ANALYSIS OF ALTERED HYDROLOGIC REGIME IN THE CLINTON RIVER

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Abstract

Alteration of hydrologic regime can be a contributing factor to erosion and sedimentation issues in watersheds. On the overland plane of the watershed, changes to the land use and land cover, especially in the case of urbanization, produce more runoff and increase runoff concentration. Increased runoff volumes and peak flow also contribute to lateral and vertical streambank instability.

To promote the use of Best Management Practices (BMPs), watershed managers use modeling tools such as the Soil and Water Assessment Tool (SWAT; USDA-ARS) to assess means of reducing sedimentation. An integral part of the assessment process, which precedes model development, is the analysis of the hydrologic response of the watershed over time. This analysis, in conjunction with an analysis of the changes to land use and land cover, contributes to a better understanding of watershed hydrologic processes. This includes the development of explanations of the temporal and spatial variability of runoff production and streamflow response. This provides input to the development of a modeling strategy that focuses attention on the particular processes (and the accompanying BMPs) that will produce the greatest benefit in terms of reducing sedimentation and other water quality issues associated with increased direct runoff.

The above approach was used on the Clinton River Watershed, located north of Detroit, MI. Substantial portions of this watershed, especially in the last 15 years, have undergone a transformation from primarily agricultural land to a dominantly urban land use. Indices of basin hydrologic response were calculated for different time periods at different locations in the watershed. A hydrologic response index, commonly referred to as flashiness, was calculated for all streamgage records in the Clinton River Watershed that had a minimum 20 years of record. This was normalized to the appropriate precipitation record over the same period. The results show a strong correlation between increasing and decreasing flashiness trends and changes in watershed land use.

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INTRODUCTION

An integral step in the development of hydrologic and sedimentation modeling studies is the definition of the goals and end-uses of the models. In order to numerically depict the changes to the watershed, hydrologic indices provide an efficient means of developing a preliminary assessment of the temporal and spatial trends within the watershed prior to developing the models. The modeler can use the information derived from this statistical analysis to develop an initial hypothesis of the primary hydrologic operators and develop a modeling strategy to capture this effect. An example of this would be the association of urbanization to increased peak flows with simultaneous reduction of base flow. After developing hydrologic indices from the streamgage records of several watersheds, it may become apparent that altered streamflow patterns coincide with a significant conversion of forested or pasture land to residential development in a particular time period. In this case, the modeler would develop a modeling strategy which would include:

- Selection of a numerical model with capabilities to simulate the physical changes to the watershed
- Development of a model domain with the appropriate spatial resolution
- A scheme for parameterization of the known changes
- Model simulations to include scenarios representative of pre- and post-development conditions.

There are several processes by which altered hydrologic processes may increase sediment loads in the watershed. Increased and accelerated runoff response, commonly referred to as flashiness, suggests increased overland flow, increasing erosion rates and increasing sediment transport from hillslope to channel. This may be balanced by a shift from agricultural to urban land uses, which may reduce sediment supply at the hillslope scale. Urban runoff may contain significant amounts of sediment, pollutants and nutrients if stormflow through sewers is left untreated before it discharges into the river channel. In addition, developed land has often meant the eradication of buffer strips by riparian landowners, which may cause a significant increase in the amount of sediment and pollutants reaching a river channel.

There are several physical processes associated with erosion and sediment transport that are highly sensitive to changes in streamflow and velocities. All of the processes are proportional minimally to the squared power of flow, while others are proportional to the fourth and up to the sixth power of flow (Cotton, 1999). With these relationships, a seemingly insignificant increase in watershed response, such as a 10% increase, can result in sedimentation processes accelerated by 21%, 46% and 77%, for processes proportional to the 2^{nd}, 4^{th} and 6^{th} powers of streamflow, respectively.

In a sedimentation study of the Menomonee River near Milwaukee, Wisconsin, (USACE/Baird, 2002), it was determined that over 80% of the sediment at the lower end of the river was delivered by the largest 20% of the hydrologic events. This theoretical and practical evidence clearly demonstrates the sensitivity of sedimentation processes to the magnitude and frequency of hydrologic events.

CASE STUDY

The Clinton River is located just north of Detroit in southeastern Michigan. The main channel traverses 80 miles (128 km) from its headwaters in the western portion of the watershed, to Lake St. Clair near the city of Mt. Clemens. The watershed covers 760 square miles (1,968 km^2) of southeastern Michigan, including portions of Oakland and Macomb Counties and small areas of St. Clair and Lapeer Counties. The watershed is home to more than 1.6 million people in 56 municipalities. The southern portion of the watershed is dominantly urban, the middle section is undergoing rapid development of suburban land use, and the northern region is primarily agricultural and forested. The condition of the river and its tributaries varies dramatically, from runoff and pollution problems in urban areas, to healthier waters with thriving trout fisheries in rural areas.

A preliminary assessment of the Clinton River Watershed was performed to determine if there have been any significant changes to the hydrologic processes over the last 30 to 40 years. Substantial portions of the watershed have undergone transformations from primarily agricultural to urbanized land use, especially within the last 10 to 15 years. A common response to land use changes is a decreased basin hydrologic response, which results in higher peak flows and velocities. Although channels undergo continual changes due to the erosive forces of the streamflow, an increase in the frequency of higher flows and velocities accelerates the channel degradation process. An important consideration in discerning whether the observable channel erosion is progressing at a "natural" rate is an objective quantification of the basin response over a long period of time.

One common metric used to characterize the change in basin response is a stream flashiness index. In this analysis, the flashiness index used was numerically similar to the Richards-Baker Flashiness Index (Baker, et al., 2004). Flashiness is a characterization that quantifies the time response of a river to a rainfall event. A high degree of flashiness indicates that a river is quick to respond, usually both on the rising and falling limbs of the flow vs. time curve. Highly flashy rivers are typified by basins with steeper or rolling topography, and often with lower permeable soils, or basins with significant impervious areas. Conversely, rivers that are lower in flashiness typically have flatter terrain and often have highly permeable soils with a high degree of shallow groundwater contribution to the base streamflow. As is the case for the characterization for hydrologic and climatologic trends, long-term records are required for meaningful analysis.

The flashiness index used in this analysis was the following equation:

$$\text{Flashiness Index} = \frac{\sum_{t=1}^{n} \left| q_{t-1} - q_t \right|}{\sum_{t=1}^{n} q_t} \qquad (1)$$

This index is a ratio of the absolute value of the sum of the daily flow changes to the sum of the total daily flows. Although this index may vary spatially for a particular year, the temporal trend of this index is a relative indication of basin response to rainfall and is a good indicator of hydrologic changes in the watershed.

The flashiness index was computed for all streamgage records in the Clinton River Watershed that had a minimum of 20 years of record. In most cases, the gage records that were analyzed were operational from the 1960s through the present. It is also interesting to note that the precipitation over the same period actually had a small (albeit statistically insignificant) decrease.

The results indicate that several of the gages in the southern portion of the watershed have shown marked increases in flashiness since 1970. Others have remained steady or show minor decreases with time. The spatial distribution of the gage sites analyzed in this study is shown in Figure 1, with the 1992 land use shown in the background. The summary of the analysis is shown in Table 1 and the graphs of the index over time are shown in Figures 2 through 7.

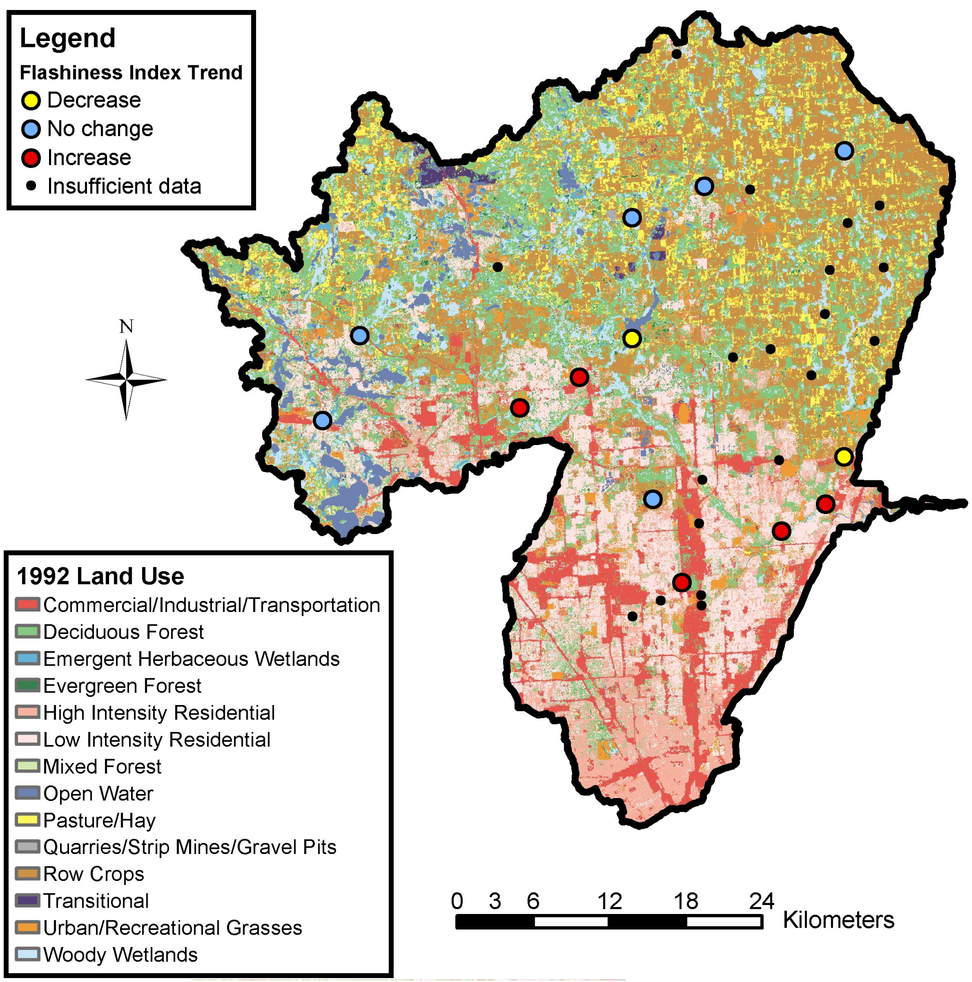

Figure 1. Clinton River Watershed - Land Use and Hydrologic Trends

Table 1 Trends in River Flashiness in the Clinton River Watershed

Gage Name	Gage Number	Trend
Clinton River near Fraser	04164000	Increase
Clinton River at Mt. Clemens	04165500	Increase
Paint Creek at Rochester	04161540	Increase
Galloway Creek near Auburn Hts	04161100	Increase
Big Beaver Creek near Warren	04162900	Increase
Stony Creek near Romeo	04161580	No Significant Change
Coon Creek E. Branch at Armada	04164300	No Significant Change
Sashabaw Creek near Drayton Plains	04160800	No Significant Change
Clinton River near Drayton Plains	04160900	No Significant Change
Plum Brook at Utica	04163400	No Significant Change
East Pond Creek at Romeo	04164100	No Significant Change
Stony Creek near Washington	04161800	Slight Decrease
North Branch Clinton River near Mt. Clemens	04164500	Slight Decrease

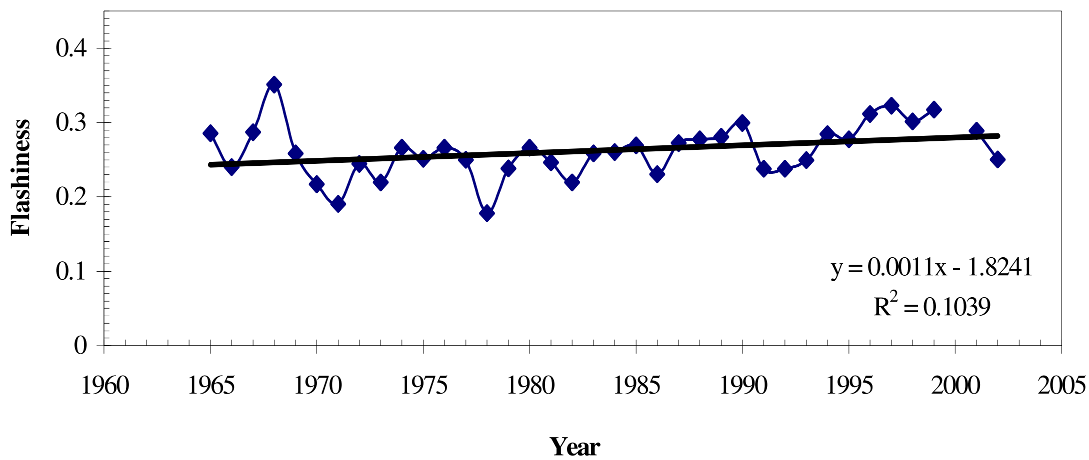

Figure 2. Gage # 04165500 Clinton River at Mt. Clemens

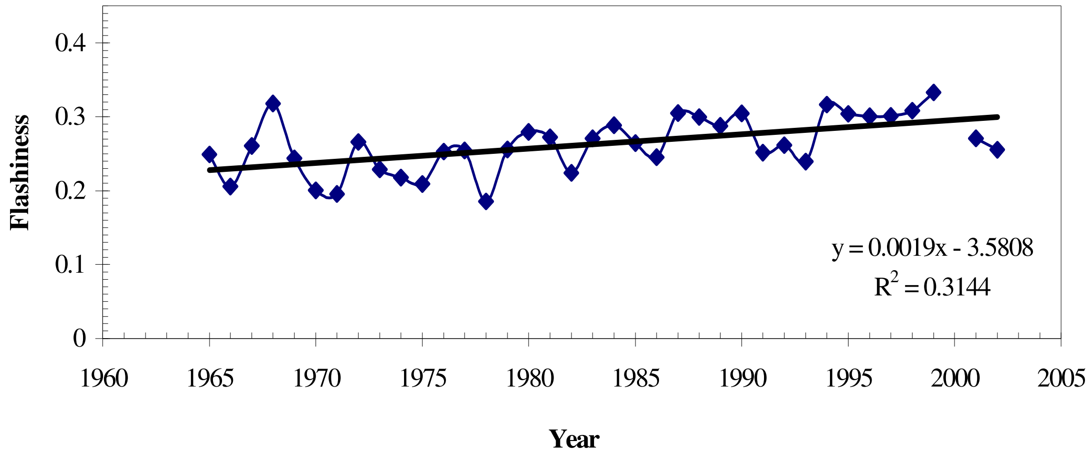

Figure 3. Gage # 04164000 Clinton River Near Fraser

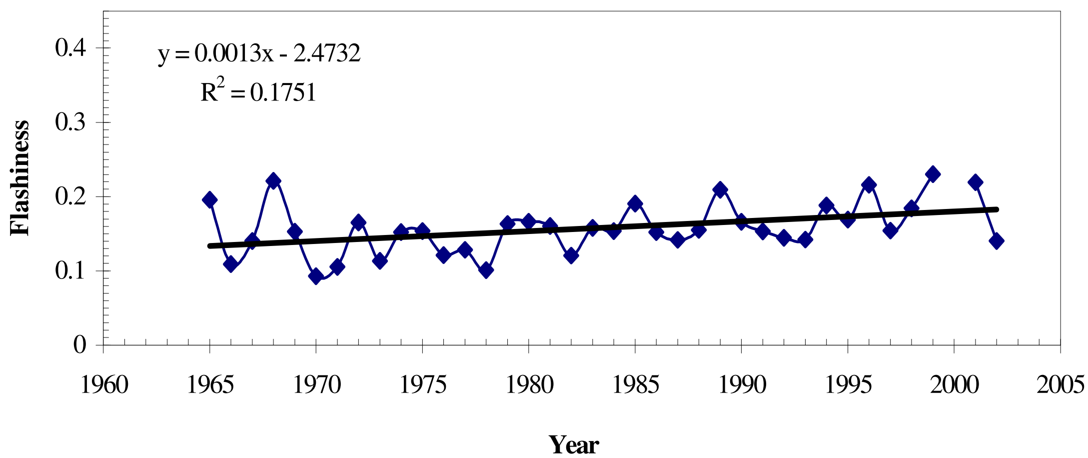

Figure 4. Gage # 04161540 Paint Creek at Rochester

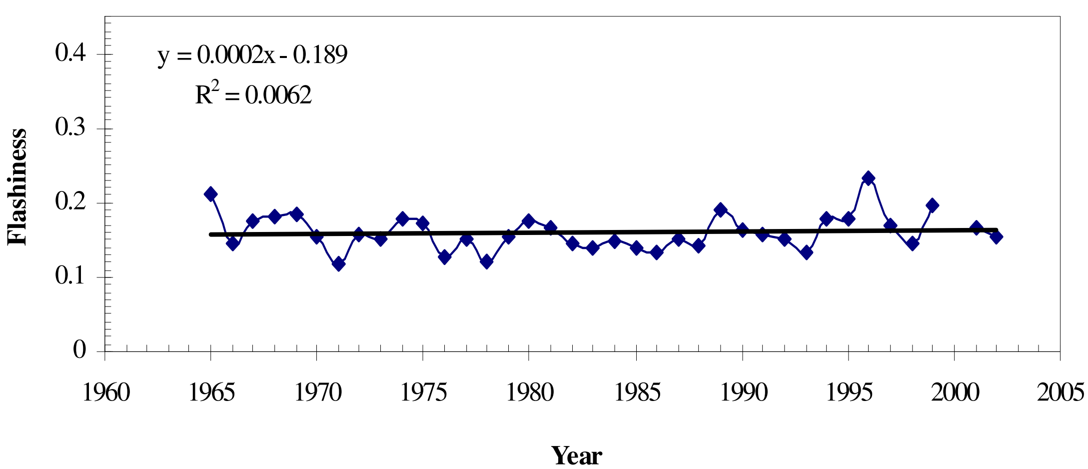

Figure 5. Gage # 04161580 Stony Creek Near Romeo

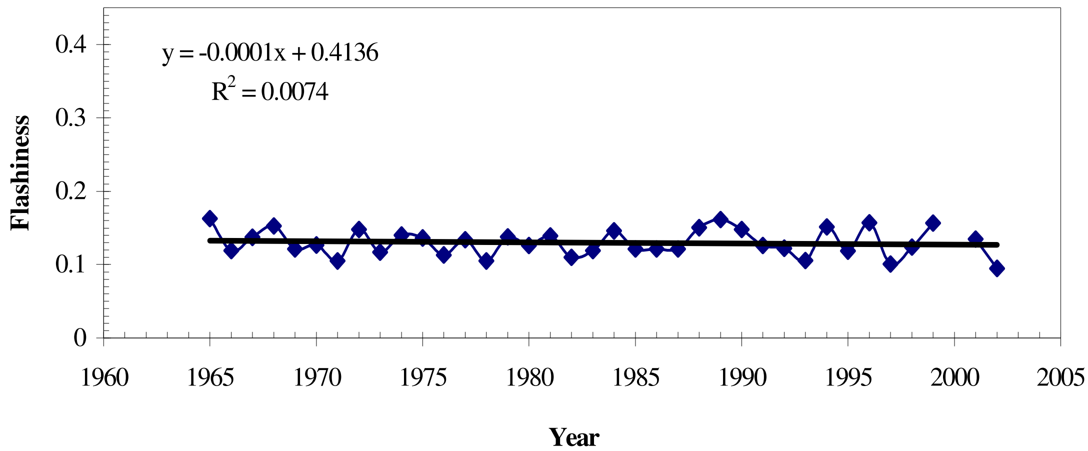

Figure 6. Gage # 04160800 Sashabaw Creek Near Drayton Plains

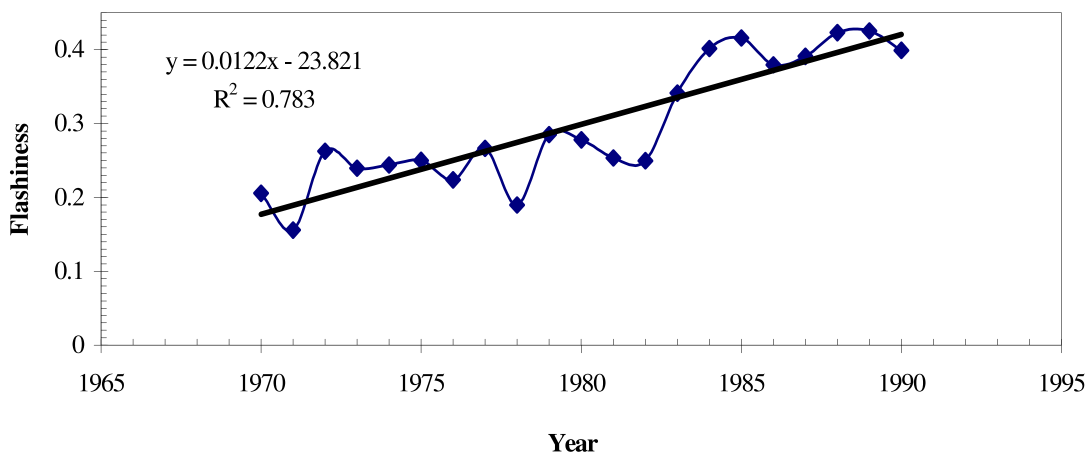

Figure 7. Gage # 04161100 Galloway Creek Near Auburn Hts.

CONCLUSIONS

The use of indices to assess the hydrologic trends can and should be an integral step in watershed investigations. There are numerous hydrologic indices that can be derived from time series data and periodic peak flow data. There are several analysis tools available to compute these, such as the Indicators of Hydrologic Alteration (The Nature Conservancy, 2005), with references to appropriate indices for a wide range of hydrologic investigations. Although the indices by themselves may not convey numerically discernible phenomena, they provide an objective means to determine if watershed processes are changing statistically over a broad temporal and spatial scale. The processes that drive sedimentation are extremely sensitive to increased velocities and flows and the frequency at which they occur. The processes increase exponentially, ranging from the 2^{nd} to 6^{th} powers of flow. These observations, combined with the understanding that the majority of sediment is transported in the largest annual events, indicates that watershed management decisions affecting hydrologic response are a key component in controlling sedimentation in watersheds and streams.

This type of analysis is also an example of a means of diagnosing the overall health of a watershed that would not be possible without comprehensive stream gaging networks, such as those supported by the USGS and other governmental agencies. It is rarely possible to develop numerical models for sedimentation processes with sufficient data to optimally calibrate or verify the models, so statistical methods play a key role in providing additional insight into the physical processes being modeled.

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