in (a), but for day of year 281-283 (October 8-10). (d): same as in (a), but for day of year 296-298 (October 23-25).

measurement site considered to be representative of the region (Fitzjarrald et al. 2001). The presence of the diurnal streamflow signal is confined to even smaller watersheds, with all stations observing the signal having drainage areas less than 80 km^2. The mean and standard deviation of the drainage area of these stations are 39.9 km^2 and 23.8 km^2 respectively.

During the final period (October 23-25), none of the network stations observe the diurnal streamflow signal, an indication of the onset of the dormant season in the region.

4.2 Streamflow recession

The network-wide average of the streamflow recessions for the three events show an increase in the median recession value for the last event in late October following the growing season, but the difference is quite small (about one-third of a day). Two factors contribute to the difficulty in detecting the streamflow recession difference using this method. First, using a high threshold such as 60% of the peak streamflow value to determine the recession value results in recessions of short duration, making it difficult to see differences in the recession. Second, the seasonal change in streamflow recession tends to be a gradual process. In spring, it takes several weeks for the streamflow recession to complete its decrease as the process of leaf emergence and development takes several weeks. A similar gradual process appears to be taking place during autumn.

Table 1: Network-wide averages of streamflow recessions (median and 95% confidence intervals for the median given) for the day of year 245 (September 2), day of year 270 (September 27), and day of year 302 (October 29).

Day of recession event	Recession value (days)
245	2.23 ± 0.59
270	2.14 ± 1.10
302	2.59 ± 0.76

5. SUMMARY AND FUTURE WORK

The seasonal change in the presence of the diurnal streamflow signal in the network was evident, with the signal appearing in about half of the network watersheds until the growing to dormant season transition in early October, when only the smallest watersheds exhibited the diurnal streamflow signal. The abrupt disappearance of the diurnal streamflow signal shown here in fall is similar to the speed at which the diurnal streamflow signal appears in the spring at the onset of the growing season (Czikowsky and Fitzjarrald 2004). We detect a slight increase in streamflow recession following the growing season in the network. The process of streamflow recession increase during the autumn transition appears to be much slower and gradual than the disappearance of the diurnal streamflow signal.

Future work includes analyzing data taken from a series of flights by the University of Wyoming King-Air aircraft over the study region in October 2003, during the growing to dormant season transition period. Fluxes of CO_2 and heat will be calculated from a series of along-valley flight legs. Vegetation state will be analyzed for these flight legs from the aircraft's downward-looking camera, with the possibility of how the timing of any changes in flux or vegetation state may correlate with the timing of the disappearance of the diurnal streamflow signal from the network.

6. ACKNOWLEDGEMENTS

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