

Management of Millers Creek Sediment Accumulation Study - Report

Prepared for: The City of Ann Arbor



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1.0 EXECUTIVE SUMMARY

The City of Ann Arbor conducted the Millers Creek Sediment Study in response to flooding on Geddes Road associated with sedimentation of Millers Creek in the City-owned Ruthven Nature Area. Millers Creek is a tributary of the Huron River located in northeast Ann Arbor (**Figure 1**). Millers Creek drains portions of property owned by the University of Michigan (31%) and property under the jurisdiction of the City of Ann Arbor (56%) and Ann Arbor Township (13%). The purpose of the study was to identify potential management recommendations for addressing the sedimentation occurring in Millers Creek at Ruthven Nature Area and associated flooding on Geddes Road. The Study evaluated sediment loading and transport throughout the Millers Creek channel network. The source and mass of sediment from streambank and streambed erosion was estimated. A sediment transport model was used to study how sediment is transported throughout Millers Creek, to simulate sedimentation observed at Ruthven Nature Area, and to evaluate potential recommendations to manage the sediment or reduce sediment loading.

The Study showed that streambank erosion is prominent throughout much of the channel network and is pronounced in some reaches. Streambank erosion is the result of channel instability caused by development, hydrological alteration, and physical alterations of the channel. The City has been working with other partners to address those concerns through implementation of the Millers Creek Watershed Improvement Plan. Sediment entering the channel network from streambank erosion is excessive due to the severity and wide-spread nature of the erosion. Using field-derived estimates of sediment loading from streambank erosion, the sediment transport model simulated deposition observed in the Ruthven Nature Area. The model was then used to simulate changes to the Huron Parkway culvert upstream of Ruthven and stabilization of unstable river reaches where most of the sediment load was originating. Those model simulations were used to develop recommendations for managing sediment or reducing sediment loading.

Recommendations fall within three categories: 1) maintenance activities, 2) sediment removal activities, and 3) sediment load reductions. Maintenance activities that were considered are intended to reduce sedimentation at Ruthven by improving the transport of sediment or by removing sediment from the channel network. Recommended maintenance activities include

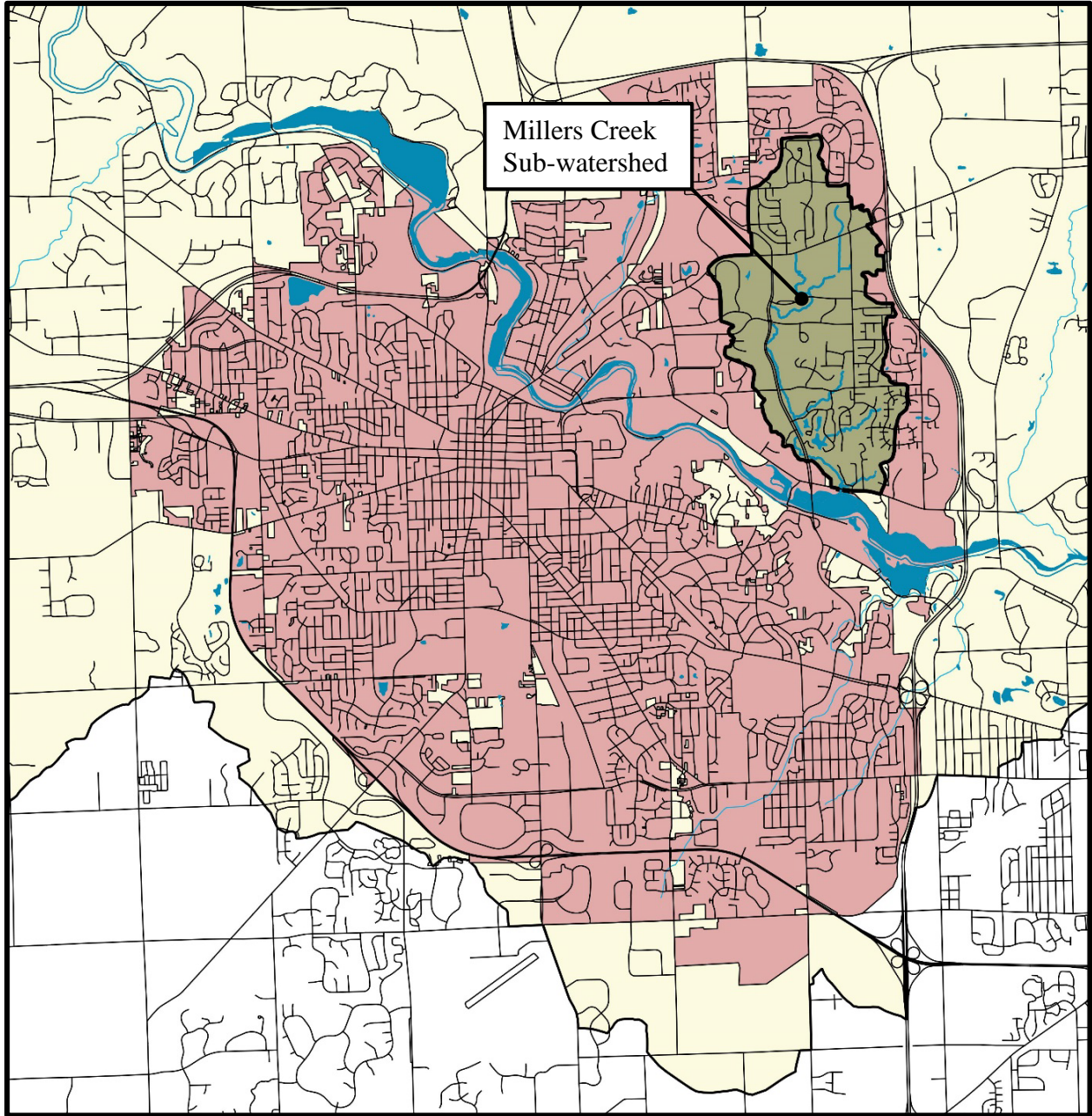


Figure 1. Location of the Millers Creek sub-watershed in the City of Ann Arbor. Beige shading represents the Huron River watershed. Light rose shading represents the corporate limits of the City.

periodic sediment removal from the Huron parkway culvert and periodic sediment removal from a concrete baffle box. Sediment maintenance activities could be combined with on-going stormwater management activities. Sediment removal activities include additional sediment removal from the Ruthven Nature Area and newly constructed sediment traps. Maintenance activities and sediment removal deal directly or indirectly with sediment that is in-stream, or already in the channel network and available for transport; this may include sediment stored in culverts and catch basins.

In contrast, sediment load reduction projects that were considered are intended to reduce the mass of sediment that reaches the channel network, primarily through streambank erosion. Stabilizing eroding streambanks, streambeds, or entire stream reaches within the Millers Creek channel network will reduce the amount of sediment that enters Millers Creek and becomes available for transport. The Study determined that streambank erosion was the primary source of excessive sediment loading and that reducing sediment loading from streambank erosion could substantially reduce sedimentation at the Ruthven Nature Area. Recommended sediment load reduction projects include streambank stabilization and reach-based channel restoration. Recommended approaches have been used successfully to stabilize streambanks between 2007 and 2009 in Millers Creek and restore extensive reaches of Malletts Creek in the City of Ann Arbor using bank reconstruction, channel modifications, and grade control structures. The recommended load reduction projects were simulated with the sediment transport model. If all of the recommendations were implemented, the mass of sediment deposited in Ruthven Nature Area between 2007 and 2012 would be 223 tons less than the model predicted deposition (234 tons).

2.0 INTRODUCTION

2.1 PROJECT OVERVIEW

Millers Creek is a tributary of the Huron River with a 2.5 square mile drainage area located in northeast Ann Arbor (**Figure 1**). It is the smallest named tributary of the Huron River, but its valley has the steepest gradient as it slopes from the headwaters at Plymouth Road to the Huron River at Geddes Lake. The City of Ann Arbor has responded to reports of flooding at Geddes Road near the point where Millers Creek flows under Geddes Road (**Figure 2**), resulting in road closures for public safety. Concerned citizens familiar with the Ruthven Nature Area alerted the City about apparent sediment accumulation along Millers Creek where it flows through the nature area.

In response, the City contracted with Environmental Consulting & Technology, Inc. of Ann Arbor to study the sediment accumulation and related road flooding (Study). The Study purpose is to determine likely causes and identify potential management actions to reduce and/or manage the sedimentation that is causing flooding on Geddes Road. While streambanks normally supply sediment to streams, extensive streambank erosion caused by unstable channel morphology and watershed hydrology results in elevated sediment supply to Millers Creek. Millers Creek meets the Huron River floodplain at Ruthven Nature Area, naturally resulting in lower stream slope and capacity to transport sediment, making it susceptible to sedimentation when the sediment load is elevated.

2.2 PROBLEM DESCRIPTION

Figure 3 shows the current location of Millers Creek in the Ruthven Nature Area. Normally Millers Creek flows under Geddes Road through a culvert located east of Gallup Park (1) that is designed for that purpose. During flood events, stormwater flows over the banks and along the east side of Huron Parkway (2A). This flow path is the result of sedimentation in the natural channel of Millers Creek (3). Sediment reduces the size of the natural channel and the amount of water that can flow through it. Then water flowing over the banks (2A) has formed a new channel (2B) along the east side of Huron Parkway. The over bank flow is conveyed through a culvert

located west of Gallup Park (4) that is not designed to convey the flow of Millers Creek, resulting in road flooding.



Figure 2. Geddes Road flooding near Gallup Park (foreground) caused by Millers Creek sediment accumulation.



Figure 3. Location of Millers Creek in the Ruthven Nature Area (2010 aerial photography).

2.3 MILLERS CREEK BACKGROUND

The Millers Creek Action Team (MCAT) completed a watershed study and management plan in 2003 in response to streambank erosion on the Pfizer property south of Plymouth Road. During the study MCAT was represented by the Michigan Department of Environmental Quality (MDEQ), City of Ann Arbor, University of Michigan, Huron River Watershed Council, Pfizer, Altarum, Pollack Design Associates, and the Washtenaw County Water Resources Commission. The study produced the Millers Creek Watershed Improvement Plan (April 20, 2004), which contains a thorough characterization of the watershed, water quality modeling, stream corridor assessments, and improvement opportunities. The plan was later approved by the MDEQ and Environmental Protection Agency for watershed funding.

Development within the Millers Creek watershed expanded rapidly from 1960 through the 1980s, including construction of Huron Parkway, commercial centers, and residential neighborhoods. In 2003, 35% of the watershed contained impervious surfaces, of which approximately 24% was directly connected to the storm sewer system. The high degree of development in the watershed has altered the hydrology of Millers Creek and physically altered portions of the channel (e.g. enclosures and relocations). The City of Ann Arbor jurisdictional limits comprise 56% of the land area, 31% is within the jurisdiction of the University of Michigan, and the remaining 13% falls within the jurisdiction of Ann Arbor Township.

The Millers Creek Watershed Improvement Plan identified and characterized morphological instability in Millers Creek and resulting channel erosion to some degree. It also identified improvements to address those problems. The following bulleted excerpts from the plan summarize the applicable findings.

- “High total suspended solids and high total phosphorus loads are most likely a result of runoff loads and stream bank and bed erosion. Flow and geomorphology data suggest the erosion loads are primarily originating in the middle reaches of the creek. These loads are then deposited in the creek delta that extends from Huron High School to the Huron River or are carried into the Huron River.”

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- “Natural channels formed to transport historic flows must now cope with frequently occurring and significantly higher flows. This new flow regime literally reshapes channels, making them deeper and wider, carrying bed and bank sediment downstream.”
 - “The high bed slope combined with extensive Directly Connected Impervious Area (DCIA) has led to some extreme downcutting. The downcutting has disconnected some of the stream from its floodplain.”
 - “On Millers Creek, the natural tendency of the stream to move its watershed to its base level (the Geddes dam elevation in the Huron River) is being accelerated by development in the watershed. The creek is cutting the stream bed down, “pulling” more and more of the landscape down with it. The stream bed and banks are being carried downstream. The wetland at Huron High School and the wetland complex between the High School and the Geddes site are basically the stream delta, where the sediment dislodged upstream comes to rest. The total suspended solids data collected for this project corroborate this description (see Figure 5.6 below). The data shows increasing average and peak TSS concentrations up to Huron High School and then a clear reduction of TSS concentrations at the Geddes station.”
 - “Plymouth Sub-Area (Reaches F and G): It is likely in this reach that the bed is more resistant to erosive forces than the banks. It appears that this reach of the channel was historically straightened. Ultimately, straightening a channel without armoring it is a lesson in futility. Open channel meandering tends to equalize the burden on stream bed and banks for dissipating the energy of moving water and sediment. Without intervention, straightened channels will reconstruct meanders.”
 - “Baxter Sub-area (Reach 9 and H): The main channel on Pfizer’s property is in some places confined and slightly incised, while in other areas, a broad and active floodplain serves to spread out the contact area and erosive force of the creek. Opportunities for bank stabilization...are present throughout the reach.”
 - “Glazier Sub-area (Reach 6): The channel just downstream of this baffle box is the steepest in Millers Creek, and the channel and its banks are very active...vertical and lateral instabilities are primarily due to the combination of high streamflow energy and high available sediment supply from eroding banks.”

- “Huron High School (Reaches 5, 4, and 3): The stream bed profile and the active stream channel are widening and cutting from Hubbard to Glazier. The stream bed is concave in its middle section and then flattens out at Huron High School. As a gross but useful simplification, it is as if the stream is hollowing itself out in the middle and transporting this material to the High School. The highly mobile but extensive deposits at the High School, in the culvert under Huron Parkway (See Figure F.21) and at the High School sampling site corroborate this scenario.”

The Millers Creek Improvement Plan recognizes that changes in watershed hydrology have caused much of the morphological instability in the watershed and includes recommended improvement opportunities to manage stormwater, stabilize streambanks and the streambed, and manage high sediment loading throughout the watershed. However, the plan did not attempt to evaluate streambank erosion severity, estimate bed and bank erosion rates, or estimate sediment loading rates. Furthermore, the plan did not assess sediment transport except at a qualitative level. While many of the findings of this Study are consistent with the Millers Creek Watershed Improvement Plan, the Millers Creek Sediment Study builds on previous knowledge by developing quantitative estimates and identifying the reaches with the most severe erosion and highest sediment loading rates.

2.4 STUDY TECHNICAL APPROACH

The Study’s technical approach included a field assessment and development of a sediment transport model. The field assessment included characterization and documentation of morphological conditions throughout the Millers Creek stream channel network. The Bank Evaluation Hazard Index (BEHI) was used to evaluate streambank erosion severity. Pebble counts were conducted to characterize the distribution of bed particle sizes. Bed particle size distributions are used as input for the sediment transport model, and provide qualitative information about morphological conditions and sources of sediment. Exposed storm sewer outfalls, utilities, and sanitary sewer manholes were evaluated to estimate potential streambed and streambank erosion rates. Bed and bank erosion pins installed in 2006 by the Huron River Watershed Council and others were measured to obtain quantitative erosion rates.

The sediment transport model has been developed by modifying and updating a hydraulic model developed by Spicer Group for the Michigan Department of Environmental Quality and the Flood Map Modernization Study funded by the Federal Emergency Management Agency (FEMA) in 2004. Survey data and bed particle size data collected in 2012 have been used to update the model.

In order to better understand morphological conditions and sediment transport characteristics throughout the entire stream channel network and to develop appropriate model inputs, the network was broken into logical study reaches (**Figure 4**) that were assessed individually but evaluated in a watershed context. Reaches were logically created using infrastructure as upstream/downstream boundaries and guided by preliminary knowledge of morphological conditions from previous studies. The Millers Creek main branch was broken into nine reaches numbered one through nine from Geddes Road to Green Road. Tributaries were also broken into reaches, but using letters A through H. Although the sediment transport model simulates the stream channel network as a continuous network of connected channels, model output was analyzed using these same reaches. This consistency allows model results to be directly compared to data and observations recorded during the field assessment. The field assessment produced estimated streambank erosion rates and annual sediment loads (tons/year) from streambank erosion for each study reach. Annual streambank erosion sediment load estimates are used as input to the sediment transport model. In addition, bed particle size distributions have been generated for each reach and input to the model.

Reaches A and B were not included in the Study because they flow through the Geddes Lakes. The Geddes Lakes trap sediment transported from Reach A/B. Therefore, Reach B has a very low sediment load downstream of the lakes. Furthermore, the minimal sediment load transported from Reach B discharges to Reach 1 (i.e. downstream of Reach 2) where sediment accumulation has not been a problem.



Figure 4. Millers Creek channel network, Washtenaw County, Michigan. Numbers and letters designate study reaches. Reaches 1 and 2 are located in the Ruthven Nature Area.

3.0 FIELD ASSESSMENT

3.1 BANK EROSION

Bank Erosion Hazard Index scores are summarized in Table 1A of Appendix A. Streambank erosion is prevalent in reaches 4 through 9 and tributary Reaches D, F, and G. Bank Erosion Hazard Index (BEHI) scores presented in Table 1A ranged from 24.8 to 49.6 (possible score of 50). These scores fall within the moderate to extreme hazard ratings. The highest BEHI scores were recorded in Reaches 6, 7, and D (**Figure 5**). Streambank erosion is also continuous in some reaches. High BEHI scores are primarily due to incised morphology; the total bank heights are typically 1.5 to more than two times greater than the bankfull bank height (bank height based on bankfull stage). This degree of incision prevents flows from leaving the channel and entering the adjacent floodplain; the historic floodplain along some reaches is never flooded. This is an unstable morphological condition. Given the high BEHI scores and prevalence of streambank erosion observed, there is potential for high bank erosion rates and sediment loading rates (tons of sediment added to the stream network per year).

Reach H has a small drainage area and appears to be stable. Bank heights are low and eroding streambanks were not observed. Sediment loading from bed and bank loading is considered natural for that reach. Reach E also has a small drainage area and is stable. Reach E consists of a poorly defined swale over most of its length and does not appear to transport sediment based on the lack of sediment transport characteristics observed. Due to their low or natural sediment loading rates, Reaches H and E were not modeled with the sediment transport model or included in other sediment loading analyses for this Study.

Reach B drains through the artificial lakes in the Geddes Lakes housing complex. Sediment transported within Reach B is trapped in the lakes, so it is not transported to Reach A and into Millers Creek (Reach 1). Reach A is characterized as a wetland drainage with a small, low energy stream channel. The bed and banks consist of primarily organic soils. Erosion and sediment transport are low. Furthermore, Reach A discharges to Millers Creek downstream, of Reach 2 where sedimentation is problematic. Therefore, Reaches A and B are also not included in the sediment transport model or other sediment transport analyses.



Figure 5. Severe bank erosion in Reach 6.

Six bank erosion pins (**Figure 6**) installed in 2006 by the Huron River Watershed Council (HRWC) and its project partners were measured during the field assessment – one in Reach 7, one in Reach G, and five in Reach F. Calculated annual erosion rates ranged from 0.04 ft/yr to 0.33 ft/yr, with a mean of 0.14 ft/yr. Two of the eroding banks in Reach F with erosion pins had moved more than two feet since installed in 2006. Although the bank erosion rate is not extreme except in isolated locations within any given reach, streambank erosion is extensive within several reaches, particularly Reaches 5, 6, 7, 8, D, and F. In these reaches more than 50% of the streambank length is experiencing accelerated erosion.



Figure 6. Completely exposed 24-inch erosion pin, Reach F

The measured bank erosion rates were used to develop reach-average rates for each reach, including reaches without bank erosion pins, based on BEHI scores and using linear scaling. Researchers have shown the quantifiable relationship between BEHI scores and measured streambank erosion rates. The annual erosion rate estimates were in turn used to develop annual sediment loading estimates for each reach. Sediment load was calculated as the product of annual bank erosion rate, reach-average bank height, and the estimated length of eroding streambank in each reach. Estimated sediment loads range from one ton per year in Reach 3 to 159 tons per year in Reach D (Table 1).

Table 1. Estimated annual bank erosion and sediment loading rates for Millers Creek, Washtenaw County, Michigan.

Reach	Length (feet)	Percent Reach With Erosion	Eroding Bank Length (feet)	Mean Bank Height (feet)	Reach Average BEHI Score	Estimated Erosion Rate (ft/yr)	Volume Soil Eroded (cft)	Volume Soil Eroded (cyd)	Mass Soil Eroded (tons/yr)
3	1,063	50%	532	1.0	NA	0.04	21	1	1
4	642	30%	193	4.2	34.5	0.11	89	3	4
5	1,311	80%	1,049	4.0	NA	0.09	378	14	17
6	1,810	70%	1,267	6.3	35.6	0.14	1117	41	50
7	1,022	60%	613	6.2	38.7	0.25	950	35	42
8	2,430	90%	2,187	3.8	34.5	0.09	738	27	33
9	1,868	50%	934	3.4	30.7	0.04	125	5	6
D	1,904	90%	1,713	6.3	39.3	0.33	3581	133	159
F	1,955	100%	1,955	3.8	36.1	0.16	1176	44	52
G	659	40%	264	2.7	31.4	0.06	43	2	2

3.2 BED EROSION

Table 2A in Appendix A summarizes the bed erosion estimates. Five bed erosion pins (**Figure 7**) installed in 2006 by HRWC and its project partners were measured during the field assessment – one in Reach 7 and four in Reach F. Calculated annual erosion rates ranged from 0.02 ft/yr to 0.12 ft/yr, with a mean of 0.07 ft/yr.

Bed erosion rates were also estimated from four storm sewer outfalls and one road culvert that had been undermined by bed erosion. Three of the storm sewer outfalls are located in Reach 6 and one is located in Reach 4 (**Figure 8**). The road culvert is located in Reach D. Two of the Reach 6 storm sewer outfalls were repaired by the City in 2007-2009 as part of a streambank stabilization project between Hubbard Road and Glazier Way. However, ECT collected data on those two structures during design in 2007. It is assumed that the storm sewer outfalls were all installed by 1970 following completion of Huron Parkway construction in the mid to late ‘60s. The road culvert in Reach D was constructed in approximately 1965 based on review of historical aerial photographs. Using measured distances from the structures to the bed in 2007 and 2012 bed erosion rates were calculated. Rates ranged from 0.03 ft/yr to 0.14 ft/yr with a mean of 0.08 ft/yr. These rates are very similar to the bed erosion pin rates over a more recent period.

When the bed erosion pin and structure rates are combined, the rates range from 0.02 ft/yr to 0.14 ft/yr with a mean of 0.07 ft/yr. Although the structure bed erosion rates are estimated for a much longer period of time, they seem to agree well with the shorter six-year period from 2006 to 2012 for the bed erosion pins, indicating bed erosion rates in Millers Creek have been fairly constant over time.

The estimated bed erosion rates were used to estimate the amount of bed lowering that could be expected over the period of the sediment transport model (2004 to 2012). Those estimates ranged from a minimum of 0.2 feet to a maximum of 1.1 feet with a mean of 0.6 feet. Model results should be consistent with these values. Table 3 summarizes the bed erosion rate estimates and bed lowering estimates which are used to validate the sediment transport model.

Exposed clay was observed in the bed at all five measured bed erosion pins, indicating that bed erosion is primarily occurring in clay. Clay is not the material that is being deposited in the Ruthven Nature Area. Given the low bed erosion rates (approximately half of the bank erosion rates), exposed clay bed, and sand/gravel deposition at Ruthven Nature Area, bed erosion is not a major source of sediment load contributing to the sediment accumulation in Reach 2.



Figure 7. Bed erosion pin installed in Reach 7 in 2006



Figure 8. Storm sewer outfall in Reach 4 showing degree of bed lowering

3.3 SEDIMENT PARTICLE SIZE

Sediment particle size gradations were determined for each reach using either a pebble count method or sieve analysis. Sediment gradations were determined at a single point within a reach and extrapolated to the entire reach. Therefore, the sample location was chosen to be as representative as possible of prevailing conditions observed within the reach. The gradations were used as input for the sediment transport model. Sediment particle size gradation data are summarized in Table 3A of Appendix A.

Particle size gradations are necessary for sediment transport modeling, but the data also serve as a diagnostic tool providing qualitative information about morphological conditions and sediment transport characteristics. A sediment sample was collected from the baffle box and submitted to a lab for sieve analysis. The baffle box is located at the downstream end of a 60-inch culvert enclosure of Millers Creek under Huron Parkway. It stores a limited supply of sediment that is

transported from upstream reaches (7, 8, 9, D, and F). Therefore, the stored sediments are indicative of upstream sediment supply and transport characteristics. It is reasonable to conclude that the sediment is representative of the upstream sediment load from bank erosion. Because the material was transported from upstream, it is also reasonable to conclude that the stream has the capacity to transport the sediment sizes observed in the baffle box. The baffle box sieve data are compared to streambed pebble count data for Reaches 2, 3, and 4 in **Figure 9**. This comparison shows that the material transported from upstream of the baffle box is nearly identical to material on the bed of Reaches 3 and 4. Furthermore, as a source-assessment approach these data verify that the upper watershed can be contributing to sediment aggradation in Reaches 2 and 3 based on material character alone. That is, reaches upstream of the baffle box are producing and transporting sediments similar to the sand and gravel observed on the Ruthven Nature Area streambed.

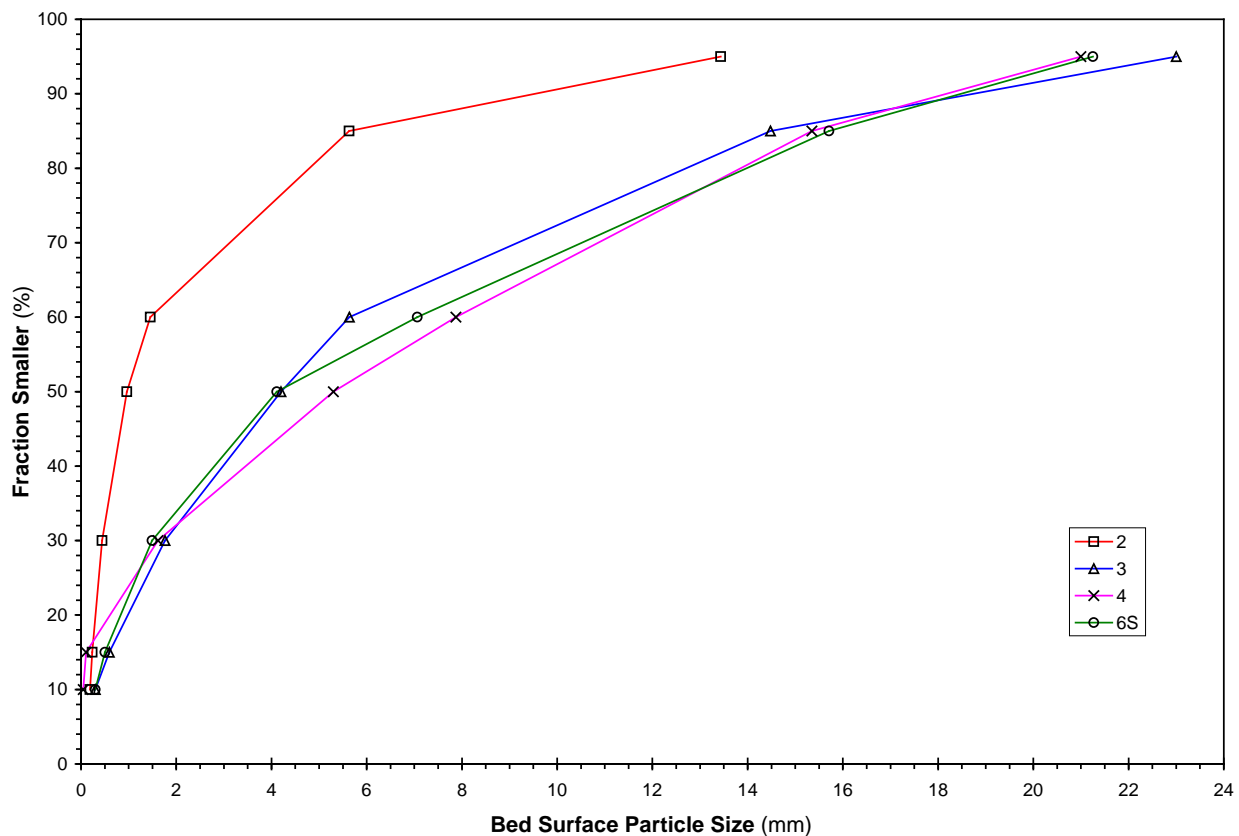


Figure 9. Bed sediment particle size gradation in Reaches 2, 3, and 4 compared to the gradation of sediment stored in the Reach 6 concrete baffle box (6S), Millers Creek, Washtenaw County, Michigan

4.0 HYDRAULIC AND SEDIMENT TRANSPORT MODELING

Spicer Group conducted hydraulic and sediment transport modeling on behalf of ECT as a sub-contractor. Spicer developed a hydraulic model for Millers Creek on behalf of the Federal Emergency Management Agency (FEMA) and Michigan Department of Environmental Quality (MDEQ) in 2004 for FEMA's flood Map Modernization study. The hydraulic model was developed in HEC-RAS, which has the capability to also model sediment transport. This model was selected as the model for the Millers Creek Sediment Study. It was modified and developed as described in the following sections.

4.1 SURVEYING

Given the HEC-RAS model FEMA Map Modernization HEC-RAS model for Millers Creek was developed in 2004, additional cross-section surveying was conducted to obtain recent cross-section profiles. In 2012, Spicer Group resurveyed a sub-set of the original FEMA cross-sections to document rate of change at those cross-sections between 2004 and 2012. New cross-sections were surveyed to add detail to the model in areas that were identified as being critical for erosion or deposition (e.g. Ruthven Nature Area). New cross-sections were also surveyed to add previously unmodeled tributaries of Millers Creek including Reaches F and G, Reach H, and Reaches C and D (Lake Haven Tributary). All survey data are referenced to the North American Vertical Datum of 1988 (NAVD88). The horizontal datum used for this analysis is the North American Datum of 1983 (NAD83) Michigan State Plane, South Zone, with all units in international feet.

4.2 METHODS

A hydraulic and sediment transport analysis has been completed for Millers Creek to determine long term sediment transport spanning an eight year period from 2004 to 2012. This period was selected because stream conditions were accurately measured in 2004 and 2012.

4.2.1 HYDRAULIC MODEL

The development of the model involved long term hydrologic and hydraulic analysis. Hourly rainfall data were collected from the National Climatic Data Center for the City of Ann Arbor from 2004 to 2012 and run through HEC-HMS to determine long-term runoff flow rates. The modeled

flow rates were compared to stream gauge data on Millers Creek (located at Huron High School, along Glazier Way, and near Plymouth Road) for up to 15 storm events. The calibrated runoff flow rates were used as input hydrographs in the 2004 FEMA hydraulic model developed using HEC-RAS.

Several changes were made to the 2004 FEMA model to prepare the model for sediment transport modeling throughout the entire Millers Creek channel network. The first change was necessary because the City of Ann Arbor stabilized eight streambanks in 2007 between Glazier Way and Hubbard (Study Reach 6). The affected 2004 FEMA cross-sections were modified to represent the modified streambank and channel cross-sections. Because the FEMA model starts in 2004 and the streambank project occurred in 2007, the time period was broken into two periods (2004-2007; 2007-2012) that were modeled separately in HEC-RAS. This time-period break allowed the 2007 cross-section changes in Reach 6 to be made in the middle of the modeling period.

The second modification was necessary to add important tributaries that were not included in the 2004 FEMA model: the Lake Haven Tributary (Study Reaches C and D) and the Plymouth Road Tributary (Reaches F and G). Lastly, the sediment transport functions within HEC-RAS do not allow for junctions, so any reaches or branches that were connected using a junction were removed and the main reach adjusted for that change. The tributaries were modeled separately and the hydraulic and sediment transport output was as input for the mainstem Millers Creek hydraulic and sediment transport model in the form of flow hydrographs and sediment rating curves respectively.

The Manning's n values, ineffective flow areas, blocked obstructions, and expansion and contraction coefficients remained the same as the 2004 model (see 2004 FEMA report for details) except where field observations indicated a change in those conditions. Sediment accumulation in Ruthven, for example, required a change in the Manning's n-value to simulate the effect sediment accumulation has on channel roughness as discussed below.

4.2.2 SEDIMENT TRANSPORT MODEL

The following sediment transport parameters were specified in the model for each cross-section:

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- Maximum allowable cut - the depth to which erosion can occur. For the model, the maximum cut was determined by field observations and in consultation with ECT. Potential streambed erosion rates were estimated using field data described under Section 3.3 of this report.
 - Left and right station - the horizontal extents to which erosion or deposition can occur. For the model, the left and right stations were set to the bank stations. This is a conservative model approach that prevents HEC-RAS from unrealistically spreading sediment deposition evenly across the entire floodplain cross-section.
 - Bed gradation - the size distribution of bed material within a particular reach defined as “% finer than.” The sediment size distribution information for each reach was determined by sieve analysis and pebble counts as described under Section 3.3 of this report.

The sediment transport function can use a variety of calculation techniques which are broken down into the transport function, sorting method, and fall velocity method. For a detailed discussion of each methodology, please refer to the HEC-RAS User's Manual or Hydraulic Reference Guide.

The following techniques were used in this model:

- Transport Function - Yang. This function is based on stream power and was determined to be best suited for simulating and evaluating the transport of sediment loads from reach-to-reach. This decision is supported primarily by the sediment sieve data obtained by the City of Ann Arbor within the Ruthven sediment accumulation area of Reach 2. Those data indicate that the particle size distribution is well below the incipient motion size of bed material observed throughout the reaches, meaning Millers Creek has sufficient energy or competency to readily transport the sediment particle size found in the Ruthven sediment accumulation area. The more important question then becomes one of stream power, or the ability of Millers Creek to transport a mass of sediment over time. Stream power is the best way to evaluate and model a stream's capacity or ability to transport sediment mass with time. Stream power is more strongly tied to discharge, whereas shear stress (energy exerted on the bed material) is more strongly tied to channel slope.
- Sorting Method - Exner 5, the HEC-RAS default method, was used.
- Fall Velocity Method - Report 12, the HEC-RAS default method, was used.

The sediment transport model is limited in that it only predicts erosion or deposition within the stream channel and does not account for bank erosion due to sloughing or lateral movement. Bank erosion sediment loads were determined using field observations and measurements for each reach and input into the model as a steady mass influx of sediment. The model requires a mass load for a period of time with a specific size gradation. Annual mass loading rates for each reach were used as input; see Section 3.1 of this report for a description of estimated streambank sediment loading rate.

Soil samples were not collected from streambanks because the sheer number of samples required to be statistically significant would add substantial cost to the study and soils in general have a high degree of variability. Instead the United States Department of Agriculture soil survey and field observations were used to characterize soils along the Millers Creek corridor, and estimate a generalized particle size distribution. The predominant soil type within the corridor is a loam soil, primarily the Miami, Sloan, Fox, and Matherton soil series. The Miami and Sloan soil series are primarily a silt/clay loam, but the Miami series trends toward sandy in some locations and can often include gravel, particularly at deeper strata (e.g. in the bottom of streambanks along incised stream channel). The Matherton soil series is a sandy-loam. Field observations indicated that streambanks contained a high percentage of silts and clays, but sand and gravel lenses were common, especially at the base of eroding streambanks where Millers Creek has downcut. Therefore, the estimated particle size distribution contains a high degree of silt and clay (one-half combined). Approximately one-third of the distribution is sand-size particles, while 15% is gravel size particles. The following table presents the streambank particle size gradation used in the model to represent the sediment loads from streambank erosion. The bank load size gradation described below closely resembles the typical loamy soils that predominate along the Millers Creek corridor.

Sediment Size % of Total

0 – 0.062 mm	50%
0.062 – 2 mm	35%
2 – 64 mm	10%
64 – 256 mm	5%

The initial sediment transport model was run for a time span from 2004 to 2007. The 2007 time break was required to allow for adjustments to the channel cross-sections in Reach 6 where the City of Ann Arbor stabilized eight streambanks. The as-built cross-sections for the eight streambanks were used as the initial conditions for the 2007 to 2012 model run. The 2004 to 2007 model run output was compared to survey data within the reach between Glazier Way and Hubbard Road. The attenuated flows and channel elevations were calibrated to the stream gages and as-built survey data in 2007. The calibrated results were used as the initial conditions for the 2007-2012 model. The 2012 results were validated against the survey cross-sections in Ruthven Nature Preserve, Huron High School, the Lake Haven Drive branch, and several other locations along Millers Creek.

The sediment transport model was calibrated to known flow rates and channel elevations by a combination of the following:

- Adjusting the Manning's n values in the floodplain area and channel to reflect sediment deposition and vegetation.
- Adjusting the amount of sediment deposition in culverts to match field observations.

4.3 RESULTS

4.3.1 EXISTING CONDITIONS

Figure 10 shows the bed profile through Reaches 3 and 2 based on the average bed elevation of the 2007 and 2012 cross-sectional model output. **Figures 11 through 15** show the cross-sectional changes in bed elevation predicted by the sediment transport model through Reaches 3 and 2. The sediment transport model predicted 234 tons of sediment deposition through Reaches 3 and 2 between 2007 and 2012 or 47 tons per year, resulting in an average increase in the bed elevation of 0.84 feet. The maximum predicted bed elevation increase was 2.5 feet, which occurred downstream of the Huron Parkway culvert.

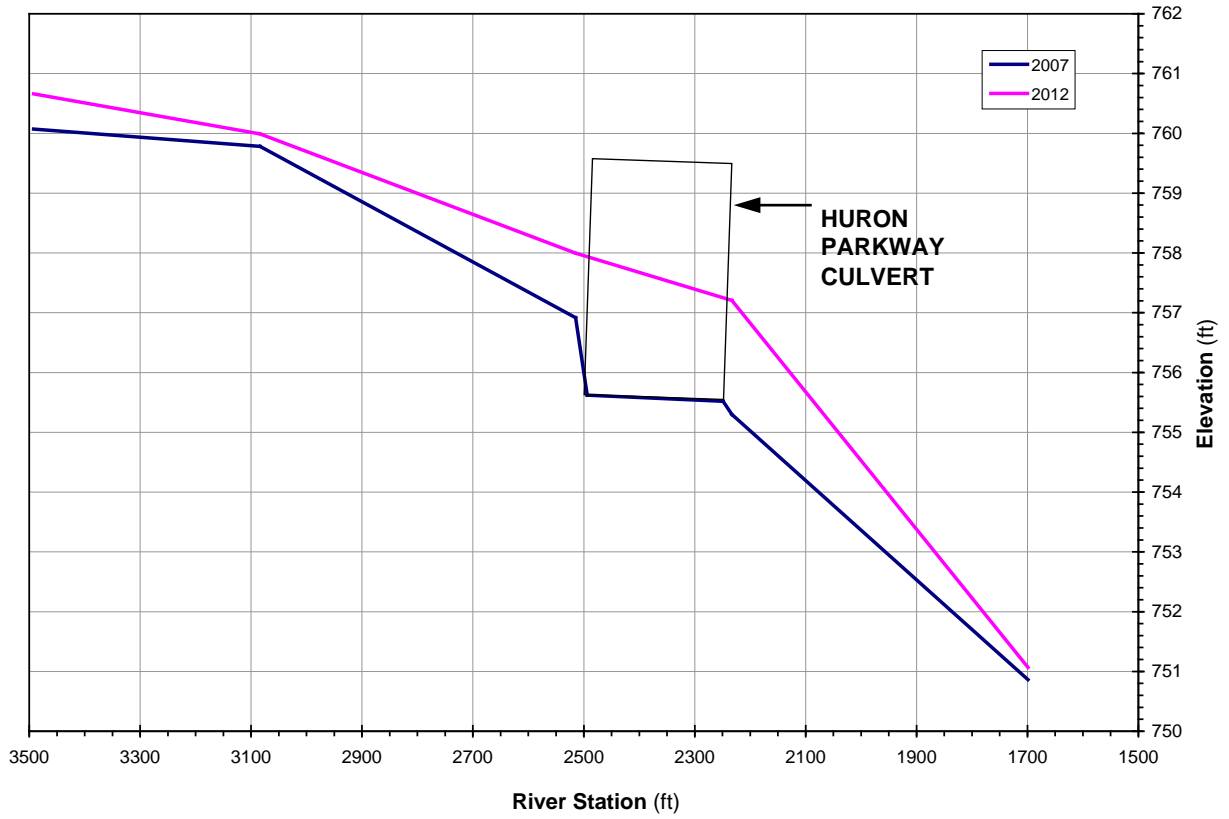


Figure 10. Reach 3 and 2 model predicted 2007 and 2012 bed profiles showing increase in bed elevation resulting from sediment deposition, Millers Creek, Washtenaw County, Michigan

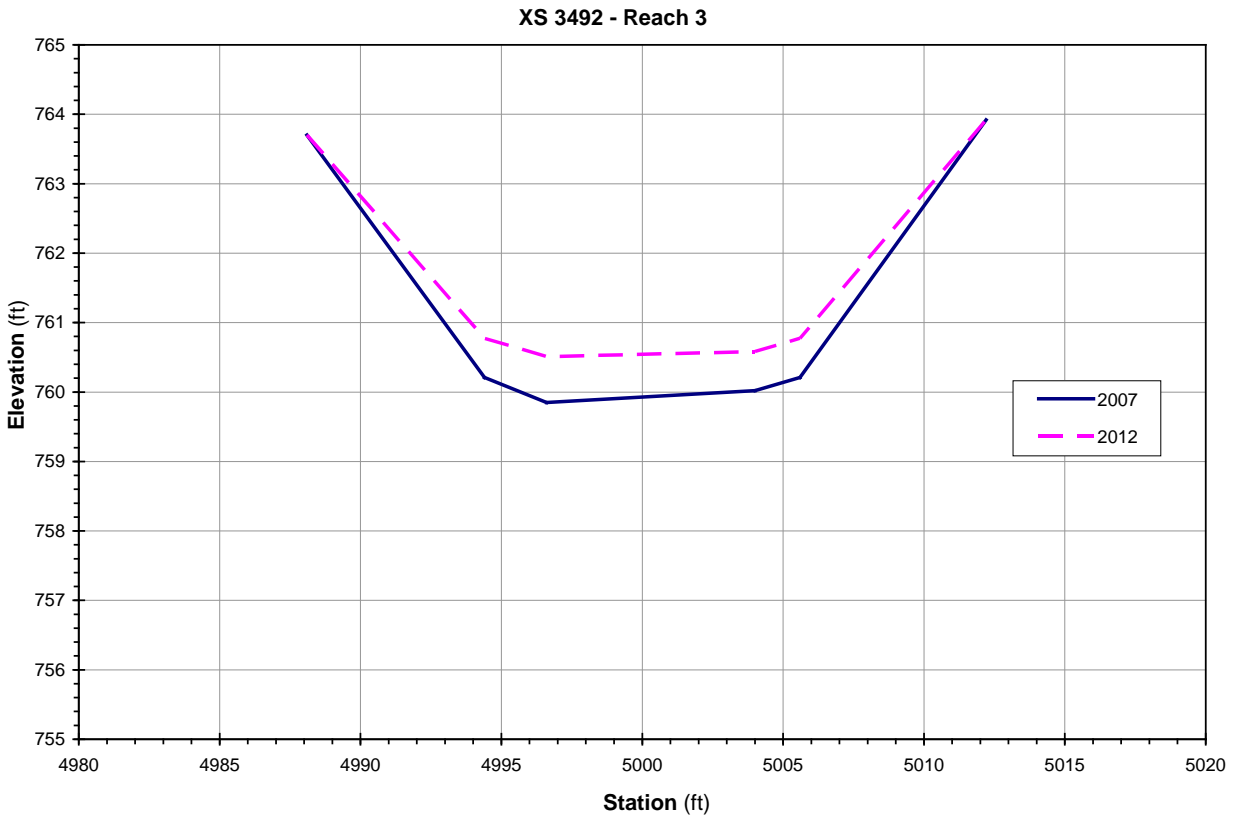


Figure 11. Model cross-section 3492, Reach 3, bed elevation change between 2007 and 2012 due to sediment deposition, Millers Creek, Washtenaw County, Michigan

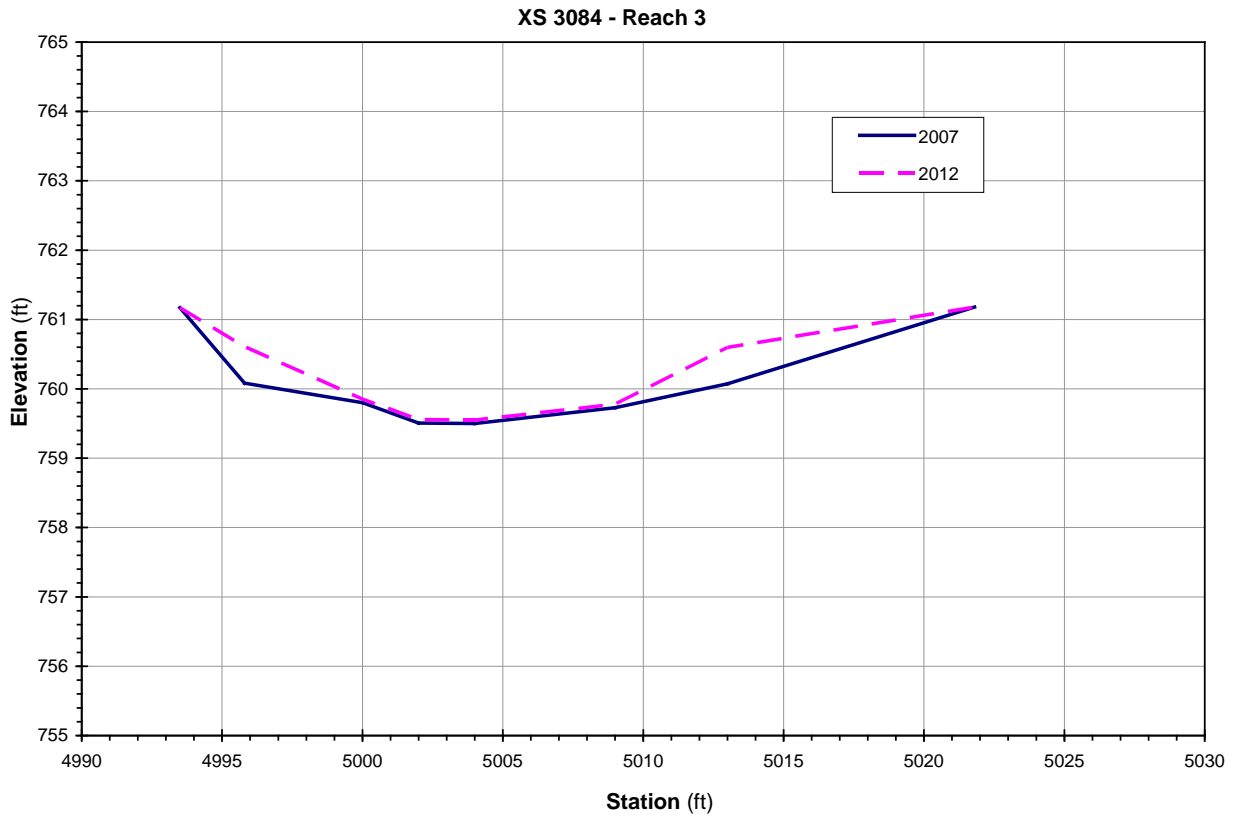


Figure 12. Model cross-section 3084, Reach 3, bed elevation change between 2007 and 2012 due to sediment deposition, Millers Creek, Washtenaw County, Michigan

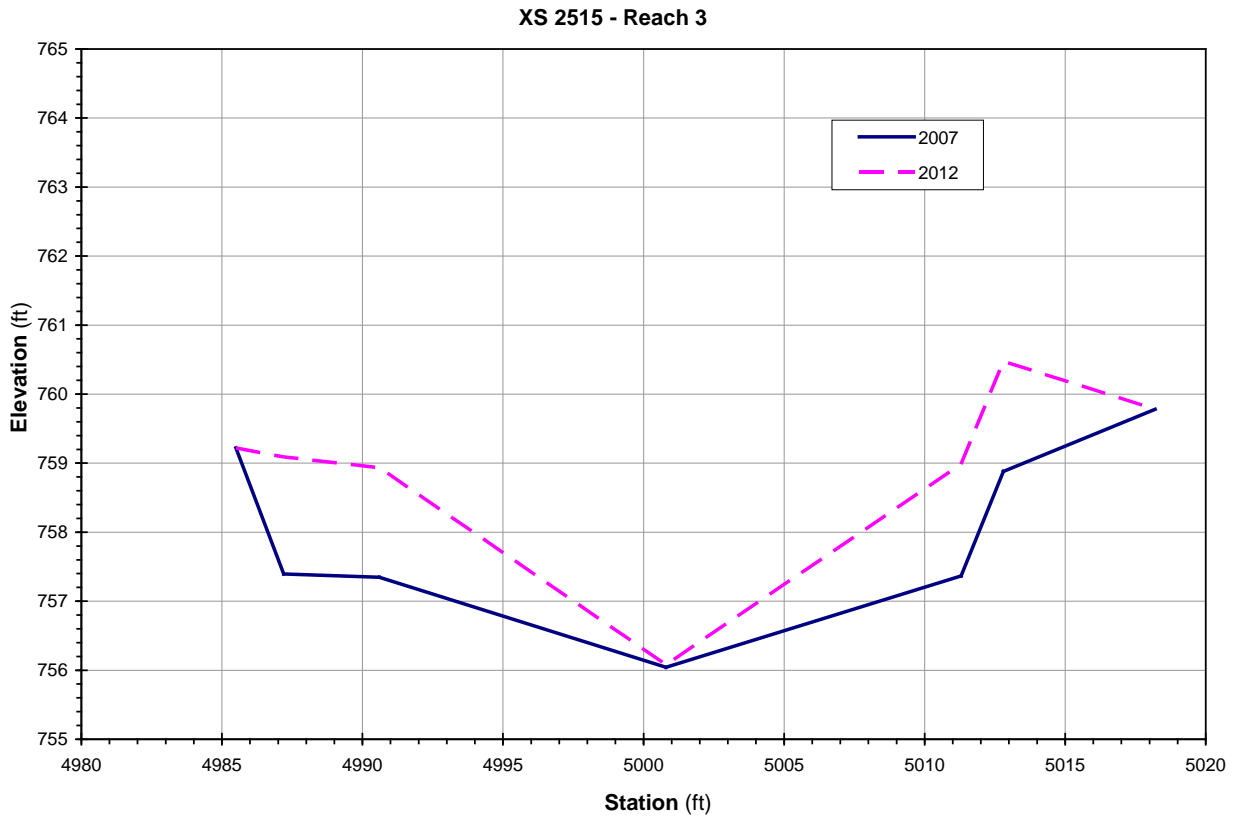


Figure 13. Model cross-section 2515, Reach 3, bed elevation change between 2007 and 2012 due to sediment deposition, Millers Creek, Washtenaw County, Michigan

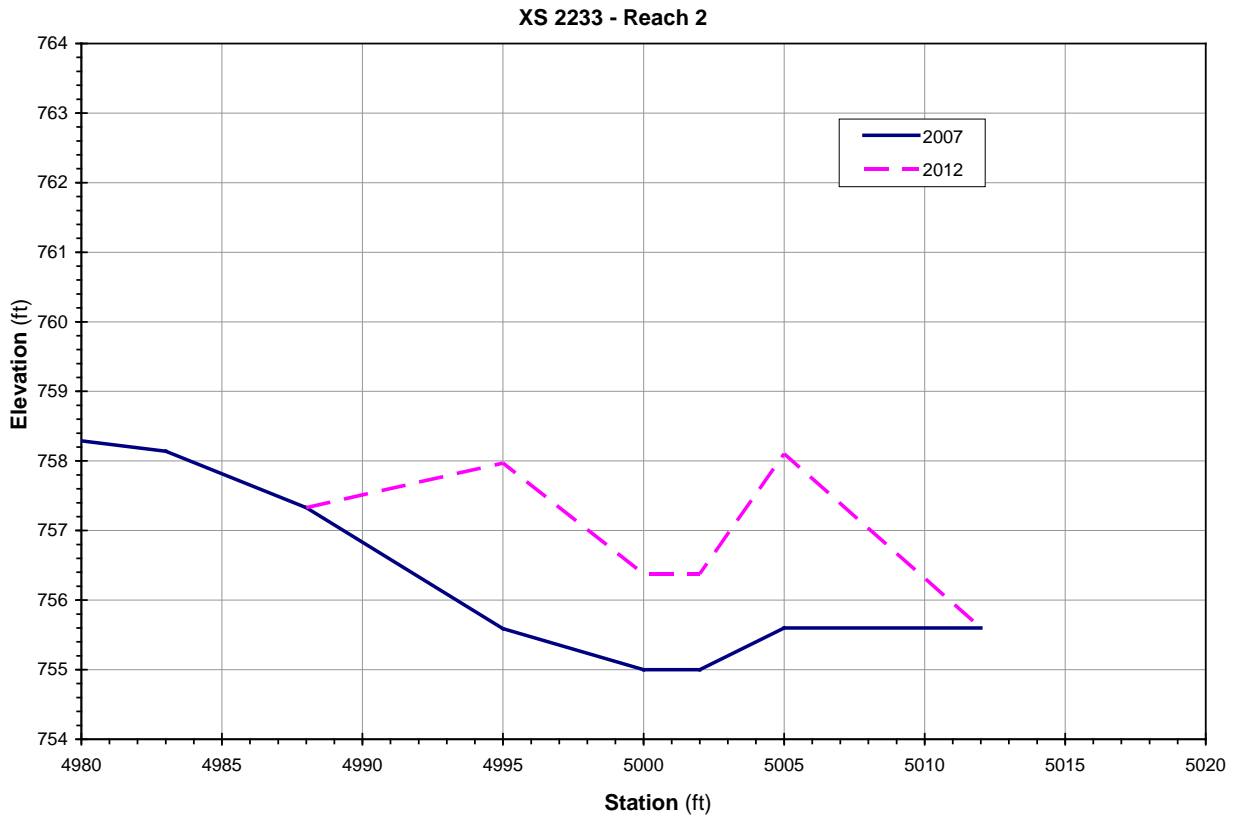


Figure 7. Model cross-section 2233, Reach 2, bed elevation change between 2007 and 2012 due to sediment deposition, Millers Creek, Washtenaw County, Michigan

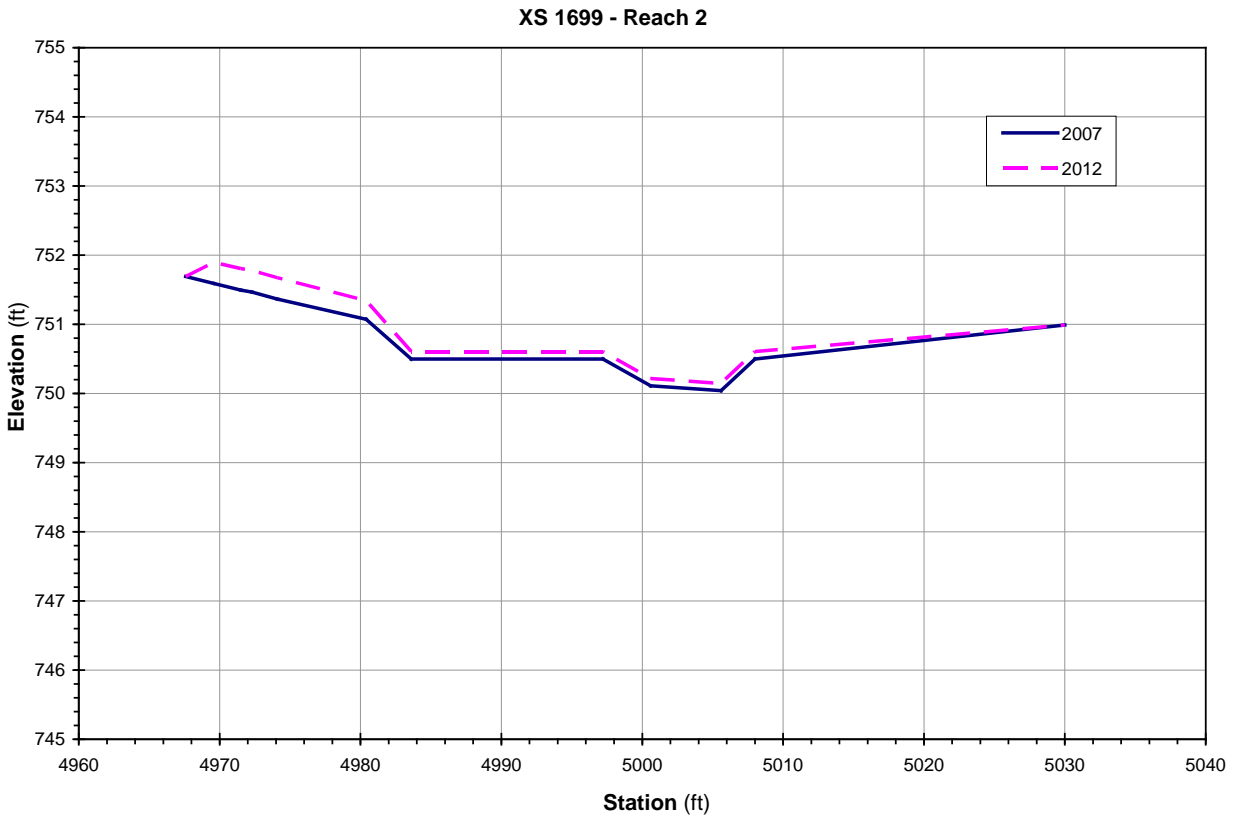


Figure 8. Model cross-section 1699, Reach 2, bed elevation change between 2007 and 2012 due to sediment deposition, Millers Creek, Washtenaw County, Michigan

4.3.2 MODEL SIMULATIONS

The sediment transport model was used to simulate changes to the Huron parkway culverts and reduction of sediment loads from streambank erosion. The purpose of model simulations was to determine if the Huron Parkway culvert (and potentially other infrastructure) could be causing the observed sediment deposition in Reach 3 and 2. To simulate the effects of the Huron Parkway culverts on sediment transport, the culverts were removed from the model and Millers Creek was modeled as an open channel between model cross-sections located upstream and downstream of the culverts. In addition, the size of the culverts were reduced. To simulate implementation of sediment load reduction projects the bank load estimates were reduced to background loads. The sediment transport was developed for the existing conditions scenario using annual bank loads estimated from estimated annual bank erosion rates. The estimated bank erosion rates reflect the existing unstable morphology of Millers Creek. Those rates were reduced to the minimum measured and estimated bank erosion rate to simulate natural or background erosion rates.

Removing the Huron Parkway culverts reduced the mass of sediment deposited in Reaches 2 and 3 between 2007 and 2012 from 47 to 45 tons per year (234 to 223 tons). This is insignificant given the decrease in total mass deposited was only 2.2 tons per year or 5% of the average annual load deposited. Between 2012 and 2013 alone an additional 45 tons of sediment would have been deposited and the same condition would exist. While the culverts do contribute to the sediment deposition, the contribution is minor compared to the total mass of sediment in transport and the prevailing channel conditions (e.g. slope and channel roughness).

When the size of the culverts was reduced the mass of sediment deposited in Reach 2 decreased, but the mass increased considerably in Reach 3 and 4. This is expected given a reduction in culvert cross-sectional area would decrease discharge and increase the upstream water surface profile. Basically, decreasing the size of the culverts creates sediment traps upstream of the culverts. This simulation indicates that sediment trapping upstream of Reach 2 could alleviate the sediment deposition observed in Reach 2. However, creating sediment traps by reducing culvert size/capacity would not be desirable because it could cause flooding during high flow events. Reducing the bank loads to background or natural loading rates decreased the mass of sediment deposited in Reaches 2 and 3 from 47 to 2 tons/year. Simulating a reduction in bank loading rates

indicates that the sediment load reduction projects could alleviate the sediment deposition observed in the Ruthven Nature Area.

5.0 RECOMMENDATIONS

The sediment loading to Millers Creek from streambank erosion is elevated above natural background levels due to morphological instability throughout the drainage network upstream of study Reach 3. Sediment transport within all of the study reaches upstream of Reach 3 (except Reach C) is efficient, resulting in net export of sediment to the next downstream reach. Only Reach C is storing appreciable quantities of sediment transported from Reach D via accumulation on the streambed and floodplain. Cumulatively, the mass of sediment that is transported into Reach 2 in the Ruthven Nature Area cannot be transported through Reach 2 and consequently results in streambed aggradation (a progressive increase in bed elevation). Unless the sediment load from streambank erosion is substantially reduced, aggradation will continue in Reach 2. Therefore, the City is considering recommendations to 1) manage the sediment through routine channel and infrastructure maintenance and 2) reduce sediment loading by stabilizing streambanks or entire stream reaches. Recommended activities and projects are summarized in Table 4A of Appendix A and detailed in the following sections.

In-stream sediment management and sediment load reduction are fundamentally different activities. The term “in-stream” means that the sediment is located on the bed within the Millers Creek channel network and in the storm sewer system that discharges to Millers Creek. The sediment is loaded to the channel network from watershed runoff, streambank erosion, and stream bed erosion processes. Combined these sources represent the entire sediment load of the system. This study focused on sources of sediment within the water course itself, and determined that streambank erosion processes were the primary source of sediment to Millers Creek throughout the majority of the channel network. Flowing water erodes soil particles from streambanks, entrains those soil particles into the water column, deposited on the bed, and transported downstream. Once streambank soil particles are actively being transported they can potentially reach the Ruthven Nature Area and contribute to the documented sedimentation and flooding problems. Sediment management activities are designed and planned to remove the sediment from Millers Creek at strategic locations before it reaches Ruthven Nature Area. Such activities can include maintenance activities (removing sediment from existing infrastructure) and sediment trap-and-removal (constructing new facilities to trap and remove sediment). A simple, common

example of a maintenance activity is the periodic removal of sediment from storm sewer catch basins that contain sediment sumps. Many of the catch basins in the storm sewer network discharging to Millers Creek do not contain sediment sumps, but the use of catch basins with sediment sumps is common practice today. Another more pertinent example is the City's periodic removal of one to two tons of sediment from a baffle box located in Millers Creek at the head of Reach 6. It is not known how frequently sediment has been removed, but the baffle box most likely reaches its maximum storage capacity quickly, perhaps during a single storm event. A simple common example of a sediment trap-and removal facility is construction of an excavated basin in the natural streambed that can be periodically excavated when full. There are currently no such trap-and-removal facilities in the Millers Creek channel network.

In contrast, sediment load reduction projects are designed to prevent soil particles from being eroded from streambanks and entering Millers Creek. In other words, they reduce the amount of sediment entering Millers Creek (hence the term "load reduction"). In theory, the current sediment load could be reduced to background or natural loads in Millers Creek. In practice, that goal would be unattainable due to the highly altered state of the Millers Creek watershed and channel network. Nonetheless, it is reasonable to project that sediment loads could be reduced enough to prevent the sedimentation and flooding problems documented in the Ruthven Nature Area. Sediment load reduction projects can include streambank stabilization through armoring or physical alteration of the bank and/or channel. Armoring involves the use of vegetation, erosion control fabrics, revetment (e.g. riprap), and/or soil retaining structures to increase the resistance of streambank soils to erosion. Physical alteration may include practices such as sloping streambank soils, widening the channel, increasing flood conveyance capacity, installing flow deflectors, and decreasing the slope of the channel. Physical alterations to the channel and bank are designed to increase the structural integrity of the streambank or reduce the energy contained within the flow immediately adjacent to the streambank. All of these practices were used by the City in 2007 to stabilize eight eroding streambanks in Reach 6 (Glazier to Hubbard Streambank Stabilization Project).

Implementing sediment load reduction projects may not be feasible in some reaches due to funding and property access constraints. At the very least, sediment reduction project implementation may

take several years to achieve based on available funding. During the interim, shorter-term sediment management activities may be required to manage in-stream sediment and prevent Reach 2 aggradation and additional Geddes Road flooding events. As long as the loads remain excessive, the excess load will need to be removed from the system annually or periodically. Sediment management activities can be used to manage the sediment load indefinitely (if desirable) or until substantial bank load reductions can be achieved.

5.1 RECOMMENDED MAINTENANCE ACTIVITIES

Table 5.1-1 presents a list of recommended maintenance activities that are predicated on the need to manage sediment in the Millers Creek channel network at one or more locations. The recommended activities have the potential to reduce the mass of sediment deposited in Reach 2 annually by removing sediment from the system rather than to reduce the amount of sediment entering the system. Removing sediment from the system will limit the impact that sediment would otherwise have on the channel of Millers Creek [particularly in Reaches 2 (Ruthven Nature Area) and 3 (Huron High School)] and infrastructure (i.e. culverts). Each of the recommended activities in Table 5.1-1 are described in the following report sections. A discussion of environmental impacts and permitting requirements is included in Section 5.2.6.

Table 5.1-1. Channel and infrastructure maintenance recommendations for achieving in-stream sediment management on Millers Creek.

Description	Study Reach	Preliminary Capital Cost	Maintenance Schedule	Preliminary Annual Maintenance Cost	Ruthven Sediment Reduction Potential (tons/year)	\$/Ton/Year
Reach 6 Baffle Box	6	\$0	Quarterly	\$3,000	<1	\$3,000
Huron Parkway culvert cleanout	2/3	\$0	Annually	\$5,000	<1	\$5,000

5.1.1 HURON PARKWAY CULVERT CLEAN-OUT

The sediment transport model showed an improvement in sediment transport efficiency in Reach 2 with simulated removal of the Huron Parkway culvert between Reaches 3 and 2 (**Figure 10**). The project team simulated the effects of the two Huron Parkway culverts located between Reaches 3 and 4 and Reaches 2 and 3 by removing the culverts from the hydraulic and sediment transport models. Removing the culverts resulted in a 5% reduction (2 tons/year) in the amount of sediment deposited in Reach 2 over the modeled period. While keeping the culverts free of sediment will not create the same sediment transport efficiency as removing them, sediment transport through the culverts will be more efficient if they do not contain sediment. Given this is a low-cost maintenance activity the potential improvement in sediment transport efficiency is feasible. The small gain in sediment transport efficiency predicted by the hydraulic and sediment transport models would not warrant the cost of replacing the culverts with bridges or larger culverts. Annual maintenance inspections would be required to determine the need for sediment removal. Removing sediment from the Huron Parkway culverts would not require a permit providing the work is done within the confines of the culvert and does not require alteration or diversion of the watercourse upstream or downstream of the culvert.

5.1.2 REACH 6 BAFFLE BOX SEDIMENT REMOVAL

The City removes sediment from a concrete baffle box located at the upstream end of Reach 6 (**Figure 11**). The baffle box stores some sediment in the sand to medium gravel size range (coarse-grained bed load material), but has limited storage capacity, with an average sediment depth of approximately one foot and mass of approximately two tons. After sediment removal, the structure fills to its maximum capacity in a short period of time during high flow events. Due to its low storage capacity, removing sediment from the baffle box would not substantially reduce annual sediment deposition in the Ruthven Nature Area (Reach 2). Nonetheless, removing sediment from the baffle box does contribute to overall sediment management goals and may be necessary to maintain proper hydraulic function. This study did not attempt to identify the intended purpose of the structure or analyze its hydraulic function. Given the low storage capacity, the structure would require regular inspection to determine when sediment needs to be removed and sediment removal may be required multiple times annually to maintain sediment storage capacity; quarterly sediment

removal is assumed. Inspections are recommended after the spring high flow period and after substantial precipitation/runoff events.



Figure 10. Location of the Huron Parkway Culvert (top) and photo (bottom) of the upstream end of the culvert showing sediment accumulation immediately upstream of the culvert and extending into the culvert.



Figure 11. Location of the Reach 6 baffle box (top) and photo (bottom) of the baffle box as viewed from above

5.2 RECOMMENDED SEDIMENT REMOVAL ACTIVITIES

Table 5.2-1 presents a list of recommended sediment removal activities that are predicated on the need to manage sediment in the Millers Creek channel network at one or more locations. The goal of sediment trapping and removal activities would be to capture and remove sediment loads from channel erosion. That is, the recommended activities have the potential to reduce the mass of sediment deposited in Reach 2 annually by removing sediment from the system rather than to reduce the amount of sediment entering the system. Removing sediment from the system will limit the impact that sediment would otherwise have on the channel of Millers Creek [particularly in Reaches 2 (Ruthven Nature Area) and 3 (Huron High School)] and infrastructure (i.e. culverts). Each of the recommended activities in Table 5.2-1 are described in the following report sections. A discussion of environmental impacts and permitting requirements is included in Section 5.2.6.

Table 5.2-1. Recommended sediment removal activities including new trap-and-removal facilities.

Description	Study Reach	Preliminary Capital Cost	Maintenance Schedule	Preliminary Annual Maintenance Cost	Ruthven Sediment Reduction Potential (tons/year)	\$/Ton
Expanded sediment removal in Ruthven Nature Area	2	\$20,000	None	\$0	<1†	\$20,000
Regional trap-and-removal with stormwater detention*	3	\$250,000	Bi-annually	\$10,000	47	\$5,532

† Assumed to be equal to cleanup of the Huron Parkway Culvert.

* See text for alternatives

Based on year-1 costs including capital cost and the first year of maintenance

Sediment trap-and-removal activities were not evaluated with the hydraulic/sediment transport model. Instead the annual mass of sediment that could be trapped and removed was estimated based on their potential size and a trapping efficiency of 70%. Given the mass of sediment that could be removed from the system annually exceeds the mass deposited in Ruthven annually, the estimated Ruthven sediment reduction potential is equal to the estimated annual mass deposited in Ruthven, or 47 tons per year.

5.2.1 RUTHVEN NATURE AREA EXPANDED SEDIMENT REMOVAL

The City removed sediment from the channel of Millers Creek in Reach 2 in late summer of 2012 under a permit from the Michigan Department of Environmental Quality. The sediment removal work extended from the Huron Parkway culvert downstream approximately 325 feet. Sediment removal was planned for this reach because the channel of Millers Creek was still discrete and discernable. Downstream of that point the channel of Millers Creek was braided (i.e. represented by multiple smaller channels) and less discernable. This braided condition existed because of sediment accumulation. Therefore, the sediment removal could be extended downstream approximately 100 feet farther to improve flow conveyance capacity in the Ruthven Nature Area (**Figure 12**). This activity would not decrease the water surface elevation at the Huron Parkway culvert directly or significantly decrease the mass of sediment deposited in Ruthven Nature Area annually, but it could result in improved sediment transport characteristics through Reach 2 by decreasing channel roughness. Channel roughness can cause a backwater condition that increases the upstream water surface elevation. Still, this activity would not result in a dewatering of the Huron Parkway culvert because water surface elevation is controlled by the reach-average slope, which would not be changed by extending the dredging in Ruthven Nature Area in the downstream direction.

5.2.2 HURON HIGH SCHOOL (REACH 3) REGIONAL TRAP-AND-REMOVAL FACILITY

A regional trap-and-removal facility is recommended in Reach 3 (**Figure 13**). The facility should have related access and operational space designed and built into the site to facilitate future maintenance and reduce the future cost of removing sediment from the trap. Sediment trapping and removal can be combined with a regional stormwater management basin similar to those constructed recently at County Farm Park in the City of Ann Arbor (**Figure 14-1**); although the County Farm Park facility is truly an off-line detention basin with a sediment forebay, a similar configuration with a true in-line sediment trap could be constructed in Reach 3. A second example is shown in **Figure 14-2**, which shows a regional detention facility in Northglenn, Colorado that includes a sediment trapping forebay (background).



Figure 12. Location of Reach 2 expanded sediment removal (top) and photo (bottom) of sediment removal completed in 2012.

Reach 3 is recommended for the regional trap-and-removal facility because it has the greatest potential in terms of available land area; would result in minor environmental impacts; has reasonable access to Huron Parkway; already experiences sediment deposition; and is located downstream of documented sediment loading from bank erosion.. Reach 3 wetland detention and sediment trapping was also identified in the Millers Creek Watershed Improvement Plan (Improvement Plan) as Focus Area #12. The Improvement Plan recommended the potential for installing a diversion structure to route high flows through wetland adjacent to Millers Creek in Reach 3 and sediment trapping upstream of the Huron Parkway culvert.

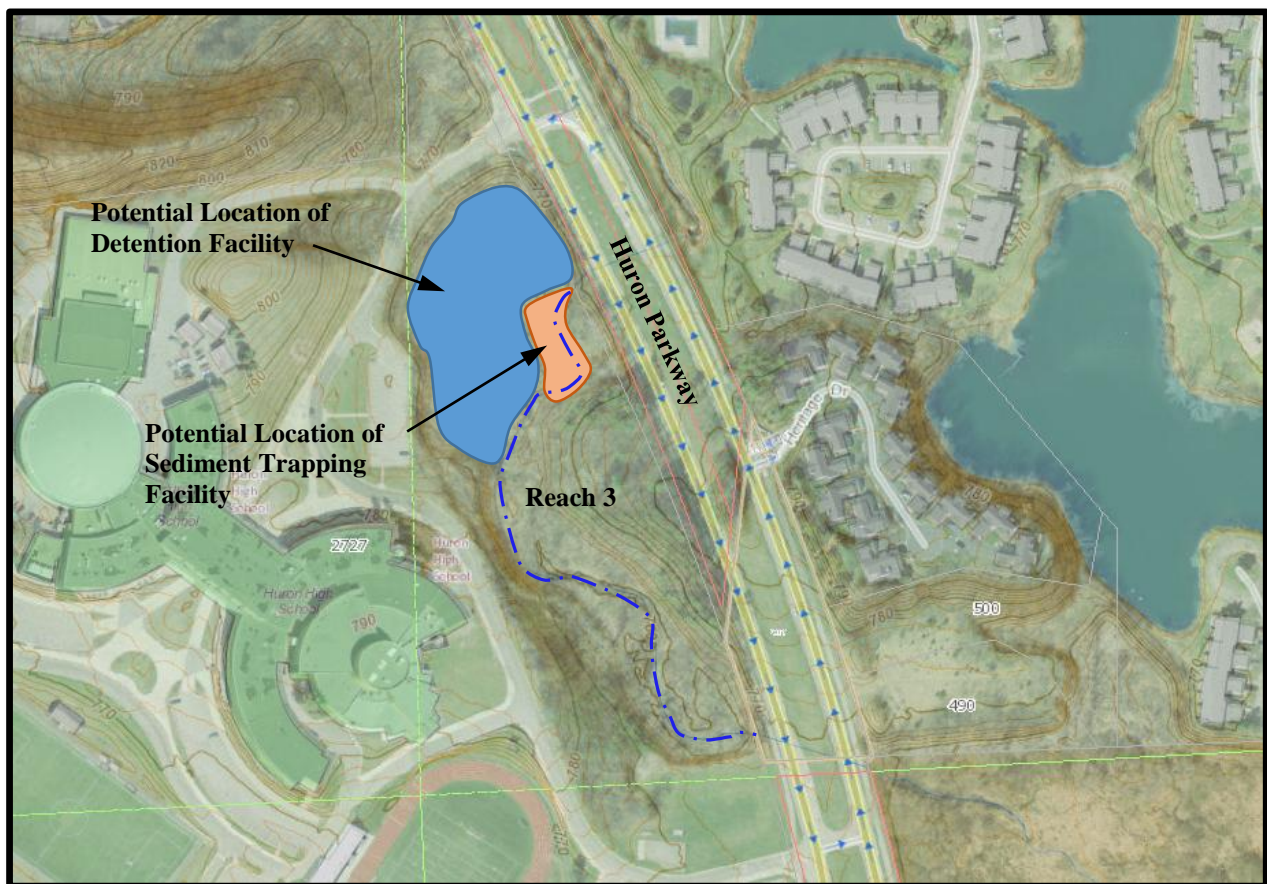


Figure 13. Location of the Reach 3 regional sediment trap and detention basin recommendation, Ann Arbor, MI.



Figure 14-1. County Farm Park sediment forebay (foreground) and stormwater detention basin (background), Ann Arbor, MI.



Figure 14-2. Regional Stormwater Detention Basin with Sediment Trapping Forebay, Northglenn, CO.

Sediment basins reduce the streams ability to transport its sediment load at a specific point, thereby encouraging sediment deposition where it can be readily removed rather than where it causes problems. Appendix A of the interagency Stream Corridor Restoration¹ guidebook defines a sediment basin as, “Barriers, often employed in conjunction with excavated pools, constructed across a drainage way or off-stream and connected to the stream by a flow diversion channel to trap and store waterborne sediment and debris.” In other words sediment basins are constructed in-line (within the stream) or off-line (adjacent to, but connected) and are used to collect (i.e. trap) sediments being transported by a stream. Sediment trapping is accomplished by elevating the water surface profile and reducing flow velocity with a structure (e.g. low-head dam, weir, or earthen berm) or an excavated pool; sometimes structures and excavations are used together to balance excavation and structural costs or to manage water levels.

The guidebook further describes the purpose of sediment basins. Among the applications listed, sediment basins can be used to “Temporarily reduce excessive sediment loads until the upstream watershed can be protected from accelerated erosion.” This is precisely the application recommended. However, sediment basins could, in theory, be used to manage sediment in Millers Creek indefinitely with increasing cumulative cost. The guidebook also highlights a few other important characteristics of sediment basins: 1) They can be integrated with larger stormwater management features such as regional detention basins; 2) they trap larger particle sizes in the sand to gravel range (this is the material being deposited in Ruthven); and 3) they require periodic sediment removal to maintain their capacity and effectiveness.

Land adjacent to Millers Creek in Reach 3 is owned by Ann Arbor Public Schools. Therefore, use of Reach 3 for sediment trapping and/or stormwater management would require a land sale/swap or access agreement with Ann Arbor Public Schools. Because the City does not own the property either side of Millers Creek in Reach 3 (Ann Arbor Public Schools owns the property except for the Huron Parkway right-of-way), the City may have to pursue other alternatives during implementation. Two alternatives are discussed below.

¹ FISRWG. 1998. Stream Corridor Restoration: Principles, Processes, and Practices. By the Federal Interagency Stream Restoration Working Group (FISRWG). GPO Item No. 0120-A;SuDocs No. A57.6/2:EN3/PT.653. Also adopted as part of the USDA-NRCS Engineering Handbook, Part 653.

A trap-and-removal facility at Reach 3 could be constructed with a capacity exceeding the average annual rate of deposition in Reach 2 (47 tons/year). Therefore, this recommendation has the potential to reduce sedimentation in Reach 2 by 47 tons/year and eliminate excessive deposition in Reach 2. It would require sediment removal every other year. Annual inspections are recommended to determine when the sediment trap has reached 80% of its capacity.

5.2.2.1 Alternative 1: Ruthven Nature Area (Reach 2) Periodic Sediment Removal

Alternative one involves periodic sediment removal in Reach 2 where sediment was removed in 2012 under a permit (Table 5.2-2), as an alternative location to Reach 3. Sediment trapping in Reach 2 was recommended in the Millers Creek Watershed Improvement Plan as part of Focus Area #12. Given the City has already removed sediment from this area, it could continue to be used as a long-term regional sediment removal site if desired (**Figure 15**). Land adjacent to Reach 2 is located in the City-owned Ruthven Nature Area. Therefore, land purchase or access agreements with other property owners would not be required. However, due to the presence and extent of wetlands adjacent to the south side of Millers Creek, environmental impacts could be greater than establishment of a trap-and-removal facility in Reach 3. Furthermore, Reach 2 would not be suitable for developing a regional detention facility in concert with the sediment trap. A sediment basin with a capacity equivalent to the annual average rate of deposition (47 tons/year) in Reach 2 is feasible. Therefore, a sediment trap in Reach 2 would have the capacity to trap up to 47/tons per year, and averting the previous flooding problems associated with excessive deposition in Reach 2. However, all of the storage would have to be constructed below the existing bed elevation (created via excavation below the bed only); due to the low relief of adjacent lands relative to the streambank elevation, it would not be feasible to use structures to create a sediment trap by raising the water surface elevation. Reach 3 offers greater design flexibility in this sense. The existing sediment removal area in Reach 2 (**Figure 15**) would require alteration to improve sediment trapping efficiency and facilitate periodic sediment removal. Those alterations would include excavation of the channel and creation of a larger staging and access area along the south side of Millers Creek.

Given the existing sediment removal area located in Reach 2 is located in the Ruthven Nature Area, the project team evaluated whether this sediment removal location could also create

opportunities for improving public access to Ruthven Nature Area. The sediment removal was conducted along the reach of Millers Creek where sediment accumulation is occurring, extending east from Huron Parkway approximately 200 feet. Creating access to the sediment removal area would increase access to the very northwest corner of Ruthven Nature Area, but would not provide access to a large portion of the nature area. Creating public parking or amenities in the northwest corner of the nature area, therefore, would provide limited public access. Furthermore, the nature area contains wetlands along both sides of Millers Creek throughout the nature area. The potential for public access development in the wetland portions is limited due to the potential for wetland impacts. Approximately two-thirds of the nature area is comprised of wetland habitats. Upland located in the southwestern corner of the nature area contains potential park development or public access potential, but access to this area is not necessary to manage sediment in Reach 2. Sediment accumulation is not a problem downstream of Reach 2 or in closer proximity to the upland portion of Ruthven Nature Area. In light of these site conditions, the project team determined that managing sediment in Reach 2 would not create viable public access opportunities within the Ruthven Nature Area.

Table 5.2-2. Alternative sediment trap-and-removal facility locations.

Description	Study Reach	Preliminary Capital Cost	Maintenance Schedule	Preliminary Annual Maintenance Cost	Ruthven Sediment Reduction Potential (tons/year)	\$/Ton
Ruthven Nature Area Sediment Trapping	2	\$10,000	Bi-annually	\$10,000	47	\$426
Multiple Sediment Traps		\$50,000	Bi-annually	\$15,000	47	\$1,383

Based on year-1 costs including capital cost and the first year of maintenance



Figure 15. Location of Reach 2 sediment trap-and-removal (top) and photo (bottom) of 2012 sediment removal area.

5.2.2.1 Alternative 2: Multiple Trap-and-Removal Facilities

Alternative two is a diffused sediment removal approach based on establishment of up to four smaller sediment trap-and-removal facilities (Table 5.2-2). This approach is used by other municipalities such as Duluth, Minnesota to manage in-stream sediment at multiple locations throughout a watershed (**Figure 16**). The three locations with the best potential include the end of Study Reach 8 at Huron Parkway, the confluence of Study Reaches F and 9, and the confluence of Study Reaches 5 and C (**Figure 17**). The City does not own property at any of these locations. Therefore, land purchase or access agreements would be required. Each facility would consist of a construction pad; excavated sand trap measuring 100 feet in length, 20 feet wide, and 2 feet deep; access; and staging area. It may also be possible to construct sediment traps at some of the locations using structures to raise the water surface. The Reach F/9 facility could trap-and-remove up to 60 tons annually from Reach F, G, and 9. The Reach 8 facility could trap and remove up to 33 tons annually from Reach 8. The Reach 5/C facility could trap and remove 115 tons annually from Reaches 5, 6, 7, and D. All three traps would require maintenance every one to two years; annual inspections would be required. Combined the three facilities could reduce the deposition in Reach 2 by 47 tons/year – the same potential as a regional facility at Reach 3.



Figure 16. Sediment trap maintenance in Duluth, MN.



Figure 17. Alternative 2 potential sediment trap locations.

5.2.3 PERMITTING REQUIREMENTS AND ENVIRONMENTAL IMPACTS

All inline or offline sediment basins and detention basins would require a permit from the MDEQ under Part 301 (Inland Lakes and Streams) of NREPA and potentially Part 303 (Wetland Protection) if any wetland impacts are necessary. Part 31 (Floodplains) also applies given the activities would occur within the FEMA 100-year floodplain of Millers Creek; however, flood impacts are not expected. Permits would also be required for periodic maintenance dredging to remove trapped sediment from the system and restore the trap capacity. Maintenance dredging could be permitted under Part 301 as a minor permit.

The Indiana bat is a federally protected species under the Endangered Species Act (ESA). During the summer breeding season, the Indiana bat roosts in certain types and sizes of trees in southern Michigan. Forested areas along Millers Creek in Reach 3 could provide Indiana bat habitat. Constructing a regional trap-and-removal facility in Reach 3 would impact approximately 2 to 3 acres of upland forest of moderate quality, including potential bat roosting trees. However, construction can be scheduled to avoid the species when it is present on the site and using available roosting habitat. Alternatively, a bat survey can be conducted to determine if bats are actually using any of the trees. However, bat surveys are extremely expensive. If federal funding is used to construct a project, then an informal consultation with the U.S. Fish & Wildlife Service will be required.

Reach 3 contains wetlands along Millers Creek. However, approximately four acres in the central portion of the reach along Huron Parkway is forested upland (between the two Huron Parkway culverts). The western edge of the forested upland area is in close proximity to Millers Creek. This upland area could serve as a point of access off Huron Parkway, staging, and construction operations during sediment removal. Due to available upland adjacent to Millers Creek, wetland impacts should be lower than the impact associated with a regional sediment trap-and-removal facility in Reach 2.

The City of Ann Arbor obtained a permit to remove sediment from Reach 2 from the Michigan Department of Environmental Quality under Parts 301 and 303 of the Natural Resources and Environmental Protection Act. Given this reach has now been dredged under a permit, the City

would be able to obtain future permits for maintenance dredging. However, access and operational space are limited due to the presence of wetlands regulated by the State of Michigan. Expanding operational space and formalizing access in Reach 2 would likely increase wetland impacts under future permits. Constructing a sediment trap-and-removal facility in Reach 2 would likely impact more wetland area than in Reach 3. Nonetheless, it can be considered as an alternative to Reach 3.

Constructing and maintaining multiple trap-and-removal facilities will tend to distribute environmental impacts over a greater geographic area compared to a single regional trap-and-removal facility in Reach 3. However, the potential environmental impacts at the recommended sites would be minimal due to no or limited wetland acreage and low quality riparian habitat. All of the sites have moderate levels of disturbance associated primarily with urban development along the Millers Creek corridor. Nonetheless, the overall foot print of four or five sediment trap-and-removal facilities distributed throughout the drainage network will be greater than one regional facility and they will alter existing riparian vegetation in the Millers Creek corridor. Excavating a sediment trap in Millers Creek would not have substantial environmental impacts because the quality of stream habitat at the locations recommended is poor and currently does not support a diverse aquatic community. There are no sensitive wildlife or aquatic organisms that would be impacted.

5.3 RECOMMENDED SEDIMENT LOAD REDUCTION ACTIVITIES

The sediment load coming from streambank erosion is excessive compared to expected natural background conditions due to morphological instability throughout the Millers Creek channel network. Due to site specific conditions and erosion rates in each reach, some reaches are generating higher loads than others. It is possible to eliminate or significantly reduce sediment accumulation in Ruthven by reducing the annual bank erosion load within certain reaches and without having to address bank erosion in every reach. In other words, sediment load reduction projects can be prioritized based on their potential to reduce sediment accumulation in Ruthven Nature Area (Reach 2).

Recommended sediment load reduction projects were not individually modeled due to the time required to setup and run the sediment transport model. Rather, all of the recommended load reduction projects were modeled together, simulating the result of complete implementation. The potential reduction in sediment accumulation at Ruthven Nature Area for each recommendation/reach was estimated using bank loading estimates. For this purpose, the bank load estimates of each reach were assumed to be proportional to the amount of sediment deposited in Ruthven annually. The sediment transport model predicted deposition of 234 tons of sediment in Reach 2 over the model period, or 47 tons per year. When the load reduction projects were simulated by reducing bank load estimates to background (see Section 4.3.2) the mass deposited decreased to 2 tons per year, a decrease of 45 tons per year. The estimated bank load for Reach 6, for example, is 50 tons per year or 14% of the total bank load (355 tons per year). Therefore, the Reach 6 potential sediment load reduction is 14% of 45 tons or 6.3 tons/year. Table 5.3-1 shows this estimation for all of the recommended load reduction projects.

Table 5.3-1. Estimated sediment accumulation reduction potential for each recommended load reduction project based on portion of total bank erosion sediment load.

Recommendation	Study Reach	Bank Load Estimate (tons/year)	Percent of Total Load	Potential Sediment Accumulation Reduction (tons/year)
Reach D Channel Modification	D	159	44.8%	20.2
Reach 6/7 Channel Modification	6/7	92	25.9%	11.7
Reach F/G Reconstruction	F/G	54	15.2%	6.8
Reach 6/7 Bank Stabilization Alternative	6/7			5.8 [†]
Reach 8 Channel Modification	8	33	9.3%	4.2
Reach 5 Channel Modification	5	17	4.8%	2.2

[†] Assumed to be 50% of restoration potential based on stabilization of severely eroding banks only.

Using information obtained during the field assessment and sediment modeling results, a set of projects has been identified for all reaches with a moderate or higher (> 10 tons per year) sediment loading rate that once implemented would eliminate problematic sediment accumulation in Reach 2. This includes load reduction projects in Reaches 5, 6, 7, 8, D, and F/G. Reach G is included with Reach F despite having a loading rate lower than 10 tons/year because a previously designed restoration project included Reaches F and G together as discussed below. Table 5.3-2 lists the

sediment load reduction projects in order of priority. The prioritization is based on cost per ton of sediment deposition that can be achieved. The sediment transport model predicts a reduction of sediment accumulation in Ruthven Nature Area of 45 tons/year when these sediment load reduction projects are implemented. This was simulated by setting the bank loading estimates to background. The model predicts that 47 tons/year were deposited over the period modeled under existing conditions. Therefore, modeling shows that the recommended sediment load reduction projects could eliminate the Ruthven Nature Area sediment accumulation once fully implemented. See Section 5.2.7 for discussion on permitting requirements and environmental impacts.

Table 5.3-2. Recommended sediment load reduction projects for Millers Creek.

Recommendation	Study Reach	Preliminary Capital Cost	Maintenance Schedule	Preliminary Annual Maintenance Cost	Ruthven Sediment Reduction Potential (tons/year)	\$/Ton
Reach D Channel Modification	D	\$850,000	Annual	\$2,000	20	\$33,500
Reach F/G Reconstruction	F/G	\$670,000	Annual	\$2,000	7	\$121,429
Reach 6/7 Channel Modification	6/7	\$1,500,000	Annual	\$2,000	11	\$136,364
Reach 6/7 Bank Stabilization Option	6/7	\$800,000	Annual	\$2,000	5	\$160,000
Reach 8 Channel Modification	8	\$750,000	Annual	\$2,000	4	\$187,500
Reach 5 Channel Modification	5	\$460,000	Annual	\$2,000	2	\$230,000

† Mass of sediment in tons/year over the model period. The model predicted mass of sediment deposited at Ruthven over the model period is 47 tons/year.

Total is based on the restoration option for Reaches 6 and 7

As discussed in Section 2.0 of this report, Reaches A and B were not included in the Study because the sediment load from that part of the watershed is trapped in the Geddes Lakes or discharges to Millers Creek downstream of the sediment accumulation area in Reach 2. Consequently, recommendations have not been made for Reaches A and B. Recommendations for load reduction projects were also not made for Reaches 2 and 3 because those reaches have net deposition and do

not export sediment load. Load reduction recommendations were not made for Reaches 9, H, and E either because sediment loads were less than 10 tons per year in those reaches. Reaches H and E are fairly stable channels with natural sediment loading and transport rates based on field observations. Some portions of Reach 9 are incised and erosional while others are somewhat stable and connected to a functional floodplain. The estimated bank load for Reach 9 is six tons per year, which is less than 5% of the total bank load estimate. Therefore, it would not be prudent to allocate resources on load reduction efforts in Reach 9 given they would not substantially address the problem.

5.3.1 STREAM RESTORATION AND STABILIZATION PRACTICES

The following description of sediment load reduction projects contain several terms that need to be defined for proper understanding. First, the term “restoration” has many meanings and is usually defined in the context of project goals and objectives. In the simplest sense, “restoration” involves moving a stream from its existing undesirable condition to some future desirable condition. In the context of managing sediment in Millers Creek, the pertinent condition involves channel stability. For other projects, condition may have more to do with habitat for aquatic organisms or other facets of stream function. Stream condition is considered to be stable when the channel is able to convey the water and sediment delivered to the channel from its watershed and channel margins (i.e., bed and banks) without aggrading (sediment accumulates on the bed) or degrading (the channel bed or banks erode excessively). Streams become unstable when some type of disturbance or alteration changes the amount and rate of water and sediment entering a stream. In the case of Millers Creek, the channel network is unstable: the bed and banks have been eroding excessively and sediment has been accumulating in Reaches 2 and 3. Sediment accumulation in Reach 2 has caused periodic flooding. This is the current undesirable condition of Millers Creek.

From a restoration perspective, the next step is defining the desired future condition. Given the field assessment results documented in Section 2 of this report, it will be necessary to reduce erosion in the Millers Creek channel network to reduce the sediment accumulation in Ruthven. Therefore, the desired future condition is a stable channel upstream of Ruthven where channel erosion is excessive. As described in Section 2 of this report, bank erosion is the primary source

of excessive sediment loading to Millers Creek. Banks are eroding due to channel instability caused by alterations and disturbances in the channel network and watershed. Multiple partners are working together to implement the Millers Creek Watershed Improvement Plan and address watershed-wide disturbances such as altered watershed hydrology. However, the erosive Millers Creek channel network can be stabilized to reduce sediment accumulation in Ruthven.

The next question to be addressed is how the channel can be stabilized. The following recommend load reduction projects use three general approaches that require definition in this context: 1) bank stabilization, 2) channel modification, and 3) channel reconstruction. The goal of all three approaches is to improve stability and decrease channel erosion with varying levels of effort. Bank stabilization involves stabilization of specific, isolated eroding stream banks by altering flow, altering the bank, and/or armoring the bank. Bed grade control structures can also be used to help stabilize a bank if streambed erosion is part of the cause. Channel modifications could include several different techniques commonly used to stabilize a channel, including channel regrading, bank regrading and reconstruction, bed grade control structures, and current deflecting devices. The main difference is that the entire length of channel requires modifications to create stability as opposed to individual streambanks. In Reach 8, for example, streambank erosion is nearly continuous. Therefore, modifications to the channel are required as opposed to stabilization of individual, isolated eroding streambanks. Channel modifications can be effective and lower cost when the existing channel can be used and modified to create stability or where space constraints and cost make channel reconstruction unfeasible. Channel reconstruction involves construction of a new parallel channel to replace the existing channel. The new channel is design constructed using a natural channel design. Natural channel design is based on creation of a channel that mimics natural form in three dimensions (planform, profile, and dimension) and function. This approach is typically the most costly approach per linear feet of stream and consumes the most land area of the three approaches discussed. Appendix B contains a compendium of stream restoration and stabilization techniques taken from the literature.

5.3.2 REACH F & G RECONSTRUCTION

This project was previously funded by a Michigan 319/CMI grant with cost share by Pfizer. Design was 85% complete and ready for engineering review by the Department of Environmental Quality. After Pfizer moved its operations from the facility at Huron Parkway and Plymouth Road, the project was abandoned. Given the level of design work that has already gone into this project, it is a good candidate for reducing annual sediment load. Restoration of Reaches F and G as designed is based on channel reconstruction using natural channel design. That is, a complete new, parallel channel is created to replace the existing channel. There is sufficient space, environmental impacts would be low, and the historical floodplain is still intact; therefore, reconstruction is an appropriate approach. Reconstruction of Reaches F and G would reduce the amount of sediment deposited at Ruthven over the modeled period by 6.8 tons per year. The property is now owned by the University of Michigan. **Figure 18** depicts the location of Reaches F and G.

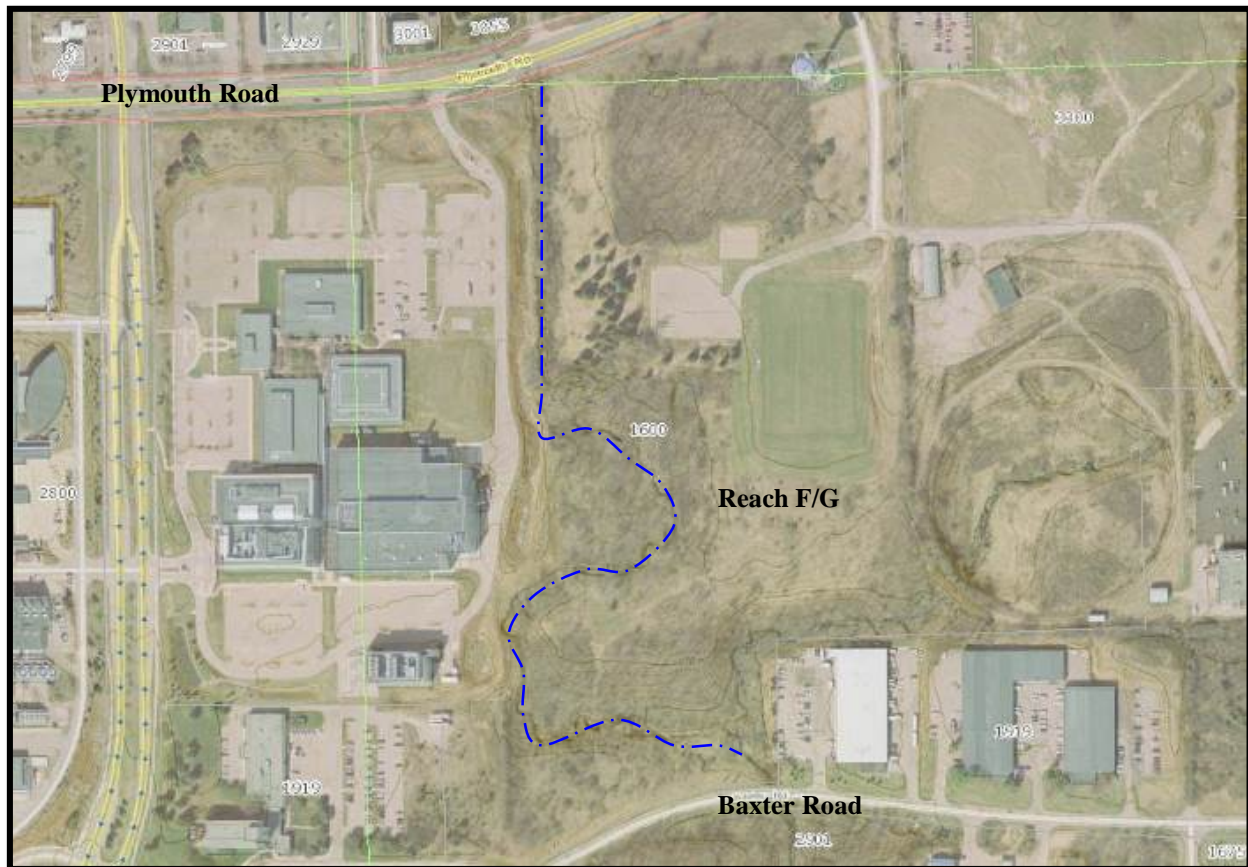


Figure 18. Reaches F & G vicinity map

5.3.3 REACH D CHANNEL MODIFICATION

Reach D is Focus Area #11 in the Millers Creek Watershed Improvement Plan. The Improvement Plan identified “significant bank erosion” in this reach. Reach D is located on property owned by the City of Ann Arbor (Glazier Hill Park) and the First United Methodist Church of Ann Arbor (1001 Green Road). Reach D starts at the end of a large storm sewer that drains most if not all of the northern residential neighborhood (south end of Pepper Pike Street) (**Figure 19**). The energy and volume of flow from the storm sewer has caused extensive bed and bank erosion in Reach D leading to channel enlargement and loss of floodplain connectivity; the worst erosion is located upstream of Glazier Way. However, a road culvert located in the Geddes Lake community is perched six feet above the bed, indicating extensive bed erosion in that area as well. Sediment load from Reach D is accumulating in sections of Reach C, but is also being transported into Millers Creek where it is eventually transported into Reaches 2 and 3. Erosion in Reach D is so extensive that streambank stabilization alone is not a practical approach to reducing the sediment loading. Furthermore, there is limited space to support channel reconstruction. Therefore, channel modifications is the recommended approach to effectively reduce erosion and sediment loading. Structural channel modifications will be necessary due to limited access, limited space, proximity to an adjacent sanitary sewer, steep valley slope, and high energy flow. Applicable structural modifications may include bed grade control structures such as cross-vanes, riffles, and boulder weirs; vertical retaining structures in meanders, and flow deflecting/centering devices. Bank armoring using hard revetments such as riprap will also be required. Extensive clearing along the banks and bank grading will be necessary to stabilize the channel margins. Restoration of Reach D would reduce the amount of sediment deposited at Ruthven over the modeled period by 20.2 tons per year.

The City of Ann Arbor Capital Improvement Plan includes a capital maintenance project in Reach D. The project includes lining the existing sanitary sewer line that parallels Reach D. Depending on access requirements, it may be possible to conduct Reach D restoration work simultaneously with sanitary sewer line work.



Figure 19. Reach D vicinity map showing north half of Reach D located north of Glazier Way

5.3.4 REACH 6 AND 7 CHANNEL MODIFICATION

Section 5.3.5 presents a recommendation for bank stabilization in Reaches 6 and 7 (**Figure 20**), which has the potential to reduce sediment load by a lesser amount than Reach 6 and 7 restoration. The streambank stabilization recommendation only addresses the most severe eroding streambanks within Reaches 6 and 7. Additional streambank erosion is likely to occur along streambanks not treated and bed instability continues to be a problem in Reaches 6 and 7. Although a more expensive option, channel modifications to Reaches 6 and 7 will more effectively address long-term channel instability and sediment loading. Channel reconstruction is not appropriate because the historical floodplain is no longer intact and space is limited given the proximity of Huron Parkway, presence of utilities, and extensive private land ownership. Modification of

Reaches 6 and 7 will require extensive grading along the east side of Reaches 6 and 7 located on property owned by the University of Michigan. The least costly approaches to channel restoration in Reaches 6 and 7 are the Priority-II or Priority-III approaches (Rosgen 1996)². Priority-II and Priority-III are conceptual restoration approaches that attempt to achieve morphological stability in incised stream channels by creating a stable bankfull channel with flood conveyance capacity on small (relative to typical natural floodplain widths) bankfull or floodplain benches constructed adjacent to the channel (one or both sides). Priority-II involves creation of a meandering channel within an excavated floodplain at a lower elevation than the stream's historical floodplain. The streambed remains at its existing elevation, but the floodplain is lowered. Priority-II requires extensive excavation adjacent to one or both sides of the existing channel.

Priority-III involves creation of smaller bankfull or floodplain terraces on one or both sides of the channel, achieved by raising the streambed elevation and widening the water course. Priority-III results in a less sinuous channel with narrower floodplain benches. The two approaches differ primarily in the degree of channel modification and size of the created floodplain. Priority-III is a lower cost approach due to lower excavation quantities and less space. However, the Priority-III approach is usually more dependent upon in-stream grade control structures to control bed elevation/erosion and deflecting flows away from streambanks and armoring streambanks (e.g., riprap and retaining walls) to achieve stability.

Restoration of Reaches 6 and 7 would reduce the amount of sediment deposited at Ruthven over the modeled period by 11.7 tons per year. Both approaches would substantially alter property owned by the University of Michigan and require the University's approval and participation.

² Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Spring, CO.

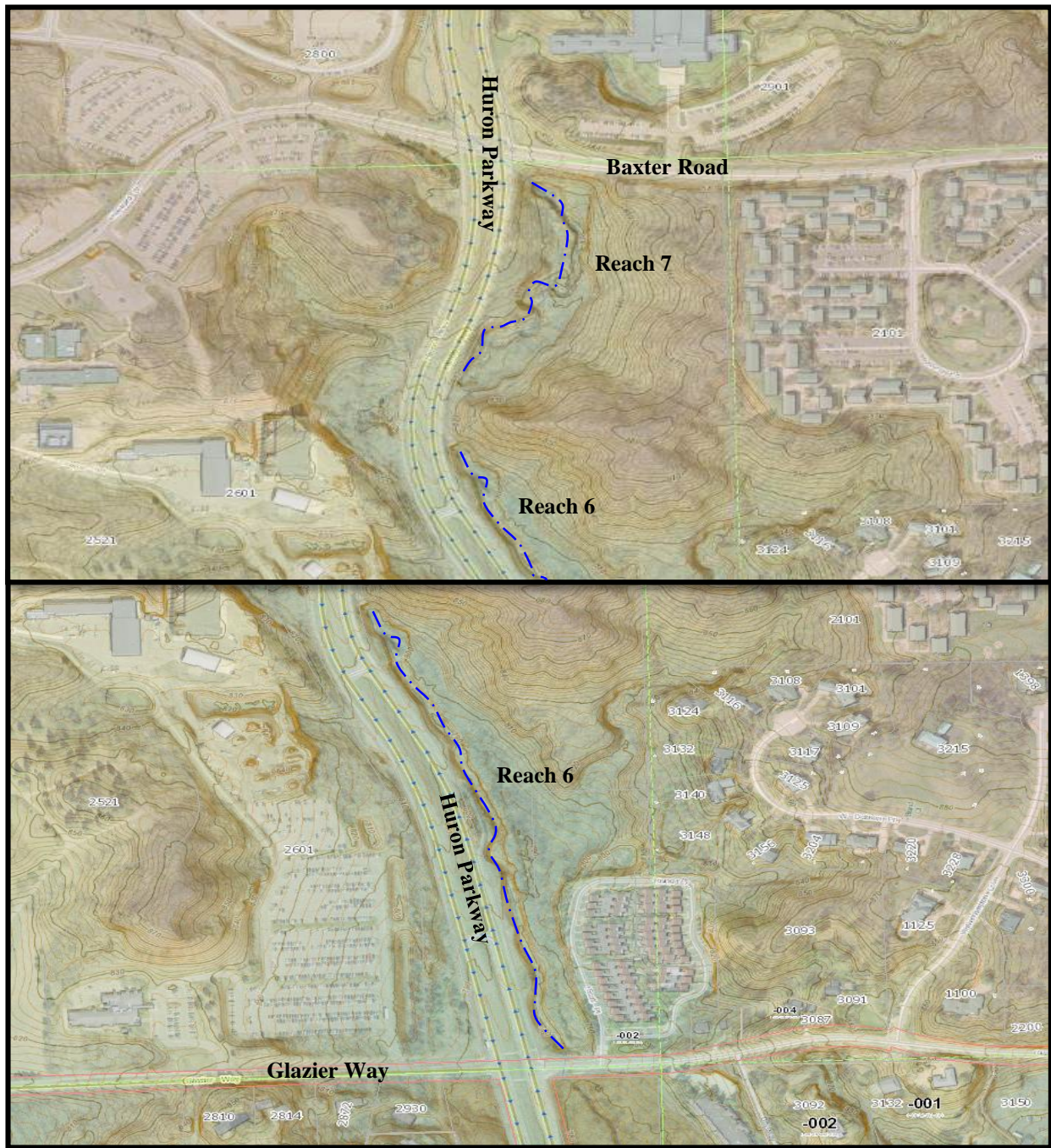


Figure 20. Reach 6 (bottom) and Reach 7 (top) vicinity maps

5.3.5 REACH 6 AND 7 STREAMBANK STABILIZATION ALTERNATIVE

Reach 6/7 bank stabilization is a lower cost alternative to complete channel restoration. Between 2007 and 2009 the City stabilized eight streambank erosion sites totaling 1,400 feet in Reach 6 along the west side of Millers Creek at an approximate cost of \$750,000 (**Figure 20**). The primary purpose of the stabilization project was to protect infrastructure being threatened by rapid lateral migration caused by accelerated erosion and improve public safety (the high banks in vicinity of the pedestrian path presented a fall hazard). However, the project also substantially reduced sediment loading to Millers Creek within Reach 6. Still, there is an estimated 1,200 feet of severely eroding streambanks in Reach 6 contributing an estimated 50 tons per year of sediment. The most severe eroding streambanks in Reach 6 are located on the east side of Millers Creek on property owned by the University of Michigan. However, there are eroding banks located throughout Reaches 6 and 7 on both the east and west side of Millers Creek. Stabilizing streambanks in Reaches 6 and 7 could reduce the amount of sediment deposited at Ruthven over the modeled period by 5.8 tons per year, approximately 50% of the load reduction that can be achieved through restoration. Proven techniques [such as geocell walls, reinforced soil encapsulation, boulder toe, riprap toe, bank sloping, and bioengineering (use of vegetative materials and establishment of native vegetation)], used in Reach 6 between 2007 and 2009 are recommended for both reaches (**Figure 22**).

5.3.6 REACH 8 CHANNEL MODIFICATION

Reach 8 is entirely located on property owned by the University of Michigan. Part of Reach 8 flows near, and even under a wing of, the North Campus Administrative Complex building (**Figure 23**). Bank erosion and instability in Reach 8 is nearly continuous although the erosion rates vary considerably. Bank heights are typically low and some floodplain connectivity still exists for flood dissipation.

The restoration potential for Reach 8 is high and could be accomplished by modifying the existing channel using grade control and river training structures (e.g. rock vanes) and streambank reconstruction similar to approaches recently used on Malletts Creek in the City of Ann Arbor (**Figure 24**). Restoration of Reach 8 would reduce the amount of sediment deposited at Ruthven over the modeled period by 4.2 tons per year.

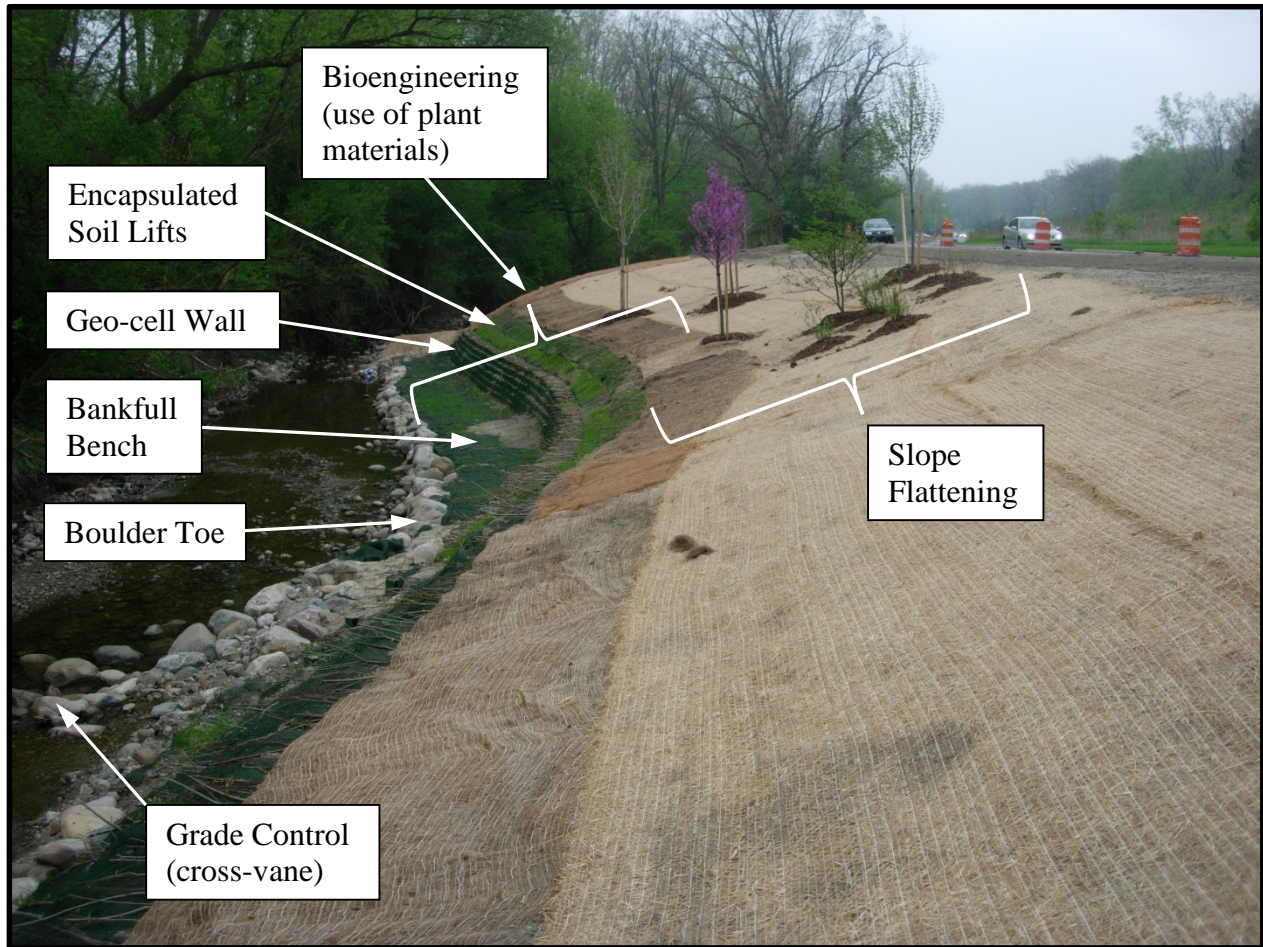


Figure 22. 2007-2009 streambank stabilization in Reach 6 using a combination of effective stabilization techniques

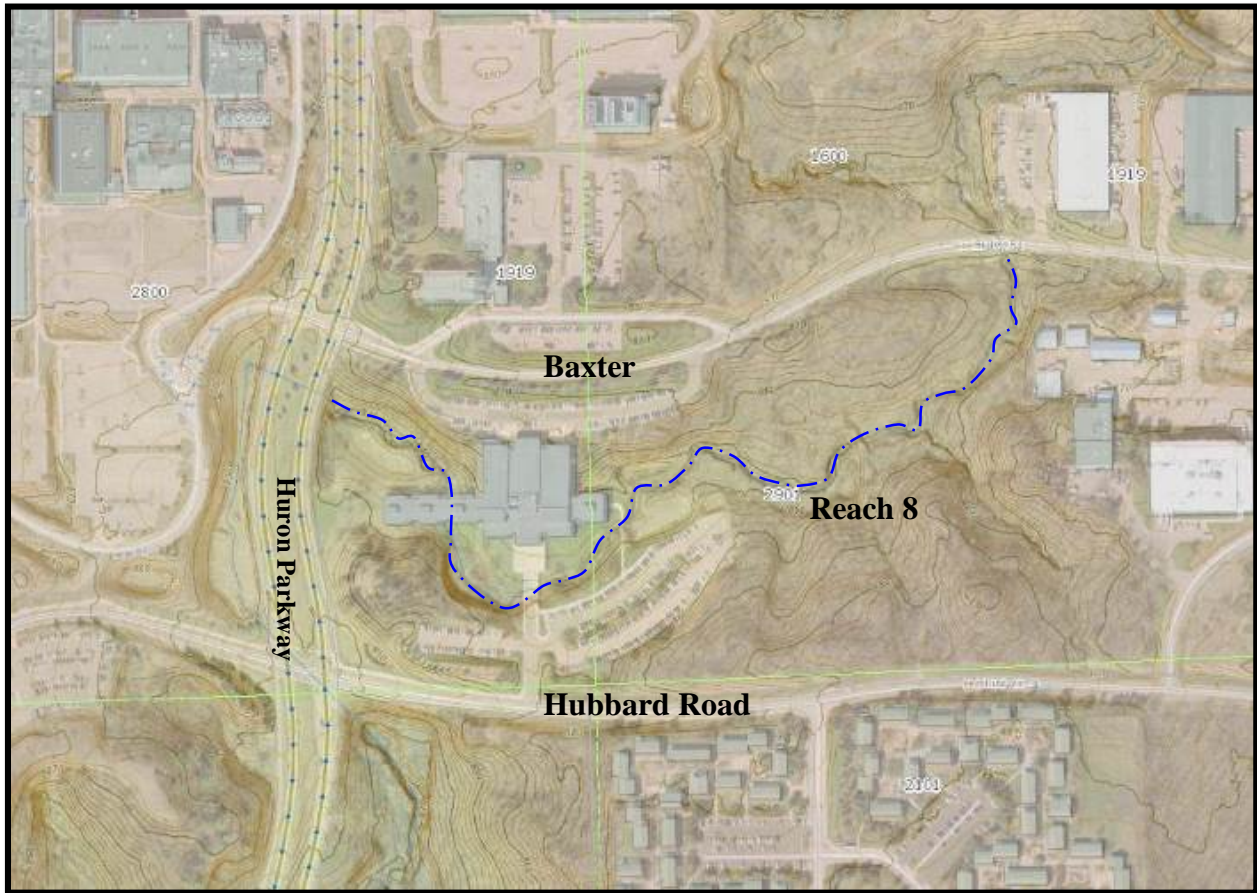


Figure 23. Reach 8 vicinity map

5.3.7 REACH 5 CHANNEL MODIFICATION

Most of Reach 5 is owned by the City (Oakridge Park) (**Figure 25**). The very southern end of Reach 5 is privately owned. Reach 5 is very similar to Reach 8, although erosion severity is lower. Bank erosion and instability in Reach 5 is nearly continuous although the erosion rates vary considerably. Bank heights are typically low and some floodplain connectivity still exists for flood dissipation. The restoration potential for Reach 5 is high and could be accomplished by modifying the channel using structures and streambank stabilization similar to approaches recently used on Malletts Creek in the City of Ann Arbor (**Figure 24**). Restoration of Reach 5 would reduce the amount of sediment deposited at Ruthven over the modeled period by 9 tons per year.



Figure 24. 2012 Mallets Creek channel restoration at County Farm Park (top) and Huron Parkway (bottom) using a combination of bank stabilization techniques and in-stream grade control structures

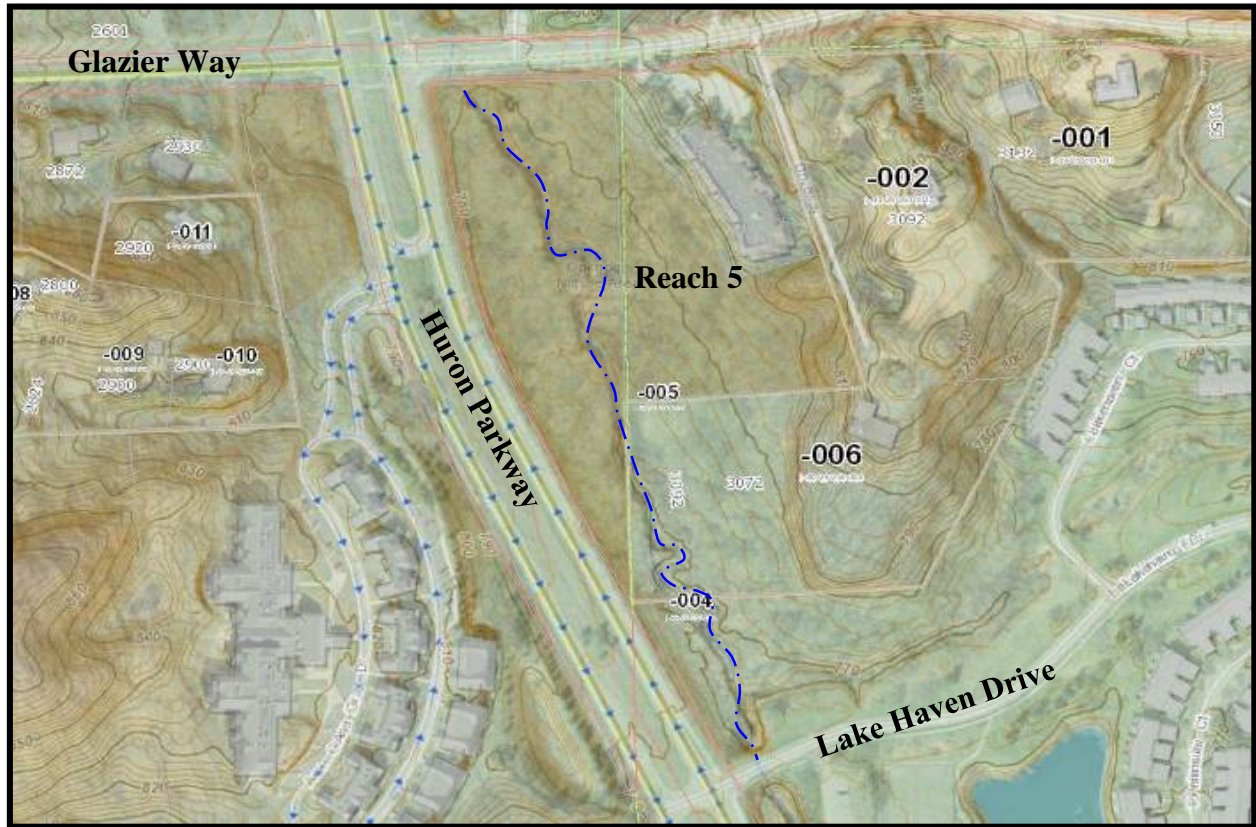


Figure 25. Reach 5 vicinity map

5.3.8 PERMITTING REQUIREMENTS AND ENVIRONMENTAL IMPACTS

All of the sediment load reduction projects would require a permit from the MDEQ under Parts 301 (Inland Lakes & Streams), 303 (Wetland Protection), and 31 (Floodplains) of Michigan's NREPA (1994).

The existing 85% design plans for restoration of Reaches F and G indicate new channel construction parallel to the existing channel. Therefore, the foot print of the project is significant when considering required excavation for the new channel, filling of the old channel, and construction disturbances. However, the habitat quality within the project foot print is low quality, primarily early succession forest with abundant invasive species such as common buckthorn, honeysuckle, and garlic mustard. Wetland impacts would be minor and could easily be offset through wetland creation along the restored stream channel. Wetland mitigation would probably

not be necessary. The project already had the support of the Michigan Department of Environmental Quality.

The City of Ann Arbor obtained a permit to remove sediment from Reach 2 from the Michigan Department of Environmental Quality under Parts 301 and 303 of the Natural Resources and Environmental Protection Act. Given this reach has now been dredged under a permit, the City would be able to obtain future permits for maintenance dredging. However, access and operational space are limited due to the presence of wetlands regulated by the State of Michigan. Expanding operational space and formalizing access in Reach 2 would likely increase wetland impacts under future permits. Due to the potential for wetland impacts, Reach 2 may not be the most desirable location for continued annual or periodic sediment removal.

The Indiana bat is a federally protected species under the Endangered Species Act (ESA). During the summer breeding season, the Indiana bat roosts in certain types and sizes of trees in southern Michigan. Forested areas along Millers Creek in Reaches 3, 5, 7, 8, and D could provide Indiana bat habitat. It is not known whether or not the Indiana bat is using habitat in these areas. This issue would need to be addressed during permitting. Construction can be scheduled to avoid impacts while the Indiana bat is on site and using available roosting habitat. Alternatively, a bat survey can be conducted to determine if bats are actually using any of the trees. However, bat surveys are extremely expensive. If federal funding is used to construct a project, then an informal consultation with the U.S. Fish & Wildlife Service will be required.

Wetlands may be present along Reach D, but the acreage would be low and potential wetland impacts should not exceed the threshold requiring mitigation (0.3 acres); furthermore, the impacts would be temporary. The stream valley along Reach D contains a hardwood forest of low to medium quality. Invasive species are abundant and degrade the habitat conditions. Nonetheless, mature hardwood trees provide habitat for song birds and small mammals.

Reach 5 is completely lined with forested uplands on both sides, but small emergent and scrub-shrub wetland pockets are also present. The hardwood forests are of medium quality with low deciduous tree species diversity and the presence of invasive shrubs and forbs in the under story.

Construction in Reach 5 could impact wetlands but the impacts would be minimal and temporary. Wetland mitigation could potentially be avoided by minimizing permanent wetland impacts. Due to their small size and isolation from the stream, the higher quality emergent wetlands could be avoided. Construction in Reach 5 would impact approximately two acres of forested riparian habitat along the west side of Millers Creek. Limited construction access and operation would be required along the east side. This loss of habitat would primarily impact song birds and small mammals such as squirrels.

Wetlands may also be present along Reach 8, but the acreage would be low and potential wetland impacts should not exceed the threshold requiring mitigation (0.3 acres). The stream valley along Reach 8 contains a hardwood forest of low to medium quality. Invasive species are abundant and degrade the habitat conditions. Nonetheless, mature hardwood trees provide habitat for song birds and small mammals. Nearly continuous riparian disturbance would be required to stabilize Reach 8 along the north side of Millers Creek (hill slopes are much steeper along the south side). Therefore, Reach 8 restoration would impact a significant number of trees within the hardwood forest.

Wetlands are absent or very rare along either side of Millers Creek along Reaches 6 and 7, so wetland impacts would not occur or would be minimal. Riparian habitat quality is poor along the west side of Reach 6 where Millers Creek is located in close proximity to Huron Parkway. The west side of Reach 7 and east side of Reaches 6 and 7 (University of Michigan properties) contain higher quality hardwood forests that also contain abundant invasive species such as common buckthorn, garlic mustard, European honeysuckle, and tree of heaven. The higher quality forested habitat provides wildlife for a variety of song birds and small mammals. However, impacts to the forested community can be minimized for streambank stabilization by aligning access roads to reduce necessary tree removals and minimizing the construction foot print at each stabilization site.

Restoration of Reaches 6 and 7 will require extensive excavation adjacent to the channel (potentially both sides) and would impact more of the riparian habitat than the streambank stabilization option. Riparian impacts associated with restoration of Reach 6 and 7 would occur

primarily east of the channel (on University-owned property) and in Reach 7 where mature hardwood forest exists. In addition, the Priority II restoration option could impact 30% more forested riparian habitat than the Priority-II option because the Priority-II option results in a wider floodplain and project foot print.

APPENDIX A
TABLES

Table 1A. Bank Erosion Hazard Index (BEHI) scoring for twenty-two eroding streambanks in Millers Creek, Washtenaw County, Michigan

Reach	Site	Bank Height to Bankfull Height Ratio	Root Depth to Bankfull Height Ratio	Root Density	Bank Angle	Surface Protection	Sub-total	Adjustment	Total BEHI Score	BEHI Rank
4	1	10.0	3.7	5.9	5.9	1.9	27.4	2	29.4	Moderate
4	2	10.0	3.0	5.9	7.9	5.0	31.8	2	33.8	High
5	1	10.0	3.0	7.1	5.9	10.0	36.0	2	38.0	High
6	1	5.9	3.0	7.2	5.9	9.0	31.0	11	42.0	Very High
6	2	5.9	3.0	8.5	7.9	9.0	34.3	12	46.3	Extreme
6	3	5.7	2.5	7.9	7.9	5.6	29.6	15	44.6	Very High
6	4	6.2	1.1	5.9	8.2	5.0	26.4	9	35.4	High
6	5	10.0	2.1	4.8	6.4	7.1	30.4	9	39.4	High
7	1	7.8	1.0	4.8	3.0	2.2	18.8	6	24.8	Moderate
7	2	10.0	2.5	5.9	6.4	3.5	28.3	8	36.3	High
8	1	7.7	3.0	7.9	4.6	5.9	29.1	5	34.1	High
8	2	7.7	1.7	7.9	5.9	5.9	29.1	5	34.1	High
8	3	8.8	1.0	5.6	3.9	4.8	24.1	5	29.1	Moderate
8	4	8.5	1.0	4.5	7.9	4.5	26.4	5	31.4	High
9	1	5.8	1.0	5.9	5.9	5.2	23.8	5	28.8	Moderate
9	2	7.8	1.8	5.6	7.9	4.5	27.6	5	32.6	High
D	1	6.2	1	3.5	6.5	2.5	19.7	11	30.7	High
D	2L	4	1	5.7	7.9	5	23.6	14	37.6	High
D	2U	10	5.9	5.9	7.9	5.9	35.6	14	49.6	Extreme
F	1	8.4	1.9	5.0	6.4	4.4	26.1	8	34.1	High
F	2	10.0	3.3	4.5	8.3	4.5	30.6	7	37.6	High
F	3	8.3	3.2	3.5	7.9	2.5	25.4	6	31.4	High
F	4	10.0	1.0	4.5	7.9	2.5	25.9	7	32.9	High
F	5	10.0	5.8	5.9	5.9	9.0	36.6	8	44.6	Very High
G	1	8.4	4.5	3.0	7.9	3.0	26.8	2	28.8	Moderate

Reach	Measurement Type	Exposure Measurement (feet)	Years	Annual Erosion Rate (ft/yr)
F	Pin	0.11	6	0.02
F	Pin	0.66	6	0.11
F	Pin	0.38	6	0.06
F	Pin	0.23	6	0.04
G	Pin	0.00	6	0.00
G	Pin	0.00	6	0.00
7	Pin	0.70	6	0.12
6	Outfall	3.00	37	0.08
6	Outfall	4.00	37	0.11

Table 2A. Estimated annual bed erosion rates for Millers Creek, Washtenaw County, Michigan.

Table 3A. Sediment particle size gradations for bed and storage samples collected from Millers Creek, Washtenaw County, Michigan Samples with an 'S' designation indicate data were obtained by laboratory sieve analysis. All other data were derived by field pebble counts.

Parameter	Reach											
	1S	2S	3	4	5	6	6S	7	8	8S	9	9S
%SILT/CLAY	2.8	2.8	5.4	15.9	14.2	0.0	2.2	0.0	2.9	2.1	1.0	9.4
%SAND	88.0	81.4	26.1	17.8	8.3	22.2	50.4	24.0	43.8	71.2	55.0	57.6
%GRAVEL	9.1	15.8	68.5	66.4	77.5	65.7	47.5	65.6	53.3	26.7	44.0	33.0
% COBBLE	0.0	0.0	0.0	0.0	0.0	12.1	0.0	10.4	0.0	0.0	0.0	0.0
10	0.2	0.2	0.3	0.0	0.2	0.3	0.3	1.1	0.2	0.2	0.2	0.2
15	0.2	0.2	0.6	0.1	0.6	0.4	0.5	1.4	0.4	0.3	0.3	0.2
30	0.3	0.4	1.8	1.6	4.5	6.8	1.5	2.9	0.9	0.6	0.5	0.6
50	0.6	1.0	4.2	5.3	11.0	14.0	4.1	9.6	2.4	1.8	1.4	2.4
60	0.9	1.5	5.6	7.9	13.4	18.3	7.1	13.3	4.4	2.7	2.7	5.1
85	3.0	5.6	14.5	15.3	22.9	45.3	15.7	43.1	17.8	9.5	13.0	11.7
95	9.5	13.4	23.0	21.0	35.0	110.0	21.3	79.0	33.0	17.0	19.0	21.3
D50 DESC	Sand	Sand	Gravel	Gravel	Gravel	Gravel	Gravel	Gravel	Gravel	Sand	Sand	Gravel
D15+D50+D85	3.8	6.8	19.3	20.8	34.5	59.7	20.3	54.1	20.5	11.6	14.7	14.3

Table 4A. Summary of recommended maintenance, sediment removal, and sediment reduction projects.

Description	Study Reach	Preliminary Capital Cost	Maintenance Schedule	Preliminary Maintenance Cost (per event)	Ruthven Sediment Reduction Potential (tons/year)	\$/Ton
Maintenance Activities						
Baffle Box Cleanout	6	\$0	Quarterly	\$2,000	<1	\$2,000
Huron Parkway Culvert Cleanout	2/3	\$0	Annually	\$3,000	<1	\$3,000
Sediment Removal Projects						
Regional Trap-and-Removal	3	\$250,000	Bi-annually	\$10,000	47	\$5,532
Ruthven Expanded Sediment Removal	2	\$20,000	None	\$0	<1	\$20,000
Sediment Load Reduction Projects						
Reach D Channel Modification	D	\$850,000	Annual Inspection	\$2,000	20	\$33,500
Reach F/G Reconstruction	F/G	\$670,000	Annual Inspection	\$2,000	7	\$121,429
Reach 6/7 Channel Modification	6/7	\$1,500,000	Annual Inspection	\$2,000	11	\$136,364
Reach 6/7 Bank Stabilization Alternative	6/7	\$800,000	Annual Inspection	\$2,000	5	\$160,000
Reach 8 Channel Modification	8	\$750,000	Annual Inspection	\$2,000	4	\$187,500
Reach 5 Channel Modification	5	\$460,000	Annual Inspection	\$2,000	2	\$230,000

APPENDIX B
STREAMBANK STABILIZATION TECHNIQUES

Large Woody Debris

Large woody debris (LWD) structures (aka engineered log jams) made from felled trees may be used to deflect erosive flows and promote sediment deposition at the base of eroding banks. Large woody debris can be arranged to simulate a transverse deflective structure similar to vanes and spurs.

Using large woody debris in Millers Creek would induce debris accumulation and potentially log jams that lead to erosion or a treatment failure. Furthermore, large woody debris structures are susceptible to decay and dislodgment. Dislodgment in particular could potentially lead to structural damage downstream of the treatment site. Large woody debris is not considered applicable to Millers Creek.

Willow Pole/Posts

Posts and pole plantings are methods intended to provide mechanical bank protection. Willow and cottonwood species are recommended for their ability to root and grow, particularly if they are planted deep into the streambanks. Larger and longer than live stakes, the posts and poles can provide better mechanical bank protection during the period of plant establishment by slowing the rate of flow along the streambank slope and inducing sedimentation.

Large willow posts or poles (2 to 4 inches in diameter) are difficult to find in Michigan and are not normally available through nurseries as are live stakes and other plant materials used in bioengineering. As a purely mechanical technique, it probably is not very useful in Millers Creek given the other techniques available. Furthermore, 100% vegetative and/or 100% biodegradable techniques are not recommended for Millers Creek due to high storm flow velocities. There are more suitable techniques designed to establish vegetation. Therefore, this technique is not considered to be applicable to Millers Creek.

Longitudinal Stone Toe

A longitudinal stone toe is continuous bank protection consisting of riprap or natural weathered stone placed longitudinally along the toe of the streambank only. The success of this method depends upon the ability of stone to self-adjust or "launch" into scour holes formed on the stream side of the revetment. Longitudinal stone toes usually require much less bank disturbance and the bank landward of the toe may be sloped and/or revegetated by planting or through natural succession.

Longitudinal stone toes protect streambanks via armoring where streambank erosion most often occurs and causes total bank failure. This technique requires much less riprap than conventional bank revetments that extend up the bank a considerable distance from the toe or cover the entire bank. This technique also has less ecological impact than other types of hard armoring. This technique is applicable to Millers Creek.

Coconut Fiber Rolls (Biodegradable Inert Toe or Facade)

Coconut fiber (coir) rolls are manufactured, elongated cylindrical structures that are placed at the bottom of stream banks to help prevent erosion and scour. The coconut husk fibers are bound together with geotextile netting with 35 cm or 40 cm (12 in or 18 in) diameters and lengths of 6 meters (20 ft). Coir is fairly long-lasting, typically 5-7 years, but must be designed with riparian revegetation to attain permanent solutions. Proper anchoring is critical and generally coir rolls are

not recommended for areas with high velocities and shear. Brushlayering and Live Stakes are good candidates for combining with coconut fiber rolls.

Use of biodegradable inert (i.e., non-living) fascines, bundles, or facades is a very ecologically sensitive approach to streambank and shoreline stabilization. It provides some toe armoring and surface protection during plant establishment. However, once the biodegradable materials have decomposed, the treatment relies completely on plants to stabilize the streambank. This is suitable under some conditions, typically where flow velocities do not exceed 3 ft/sec at the toe. In Millers Creek, flow velocities are too high to rely solely on vegetative treatments, primarily due to channel incision and physical channel alterations. Thus, this technique is considered not applicable to Millers Creek.

Gabion Baskets

Gabions are rectangular baskets made of twisted or welded-wire mesh that are filled with rock. These flexible and pervious structures can be used individually or stacked like building blocks to reinforce steep banks. Used alone, rock-filled gabions provide insufficient habitat benefit. However, woody vegetation, such as brushlayering, post and poles, can be incorporated by inserting the cuttings all the way through the basket during filling, and penetrating the native subsoil. The woody vegetation can provide additional reinforcement and longevity to the structure while helping to mitigate for loss of habitat.

Although the environmental impacts commonly associated with gabions are significant, gabion baskets can be very effective at stabilizing streambanks while creating a vertical or near vertical profile where space constraints require such. This technique is applicable to Millers Creek.

Cribwalls

A cribwall is a gravity retaining structure consisting of a hollow, box-like inter-locking arrangement of structural beams (usually wood). The interior of the cribwall is filled with rock or soil. In conventional cribwalls, the structural members are fabricated from concrete, wood logs, and dimensioned timbers (usually treated wood). In live cribwalls, the structural members are usually untreated log or timber members. The structure is filled with a suitable backfill material and live branch cuttings are inserted through openings between logs at the front of the structure and imbedded in the crib fill. These cuttings eventually root inside the fill and the growing roots gradually permeate and reinforce the fill within the structure.

Cribwalls are an effective means of stabilizing stream banks while creating a vertical or near vertical face where space constraints require such. They do have height limitations, and, if constructed from wood, eventually decompose, leaving vegetation alone to stabilize the streambank. This technique is applicable to Millers Creek, but will need to be combined with another treatment to treat the slope above them due to excessive bank heights.

Mechanically Stabilized Earth (MSE)

This technique consists of soil wrapped in natural fabric, e.g., coir, or synthetic geotextiles (Turf Reinforcement Mats (TRMs) or Erosion Control Blankets (ECBs)) or geogrids. The fabric wrapping provides the primary soil reinforcement; however, internal geogrid membranes placed at vertical intervals between the layers provide additional lateral soil reinforcement. The durability

of this structure varies widely and is dictated by the material used to form the soil encapsulation. Materials vary from light-weight, 100% biodegradable fabrics to rigid synthetic geogrids and facades.

This technique presents a lot of flexibility in terms of construction options and can be designed to meet a range of durability and environmental requirements. MSEs are an effective means of stabilizing streambanks while creating a near vertical face where space constraints require such. This technique is applicable to Millers Creek.

Geocell Wall

Geocell walls aggregate or soil filled synthetic cellular containment systems. They can be based solely on gravity or reinforced with geogrid. The leading edge cell can be filled with soil and vegetated. One advantage of geocell walls is that when filled with aggregate and manufactured with perforations, they drain readily after being wetted by high water, lending to their stability.

Geocell walls are applicable to Millers Creek.

Live Siltation

Live siltation is a bioengineering technique involving the installation of a living or a non-living brushy system at the water's edge. Willow cuttings are the most common. Live siltation construction is intended to increase roughness at the stream edge thereby encouraging deposition and reducing bank erosion. The embedded branches and roots also reinforce the bank, reduce geotechnical failure while the branches and leaves provide cover, aquatic food sources and organic matter.

Live siltation is a technique that is designed to stabilize the toe of an eroding streambank with vegetation alone. While desirable under some conditions and certainly environmentally friendly, techniques involving the use of vegetation alone are not applicable to Millers Creek.

Vegetation Alone

Vegetation can be viewed as a living, organic ground cover consisting of grasses/legumes, forbs, and/or woody plants. Vegetation is established on bare soils in order to help prevent surficial erosion, minimize shallow seated mass movement, provide habitat, and enhance aesthetics or visual appearance. Plant roots stabilize soils, plants dewater soil through transpiration, and above ground biomass intercepts rain and slows surface runoff that can otherwise cause rilling.

While desirable under some conditions and certainly environmentally friendly, techniques involving the use of vegetation alone are not applicable to Millers Creek.

Live Brush Layering

Live brushlayers are rows of live woody cuttings that are layered, alternating with successive lifts of soil fill, to construct a reinforced slope or embankment. Vertical spacing depends on slope gradient and soil conditions. Live Brush Layering provides enhanced geotechnical stability, improved soil drainage, superior erosion control and is one of the most effective ways to establish vegetation from live cuttings. Inherently, live brush layering in applications where soil from the streambank can be excavated and then replaced while incorporating the brush layers.

Live brush layering is an excellent means of using live plant materials to reinforce soil and establish permanent vegetation on streambanks. As noted with other techniques, vegetation alone is not applicable to Millers Creek, but this technique is applicable when combined with other techniques.

Live Staking

Live stakes are very useful as a revegetation technique, a soil reinforcement technique, and as a way to anchor erosion control materials. They are usually cut from the stem or branches of willow species and the stakes are typically 0.5-1.0 m (1.5 – 3.3 ft) long. The portion of the stem in the soil will grow roots and the exposed portion will develop into a bushy riparian plant. This technique is referred to as Joint Planting when the stakes are inserted into or through riprap. Live staking is a very flexible technique because it can be used to establish vegetation under a variety of conditions, particularly when excavation or the streambank is not desirable.

Live staking is an excellent means of using live plant materials to establish permanent vegetation on streambanks. As noted with other techniques, vegetation alone is not applicable to Millers Creek, but this technique is applicable when combined with other techniques.

Live Fascines

Live fascines are bundles of live (and non-living) branch cuttings placed in long rows in shallow trenches across the slope on contour or at an angle. Fascines are intended to grow vegetatively while the terraces formed will trap sediment and detritus, promoting vegetative establishment. Fascines can be utilized as a resistive measure at the stream edge and for erosion control on long bank slopes above annual high water. Fascines are also an effective way to anchor Erosion Control Blankets (ECBs) and Turf Reinforcement Mats (TRMs). Inherently, live fascines require an existing slope of 1:2 or flatter or, as is often the case, regrading of the existing streambank to a more stable slope.

Live fascines are an excellent means of using live plant materials to establish permanent vegetation on streambanks. As noted with other techniques, vegetation alone is not applicable to Millers Creek, but this technique is applicable when combined with other techniques.

Turf Reinforcement Mats

Turf Reinforcement Mats (TRMs) are similar to Erosion Control Blankets, but they are more permanent, designed to resist shear and tractive forces, and they are usually specified for banks subjected to flowing water. The mats are composed of ultraviolet (UV) stabilized polymeric fibers, filaments, and/or nettings, integrating together to form a three-dimensional matrix 5 to 20 mm (.2 to .79 in) thick. TRMs are a biotechnical practice, intended to work with vegetation (roots and shoots) in a mutually reinforcing manner. As such, vegetated TRMs can resist higher tractive forces than either vegetation or TRMs can alone.

TRMs can be used as permanent surface protection with vegetation on prepared slopes in lieu of temporary erosion control blankets. They can also be used to construct mechanically stabilized earth systems. TRMs are applicable to Millers Creek as a component or in combination with other techniques.

Erosion Control Blanket

Erosion Control Blankets (ECBs) are a temporary rolled erosion control product consisting of flexible nets or mats, manufactured from both natural and synthetic materials, which can be brought to a site, rolled out, and fastened down on a slope. ECBs are typically manufactured of fibers such as straw, wood, excelsior, coconut, or a combination, and then stitched to or between geosynthetic or woven natural fiber netting. Various grades of biodegradable fibers and netting can be specified depending on required durability and environmental sensitivity.

Erosion control blankets provided short to extended term surface protection on graded streambanks to allow plant establishment. They can also be used to construct mechanically stabilized earth systems. Erosion control blankets are applicable to Millers Creek as a component or in combination with other techniques.

Root Wad Revetments

Rootwad and tree revetments are structures constructed from interlocking tree materials. These structures are continuous and resistive type methods, distinguishable from discontinuous and redirective methods such as Large Woody Debris (LWD) structures or rootwad deflectors. Rootwad revetments and tree revetments are primarily intended to resist erosive flows and are usually used on the outer bank of a meander bend when habitat diversity is desirable and tree materials are available and naturally-occurring.

Root wad revetment is typically more applicable in situations where streambank erosion occurs in more remote or natural areas when the use of natural materials that can be gained on-site or nearby and that are more ecologically sensitive are most desirable. They are prone to decay and dislodgment. Root wad revetments are not considered applicable to Millers Creek.

Live Brush Mattress

A live brush mattress is a thick blanket (15-30 cm (6-12 in)) of live brushy cuttings and soil fill. The mattresses are usually constructed from live willow branches or other species that easily root from cuttings. Brush mattresses are used to simultaneously revegetate and armor the bank. The dense layer of brush increases roughness, reducing velocities at the bank face and protecting it from scour, while trapping sediment and providing habitat directly along the waters' edge. Brush mattresses are an excellent candidate for combining with structural techniques such as longitudinal rock toe protection.

Live brush mattresses can be a good way to establish vegetation and provide temporary surface protection lasting up to 12 months. It can be used in place of erosion control blankets to provide surface protection. Live brush mattresses are applicable to Millers Creek.

Vegetated Articulated Concrete Blocks (or Mattresses)

An Articulated Concrete Block (ACB) system consists of durable concrete blocks that are placed together to form a matrix overlay or armor layer. Articulated block systems are flexible and can conform to slight irregularities in slope topography caused by settlement. The blocks are placed on a filter course (typically a geofabric) to prevent washout of fines through the blocks. ACBs provide very little habitat enhancements alone, therefore these systems must be combined with

vegetation to be considered environmentally-sensitive. Vegetation in the form of live cuttings or grass plugs is inserted through openings in the blocks into the native soil beneath the blocks.

ACBs require slope preparation prior to installation. Therefore, they are not appropriate where space constraints will not allow bank regrading. Furthermore, they require riprap toe protection to prevent undermining and plant support is limited. The technique is applicable, but only where the bank can be back sloped.

Plain Riprap Revetment

Riprap revetment is a resistive technique that uses naturally-occurring weathered rock or crushed rock such as limestone. A variety of stone sizes can be used depending on site-specific flow velocities. Natural weathered stone is sometime more desirable due to its natural appearance, but typically requires large rock sizes due to its tendency to tumble and dislodge from the revetment face. Natural stone is often less available and more expensive to obtain as well. Crushed rock such as limestone is readily available in some areas, is less expensive, and tends to “lock” together within the revetment face better than weathered natural stone.

This technique has already been successfully used on Millers Creek to stabilize site HG13. This technique is applicable to Millers Creek except where slope flattening is not possible due to space constraints.

Soil Covered Riprap

Two configurations have been used: (1), an ordinary riprap blanket is covered with a layer of soil 30-60 cm (1-2 ft) thick from the top of the revetment down to base flow elevation, or (2), a crown cap of soil and plant material is placed over a riprap toe running along the base of a steep bank, effectively reducing bank angle. Soils used for fill should not be highly erosive. A variety of methods may be used to establish plant materials including hydroseeding, seeding and mulching, sodding, and incorporation of willow cuttings or root stock in the fill materials.

This technique could be applicable on Millers Creek above a certain design flow elevation. Millers Creek flows are too flashy to hold soils below a certain design flow elevation. Lastly, like plain riprap revetment, soil covered riprap would require back sloping, which is not possible at all sites.

Gabion Mattresses

Gabion mattresses differ from gabion baskets as they are shallow, (0.5-1.5 m (20-60 in)) deep, rectangular containers made of welded wire mesh, and filled with rock. Gabion mattresses are not stacked but placed directly and continuously on the prepared banks. They are intended to protect the bed or lower banks of a stream against erosion. A gabion mattress can be used as either a revetment to stabilize a streambank, or when used in a channel, to decrease the effects of scour. Live cuttings are introduced through the rock filled mattress and inserted into native soil beneath.

Gabion mattresses are similar to articulated concrete blocks. They are applicable in Millers Creek where bank sloping can be achieved.

Slope Flattening

Flattening or bank reshaping stabilizes an eroding streambank by reducing its slope angle or gradient. Slope flattening is usually done in conjunction with other bank protection treatments, including installation of toe protection, placement of bank armor, re-vegetation or erosion control, and/or installation of drainage measures. Flattening or gradient reduction can be accomplished in several ways: 1) by removal of material near the crest, 2) by adding soil or fill at the bottom, or 3) by placing a toe structure at the bottom and adding a sloping fill behind it. Right-of-way constraints may limit or preclude the first two alternatives because both entail either moving the crest back or extending the toe forward.

Slope flattening is applicable to Millers Creek where space constraints are not an issue. However, slope flattening has the potential to disturb existing vegetated buffers, at least until vegetation becomes re-established on the stabilized streambank.

Channel Realignment

Channel realignment involves physical channel changes to move the predominant flow path away from the toe of the streambank. It can be accomplished by constructing flood plain shelves using soils from off-site or by relocating existing in-stream sediments. Basically, a new stable channel margin is formed farther away from the streambank. Channel realignment can also involve removal of sediments to change the shape of the channel or remove in-stream bars or sediment deposits that are obstructing flows or directing flows toward a streambank.

Because Millers Creek has a highly unstable bed and streambank erosion is prominent, sediment tends to form numerous lateral bars and mid-channel bars where the channel is over widened. This problem can be addressed by manipulating the channel. Channel realignment is applicable to Millers Creek in some locations.

Grade Control Structures

Grade control structures are used to fix or raise the bed elevation for the purpose of adjusting the bed and water surface slope. The slope adjustments results in lower flow velocity and energy, thereby decreasing bed erosion along a reach. Grade control structures commonly used in stream restoration include cross-vanes, boulder weir, W-weir, and riffles. Wood and stone are common materials used to construct grade control structures, stone being the more common material.

River Training Structures

River training structures are structures used to alter the direction of flow, usually directing flow away from a bank or vulnerable infrastructure. Training structures are also used to center flow in the middle of the channel, thereby reducing near-bank stress, and maintaining the thalweg (deepest part of the channel) away from banks. In combination, training structures can also be used to maintain a meandering low-flow channel in a straightened channel.

Cross Vanes

Cross vanes (aka. vortex weirs) are "V" shaped, upstream pointing, rock structures stretching across the width of the stream. Cross vanes redirect water away from the streambanks, and into the center of the channel. This serves to decrease shear stress on unstable banks, as well as create aquatic habitat in the scour pools formed by the redirected flow. Cross vanes are designed to be

overtopped at all flows. The lowest part of the structure is the vortex of the "V", which is at the point farthest upstream. The crests are sloped 3-5% with the ends of the vanes keyed into the streambanks at an elevation approximate to annual high water or bankfull stage. This shape forms a scour pool inside of the "V". Cross vanes are particularly useful for modifying flow patterns, enhancing in-stream habitat, substrate complexity and providing in grade control. Double cross vanes (W weirs) are a variation suitable for wider channels.

Cross vanes could potentially be used in Millers Creek to control bed degradation in the vicinity of streambank stabilization sites. Cross vanes placed immediately downstream of streambank stabilization sites will flatten the upstream water surface, focus stream flow toward the middle of the channel, and stabilize the riverbed upstream of the structure.

Newbury Rock Riffles

Newbury rock riffles are ramps or low weirs with long aprons made from riprap or small boulders that are constructed at intervals along a channel approaching natural riffle spacing (5 to 7 channel widths). The structures are built by placing rock fill within an existing channel. The upstream slope of the rock fill is typically much steeper than the downstream slope, which creates a longitudinal profile quite similar to natural riffles. These structures provide limited grade control, pool and riffle habitat, and visual diversity in otherwise uniform channels.

Like cross vanes, Newbury rock riffles could be used to control bed degradation in Millers Creek. They are more ecologically friendly because they mimic natural riffles to some extent, but typically require more rock than a cross-vane.

Spur Dikes (barbs or spurs)

Spur dikes are transverse structures constructed of rock, woody debris or reinforced soil that extend into the stream from the bank and reduce streambank erosion by deflecting flows away from the bank. Spur dikes are discontinuous; that is, portions of the bank between the structures are often untreated. Transverse river training structures often provide pool habitat and physical diversity. Two to five structures are typically placed in series along straight or convex bank lines where flow lines are roughly parallel to the bank.

Spur dikes are not well suited for small, narrow streams that are incised because they require a steep top slope and excessive height relative to channel dimensions. Therefore, spur dikes are generally considered not applicable for Millers Creek.

Vanes

Vanes are deflective structures constructed of large woody debris or rock. They differ from transverse structures like spur dikes in that they are angled upstream into the flow at 20 to 30 degrees. Generally, two or three vanes are constructed along the outer bank of a bend in order to redirect flows near the bank to the center of the channel. Typically, vanes project 1/3 of the stream width. The riverward tips are at channel grade, and the crests slope upward to reach bankfull stage elevation at the streambank. Vanes are discontinuous; that is, portions of the bank between the structures are often not treated. Vanes can create habitat by increasing hydraulic diversity and generating streambed scour.

Vanes are not well suited for incised stream channels like Millers Creek because high flows contained in the incised channel at flows exceeding bankfull tend to erode streambanks above the elevation of the vanes and cause flanking. However, vanes may be used in some cases in Millers Creek if carefully planned and designed.

Bendway Weirs

Like spurs, bendway weirs are transverse deflective structures constructed of rock. They are designed to iteratively capture and then safely redirect the flow toward the middle of the channel throughout a meander bend. A minimum of five structures are typically placed in series along straight or convex bank lines requiring protection. Bendway weirs differ from spurs and vanes in that they form a control system all the way through the meander. Bendway weirs are generally longer ($1/3 - 1/2$ stream width) and lower than barbs or spurs, flat crested and are designed to be continuously submerged or at least be overtopped by the design flows. Transverse river training structures often provide pool habitat and physical diversity.

Bendway weirs are designed to manage the thalweg location throughout a stream meander bend. In Millers Creek, there is no defined thalweg in many locations. Furthermore, the thalweg is not the leading cause of streambank erosion. High energy flows is the leading cause. The bendway weirs would typically be submerged at these higher flows due to the way they are designed. Consequently, they likely would not prevent the streambank erosion observed in Millers Creek. In addition, they often create unpredictable “scallop” between the structures due to erosion. Bendway weirs are not applicable to the Millers Creek project.