

Application of Hydrologic Metrics to Quantify Stream Health in Small-Scale Urban Environments

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Abstract. Numerous studies have been conducted to assess the impacts of urbanization on stream geomorphology and ecology. Recent research has shown benthic macroinvertebrates to be good indicators of stream health. Furthermore, significant correlations have been shown to exist between these benthic indicators and certain hydrologic metrics in receiving streams. These studies have used stream gage data and/or computer models to study such relationships but the scale of the watersheds has been large; typically greater than two square miles. This study examines the application of such research to a small-scale urban environment in Fort Collins, Colorado. The study uses benthic data collected approximately 10 years ago and stream flow measurements from the City's flood early warning system. These data provide an opportunity to determine if the findings in other research can be applied to relatively small urban streams. Such trends could help guide development and stream rehabilitation efforts in the City to minimize future impacts of urbanization on these streams and provide guidance in prioritizing stream reaches for rehabilitation. However, the use of such small scale real data in an ever-changing urban environment makes the application of hypothetical trends more difficult. Stream alteration, data limitations, and annual runoff variations present additional challenges for developing relationships between stream health and hydrology that are seen to exist in larger watersheds.

1. Introduction

Historically, stream rehabilitation has focused on the physical aspects of streams however this approach has been shown to be ineffective (Booth and Jackson, 1997). If in-stream rehabilitation is performed without making changes to contributing areas, the rehabilitation will be unlikely to be a sustainable solution. Therefore, more recent research has focused primarily on the characteristics of watersheds which drain to receiving streams (Booth and Jackson, 1997; McMahon and Cuffney, 2000; Roesner et al., 2001; Konrad & Burges, 2001; Konrad and Booth, 2002; Roy et al., 2003; Booth et al., 2004, Nehrke & Roesner, 2004; Voelz et al., 2005; Edgerly, 2006; Sprague et al., 2006; Pomeroy, 2007; DeGasperi et al. 2009). To adequately rehabilitate streams, there must be a way of quantifying the effect that upland regions have on streams.

Stream health has historically been assessed based on chemical water quality parameters (Booth et al., 2004). New research however suggests that stream quality may be aptly determined by analyzing benthic macroinvertebrate communities (Roy et al., 2003; Booth et al., 2004; Voelz et al., 2005; Sprague et al., 2006; Pomeroy, 2007; DeGasperi et al., 2009). Therefore, any metric used to assess the impact of urbanization on stream health must be sensitive to benthic communities and measures of urban development. Such a metric must not place emphasis solely on control of water quality and storm magnitude but instead must consider all aspects of the flow regime to adequately protect aquatic ecosystems from human development (Poff et al., 1997).

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Urbanization and resulting increases in uncontrolled impervious areas alters the natural flow regime by causing runoff volumes and rates to be increased (Booth & Jackson, 1997). Additionally, the frequency of high flow events will increase. The duration however, will decrease as runoff can travel more quickly in pipes and on impervious surfaces than via groundwater or as surface runoff from natural land (Booth & Jackson, 1997). Therefore an appropriate metric for the determination of the effects of urban development must account for these changes in flow regime. One such metric is the $T_{0.5}$. This metric, defined as the percent of time which stream flow exceeds the half-year storm peak discharge, has been shown to correlate directly to urbanization and benthic macroinvertebrate health (Booth et al., 2004; Pomeroy, 2007). As urbanization increases, the $T_{0.5}$ tends to decrease due to the shorter travel time of runoff in urban settings. This lowering of the $T_{0.5}$ corresponds to decreasing benthic health.

Mitigation of the hydrologic effects of urbanization may be done through the addition of best management practices (BMPs). BMPs are intended to reduce stormwater flows to match pre-development hydrology. It is hypothesized that the use of BMPs will positively affect stream health and increase the $T_{0.5}$ as peak flows are attenuated.

This study applies prior knowledge of the correlation between the $T_{0.5}$ and benthic macroinvertebrate health to assess the suitability of streams for rehabilitation. The study, conducted in Fort Collins, CO, uses continuous stream gage records to calculate the $T_{0.5}$ and compares these measurements to existing benthic data collected in the City.

2. Study Area

Fort Collins, CO is located in the Colorado Front Range along the eastern slope of the Rocky Mountains. Recent development and urban sprawl have caused rapid growth in the City whose population has increased from just under 119,000 in 2000 to over 136,000 in 2008 (U. S. Census Bureau). Starting in the middle to late 1800's, irrigation canals were constructed to support agriculture in the region (Watrous, 1911, p. 71). These canals draw water from the Cache La Poudre River and flow from north to south through the City. Additionally, there are two major creeks that flow from west to east through Fort Collins. Spring Creek flows through the northern part of the City while Fossil Creek drains much of the southern part of the City. Boxelder Creek which enters the Cache La Poudre River from the north drains a relatively small area of Fort Collins. Gage data gathered from the City of Fort Collins' Flood Warning System is used to assess in-stream hydrology at various places throughout the City. These gages provide roughly nine years of continuous flow records at four locations on Spring Creek, two on Fossil Creek, and one on Boxelder Creek. Figure 1 shows the location of these gages throughout Fort Collins. It should be noted that the gage located on Boxelder Creek is north of the City and is therefore not shown.

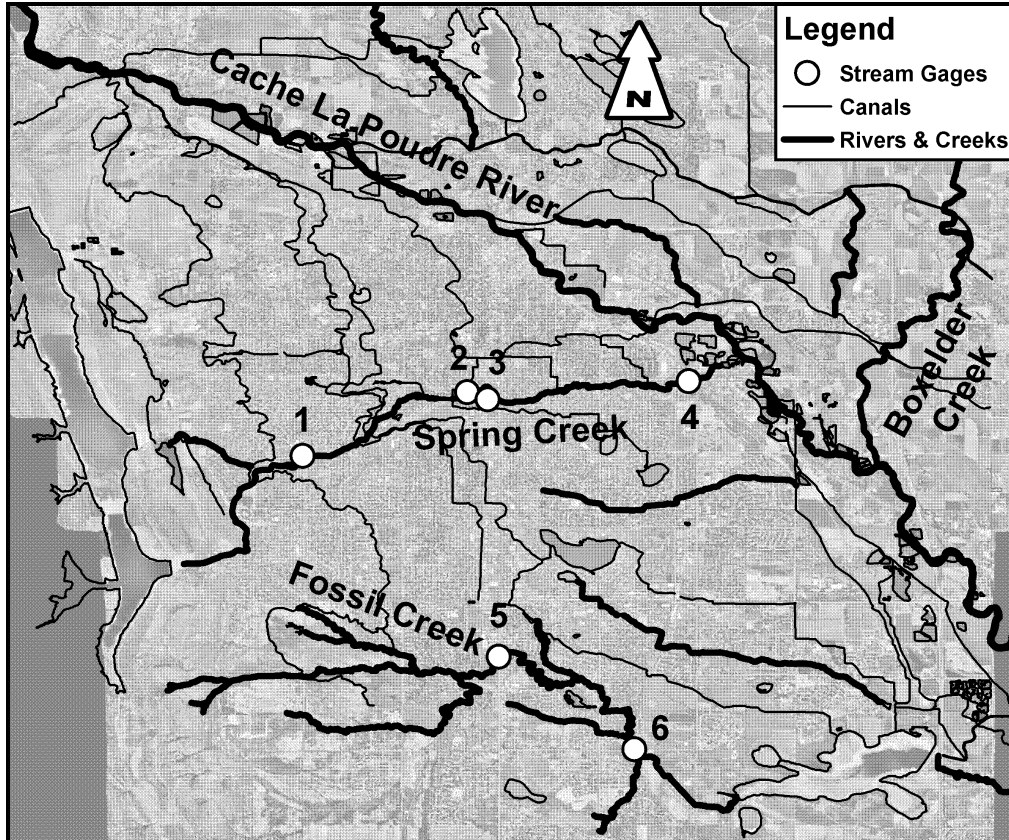


Figure 1: City of Fort Collins Streams, Canals, and Flow Gages (Source: City of Fort Collins)

3. Methods and Approach

The $T_{0.5}$ metric was used as a tool to determine the suitability of streams for rehabilitation. It was coupled with benthic data to determine possible correlations between urban development and stream health.

3.1. Calculation of $T_{0.5}$ Metric

Values of the $T_{0.5}$ metric were calculated for each of the stream gages in Fort Collins. Gage data was generally available on an hourly basis. However, due to the climate in the Colorado Front Range, stream gages are removed each fall and redeployed each spring so as to prevent ice damage to the gages. Therefore, only summer data (May through September) is consistently available.

To calculate the $T_{0.5}$, the peak flow for the half-year storm ($Q_{0.5}$) was determined using a partial duration series (Langbein, 1949). Peak flows were ranked from highest to lowest and the $Q_{0.5}$ was determined using the plotting position formula suggested by Cunnane (1978). Since the gages did not record year-round, only the time that the gages were in operation was used in the calculation of the $Q_{0.5}$ and subsequently the $T_{0.5}$. Therefore, the number of years of record was reduced from nine years to roughly four years. Table 1 shows values of the $Q_{0.5}$ and $T_{0.5}$ calculated at each gage. Gage numbers correlate directly to those shown in Figure 1.

Table 1: Stream Gage $Q_{0.5}$ and $T_{0.5}$

Gage	Creek	$Q_{0.5}$ (cfs)	$T_{0.5}$
1	Spring	70	0.025%
2	Spring	157	0.068%
3	Spring	180	0.080%
4	Spring	221	0.061%
5	Fossil	97	0.271%
6	Fossil	199	0.264%
7	Boxelder	128	1.454%

3.2. Existing Benthic Data

Two previous studies in the Fort Collins area have been performed on Spring and Fossil Creeks (Hoffman, 1998; Zuellig, 2001). These studies were used to calculate two common stream metrics based on Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa. These metrics, EPT richness and %EPT, are defined as the total number of different EPT taxa and the percentage of all benthic macroinvertebrates which fall into one of the EPT orders, respectively. Both studies indicated that Plecoptera have been extirpated from the Fort Collins streams and were ignored. Therefore, the resulting metrics were ET richness and %ET. Table 2 shows the benthic scores that correlate directly to stream gage locations.

Table 2: Benthic Macroinvertebrate Data

Gage	Creek	Hoffman, 1998		Zuellig, 2001	
		ET Rich.	%ET	ET Rich.	%ET
1	Spring	N/A	N/A	N/A	N/A
2	Spring	N/A	N/A	2	1%
3	Spring	3	17%	2	17%
4	Spring	5	42%	5	44%
5	Fossil	N/A	N/A	7	83%
6	Fossil	5	39%	N/A	N/A
7	Boxelder	N/A	N/A	N/A	N/A

4. Results of Analysis

Compilation of the hydrologic data from Table 1 with the benthic data from Table 2, established a relationship between stream hydrology and benthic health. Figure 2 shows the relationship established between the benthic indices and the $T_{0.5}$. This figure shows that a general trend does exist as would have been expected based on the findings of previous research (Booth et al., 2004; Pomeroy, 2007).

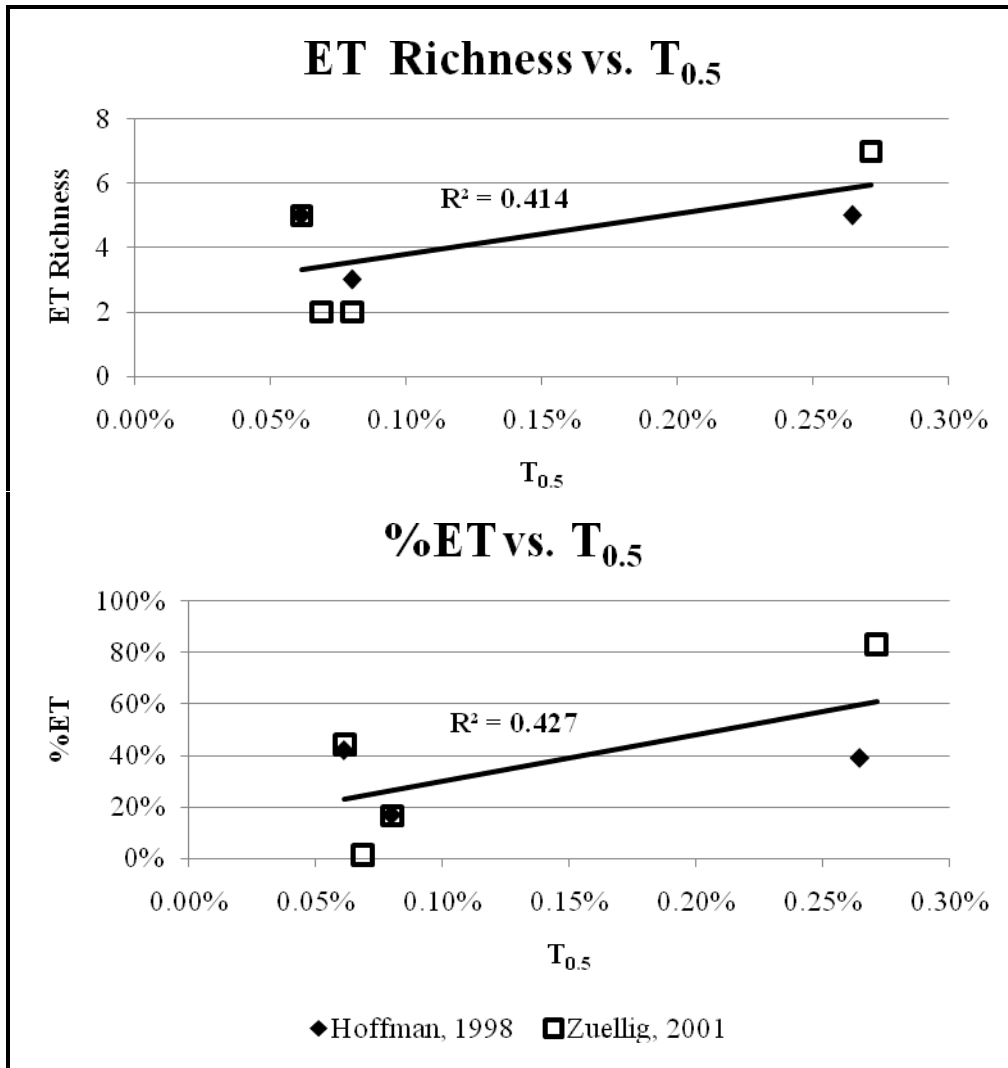


Figure 2: ET Richness and %ET versus $T_{0.5}$

5. Discussion of Results

One of the key observations from Figure 2 is that the two points with the highest $T_{0.5}$ values are both on Fossil Creek. These same points also have relatively high benthic scores. Points located on Spring Creek however tend to have low values of $T_{0.5}$ and low benthic scores. This disparity may be due to the difference in when these areas were developed. The City of Fort Collins developed first in the northern part of town in and around Spring Creek. Only recently has development spread to the Fossil Creek Watershed. Differences in the time of urbanization are relevant due to the advent of BMPs.

Much of the old development in the Spring Creek Watershed does not utilize water quality BMPs. Therefore, many small, frequent storms which contribute substantially to the $T_{0.5}$, flow uninhibited into Spring Creek. Newer developments along Fossil Creek incorporate such BMPs. These may help to attenuate the same small storms that flow freely into Spring Creek. This added attenuation may contribute to the improved aquatic health and hydrology in Fossil Creek.

Additionally, the development along Spring Creek is denser than that near Fossil Creek. Much of the Fossil Creek Watershed remains undeveloped and therefore should show fewer adverse effects from urban development. This may be further evidenced by the $T_{0.5}$ calculated on Boxelder Creek. The Boxelder Creek gauging station is north of the developed portion of Fort Collins. The area draining to this region is generally undeveloped and is fed primarily by agricultural lands. This relatively undeveloped condition has caused a particularly high value of the $T_{0.5}$ as shown above in Table 1. Though no benthic data exists for this point, the value of $T_{0.5}$ would suggest that high benthic scores could be expected.

At this time however, there is not an appropriate method to quantify a specific value of $T_{0.5}$ that is necessary to have good water quality. Sprague et al. (2006) found that for 28 sites in the Colorado Front Range that 75% of sites had EPT richness values of less than 10 with a maximum of 16. This suggests that values from the Fort Collins study may be typical of those in this area of the country. Further research must be conducted to determine an appropriate value of EPT (or ET) richness that is indicative of good stream health in the Front Range area. This would better guide decisions on the prioritization of stream remediation.

6. Conclusions

The positive correlation seen in other research between the $T_{0.5}$ and benthic stream health (Booth et al., 2004; Pomeroy, 2007) has been shown to exist in the Fort Collins urban setting. Through the use of existing data, the City may better direct its efforts in stream rehabilitation to areas with better hydrology. By more appropriately directing rehabilitation efforts, the City can allocate its funds to those places where improvements will be most sustainable. Boxelder and Fossil Creeks show the highest values of $T_{0.5}$ and are therefore presumed to have high benthic health. These areas may be prime candidates for stream rehabilitation. Conversely, Spring Creek consistently produces low values of the $T_{0.5}$. Such low values are indicative of the pervasive uncontrolled urbanization present in the area. Without adding significant stormwater controls in the regions, rehabilitation efforts will most likely be ineffective. It is the author's opinion that rehabilitation efforts would be best directed to those regions where acceptable hydrology presently exists.

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