CHAPTER 5 – CHANNEL MORPHOLOGY

Introduction

Stream channels in the Midwestern landscape naturally meander and move across their floodplains, transporting sediment and other materials downstream. This lateral channel migration generally takes place over many decades as point bars form on the inside of bends and erosion occurs on the outer banks. However, changes in watershed hydrology can upset the dynamic equilibrium between a stream and its floodplain, causing accelerated erosion, channel incision, and bank failure (Ward and Trimble 2004). As a channel deepens, high event flows can no longer spill out onto the floodplain where stream energy can be dissipated. Confinement of flow in the channel increases its erosive capacity and results in mass wasting of stream banks. Few stream invertebrates can survive in channels that are constantly being scoured by extreme water fluctuations (Morley 2000). Alterations in substrate structure and stability generally favor more tolerant species such as chironomids and oligochaetes.

Stable natural channels typically carry the discharge of a one to two-year storm event recurrence interval when at bankfull conditions (Krug and Goddard 1986). If peak discharges escalate due to increased runoff from urbanization, channels will erode until they can accommodate the larger flows. High intensity storms typically cause the most dramatic changes in channel structure, as streams may widen to twice their original size during a single storm event (Booth 1990). However, research has found that mid-bankfull events of less than a two-year frequency are also geomorphically significant (Schueler and Holland 2000c). Because urban stormwater systems typically design only for two-year peak discharge control, the increased frequency of smaller events due to urbanization can contribute to channel instability.

Several studies have shown that sediment yields from urbanizing watersheds remain high after completion of construction activities because of channel widening and downcutting. In San Diego Creek in southern California, a study from 1983 to 1993 found that two-thirds of the total stream sediment yield resulted from bank erosion as the basin transitioned from agriculture to urban land use (Trimble 1997). Another study found that bank erosion due to urbanizing land use in the Issaquah Creek watershed in western Washington accounted for 20% of the total sediment budget (Nelson and Booth 2002). Research conducted during the 1970s in the Pheasant Branch basin near Middleton, Wisconsin, found substantial channel enlargement and degredation during the first six years of basin urbanization, which then slowed over the next three years (Krug and Goddard 1986). Although all of these studies showed an increase in bank erosion with urbanization, a recent research project completed on Brewery Creek in Dane County, Wisconsin, indicated that a suburban residential development designed specifically to infiltrate stormwater produced no measurable changes in stream morphology (Selbig et al. 2004).

Although increased impervious cover within a watershed influences channel enlargement, studies have failed to establish a predictive relationship between a given level of impervious cover and the resulting increase in channel area (Schueler and Holland 2000b). Instead, research has shown that the amount of change in channel size is dependent on local stream factors, such as bed and bank material composition, stream entrenchment ratio, pre-development watershed depressional storage capacity, connectivity of the stormwater conveyance system, and channel gradient (Bledsoe and Watson 2001). Thus, monitoring is essential to understand the impacts of urbanization on individual streams.

Research Objective

The purpose of this chapter was to investigate the impacts of urban development on the channel morphology of Baird Creek. Using field measurements taken by Applied Ecological Services, Inc., (AES) in 2002, the objective of this study was to determine if the bankfull widths and channel cross-sectional areas of tributaries to Baird Creek with urbanizing watersheds have significantly changed in response to hydrologic alterations over the past two years.

Methodology

Channel Measurement

In June 2002, AES ecologists established twelve permanent stream morphology assessment sites between Interstate-43 and Huron Road as shown in Figure 5.1 (Stoll et al., 2003). Sites were located along the main channel, North Branch, South Branch, Christa McAuliffe Park Ravine, and Huron-Sitka Detention Basin Ravine. Locations were identified with a GPS unit and monument trees were established on each side of the stream. The channel cross-section was measured perpendicular to the estimated bankfull

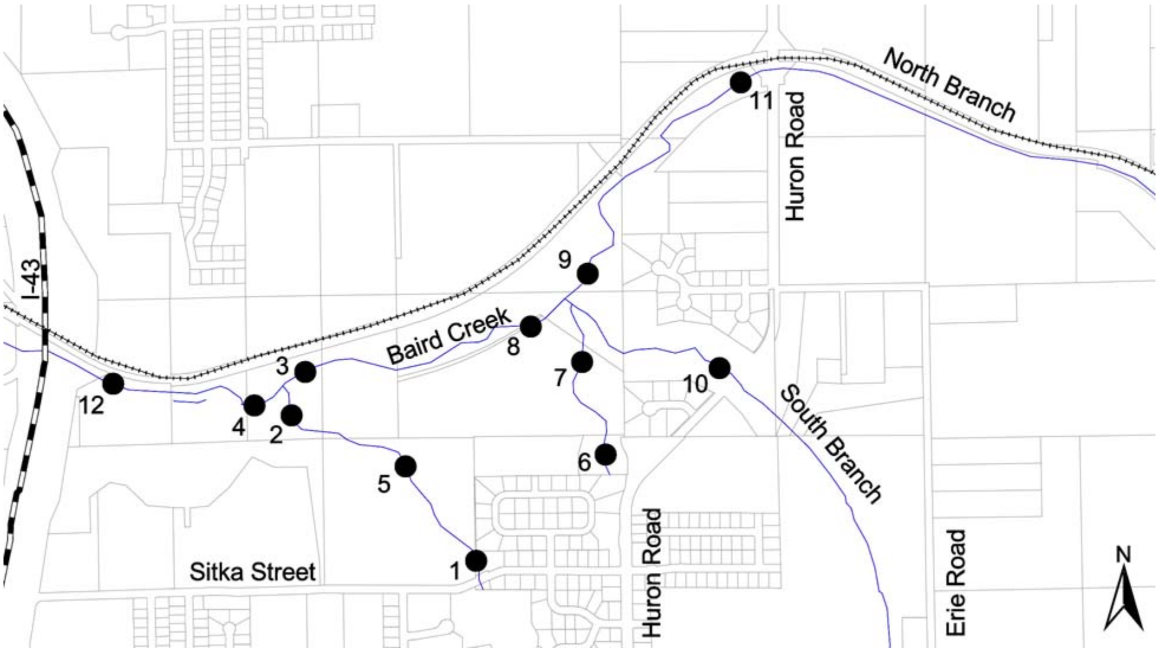

Figure 5.1. Locations of 2002 and 2004 channel morphology sampling sites on Baird Creek and its tributaries.

channel at each site, extending across the floodplain on each side of the stream. A consistent elevation was established by driving nails into each monument tree and connecting a stringline across the channel. Parameters measured relative to the established elevation included the following:

- Wetted width at low-flow
- Wetted depth at low-flow
- Distance between the tops of the right and left banks
- Bankfull width
- Bankfull depth
- Flood-prone width
- Center of the channel
- Discharge
- Bankfull width to depth ratio

For this study, the twelve original sampling sites were located and reassessed relative to the stringline elevations established by AES. Sampling was conducted in July 2004, establishing a two-year interval between the original data and the current study. Measurement methodology followed “Stream Channel Reference Sites: An Illustrated

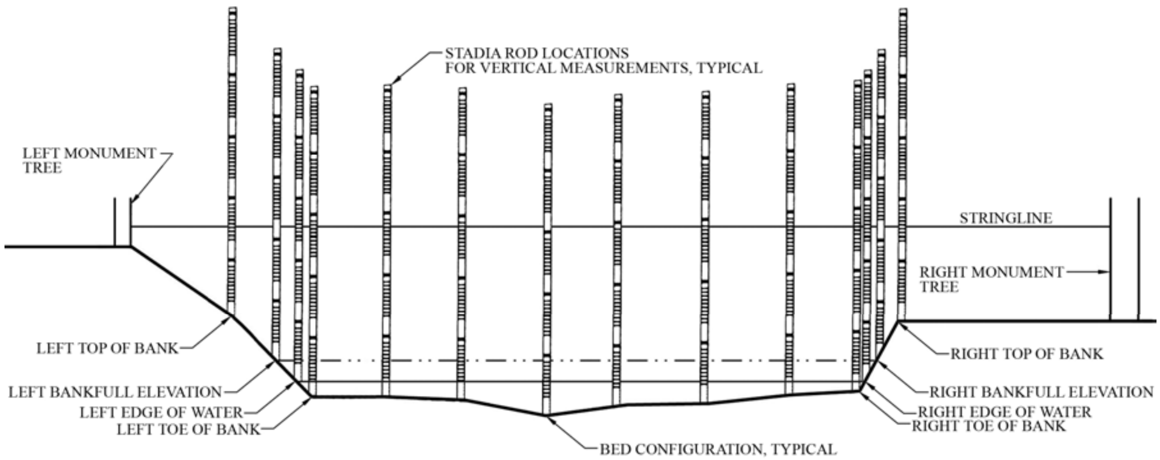

Figure 5.2. Typical measurements located horizontally and vertically in relation to the stringline at each channel morphology assessment site (After Olsen et al. 1997).

Guide to Field Technique" (Harrelson et al. 1994). Right and left banks were defined facing downstream. Additional measurements were combined with those taken during the AES study to fully characterize and record the shape of the banks and channel bed (Figure 5.2). As noted in the literature, bankfull discharge stages become more difficult to identify to identify as streams become entrenched due to recent disturbance (Ward and Trimble 2004). Common indicators of bankfull discharge used in this study included the top of pointbars, changes in vegetation, changes in bank materials, and changes in bank slope (Ward and Trimble 2004, Harrelson et al. 1994).

Analyzing Changes in Channel Morphology

According to literature, assessing changes in channel form can best be accomplished by analyzing bankfull width dimensions and by determining the percentage of channel enlargement (Schueler and Holland 2000b, Booth 1990). To compare changes in bankfull width due to land use, sites were first grouped into categories by location. Sites located on the North Branch were designated as "agricultural." Sites located on the South Branch, Christa McAuliffe Park Ravine, and Huron-Sitka Detention Basin Ravine were categorized as "urbanizing." Sites located below the confluence on Baird Creek were labeled "main channel." Because of the small sample size, analysis of variance on the ranks of the data were used in conjunction with the Tukey comparison procedure to determine if differences between location categories were significant at the 95% confidence level. All analyses were performed using SAS 9.1 computer software (SAS Institute Inc. 2003). The relative change in bankfull width was also qualitatively compared between sites by mapping the magnitude of change by location.

Channel cross-sectional area was defined as the area of the stream channel below bankfull width and depth. Differences in cross-sectional areas at the locations established on Baird Creek were determined using AutoCAD 2000 software (AutoDesk, Inc. 1999). The percentage of channel enlargement was calculated using the following equation:

$$\frac{(\text{Channel area 2004 - Channel area 2002})}{(\text{Channel area 2002})} \times 100\% = \%\ \text{Enlargement} \qquad \textit{Equation 5.1}$$

Because the data from AES did not include all pertinent channel dimensions, estimates were made for the 2002 channel area by interpolating between measurements that were recorded by AES and by extending current bank slopes to previous channel widths. Analysis of variance on the ranks of the data were used in conjunction with the Tukey comparison procedure to determine if differences in channel enlargement between the location categories defined above were significant at the 95% confidence level. Finally, the amount of channel enlargement was qualitatively compared between sites by mapping the magnitude of change by location.

Results and Discussion

The channel morphology assessment was performed on July 9 and July 12, 2004. No precipitation was recorded at the Baird Creek USGS Station on Superior Road between these two dates. Field data sheets for the study are contained in Appendix C. All data sheets include a site description, channel measurements, a scaled diagram of the cross-section produced with AutoCAD software, and a site photograph. Figure 5.3 summarizes bankfull width, bankfull depth, and channel area for bankfull conditions as measured at each of the assessment sites in 2002 and 2004. Bankfull width and depth measurements for Site 6 were missing from the 2002 AES report. Also, the recorded measurement for bankfull depth at Site 11 in 2002 was suspect for error.

Changes in Bankfull Width Measurements

Comparisons of bankfull width measurements were only possible for eleven of the twelve morphology assessment sites due to incomplete data for Site 6 in the AES study. Table 5.1 shows the category assigned to each site, bankfull width measurements from both the 2002 and 2004 surveys, and the percent change in bankfull width. Sites were ranked based on the percent change in width, with the value "1" assigned to the site with the greatest increase in size. Figure 5.4 shows the relative change in bankfull width between sites by mapping the magnitude of change by location.

The greatest change in bankfull width occurred at Site 1, which was located on the Christa McAuliffe Park Ravine tributary. All five sites on the urbanizing tributaries were ranked in the top five sites in terms of percent change. Analysis of variance on the ranks

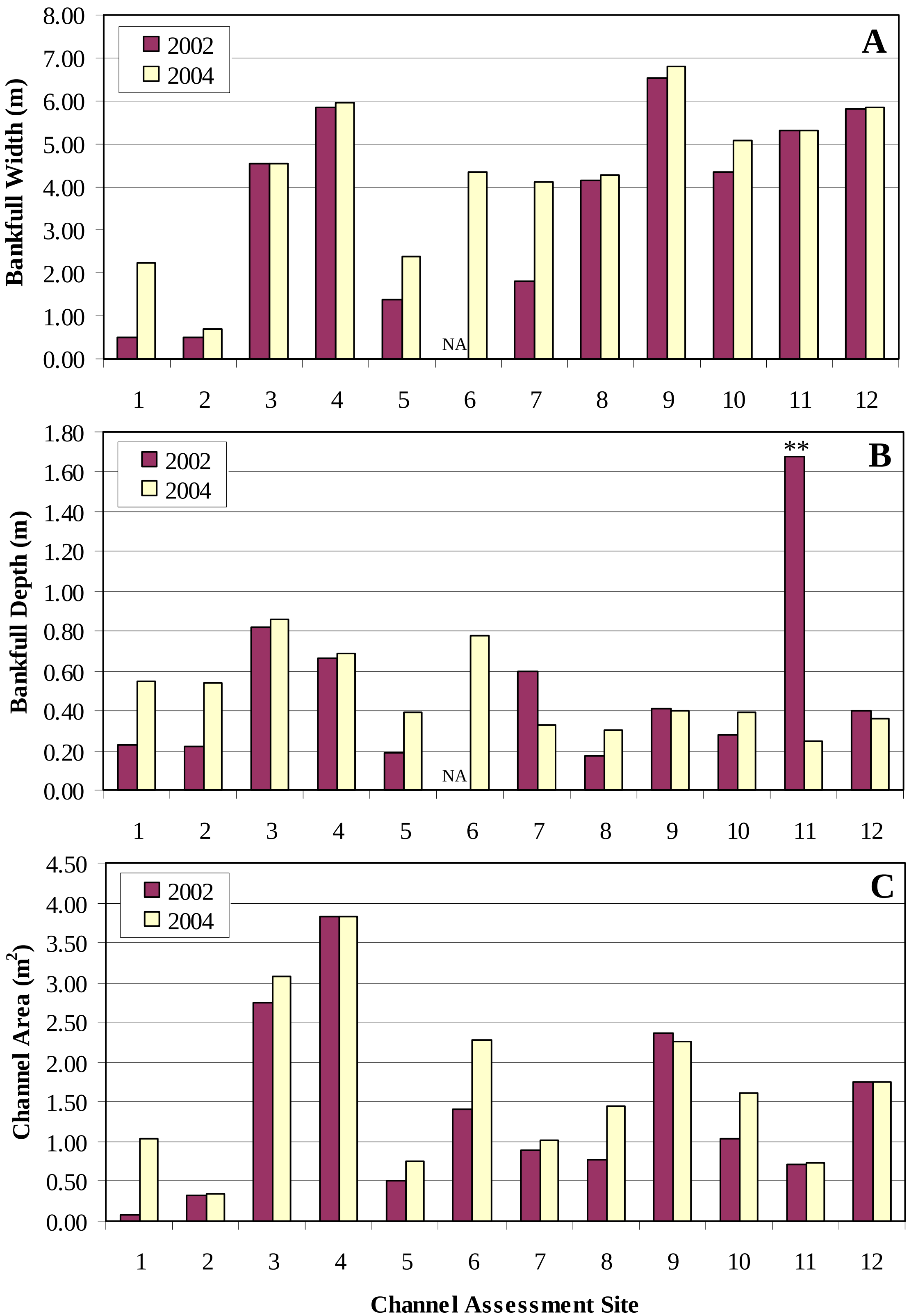

Figure 5.3. Bankfull width (A), bankfull depth (B), and channel area measurements (C) recorded during the 2002 and 2004 morphology assessments (Stoll 2003). ** Denotes a suspected measurement error.

of the data showed that the sites on the urbanizing tributaries significantly increased in bankfull width as compared to the other categories at the 95% confidence level ($p = 0.0039$). However, neither the agricultural or main channel site categories statistically differed from each other.

Table 5.1. Bankfull width at channel morphology assessment sites listed by category. Ranking is based on the percent change in bankfull width between 2002 and 2004, with the value "1" assigned to the site with the greatest increase in width. Note: Site 6 was not included due to insufficient data from the 2002 survey.

Category	Site	Bankfull Width 2002 (m)	Bankfull Width 2004 (m)	Percent Change	Ranking
Urbanizing	1	0.50	2.23	346%	1
Urbanizing	2	0.50	0.71	42%	4
Urbanizing	5	1.40	2.38	70%	3
Urbanizing	7	1.80	4.12	129%	2
Urbanizing	10	4.34	5.09	17%	5
Agricultural	9	6.55	6.80	4%	6
Agricultural	11	5.32	5.29	0%	9
Main Channel	3	4.53	4.52	0%	9
Main Channel	4	5.84	5.98	2%	7
Main Channel	8	4.17	4.26	2%	8
Main Channel	12	5.80	5.84	0%	9

Channel Area Enlargement between 2002 and 2004

Table 5.2 shows the category assigned to each site, channel area at bankfull from both the 2002 and 2004 surveys, and the percent of channel enlargement. Sites were ranked based on the percent of channel enlargement, with the value "1" assigned to the site with the greatest increase in area. Figure 5.5 shows the relative change in channel size between sites by mapping the magnitude of percent enlargement by location.

The greatest change in channel enlargement occurred at Site 1, which increased 1104% in size between 2002 and 2004. Site 9 on the North Branch was the only site to decrease in channel area due to sediment deposition. Of the six sites located on the urbanizing tributaries, four were ranked in the top five sites in terms of percent change. However, analysis of variance on the ranks of the data failed to detect a significant difference in the percent enlargement between categories at the 95% confidence level ($p = 0.0790$).

Table 5.2. Bankfull channel area at morphology assessment sites listed by category. Ranking is based on the percent of channel enlargement between 2002 and 2004, with the value "1" assigned to the site with the greatest increase in area.

Category	Site	Channel Area 2002 (m^2)	Channel Area 2004 (m^2)	Percent Channel Enlargement	Ranking
Urbanizing	1	0.09	1.04	1104%	1
Urbanizing	2	0.32	0.34	7%	8
Urbanizing	5	0.50	0.76	51%	5
Urbanizing	6	1.40	2.28	63%	3
Urbanizing	7	0.89	1.01	14%	6
Urbanizing	10	1.03	1.60	55%	4
Agricultural	9	2.35	2.26	-4%	12
Agricultural	11	0.71	0.74	5%	9
Main Channel	3	2.75	3.08	12%	7
Main Channel	4	3.83	3.83	0%	10
Main Channel	8	0.77	1.45	87%	2
Main Channel	12	1.75	1.75	0%	10

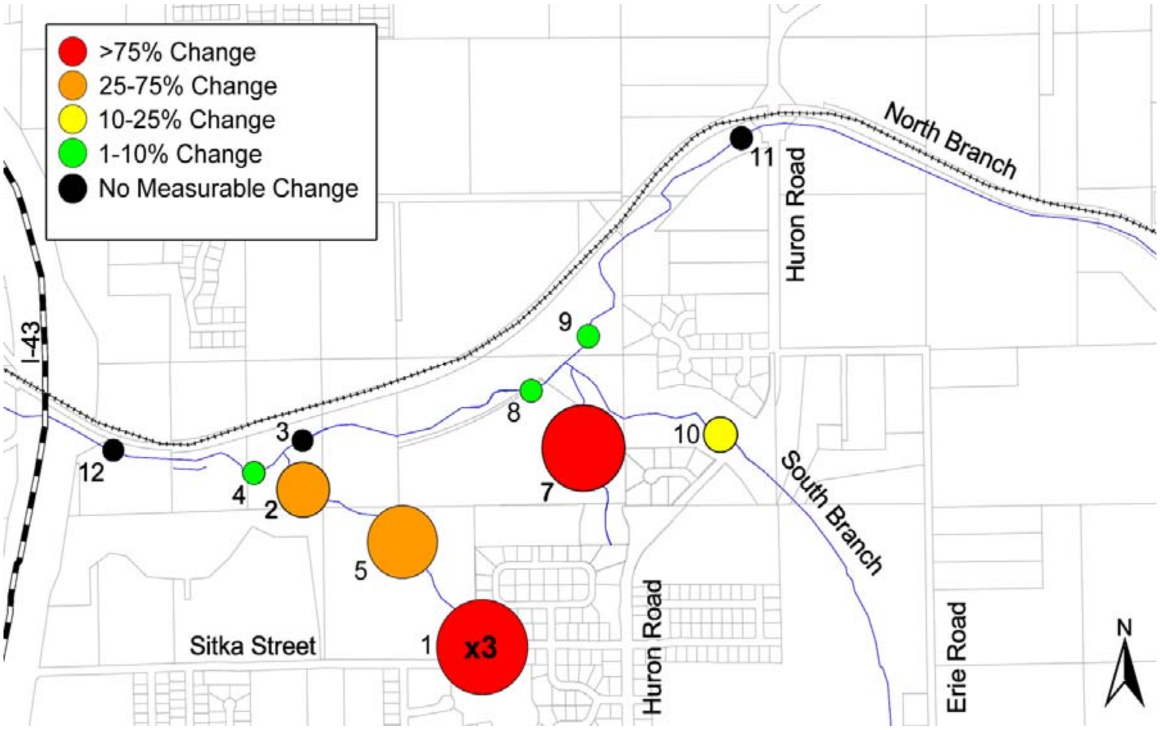

Figure 5.4. Percent change in bankfull width at the morphology assessment sites between 2002 and 2004. Bubble size indicates relative magnitude of change at each site.

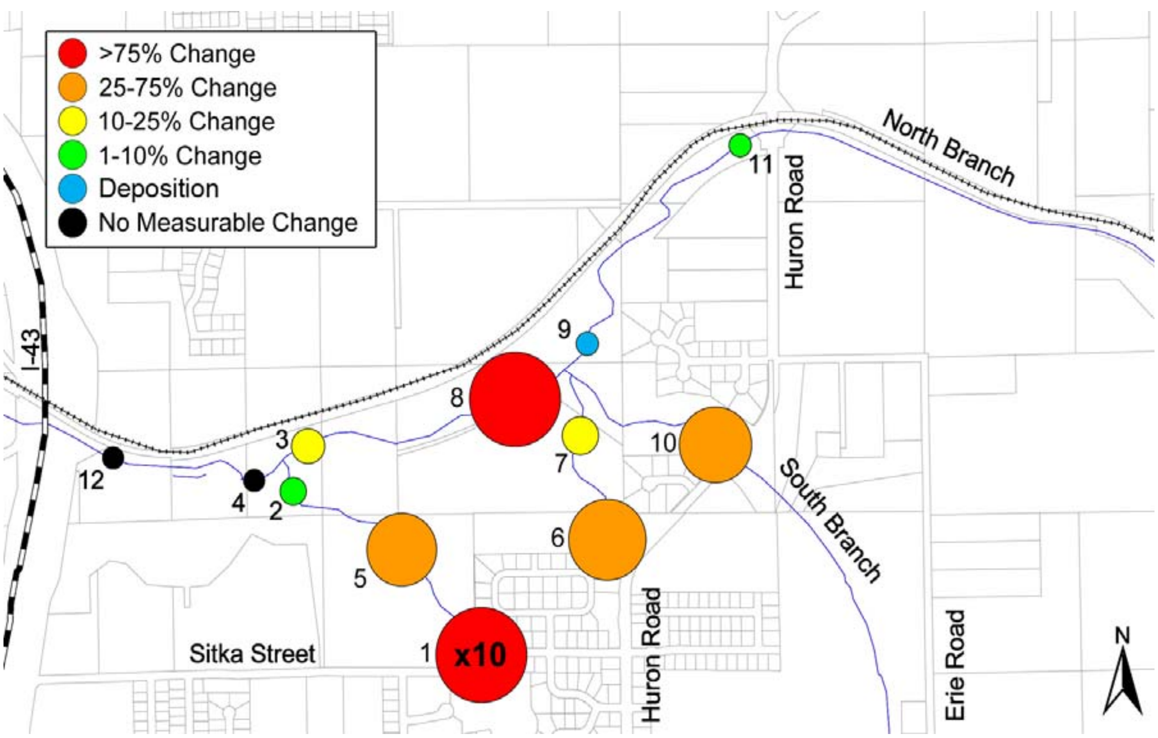

Figure 5.5. Percent of channel enlargement at the morphology assessment sites between 2002 and 2004. Bubble size indicates relative magnitude of change at each site.

Conclusions

Land use within the Baird Creek watershed has changed substantially since the first channel characterization survey was performed by AES in 2002 (See Chapter 2). Although detailed land use data from 2002 were unavailable, 18% of the Christa McAuliffe Park Ravine watershed and 19% of the Huron-Sitka Detention Pond Ravine watershed were under construction as of August 2003. Active construction work at these sites most likely began in late summer 2002 or in spring 2003. Also, as AES ecologists noted in their report, the bridge connecting Huron and Woodside Roads upstream of Site 10 on the South Branch was under construction during the 2002 survey. Any development located off this road obviously occurred after the AES field work.

Results indicated that urbanization in the Baird Creek watershed has caused impacts similar to those described in other studies (Trimble 1997, Nelson and Booth 2002). Although May 2004 was the second wettest May recorded in Green Bay history, atypical weather patterns alone cannot justify the increase in bankfull widths and cross-sectional areas observed at all the channel morphology assessment sites on urbanizing tributaries. The comparison of change in bankfull widths between assessment sites clearly showed that the urbanizing tributaries were expanding in size; however, the statistical analysis of channel enlargement was less conclusive. The lack of difference between location categories was explained by Figure 5.5, which showed that Site 8 on the main channel downstream of the confluence was most likely impacted by flows from the South Branch and Huron-Sitka Detention Basin Ravine. Also, Site 2 showed relatively little increase in channel area, which may be explained by the presence of a large wetland complex just upstream. Figure 5.6 shows how this tributary flattens out in the wetland, loses its

Figure 5.6. Photo of the wetland complex upstream of Site 2 on the Christa McAuliffe Park Ravine. Note massive sediment deposition from channel erosion upstream.

velocity, and deposits large amounts of sediment from the erosion occurring upstream. Because of the wetland's capacity to store a substantial amount of stormwater, less erosion may have occurred at Site 2 than at other locations on the urbanizing tributaries. The inconsistencies in channel enlargement that occurred at Sites 8 and 2 relative to other sites on the main channel and urbanizing tributaries explained why statistically significant differences were not found between the location categories. However, considering the results of the bankfull width comparison and the pattern of channel enlargement shown by Figure 5.5, it was concluded that urbanization has caused substantial changes in the morphology of the urbanizing tributaries of Baird Creek, although fewer impacts have been seen at the sites furthest downstream on the main channel.

Implications for Future Management

The Baird Creek Preservation Foundation has demonstrated a commitment to protecting the channel stability and aquatic ecosystem of Baird Creek. In conjunction with the City of Green Bay, the BCPF hired AES to perform an update to the 2002 report that would recommend restoration strategies for the Christa McAuliffe Park and Huron-Sitka Detention Basin Ravines (O'Leary et al. 2004). AES identified preliminary locations and conceptual details for in-stream channel stabilization techniques to repair failing banks and prevent additional channel degradation in the tributaries. Although the updated report recommended best management practices (BMPs) to promote infiltration in three other subwatersheds of Baird Creek slated for future development, no specific mention was made to implement these practices or other retrofits within the watersheds of the two degraded ravines. As noted by other researchers, focusing all efforts on repairing bank erosion without addressing the underlying cause (i.e. increased flows, impervious surfaces) results in a "band-aid" remedy that will not be sustainable over time (Booth 1991). Other solutions aimed at a watershed-based approach will be necessary to adequately protect these two tributaries.

Research performed on Brewery Creek in Dane County, WI, identified a combination of BMPs which resulted in no measurable impacts to water quality and channel morphology of the receiving stream. BMPs included in the study were infiltration medians in boulevards, reduced street widths, infiltration basins, protection of existing forest cover, bioretention swales, and vegetated stream buffers (Selbig et al. 2004). Many of these practices could be retrofitted to existing development to reduce peak storm event runoff and to lessen the potential for stream erosion. In particular, the

City of Green Bay could add bioretention swales along flow paths, require rain gardens on individual residential lots, and modify detention basins to provide additional storage, promote infiltration, and retain stormwater from smaller events. In all, focusing on reducing stormwater runoff volume instead of merely responding to adverse changes within the stream itself can potentially offer a real solution to the problem of channel degradation on the urbanizing tributaries of Baird Creek.