AN ANALYSIS OF HISTORIC FLOWS IN THE SATILLA RIVER USING TWO STATISTICAL METHODS

Duncan Elkins

AUTHOR: Graduate Student, Institute of Ecology, University of Georgia, Athens, GA 30602.
REFERENCE: Proceedings of the 2001 Georgia Water Resources Conference, held March 26-27, 2001, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, the University of Georgia, Athens, Georgia.

Abstract. As development proceeds in the Coastal Plain, increased interest has been directed toward the flow of fresh water into coastal ecosystems. As part of a larger effort investigating changes that may have taken place in three Georgia Estuaries, a historic analysis of freshwater flows into the estuary of the Satilla River was conducted. The annual mean flow on the Satilla River at Atkinson for the period of record (1931-1998) shows a slight trend upward (p= 0.1.) A further analysis of the historic flows on the Satilla River measured at the USGS station at Atkinson was performed using two different methods that used higher resolution datasets to identify more subtle changes in the hydrograph. The first analysis was performed using the Indicators of Hydrologic Alteration (IHA) trend-analysis method, developed by Richter, et al, 1996, for The Nature Conservancy. This method generates 34 metrics of alteration using daily-flow data, and significant changes were observed in maximum and minimum flows during the winter months. A second analysis was performed using a hydrologic yield calculation modeled after the method of Chagnon, et al, 1996, and Moglen and Beighley, submitted, have used to asses the impacts of urbanization of runoff characteristics for a basin. The hydrographic yield (a ratio of runoff to precipitation) after typical storm events was calculated for storms between 1948 and 1998. The ordered set of these values was then analyzed on a seasonal basis and, again, the most striking results were observed for winter storms. While the range of yield values for storms in spring, summer, and fall was reasonably consistent, there is a marked increase in the variability of yield values for winter storms. As hydrographic yield is strongly influenced by land use, this pattern suggests that seasonally changing land uses (or land uses in which the land cover changes on a seasonal basis) may significantly be affecting runoff patterns in the Satilla basin.

INTRODUCTION

Development and land use change affect natural systems and may alter the cycles and flows of energy and materials in these systems. The Georgia Coastal Plain has several pockets of significant urban development and much larger areas have undergone land use change due to agricultural or silvicultural practices. Population trends indicate that this region will likely face even more significant changes in the near future. Though the effects of development on the groundwater resources in these areas are well documented, the broader issue of how land use change affects surface runoff in these areas is less well understood. This paper presents two analyses of a long-term surface water dataset for the Satilla River that seek to determine whether a change has occurred in the amount or timing of runoff in this system.

Preliminary analysis of the annual mean flow in the Satilla River at Atkinson, GA, indicates a slight increase (p=.1), but the significance this finding and level of detail is low. Though this is a dynamic system, organisms may be most affected by acute events (floods, droughts) rather than gradual annual variation. The first flow analysis below, the IHA method, uses more 'biologically relevant,' measures. The second, a hydrographic yield calculation, measures the extent to which rainfall is detained as is runs off the landscape and provides some clues as to the drivers of change in the hydrologic regime.

BACKGROUND AND RELATED WORK

Richter, et al, 1996, have developed an analytical approach to river flow analysis that assess the human-derived impacts on 64 flow statistics or Indicators of Hydrologic Alteration (IHA). This method, though designed to highlight the effects of a discrete system stressor, such as a dam or intense groundwater pumping, can also be used for broader trend analysis. The statistics derived are designed to be more biologically relevant than the summary statistics traditionally reported in flow analyses.

Analyses of urbanizing watersheds or those focusing on other long-term changes in watershed characteristics often use another statistic, hydrologic yield, to assess changes in runoff. Most simply, the hydrologic yield is the proportion of the rain that falls on a watershed that actually runs off the watershed and into a river or stream. Factors such as deforestation or urbanization tend to increase the hydrographic yield, as vegetation intercepts and transpires precipitation while litter impedes the sheet flow of runoff, promoting infiltration. Conversely, bare soil and impervious surfaces tend to deliver stormwater to rivers and streams very quickly. Moglen and Beighley, submitted, have noted significant changes in the hydrographic yield of an urbanizing forested watershed in coastal Maryland coincident with the onset of concerted development pressure in the area.

EXPERIMENTAL DESIGN

USGS daily flow data for the years 1932-1994, were extracted from the CD database distributed by EarthInfo, inc., and from USGS website for the period of 1994-1998. Station 2228000, at Atkinson, Georgia, was judged to best represent the head-of-tide for the Satilla River; this station integrated the runoff from the largest gauged area possible without a tidal effect on flow. This dataset was analyzed using the Nature Conservancy's IHA package (Smythe Scientific Software) using the trend analysis option. This package generates a series of plots of the calculated statistics over time, then fits a trend line to these series and calculates the statistical significance of this curve fit. Statistics for which the P value of the curve fit was less than .1 were deemed to be trends. Trends for which the P value was less than .05 were deemed to be significant.

The precipitation records from the NCDC weather monitoring stations at Brunswick, GA, and on Cumberland Island, GA were used to estimate the rainfall in the Satilla River watershed. These stations were selected because of their proximity to the watershed and because both datasets extend back to 1948, giving a period of record substantially longer than other nearby coastal-plain stations. This precipitation dataset was combined with the flow records used above to derive the hydrographic yield for selected storm events, and the variation in hydrographic yield over time was analyzed with a linear regression.

METHODS

IHA Software

The USGS CD-ROM and online datasets were combined and reformatted to meet the input requirements of the IHA package. Five runs of the IHA analysis were performed, using the "trend analysis" mode on first on the entire daily dataset, then by restricting the analysis to data for a particular season, e.g. Julian days 337-60 (Dec. 1 – Feb. 29) were classified as "Winter."

Hydrographic Yield

A subset of rainstorms was isolated to reduce the variability of climatic events, dropping storms too small to produce ambiguous storm peaks or large enough to introduce non-linear runoff response and minimizing the confounding effects of overlapping storm peaks. Storm events were selected in which the 48-hour rainfall was between 1 and 4 inches. The rainfall for three days prior to the first day of the storm and four days after the second day of the storm could not exceed the 48-hour total by more than .5 inch. The ratio for a particular storm was calculated using the following equation:

$$Y = \frac{(Q_{post} - Q_{pre})}{P}$$

where Y is the Hydrographic Yield, Q_{post} is the Maximum flow, which occurred in the 10 Days following the storm period, Q_{pre} is the minimum flow during the three days prior to the storm period, and P is the 48-hour rainfall. The series of yield values for summer and winter storms are shown in figures 2.1. and 2.2. These seasons were selected because previous investigations of this type (Chagnon, et. al., 1996, Moglen and Beighley, submitted) have found summer flows to be the most indicative of land-use change and because the IHA analysis identified more significant changes in winter flows for the Satilla.

CONCLUSIONS

IHA Software

The results of the seasonal analyses are presented below (Table 1.); the monthly results were more complex, but not substantially different and have been omitted in the interest of clarity. In the tables, the character in each cell represents the direction of change, and the number of characters indicates the degree of statistical significance.

Table 1. IHA trend analysis summary

IHA statistic	Season			
	Win	Spr	Sum	Fall
1 day min	+++			
3 day min	+++			
7 day min	++++			
30 day min	+++++			
90 day min	+++++			
1 day max	+++++			
3 day max	+++++			
7 day max	+++++			
30 day max	+++++		--	
90 day max	+++++			
Base Flow		--	++	
Julian min			++	
Julian max				
Low Pulse #				
Low Pulse length				
High Pulse #	++			
High Pulse length	+++++			
Rise rate	+++++			--
Fall rate	-----			
Reversals				

Symbol	Interpretation
+++++/-----	+/- change, significance > 99%
++++/----	+/- change, significance > 97.5%
+++/---	+/- change, significance > 95%
++/--	+/- change, significance > 90%
+/-	+/- change, significance > 75%

The hydrograph of the Satilla River at Atkinson shows a significant seasonal shift towards increased minimum and maximum flows in the winter months, with concomitant increases in the number and length of high-flow events. The significant increase in the rise rate and decrease in the fall rate, combined with increased maximum flows, indicate a stormier hydrograph, with taller, broader peaks in winter. Perhaps as a result of the higher flows in winter, the base flow in summer has been reduced. This pattern is reversed in the summer, possibly because of later seasonal maximum flows.

Hydrographic Yield

The results of the hydrographic yield calculations for summer and winter storm events are shown below (Figure 1., Figure 2.). These yield values are highly variable, as might be expected, given the relatively low-resolution precipitation dataset (two coastal stations averaged over the entire watershed) relative to the spatial variability of rainfall and the inability of this method to absolutely control for antecedent conditions

Table 2. Summary Statistics for Seasonal Hydrographic Yield calculations

Statistic	Season	
	Summer	*Winter*
Mean	822.032	3400.915
Standard Error	84.81424	309.0172
Standard Deviation	1708.96	4846.745
Sample Variance	2920543	23490933

in calculating the storm runoff values. The hydrographic yield plots for spring, summer, and fall storm events were similar, and the spring and fall figures have been omitted due to space constraints. As might be expected based on the results of the IHA analysis above, the hydrographic yield plots for winter storm events are strikingly different than those from the other two seasons. While the hydrographic yield for summer storm events is variable, this variation is reasonably constant (linear regression significance = 0.342). The values for winter storm events have a significantly higher variance and appear to increase over time (regression significance = 0.003) (Table 2.)

The presence of negative values in the dataset does not indicate a loss of water from the system but rather a failing of the method used to identify storm peaks in the hydrograph and a complication posed by the location of both weather stations on the eastern end of the watershed. In a few instances the storm peak from rainfall high in the watershed had already passed the gauge at Atkinson by the time the storm system reached the weather stations. Thus, the peak analysis algorithm was initiated on the falling limb of the storm hydrograph, erroneously reported a Q_{pre} value in excess of the Q_{post} value, and generated a negative value for the Hydrographic Yield. A more sophisticated peak analysis script is in development that will be less easily 'fooled' by falling hydrographs and multiple storm peaks within the 10-day peak window.

DISCUSSION

The IHA trend analysis of these data reveals significant increases in the extreme winter flows for the Satilla River, measured both as maximum and minimum flows. These increases are not offset by decreases in the flows during other seasons. This indicates a subtle change in the seasonality of freshwater delivery to the Satilla River Estuary, with more fresh water arriving as large pulses during this season. Average winter precipitation levels for the period of record show no significant changes and no flow control structures are

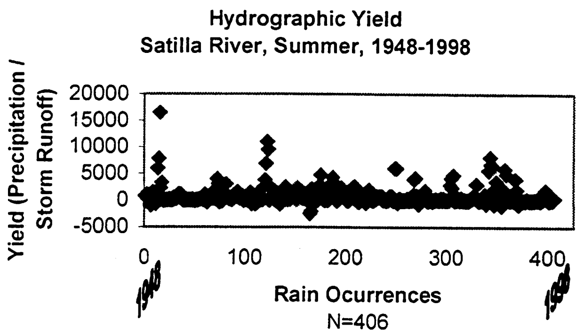

Figure 1. Plot of hydrographic yield values for summer storm events, 1948-1998.

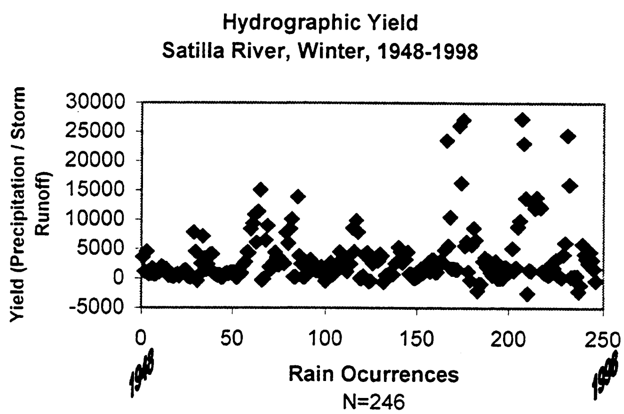

Figure 2. Plot of hydrographic yield values for winter storm events, 1948-1998.

present in this system that might explain a marked shift in the seasonality of flow.

One factor that may contribute to an increase in the variability of Hydrographic Yield values is land use change. As described above, there are two components in the calculation of Hydrographic Yield: precipitation and runoff, measured as a peak in the downstream hydrograph. For example, vegetation on forested land intercepts precipitation and transpires moisture back into the atmosphere while understory growth and forest litter impede overland flow and promote infiltration, shortening and smoothing storm peaks. Conversion to managed forest, agriculture, and urban land uses, can sharpen and increase storm peaks, as the removal of vegetation, higher incidence of bare soil, and impervious surfaces all act to increase runoff. Like precipitation, land-use change is also patchy in that individual landowners choose to develop or abandon plots of various sizes at different times. If the trend of land-use change over time is toward the conversion of forested lands to other land uses, the variability in the potential hydrographic yield of a rainfall at any point in the watershed should increases until some midpoint is reached, after which further build-out will actually decrease the potential variability in hydrographic yield, though the overall average hydrographic yield may continue to increase. This analysis suggests that the Satilla River watershed is still in the first phase of this process.

Land use change alone does not explain the seasonality of the changes in flow or yield unless the land cover, itself, varies seasonally in its interception or detention of rainfall. For example, row crops intercept and transpire more water during the growing season than they do after harvest unless, of course, a cover crop is used in the alternate seasons. Future research will address the land cover changes in the Satilla River basin to identify areas where such seasonally varying land uses exist. Other seasonal water uses (e.g. aquaculture, irrigation) will also be investigated as potential contributors to this phenomenon.

ACKNOWLEDGEMENTS

I would like to thank Joan Sheldon, Drs. R. G. Wiegert, Merryl Alber, and Alice Chalmers for their support and assistance. Financial support was provided by the Georgia Costal Management Program, NOAA Awards NA87OZ0231 and NA97OZ0159.

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