The pages in this document were taken from the “Millers Creek Watershed Improvement Plan” published in April 2004. The entire document can be found at http://www.aamillerscreek.org/Findings.htm.

Millers Creek Watershed Improvement Plan

Excerpt Showing an Example of a Management Plan Purpose and Process Summary

April 2004

3.3 Methods

3.3.1 Field Work

Watershed Assessment

The watershed assessment included delineation of the watershed boundaries, including critical storm sewer connections and direct drainage. This included analysis of the AA GIS topographic map, review of the AA Storm Water Master Plan, and other design and construction drawings on record to locate storm sewer drainage divides. A field assessment of the condition of all detention ponds, wetlands and drainage structures was also conducted. Engineers inspected culverts, identifying the location of problems such as fallen end sections, undermined inlets and detention basins without extended detention. In addition, potential watershed problem and opportunity areas were identified (See **Appendices D, E and H**). The watershed delineation verification and the location of problem and opportunity areas were photographed and located using GPS technology (See **Appendix E**). Study sites were chosen during this process to represent the major tributaries and sections of Millers Creek (See **Figure 3.1**). Staff gages were installed at seven study sites. The Narrow Gage site was excluded (See **Appendix G**).

Flow, Water Level and Rain Measurements

HRWC developed rating curves for staff gages at seven study sites and for pressure transducers (water level recorders), at three of those study sites (Plymouth, Glazier and Meadows) by measuring flow with a current meter during a variety of flow periods from June 2002 until November 2002 (See **Figures 3.2** and **3.3** and **Appendix G**). Due to the rapidity

Figure 3.2. Volunteers measure flow at the study site near Huron High School.

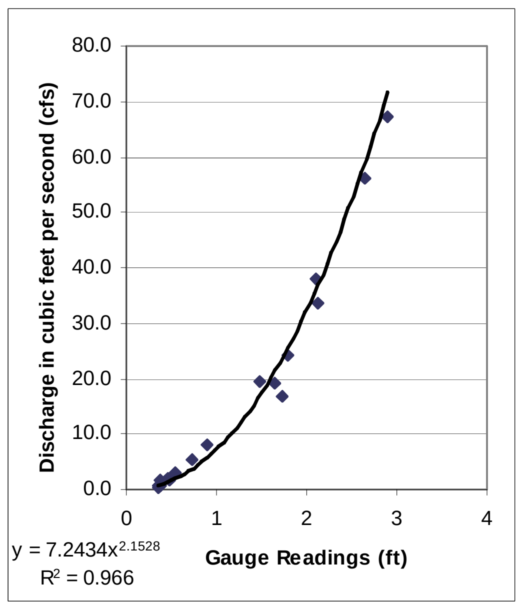

Figure 3.3. Rating Curve for Millers Creek near the Huron High School.

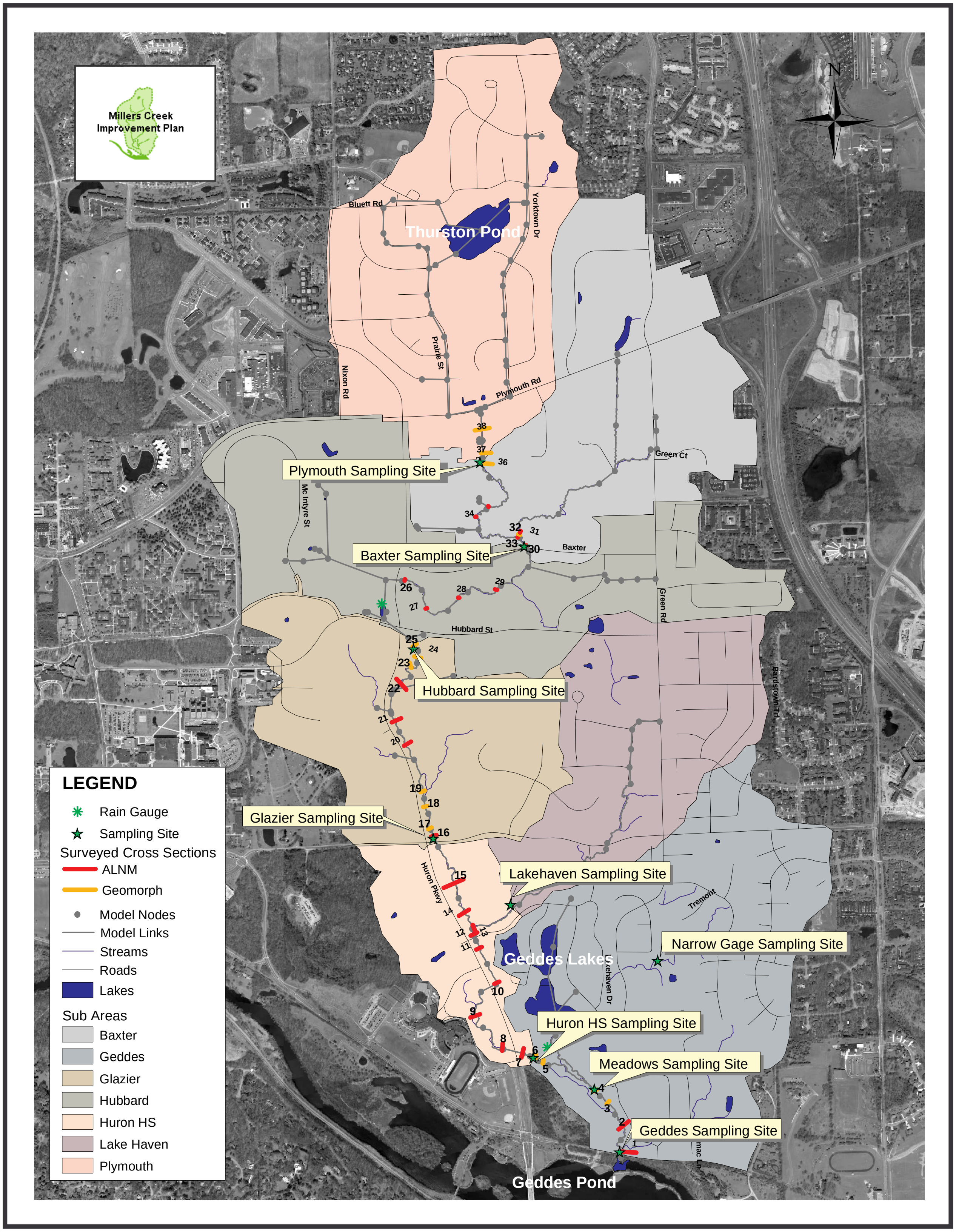

Figure 3.1 Subarea, Sampling Site, and Cross Section Locations

and magnitude of storm flows, velocity measurements during big events were conducted using a custom-designed bridgeboard. The bridgeboard enabled measurements from the shore without a bridge. Three pressure transducers (water level recorders) continuously recorded changes in water depth. Data was collected and analyzed over almost an entire year. Rain was measured at two sites with recording tipping bucket rain gages, one near the corner of Hubbard and Huron Parkway and one near the Atmospheric Sciences Building on the campus of UM. Pfizer also has a pressure transducer installed in the Huron Parkway wetland.

Stream Temperature
Submerged maximum/minimum thermometers were read weekly between July and August 2002 to characterize the extremes and fluctuations in stream temperature during the summer.

Stream Bed and Cross-Section Survey
A bed profile and cross-section survey of the main channel of Millers Creek was conducted (See **Appendices E and I** for data). The survey started at the Plymouth Road culvert near Green Road and extended to the creek mouth at Geddes Road. Traditional surveying methods were used and tied into USGS vertical benchmarks (NGVD29). Horizontal location of the stream centerline was located by GPS and by aerial photography. The profile survey included cross sections at 500 to 1,000 foot intervals. ALNM provided the benchmarks for the HRWC geomorphology study. Huron River water surface elevations were interpolated from the 1983 FEMA study. Where needed, additional elevations were interpolated from the City of Ann Arbor GIS 5-foot contour topographic map. The Project Team also provided vertical control survey for the staff gage and transducer locations (see **Fig. 3.4 and Appendix G**).

Figure 3.4 A volunteer installs a transducer at the Meadows study site.

Geomorphology Study
Using a level and rod, HRWC teams measured the geomorphic characteristics of the channel along three permanently marked cross-sections at five study sites (Plymouth, Hubbard, Glazier, Huron HS and Meadows) in June through November 2002. The teams located bankfull, edge of the water, thalweg (lowest elevation) and, inflection points at each cross-section. They also measured the slope of the stream in the surveyed stretch. Team accuracy was demonstrated by repeating measurements at each transect by a different team at least once during the summer (**Figure 3.5 and 3.6**).

Figure 3.5. Volunteers measure geomorphology at the Hubbard Site

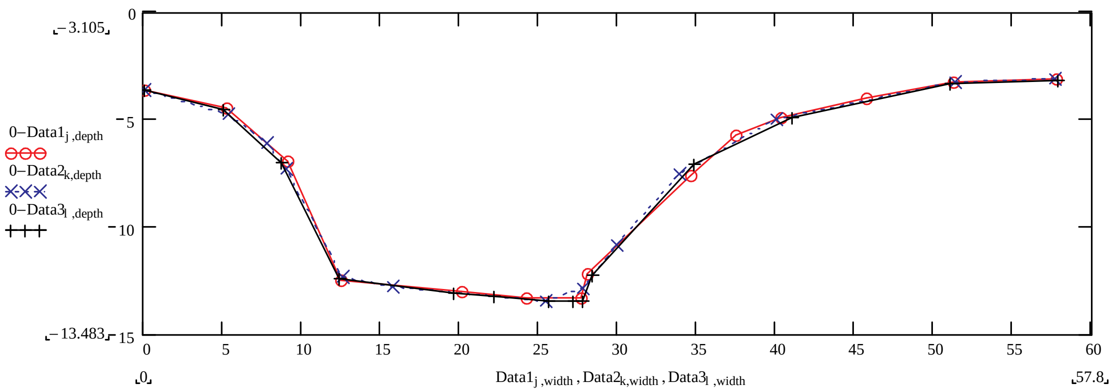

Figure 3.6. The shape of the channel at the upstream transect at the Glazier study site.

(Red circles show the results of team #1 on June 16th, 2002, blue x's show the measurements by team #2 on July 13th, 2002 and black +'s show the measurements by team #3 on July 26th, 2002.)

Sediment Sampling

Field sediment samples were collected at the Plymouth, Baxter, Hubbard, Glazier, Huron HS and Meadows sampling locations along the creek (See **Appendix I**). Samples were collected close to a stream gage. All samples were collected with a large concave spade with a metal "guard" on the handle end of the spade. Samples were taken by sinking the spade into the sediment at the base of the stream at a low angle into the flow of the stream and penetrating about 1-inch into the substrate. As the sample was pulled to the surface, the metal guard prevented suspended sediment from escaping the spade. Samples were collected across the entire width of the stream with sub-samples taken at every spade width.

For fine sediments (silts and clays), samples were wet sieved and measured with a hydrometer. Coarse samples were put through up to 14 wire mesh sieves, with the largest opening on top and a collecting pan on the bottom. The sieves were mounted, in a stack, on a sieve shaker and allowed to shake for up to 10 minutes. The total sediment retained on each sieve was weighed and used to calculate the grain size distribution.

Macroinvertebrates and Habitat

HRWC volunteers, led by trained collectors, sampled the diversity of the macroinvertebrate population at eight study sites during April 2002 and 2003, and September 2003 and also sampled winter stoneflies during January 2003 (See **Appendix J**). Collectors used a D-net to sample all habitats present at each site. HRWC volunteers measured in-stream habitat at all eight study sites. The habitat quality was scored using the nine measures identified in the Department of Environmental Quality's (MDEQ) Procedure 51.

Bank Stability/Riparian Corridor Evaluation

An inventory of the bank stability, riparian corridor vegetation (species, quality) and adjacent land use influences was conducted (See **Appendix I**). The overall creek corridor was assessed for character quality, identifying the high, medium and low quality areas, based on the various parameters collected during the inventory phase. High quality areas were utilized as reference for potential restoration areas and additional storage areas (detention, wetlands, etc.). The methods for these efforts are described below.

Streambank Erosion Evaluation Methods

A set of six criteria were used for evaluating streambank erosion potential and severity (**see Table 3.1**). Millers Creek was mapped based on the potential for erosion on a reach-wide basis. Reaches were typically defined by the study sites, road crossings and other major geomorphic boundaries (e.g., changes in channel form). During this process, TAI used GPS to map the location of severely eroding streambanks.

Figure 3.7 Elevated Plant Root Zone

Distance from Bed to Vegetative Root Zone

The bed of Millers Creek has eroded due to channelization and increased peak flows. Consequently, the plant root zone is elevated above Millers Creek in many areas (**See Figure 3.7**). Because plant roots are important in stabilizing soils, this condition makes streambanks more susceptible to erosion. The portion of the streambank that is exposed to flowing water does not contain a dense plant root matrix. The degree of bed downcutting varies throughout the watershed. Therefore, the height of the bank between the bed and rooted zone also varies. Streambanks become more susceptible to erosion as this distance increases.

Table 3.1 Criteria and scoring methodology for assessing streambank erosion in the Millers Creek corridor.

Criteria	Erosion Potential & Severity			
	1 Low	3 Moderate	5 High	7 Extreme
Distance From Bed to Vegetative Root Zone	0 feet	<1 foot	1 to 3 feet	>3 feet
Soil Erosion Potential	Low	Low/Moderate	High/Moderate	High
Average Reach Velocity	<3 ft/sec	3 to 4 ft/sec	4 to 5 ft/sec	>5 ft/sec
Vegetative Cover Type	tree/shrub/forb	shrub/forb/tree	forb/shrub	Forb
Presence and Status of Existing Erosion	0%	<25%	25% to 75%	>75%
Proximity to Structures or Infrastructure	>100 feet	50 to 100 feet	25 to 50 feet	<25 feet
Total Score	**6-15**	**16-25**	**26-34**	**35-42**

Soil Erosion Potential
Streambanks have some potential to resist erosion due to soil mechanics and presence of roots. At the extremes, clay has low erosion potential while sand has high erosion potential. Clay soils are present in the bed and banks of Millers Creek in many locations. Sandy loams are the dominant soil types in other areas. Fibrous peat is present in streambanks in some isolated reaches.

Average Reach Velocity
Flow velocity in Millers Creek is dependent upon many natural geomorphic variables but is primarily controlled by bed slope. The most important human-induced factor affecting flow velocity in Millers Creek is channel constriction, including enclosures or culverts (See **Figures 3.8 (a) and (b)**). Large sections of Millers Creek are enclosed in culverts where it is crossed or encroached upon by roads and other infrastructure. These culverts constrict flow and increase velocity. Artificially high flow velocities in Millers Creek cause bed and bank erosion. Typically, frequent flow velocities greater than 3 feet per second (fps) can begin to degrade the bed and banks of Millers Creek. In addition to culverts, contributing storm sewers discharge at high velocity into Millers Creek. This criteria was evaluated by averaging the velocities at each model node within a given reach as computed by the SWMM hydraulic model (refer to **section 4.2**).

Figures 3.8 (a) and (b) Examples of Large Concrete Culverts in Millers Creek

Vegetative Cover Type
Vegetated streambanks have a good root matrix that helps bind soil particles together and resists erosion. The type, density, and depth of the root matrix depend on the presence and type of vegetation growing on the bank. The ideal vegetative cover contains plants from the three community types: trees, shrubs, and forbs (wildflowers and grasses). A blend of these community types is present along streambanks throughout much of Millers Creek. However, the tree and shrub communities are lacking in some areas (See **Figure 3.9**). Reaches with turf grasses have the highest potential for erosion. Reaches dominated by the tree-shrub communities have the lowest erosion potential.

Figure 3.9 Example of the Vegetative Cover along a stretch of Millers Creek where trees are lacking

Presence and Status of Existing Erosion
The presence and severity of existing erosion throughout each reach was evaluated based on the amount of exposed soils in the bank. This value ranged from 0% to greater than 75%. Banks with exposed eroding soils over more than 75% of their surface area received the highest scores.

Proximity to Structures or Infrastructure
Due to corridor encroachment, roads, pedestrian safety paths, and buildings can be threatened by eroding streambanks. The worst-case scenario exists when structures are in close proximity to a severely eroding streambank. Reaches with eroding streambanks that are close to structures had a higher severity; that is, treating those banks should be a high priority.

Scoring
The above criteria were evaluated on a four-point scale: 1-low, 3-medium, 5-high, or 7-extreme (See **Table 3.1**). Then, the scores were summed for a total ranking score. Total scores could range from a low of 6 to a high of 42. The total score was then parsed to determine ranking categories of low, medium, high, and extreme.

Watershed Land Cover Assessment Methods
A detailed map of existing land cover for the Millers Creek watershed (See **Chapter 5**) was prepared. Primary data sources included interpretation of 2002 aerial photographs obtained from the City of Ann Arbor, MI, and field observations. All features interpreted from aerial photography were digitized using Arc Map Versions 3.2 & 8.2. Field observations were conducted from August 2002 to August 2003.

Wetlands within the watershed were mapped using primary and secondary sources. The following secondary sources were combined with aerial interpretation and field observations to derive approximate wetland boundaries: City of Ann Arbor Planning Department, wetland map; Washtenaw County Planning Department wetland map; and the Michigan Spatial Data Library, National Wetlands Inventory map. Approximate wetland boundaries were then combined with cover type to derive wetland types.

Stream Corridor Vegetation Assessment Methods
An inventory of existing vegetation within the Millers Creek stream corridor was performed (See **Appendix E** for data). Primary data sources for the vegetation inventory were field observations and interpretation of 2002 aerial photography (See **Watershed Land Cover Assessment Methods**). Secondary data sources included: the "University of Michigan Campus Plan Environmental Planning Study – North Campus and Surrounding Area" prepared by Andropogon Associates, Ltd & Turner Environmental, Inc., 1999; and "Pfizer 55-Acre Site Natural Features Inventory" prepared by Plantwise Native Landscapes and Ecological Restoration, 2001.

The entire length of Millers Creek and all of its tributaries were walked and inventoried. The stream corridor inventory included all vegetated communities within 100 feet of the stream edge. Significant natural plant communities that extend beyond the 200-foot stream corridor were also inventoried. Information collected includes: plant community type(s), structural diversity, dominant and unique plant species, presence/abundance of invasive species, and the presence/abundance of vegetation at the stream edge. Man-made urban encroachments to the stream corridor were also inventoried. The stream corridor vegetation assessment is subdivided based on stream reach.

Water Quality Monitoring
Two dry weather surveys and three wet weather water quality surveys were conducted between August and October 2002. Successful wet weather capture was facilitated by real-time rainfall forecast data available via the internet (See **Figure 3.10**). Water quality grab samples and staff gage readings were taken at six of the study sites during these surveys. A Quality Assurance Protection Plan (QAPP) preceded data collection to provide assurance that all data was

collected consistently and properly (See **Appendix A).** The QAPP included guidance for water quality monitoring including the use of duplicates, trip blanks, spike recoveries, etc., per USGS guidance (Lurry and Kolbe, 2000). Hand-held meters were used to analyze the samples for temperature, conductivity, pH, and dissolved oxygen. Other parameters included total suspended solids (TSS), total phosphorus, orthophosphate, and *E. coli*. The three wet weather events included a 1.78-inch rainfall in 48 hours; a 0.35-inch rainfall in six hours and 0.2-inch rainfall over five hours. Ten to twelve samples were grabbed at each station for all the water quality surveys. When possible, HRWC assisted in taking staff gage readings and measuring flow, conductivity and temperature during dry and wet weather events. In addition, limited ammonia source sampling was conducted in several detention ponds near Plymouth and the east branch of Millers Creek.

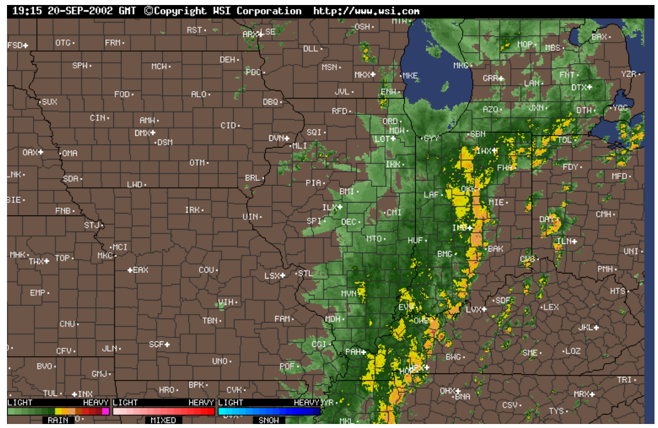

Figure 3.10 Radar Image of 9-20-02 Rainfall

3.3.2 Modeling

Hydrologic/Hydraulic Model

Stormwater and Wastewater Management Model (SWMM) RUNOFF and EXTRAN, the hydrologic and hydraulic sub-models of the U.S. EPA SWMM were used to simulate Millers Creek, its watershed and associated storm sewer. SWMM was used to estimate flow, velocity, water surface elevation, width, total area, hydraulic radius and shear stress for design recurrence interval events, including first flush (0.5 inches in six hours), 1-year (2.1 inches in 24 hours), 2-year (2.5 inches in 24 hours), 5 year (3.0 inches in 24 hours), 10-year (3.4 inches in 24 hours) and 100-year (4.9 inches in 24 hours).

RUNOFF input was compiled from local land use and land cover maps, Soil Conservation Service (SCS) soils maps, aerial photography and field reconnaissance. EXTRAN input was compiled from construction and as-built drawings, channel survey data, field reconnaissance and the flow gaging and transducer data.

RUNOFF input parameters such as percent impervious and pervious and impervious storage (interception losses and microtopographical surface storage) were adjusted to calibrate the SWMM model to measured runoff volumes. Calibration of the RUNOFF model to measured flows tended to calibrate the EXTRAN model to measured flow depths. Fine-scale calibration of EXTRAN-computed flow depths was done by adjustment of open channel Manning's n values Refer to **Chapter 4 – Model Evaluation** for more detail on the hydrologic/hydraulic modeling of existing conditions.

Water Quality Model

Contaminant loads were estimated using a mass balance model. SWMM was used to estimate flows and total suspended solids (TSS) concentrations at the six sampling stations on Millers Creek.

Total phosphorous (TP) concentrations were estimated using a correlation between TP and TSS. The mass balance model was used to compute TSS and TP loads passing through each sampling station. Flows and TSS concentrations coming from runoff nodes and offline nodes and ponds were summed at each station. TSS removals were calculated explicitly in the modeled ponds. Particle size distributions and average holding times were used to estimate pond removals.

The model was calibrated to the total suspended solids (TSS) and total phosphorus (TP) in-stream concentrations measured during the dry and wet weather events. Model calibration was accomplished by adjusting the unit area build-up and wash-off estimates of TSS for each subwatershed. Refer to **Chapter 4 – Model Evaluation** for more detail on the water quality modeling of existing conditions.

3.3.3 Public Involvement

Public involvement efforts included a website, a telephone hot-line, direct mailings, three public workshops, a business breakfast and stream walking tours. Public involvement was initiated by working with the Project Team to produce a series of informational brochures that would complement the City of Ann Arbor's storm water education permit program. Methods for this and the other efforts are described below.

Website and Hot-line

ALNM initiated and maintained a project website and a telephone hot-line to foster public information exchange. The telephone hot-line included various messages on the project and related activities and recorded messages from callers. The HRWC tracked the messages and made replies when needed.

Direct Mailings

Over the course of the Millers Creek Watershed Improvement Plan Project, the Study Team communicated with the approximately 5,000 residents (both homeowners and renters) of the Millers Creek Watershed via five direct mail pieces. The direct mailings and survey responses are located in **Appendix B.** The mailings were sent in August and October 2002, and January and July 2003. The final mailing is scheduled for delivery in February 2004. The mailings were intended to increase people's awareness of the Creek, to inform them of the improvement study and its progress, let them know about opportunities for their input and share ideas of everyday things that individuals can do to improve Millers Creek. In addition, the mailings were used to invite residents to the three Millers Creek Open Houses and two walking tours of the creek and to distribute the Millers Creek Survey. This survey asked for their concerns about and hopes for the Creek, if they wanted someone to contact them directly about the Study and the Creek, and if they wanted to participate in monitoring the conditions in the Creek. The study team mailed a postcard reminder of each Open House and information about the walking tours of the creek one to two weeks after residents received the initial brochure.

Public Workshops

The Millers Creek Study Team hosted three public workshops, called Open Houses, on October 30, 2002, February 12, 2003 and July 23, 2003. Total attendance at these functions was 130, 85 and 70, respectively. These events provided a creek "fair" atmosphere, packets of information on the project and face-to-face interaction between the public and the professional staff responsible for this study. The Open Houses featured display tables from the various groups working on issues that positively impact water quality as well as the Millers Creek Study Team. During the three Open Houses, the Study Team presented background on the Creek and the Improvement Plan, the project goal statement, initial findings of the study and specific recommendations/alternatives included in the draft plan. Attendees were asked for feedback on the goal statement and recommendations and to participate in facilitated small groups to share ideas about direction for the Improvement Plan. Evaluation reports and other feedback are found in **Appendix B.**

Business Breakfast
During March 2003, the Study Team invited representatives from 28 businesses and six bank branch offices within the Millers Creek Watershed to a “Millers Creek Breakfast,” (See **Appendix B**). Representatives from 10 businesses attended an hour and a half meeting featuring remarks by Mayor John Hieftje and Dr. David Canter (Senior Vice President of Pfizer and Director of the Ann Arbor Laboratories), an overview of Millers Creek and the Improvement Study, and a discussion of opportunities for their involvement (See **Appendix B** for details of business commitments).

Walking Tours
The Millers Creek Action Team held two walking tours of Millers Creek on November 3, 2002 and July 23, 2003. These tours offered those who live and work within the Watershed an opportunity to become familiar with the distinctive features of the landscape and some of the Creek’s most interesting characteristics from people who had studied Millers Creek. The first tour was publicized by an announcement in the Ann Arbor News, information in a direct mail postcard, and information on the phone hotline and the website. Announcement posters for the second tour were posted in area businesses and information was included in the fourth direct mail brochure, on the phone hot-line, and on the web.

3.3.4 Alternatives Analysis
The Study Team identified and analyzed a core list of watershed improvement opportunities using the methods described in detail in **Chapter 6 and Chapter 7.**

4. MODEL EVALUATION

Three computer models were used to evaluate existing conditions, a proposed build-out scenario and five alternative improvement scenarios. The first two models are part of the RUNOFF and EXTRAN U.S. EPA's Stormwater Management Model (SWMM). The third model is a custom water quality mass balance routine. All model inputs and calculations and results can be found in **Appendix C**. The RUNOFF model estimates the timing, flow rates and water quality of runoff. The EXTRAN model routes runoff through the pipes, ponds, and open channels that discharge to and comprise Millers Creek (**See Figure 4.1**). The custom water quality model applies the RUNOFF water quality loads as input for mass balance calculations that "moves" pollutants through a simplified Millers Creek channel and calculates pollutant settling losses in detention ponds. RUNOFF, EXTRAN and the custom mass balance model were calibrated to the collected flow, water surface elevation and total suspended solids and total phosphorus concentration data collected during the dry and wet weather calibration events.

4.1 Model Calibration

Model calibration is the process of achieving a correspondence between model estimates and field data. Correspondence means the model re-creates the behavior, the maximums and minimums, the variability and the timing of field observations, within some degree of acceptable deviation. For the Millers Creek SWMM models, there were three steps and three data sets for calibration. The goal of the first calibration step was to achieve agreement between measured and calculated peak flow rates and total flows. The second calibration step, partly a refinement of step one, was to adjust the assumed roughness of the channel to more closely match predicted water depth results with data. The third calibration step was to determine pollutant loading rates and concentrations that corresponded with dry and wet weather water quality grab samples.

4.1.1 Hydrologic Model Calibration

The first calibration step consisted of systematic adjustment of two critical hydrologic parameters in the RUNOFF model: the percent of directly connected impervious area (DCIA) and abstraction loss over pervious areas. Abstraction losses occur when rainfall is intercepted before it hits the ground, such as capture by leaves, stems or branches; or when rainfall hits the ground but only serves to fill small depressions in the ground before running off the landscape. Adjustments to these two parameters were made in effort to match both peak flows and total flow over each event of the wet weather water quality monitoring.

All three wet weather events were used in the calibration; however, the calibration effort focused predominantly on the data from the 3 continuous-recording pressure transducers. Comparisons were also made with the readings from the staff gages, but the continuous recording of the transducers provided the most detailed data for assessing correspondence between measured and modeled peak flows and total flow.

The percent of impervious surface area was calculated by summing up all areas of impervious surfaces delineated from the City of Ann Arbor 2002 aerial photograph. The percent of impervious surface area was estimated to be approximately 35%. The high level of detail expended in the description of land use and land cover resulted in a close correspondence in peak flows and volumes before any adjustment of calibration parameters. The calibrated DCIA was 24%. By comparison the calibrated DCIA for the recent Mallets Creek study was 24% (ECT, et al., 2000).

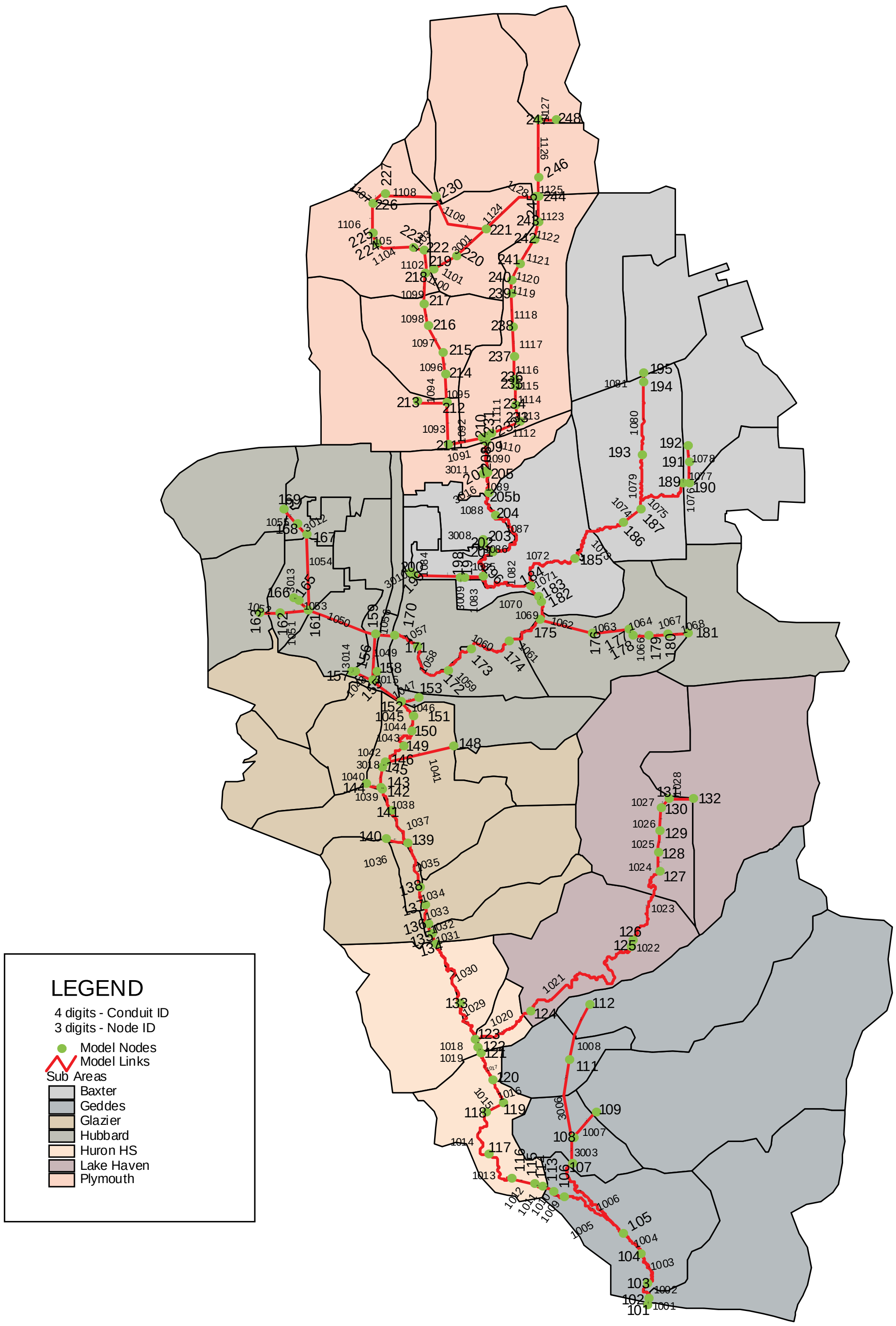

Figure 4.1 SWMM Model Schematic (with sub areas shown)

Before calibration, all pervious area depression storage was set at the recommended (Huber and Dickinson, 1988) average value of 0.1 inches; this means, the first 0.1 inches of rainfall is "permanently stored" over a given area before runoff commences. Additional pervious storage was simulated by assuming that a totally forested watershed during the growing season could intercept and store up to 0.5 inches. Additional pervious area storage for each subwatershed was calculated by multiplying the difference between the recommended default value and the assumed maximum interception and depressional area storage of a mature forest (0.5 inches), and the percentage of the subwatershed area covered by forest. Natural forests' canopy interception ranges from 15% to 40% of annual precipitation in conifer stands, and from 10% to 20% in hardwood stands (Zinke, 1967).

Examples of the calibration fits are shown in **Figures 4.2-4.4** below. In **Figure 4.2** event peak flow observations are plotted against model calculations and a best-fit regression line drawn through the points. Note that a line slope of 1 translates into an exact match between the model estimates and data, and the r^2 value (correlation coefficient) represents the strength of the regression comparison. The peak flow regression slope is 0.96 and the r^2= 0.97. The total volume fit regression slope is 1.17 with an r^2 = 0.99. Note also that the model slightly under-predicts peak flow and slightly over-predicts total volume. Final calibration was a compromise between matching peak flows but not excessively over-predicting total flow through the system. In **Figure 4.3**, calculations are plotted for the first calibration event at Glazier.

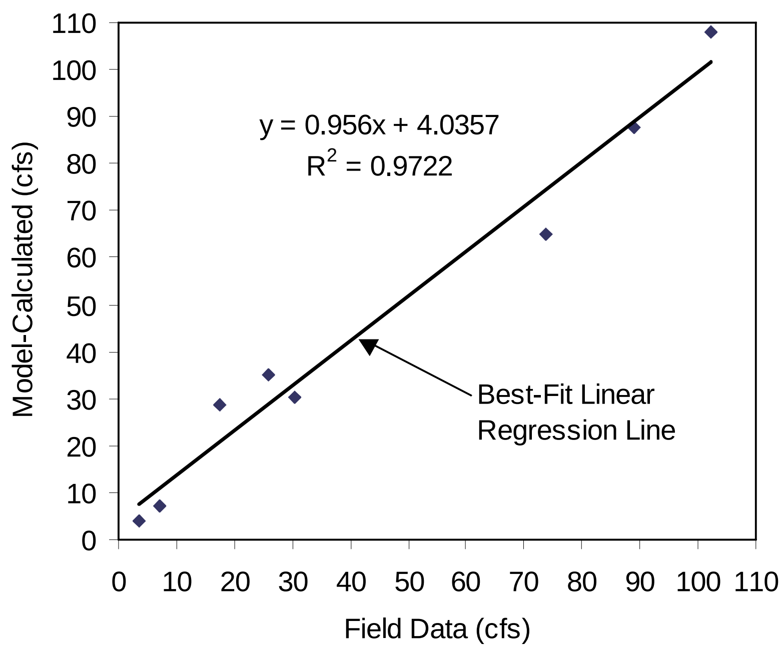

Figure 4.2 Comparison of Model-Calculated and Measured (by transducer) Peak Flow Rates for the three calibration events at the Plymouth, Glazier and Meadows Sites
Note: Meadows flow estimated for comparison purposes using Huron HS site stage-discharge relationship

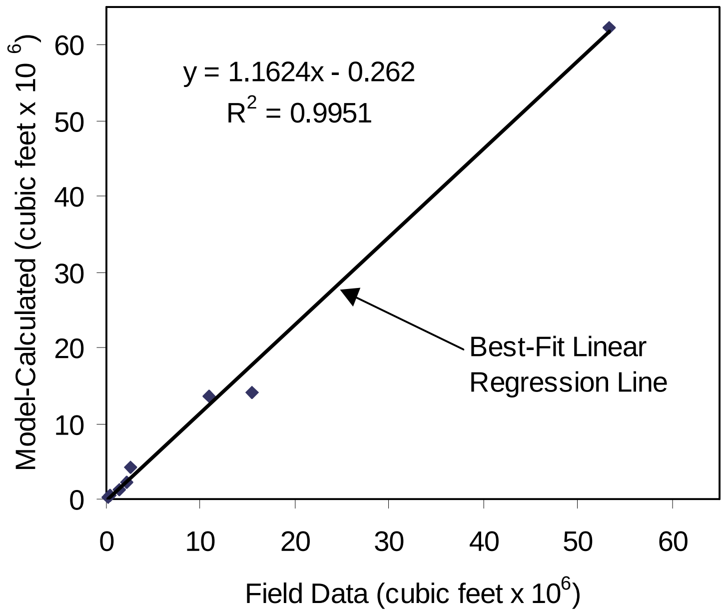

Figure 4.3 Comparison of Model-Calculated and Measured (by Transducer) Total Event Volume for the three calibration events at the Plymouth, Glazier and Meadows Sites
Note: Meadows total event volume estimated for comparison purposes using Huron HS site stage-discharge relationship

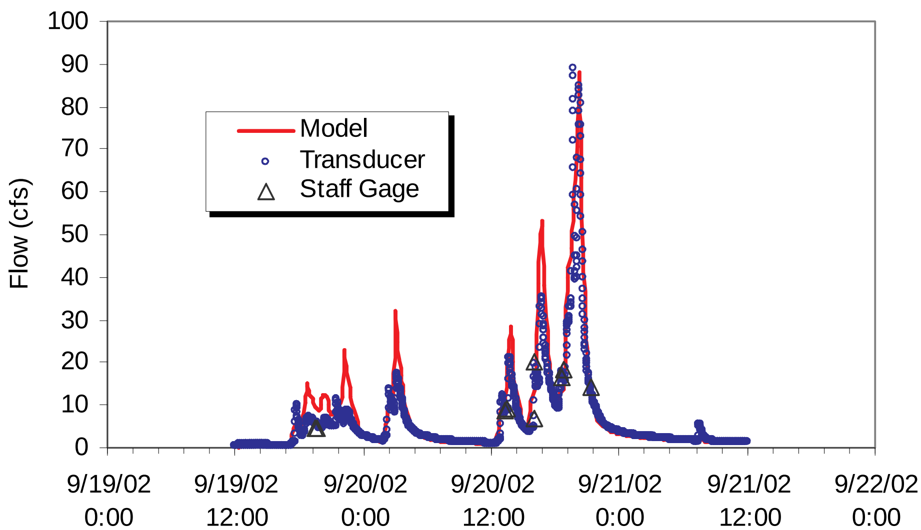

Figure 4.4 Example Flow Calibration Fit, Event 1 (Sept.19-21, 2002) at the Glazier Site

4.1.2 Hydraulic Model Calibration

The second calibration step entailed fine-tuning calibrating water depths by adjusting the Manning's "n" (or friction factor) value of the channel reaches in the EXTRAN model. This friction factor combines all factors that cause energy loss in streams due to friction into one number. Energy loss due to friction occurs at the interface between the moving water and its stream beds, banks and obstructions. Stream channel elements that cause energy losses due to friction are stream sinuosity, bed form such as step-pools, riffles, and small dunes, bed grain size, channel vegetation, and obstructions. From decades of hydrologic research, average values for stream types have been developed that produce acceptable results.

One critical determinant of the friction factor is the depth of flow. The lower the flow, the lower the water surface elevation and the higher the ratio of bed contact area to the total cross-sectional area of the flow. This means that as flows decrease the ratio of energy loss to the volume of moving water increases. Recognition of this fact played an important role in reconciling some of the variation between model results and field data.

Very little adjustment was made to the roughness coefficient in most of the model channel segments. One reach where some adjustment was necessary was just upstream of the staff gage at the Hubbard site. This reach includes a large scour pool, a significant expanse of large riprap (angular stone) and a stream bed composed mainly of coarse, granular particles. There is some uncertainty associated with how these various factors interact to affect the stream elevation at the gage. To better match flow depths, the roughness coefficient in this reach was increased by approximately 25%.

At the Plymouth and Glazier sites, apparent discrepancies between model-predicted depths of flow and transducer readings instigated a detailed investigation of the channel model at these locations. An analysis was conducted to determine how sensitive the model was to a systematic variation of channel model parameters. Parameters studied included the friction factor, bed slope, and the shape of the cross-section. Flow depths were somewhat sensitive to the fraction factor, slightly more sensitive to shape and very sensitive to slope.

At low flows (< 10 cfs), the model under-predicts flow depths, while at high flows (>50 cfs), the model over-predicts flow depths (See **Figure 4.5** below). We found that the discrepancies between model flow depths and observations at low flow depths were less than 6 inches. At the highest observed calibration flows the discrepancies could be slightly higher than 6 inches.

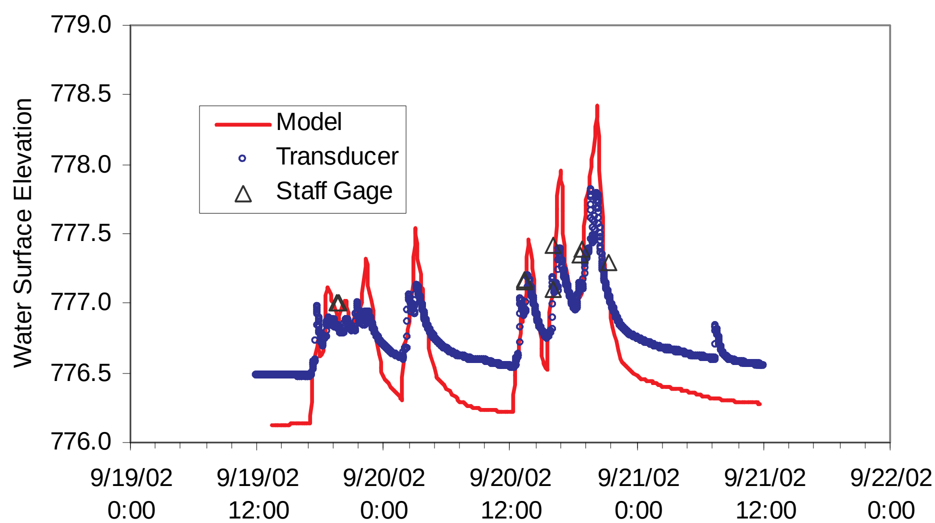

Figure 4.5 Example Water Surface Elevation Calibration Fit Event 1 (Sept.19-21, 2002) at the Glazier Site

The U.S. Army Corps Stable Analytical channel Model (SAM) was used to independently calculate Mannings n as a function of flow and bed sediment size. SAM simultaneously estimates the friction factor (based on the bed sediment grain size) and the water surface elevation. The SAM-calculated friction factor at Glazier for flows between 1 and 87 cfs ranged between 0.034 and 0.083 and decreased as flows increased. The SAM calculations demonstrated that, in general, the friction factor is inversely dependent on flow depth. In particular, for a channel like Millers Creek with very low base flows (approximately 1 cfs or less), the flow depths are in terms of inches and bed material, such as gravels and cobble, act as significant flow obstructions. The water is not necessarily flowing over some of the material, but rather around it, significantly increasing energy losses.

SWMM, like many open channel hydraulic models, applies one friction factor for all flow depths (except for overbank flows). For instance, at Glazier the friction factor was set at 0.04. The conclusion is that the lack of an adjustable friction factor limits the model's accuracy for estimating water depths at the extreme flow ranges for relatively narrow streams. Since this evaluation is focused more on understanding and managing high flows rather than low flows, this model drawback was not considered an impediment to understanding hydrology and hydraulics of Millers Creek. For high flows, the model's over-estimation of peak water surface elevations provides a conservative estimate of shear stress and flood elevations.

4.2 SWMM Model Results Summary

Model calculations for peak flow, average cross-section velocity and the 100-year floodplain for the main channel of Millers Creek are summarized in this section. **Figures 4.6 and 4.7** below summarize the calibrated model peak flow and peak velocity estimates for existing conditions. Glazier and Hubbard, the most geomorphically unstable sites, show consistently increasing velocities with increasing flows. Meadows and Geddes, the sites experiencing the most overbank flow, show decreasing velocities with increasing flows for events larger than the 1-year and 2-year storms. During larger storm events backwater from the Huron River is likely contributing to overbank flows and decreasing velocities at these downstream stations.

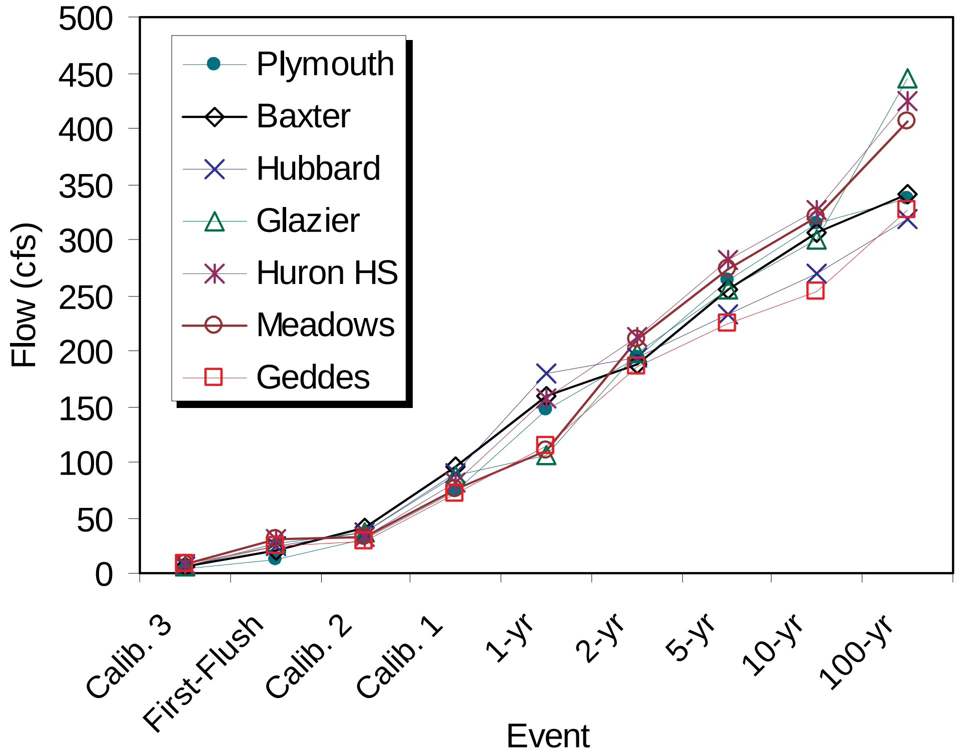

Figure 4.6 Model-Estimated Peak Flow Rates for All Existing Conditions Events

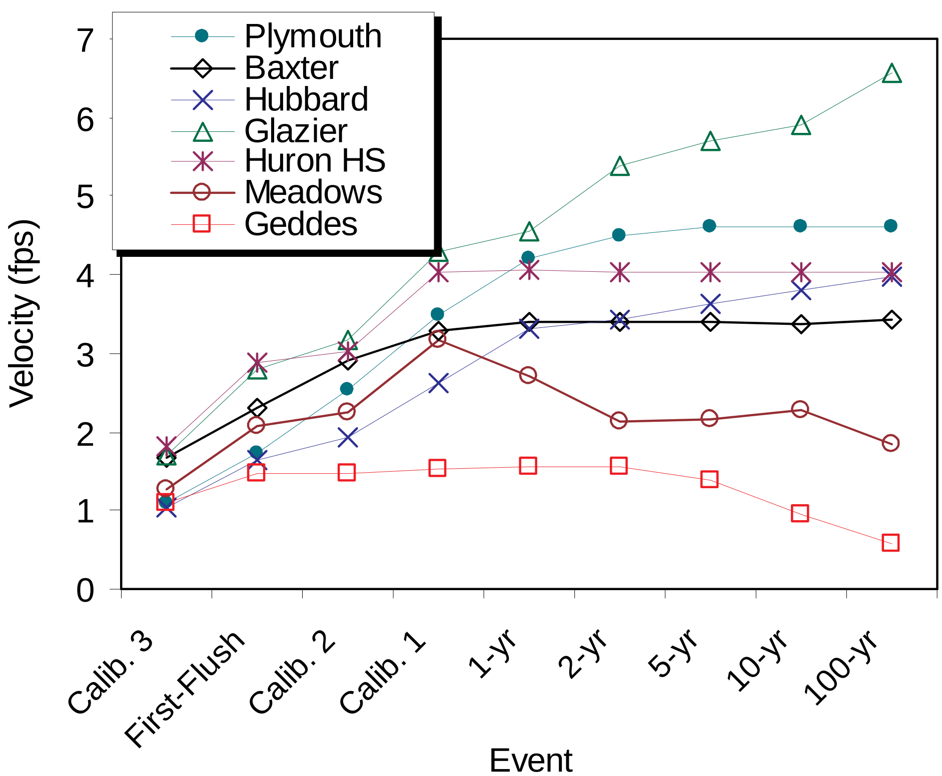

Figure 4.7 Model-Estimated Peak Velocities* for all Existing Conditions Events
(model velocity defined as the average across the channel)

4.3 Water Quality Model

Simulation of urban runoff quality is an inexact science. Uncertainties arise both in the representation of the physical, chemical and biological processes and in the acquisition of data and parameters for model algorithms. The method we selected to simulate runoff water quality using RUNOFF has shown some effectiveness in calculating pollutant loads. We chose to simulate both the "buildup" of pollutants on land surfaces and "washoff" during storm events. Water quality was simulated for the first flush, 2-year, and 10-year design events.

These loads were routed using a simple mass balance approach. RUNOFF solids loads were "moved" through the storm sewer and open channels by displacing their location in time station by station. This was done by dividing the distance between two sampling stations by an assumed average velocity (typically 2 feet per second) to derive the displacement time of the upstream station's pollutograph (the mass solids load as a function of time). After displacing the upstream load in time, it was then added to the pollutograph calculated at the downstream station. The new downstream station pollutograph was then displaced in time to "arrive" at the next downstream station and summed with that station's pollutograph, and so on, from station to station.

Total suspended solids (TSS) and total phosphorus (TP) removal of all significant ponds in the watershed, including the Pfizer ponds, Thurston Pond and Geddes Lake, were estimated explicitly. The TSS and TP removals were derived from average holding time calculated for each pond for each event, an assumed particle size distribution (from Washtenaw County NURP sampling, ECTC, 1983) and average pond depth (typically ~ 3 feet). Average holding time was calculated as the difference in time between the center of mass (centroid) of the pond inflow hydrograph and the center of mass of the pond outflow hydrograph (Guo and Adams, 1999). The time required for a particle to settle out (reach the pond bottom) was compared to average holding time. If holding time exceeded required settling time, then that particle was assumed to have settled out. Settling time to holding time was compared for the entire particle size distribution, and the percent removed was equal to the total fraction of particles in the distribution settled out. Additional ponds were added for the alternatives analysis, and those ponds and their impacts are covered in Chapter 7.

4.3.1 Water Quality Model Calibration

Runoff water quality models typically represent the generation of runoff pollutant loads as the product of pollutant build-up on surfaces and the resultant wash-off of pollutants during runoff-producing events. The mechanisms of buildup involve factors such as wind, traffic, atmospheric fallout, land surface activities, erosion, street cleaning and unaccountable activities. Although efforts have been made to include such factors in physically-based equations, it is unrealistic to assume that they can be represented with enough accuracy to determine *a priori* the amount of pollutants on the land surface at the beginning of a storm. In addition, empirical washoff equations only approximate the complex hydrodynamic (and chemical and biological) processes that occur while overland flow moves in random patterns over the land (Huber and Dickinson, 1988). SWMM, like many models, uses an equation based mainly on empirical data that calculates build up either as linear or non-linear relationship with some maximum limit or asymptote. The Millers runoff model assumed that build-up was linear and that there was an average of five dry days of build-up before an event.

In an impervious urban area, it is usually assumed that a supply of constituents is built up on the land surface during dry weather preceding a storm. Such a buildup may or may not be a function of time and factors such as traffic flow, dry fallout and street sweeping (James and Boregowda, 1985). With the storm, the material is then washed off into the drainage system.

The physics of the washoff may involve rainfall energy, or may be a function of bottom shear stress in the flow. Most often and for this evaluation, washoff is treated by an empirical equation with some physical justification.

The ten land uses that characterized the Millers Creek watershed were aggregated into five (the maximum number allowable) land use categories for SWMM. We characterized these five different land uses by street sweeping frequency, solids build-up and solids wash-off characteristics. Each subwatershed was defined by its percentage of cover for each land use. Total solids load from each subwatershed was calculated as the sum of the loads from each land use within that subwatershed.

SWMM simulates washoff at each time step by making the washoff load proportional to the runoff rate raised to a power. The pollutant build-up rates on land surfaces were taken from the Generalized Watershed Loading Functions (GWLF) model (Hath, et al., 1992) along with some correction factors based on the relative weighting of event mean concentrations (EMCs) from various land uses in the Rouge River Project (Cave et al., 1994). Although, there is some variation over the relative order of pollutant loading by land use between these data sources, generally the highest solids and phosphorus loads come from low and medium residential housing, highways and agricultural land. For this evaluation, the five land use categories and their relative solids mass loading are summarized in **Table 4.1** below.

Table 4.1 RUNOFF Water Quality Solids Build-Up Parameter by Land Use

Land Use Category	Area (ac)	Solid Load Build Up (lbs/ac/day)
Wetland	47.1	0.1
Forest/Open Shrub	418.3	1.2
Commerc/Instit.	377.0	2.5
Med/High Resid.	467.3	3.5
Low Resid.	221.2	5.5
Total	**1530.8**	**2.81**

Total phosphorus (TP) model concentrations were calculated using a regression between all total suspended solids (TSS) concentrations and all total phosphorus concentrations from the dry weather and wet weather water quality grab samples taken during this project. The linear regression for this project was calculated as TP (in ug/L) =1.34 * [TSS in mg/L] + 67.6 (r^2 = 0.58). Because the behavior of the samples taken at the Plymouth site were strikingly different than the behavior at all the other sites; e.g., only at the Plymouth site did dry weather maximum total phosphorus concentrations exceed wet weather concentrations, the Plymouth data was excluded from this regression. By comparison, the regression on the Malletts Creek projects was TP (in ug/L) = 0.96* [TSS in mg/L] + 145.3 (r^2=0.85) (ECT, et al., 2000).

Examples of the water quality calibration for TSS and TP are shown in **Figures 4.8** and **4.9** below.

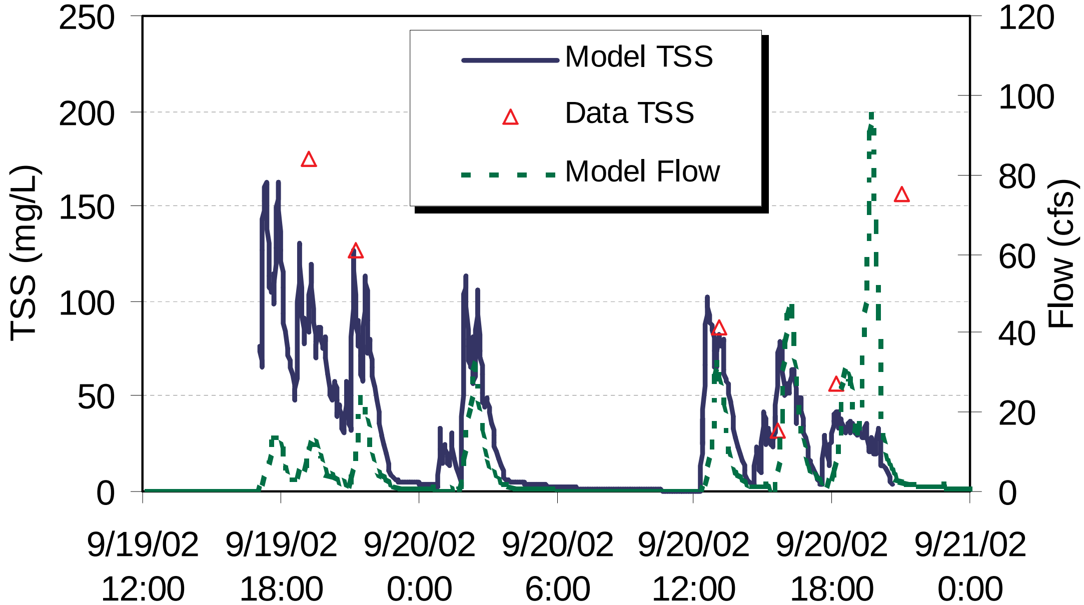

Figure 4.8 Comparison of Model-Calculated and Field Data Total Suspended Solids Concentration at the Hubbard Station for Event 1, Sept.19-21, 2002

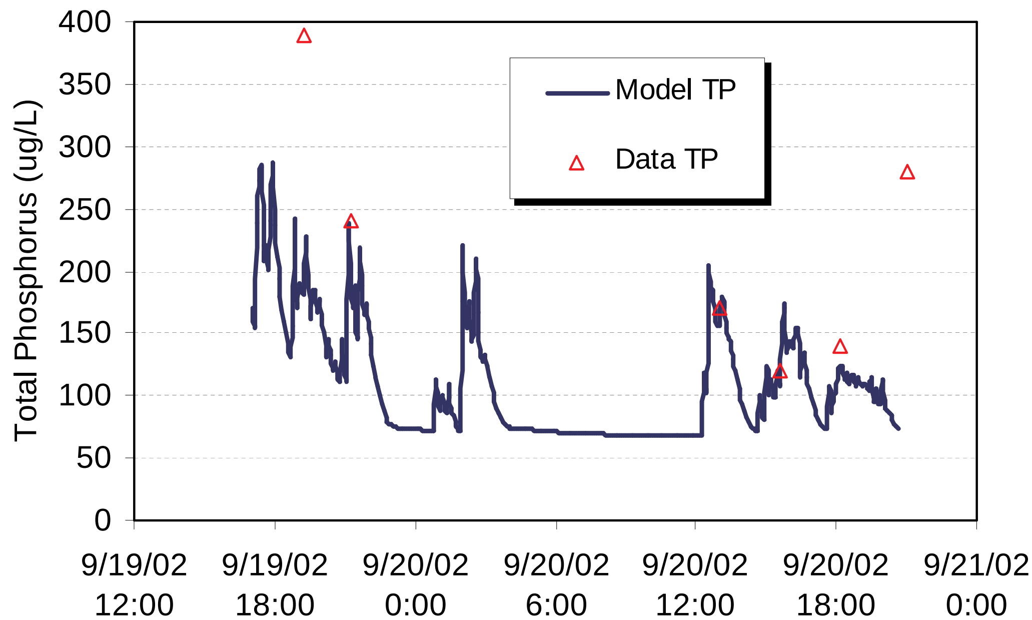

Figure 4.9 Comparison of Model-Calculated and Filed Data Total Phosphorus Concentration at the Hubbard Station for Event 1, Sept.19-21, 2002

4.3.2 Water Quality Model Results Summary

Individual Event Loads
Representative summaries of the water quality model results are shown in **Figures 4.10** and **4.11** below. In the examples shown below, TSS and TP cumulative, subarea and unit area loads are shown for the mainstem subareas of Millers Creek for the first flush rainfall event. We have described this event as 0.5 inches of rain falling in 6 hours. In Ann Arbor, most (~85%) rainfall events are 0.5 inches or less.

The highest calculated unit area load is from the Plymouth subarea. This is an area of fairly high residential development with very little storm water detention. The Glazier site has the lowest unit area load in the watershed. This is probably attributable to the fact that it has the most significant forest cover in the watershed.

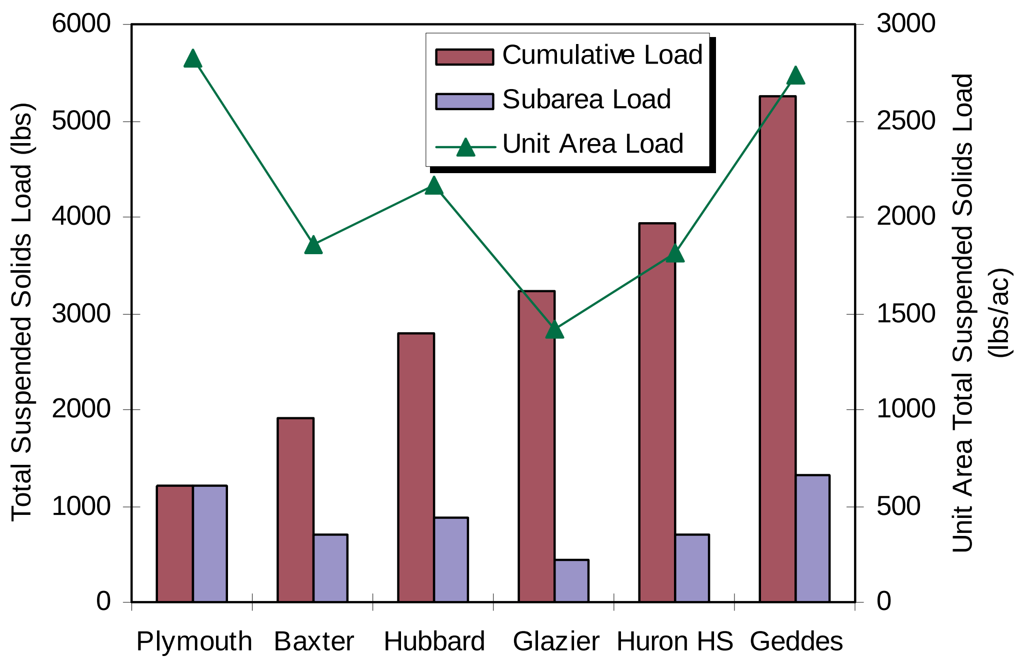

Figure 4.10 Model-Estimated Total Suspended Solids Loads for the First Flush Event (0.5 inches of rain in six hours)

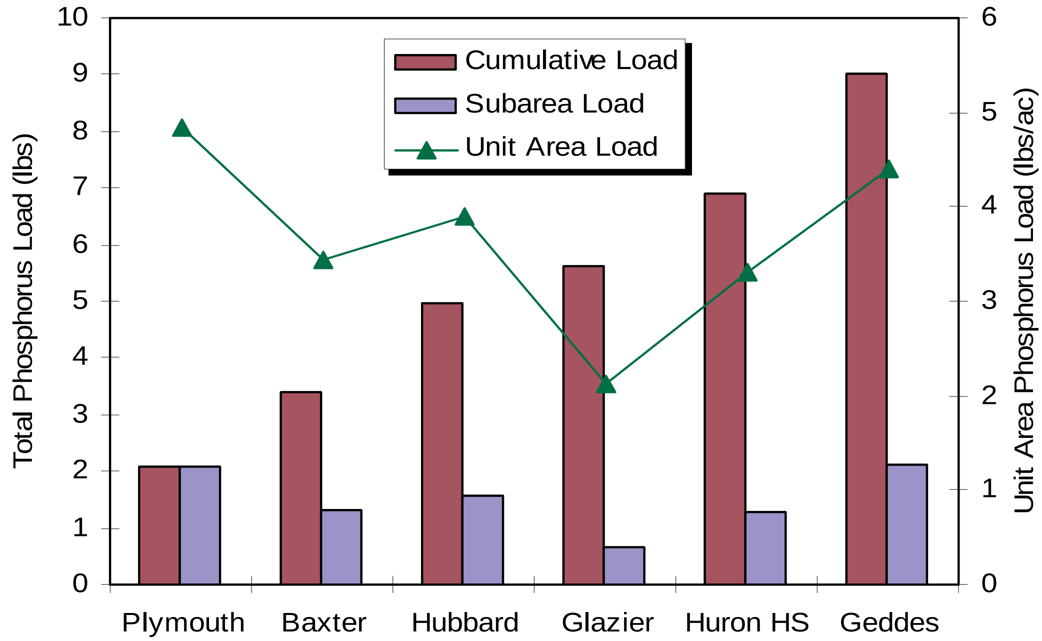

Figure 4.11 Model-Estimated Total Phosphorus Loads for the First Flush Event (0.5 inches of rain in six hours)

Annual Event Loads

The model-calculated individual event loads were used to develop an estimate of average annual total suspended solids and total phosphorus loads. As noted above, there is significant uncertainty associated with these loads; however, we have demonstrated that there is fair agreement between model-estimated flows and pollutant concentrations. These estimates represent a refinement of the non-point source loads developed for the TP TMDL for Ford and Belleville Lakes (Brenner and Rentschler, 1996).

In order to turn the individual event loads into annual load estimates, a correlation was created between total model-calculated event pollutant mass and total event rainfall for existing conditions, and applied to a frequency analysis of average daily rainfall for Ann Arbor. Load per event at each 0.1-inch rainfall increment was multiplied by its average annual frequency of occurrence to arrive at annual load per event. Total annual load was simply the sum of all event annual totals.

The analysis of annual Ann Arbor rainfall patterns was conducted using the University of Michigan rainfall records from 1881 to 2003. The average annual precipitation during this period was approximately 32 inches. Six years with average annual precipitation approximating 32 inches a year were analyzed for the frequency of occurrence of daily precipitation totals. The average frequencies of occurrence for events in 0.1-inch categories (bins) for the six selected years were calculated. For instance, a 0.5-inch, 24-hour precipitation event occurs on average 5 times a year during an average (32-inches total) precipitation year.

The total model-estimated loads at the Geddes station (the creek outlet) were then plotted against the design storm event size and a best-fit curve was fit to the points (see **Figure 4.12** below). Major uncertainties associated with these loads are TSS and TP streambank and stream bed erosion loads, and the loss of solids and associated pollutants that settle out during overbank flows between Huron High School and the Huron River. For a more conservative estimate of TP loads, another curve fit was created to bound an upper limit for the TP load from Millers Creek during an average precipitation year. Total annual TSS and TP loads are summarized in **Table 4.2** below.

Table 4.2 Total Annual Millers Creek Exported TSS and TP Loads for an Average Precipitation Year (approximately 32 inches)

	Total Suspended Solids		Total Phosphorus	
	Total Load (lbs/yr)	Annual Delivery Rate (lbs/ac/yr)	Total Load (lbs/yr)	Annual Delivery Rate (lbs/ac/yr)
Average Estimate	510,251	335	378	0.25
High Estimate	-	-	683	0.45

By comparison, loading rates computed by the HRWC for the Middle Huron Initiative Phosphorus Reduction Strategy had an annual TP loading rate from Millers Creek of 1.28 lbs/ac/yr (Brenner and Rentschler, 1996). Interestingly, Brenner and Rentschler calculated a loading rate for nearby Malletts Creek of 0.57 lbs/ac/yr, yielding a total annual load of 3,945 lbs. The Malletts Creek Restoration Plan (ECT, et al., 2001) estimated a six-month load from Malletts Creek of 2,456 lbs. If extrapolated out over a year, the ECT six-month estimate would likely yield a total annual load of 4,000 to 5,000 lbs/yr, or 0.57 to 0.73 lbs/ac/yr. Taken together, these three studies suggest that a loading rate between 0.3 to 0.7 lbs/ac/yr, with an average of 0.5 lbs/ac/yr, is a reasonable estimate for the urbanized Ann Arbor area.

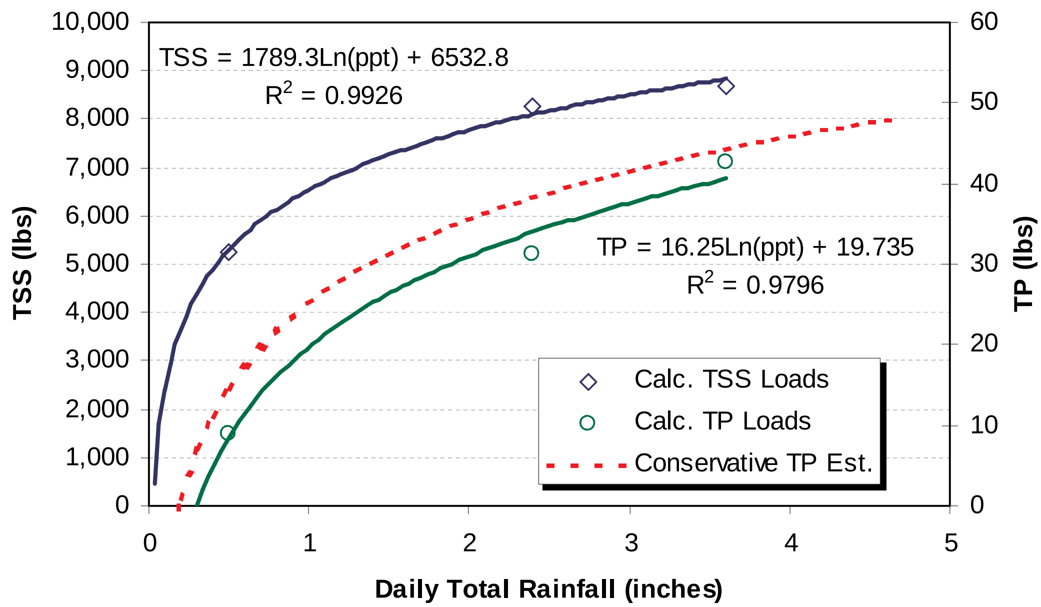

Figure 4.12 Relationships of TSS and TP Total Event Loads to Design Event Rainfall Totals

1.3 Project Overview

This project began in the spring of 2002. MCAT developed a work scope, selected a consultant team to prepare the Watershed Improvement Plan, and regularly advised and collaborated with the consultant team to create the plan. The consultant team compiled existing source data and undertook a detailed investigation of field conditions including watershed and subwatershed delineations, flow, velocity and, water quality measurements, in-stream and corridor habitat, macroinvertebrate diversity, stream bed and bank stability, and infrastructure conditions. Runoff, flow, velocity, and water quality models were developed and calibrated to field-collected data sets.

MCAT developed a vision statement for the watershed, including goals and objectives to measure progress. Watershed residents and other volunteers helped with stream monitoring and developing management recommendations. Feasibility and performance of each recommended improvement were assessed using qualitative and quantitative measures. This report was compiled to summarize and communicate project results. It includes a prioritized implementation plan, estimated costs and a monitoring plan.

1.4 Existing Conditions

Millers Creek is the steepest tributary to the Huron River. Over the mainstem of the creek, the average gradient (change in elevation over creek length) is 52 ft/mi. By comparison, the average gradient of the Huron River is 2.95 ft/mi. Approximately 36% of the 2.4 square mile (1,531 acres) Millers Creek watershed is covered in impervious surfaces – roads, roofs, driveways, and parking lots. Most of the storm sewer was designed to be self-cleaning and does not have catch basin sumps. Many built-out areas in the watershed have little or inadequate storm water detention storage, and watershed soils are predominantly poorly draining clay loams. This combination results in high peak flows arriving at the stream minutes after the onset of rainfall. The steepness and flashiness of the stream wreak havoc on the aquatic community by periodically wiping away the streambed and severely eroding the stream banks. In some locations near Huron Parkway, creek incision and meandering are threatening the bike path. All macroinvertebrate sampling, with the exception of the site near Narrow Gauge Way, has found an impoverished benthic community. This is probably due to frequent episodes of mobilized streambed. High concentrations of *E. coli* (up to 18,000 counts/100 ml), indicative of water contaminated with warm-blooded animal waste, have been found in several locations along the creek. 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.

1.5 Improvement Plan and Analysis

An extensive list of possible improvements was compiled based on field and Geographical Information Systems (GIS) analyses. Improvement feasibility was ranked qualitatively based on technological challenges, engineering design requirements (e.g., level of complexity), property ownership, public acceptance, and potential site constraints. A total of 112 separate improvements were considered. Five alternative scenarios were created to capture key improvement recommendations and to quantify the degree of hydrologic and water quality goal attainment. The alternatives analysis was structured as a series of incremental improvements: from the least costly and most highly feasible projects to the most costly and least feasible. It was assumed that there was no practical limit on the number of improvements that could be implemented to try and reach some predevelopment standard. Research has shown that streams with a high percentage of impervious surface area (>15%) are not likely to ever be completely restored to predevelopment condition (Booth, et al. 2002). This does not invalidate the need to conserve and enhance the resource, but rather imposes realistic limits for restoration success.

1.6 Quantitative Assessment and Results

Recommended improvement performance was tested using the calibrated suite of models and literature estimates of source control effectiveness. The calibrated models were adjusted to assumed build–out conditions based on the NAP and PROS plans. The build-out scenario included 30.5 acres of new residential development, 18 acres of new commercial land with an additional 80.5 acres set aside for floodplain, recreational area or conservation easements. Since the watershed is almost completely built out, and most soils are poorly drained, hydrologic control relies almost entirely on new and retrofitted best management practices (BMPs). Results also demonstrate that even with a built-out watershed, source control is still more efficient and cost-effective for protecting water quality than end of the pipe BMPs.

1.7 Implementation, Projected Costs and Funding

Implementing the Millers Watershed Improvement Plan will require the concerted efforts of the City of Ann Arbor, Washtenaw County, Ann Arbor Township, and the University of Michigan, all of which are regulated storm water communities under Phase I and II National Pollutant Discharge Elimination System (NPDES) storm water permits. These communities are responsible for ensuring water quality and addressing water use impairments. However, a committed public-private partnership, much like the one that initiated this project, will ultimately be the key to success. All individual landowners, institutions, industries, business owners, and local units of governments have a stake in the Millers Creek improvement process and can contribute to the successful implementation of the plan.

The recommended improvements include structural and non-structural BMPs. The structural BMPs include proprietary BMPs (underground storage/treatment units), detention pond retrofits, roof drain disconnects, sediment traps, detention ponds and regional off-line peak flow reduction facilities. Some of the recommended non-structural BMPs include a phosphorus-free fertilizer ordinance, street sweeping, conservation easements, public education plans and long-term performance monitoring. Except for the purchase of (some) conservation easements, these non-structural BMPs are the most cost-effective solutions for hydrologic and water quality control. Structural BMP priorities include detention pond retrofits, roof drain disconnects, sediment traps, detention facilities and two priority streambank stabilization sites. The next priority is for regional off-line peak flow reduction facilities. Recommended streambed stabilization, daylighting and some bank stabilization measures are assigned the lowest priority.

The next major step for this plan is to obtain City of Ann Arbor, the University of Michigan and the Michigan Department of Environmental Quality (MDEQ) acceptance and endorsement. MDEQ acceptance will make the watershed eligible for Clean Michigan Initiative (CMI) and Clean Water Act-Section 319 funding, two of the most significant sources of outside support. This plan also recommends that watershed stakeholders petition for creation of a Millers Creek Drainage District to provide a long-term framework for financing improvements and maintenance activities. MCAT intends to lead implementation of this plan and offer technical and administrative assistance to watershed stakeholders.