

## 4. MODEL EVALUATION

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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).

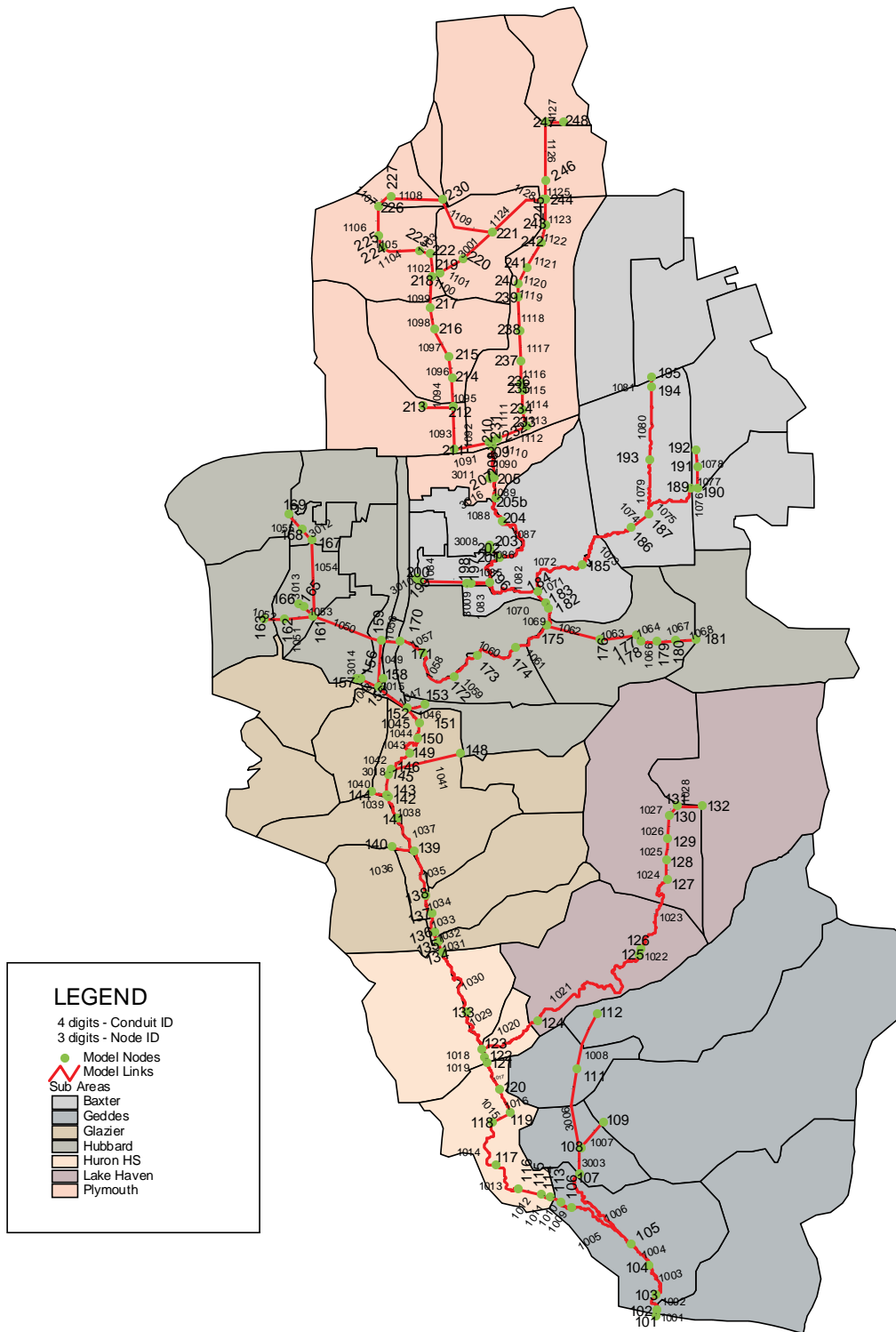
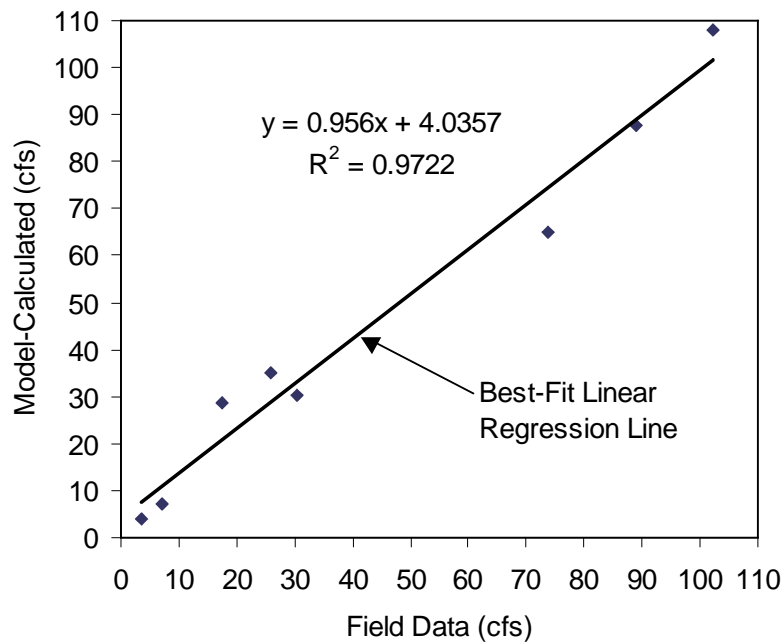


Figure 4.1 SWMM Model Schematic (with sub areas shown)

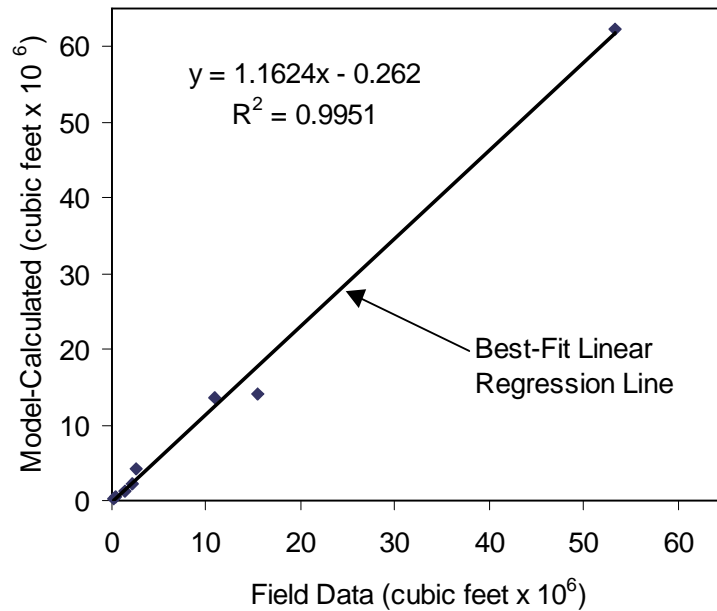
Before calibration, all pervious area depression storage was set at the recommended (Huber and Dickinson, 1988) average value of 0.1 inches; this means, the first 0.1 inches of rainfall is “permanently stored” over a given area before runoff commences. Additional pervious storage was simulated by assuming 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.



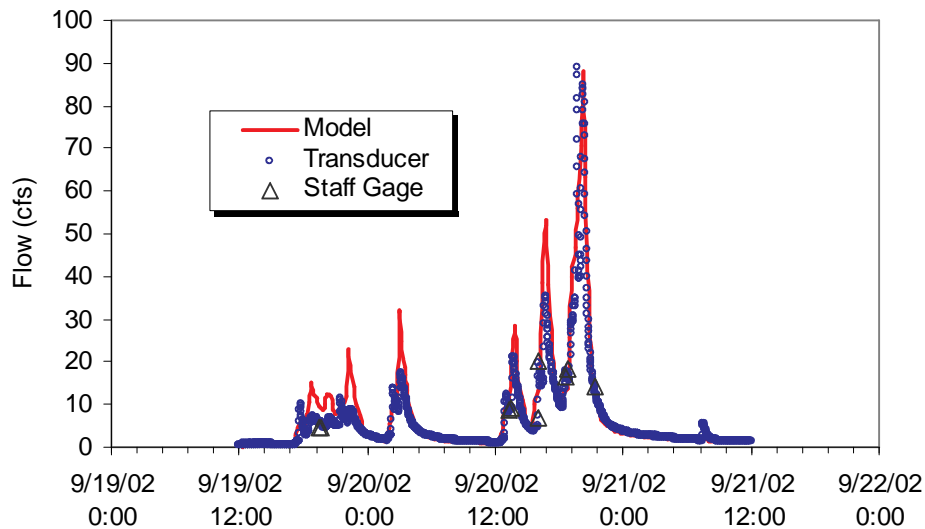
**Figure 4.2 Comparison of Model-Calculated and Measured (by transducer) Peak Flow Rates for the three calibration events at the Plymouth, Glazier and Meadows Sites**

*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

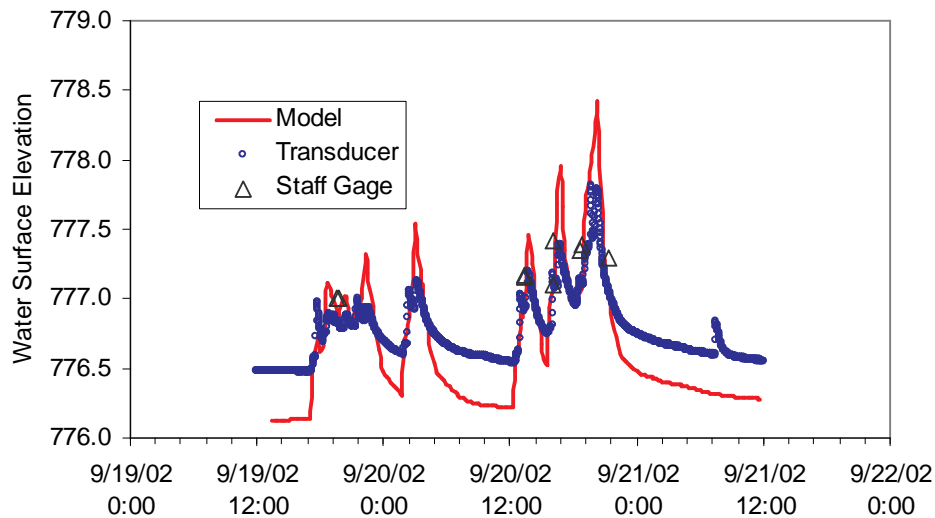
stream beds, banks and obstructions. Stream channel elements that cause energy losses due to friction are stream sinuosity, bed form such as step-pools, riffles, and small dunes, bed grain size, channel vegetation, and obstructions. From decades of hydrologic research, average values for stream types 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 friction 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.

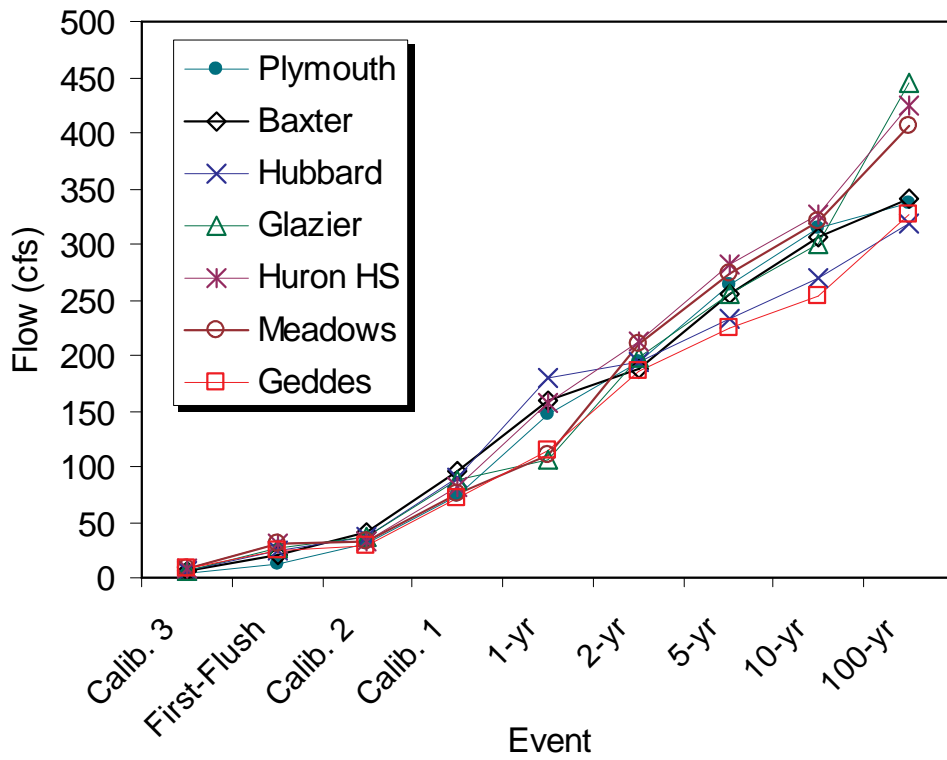


Figure 4.6 Model-Estimated Peak Flow Rates for All Existing Conditions Events

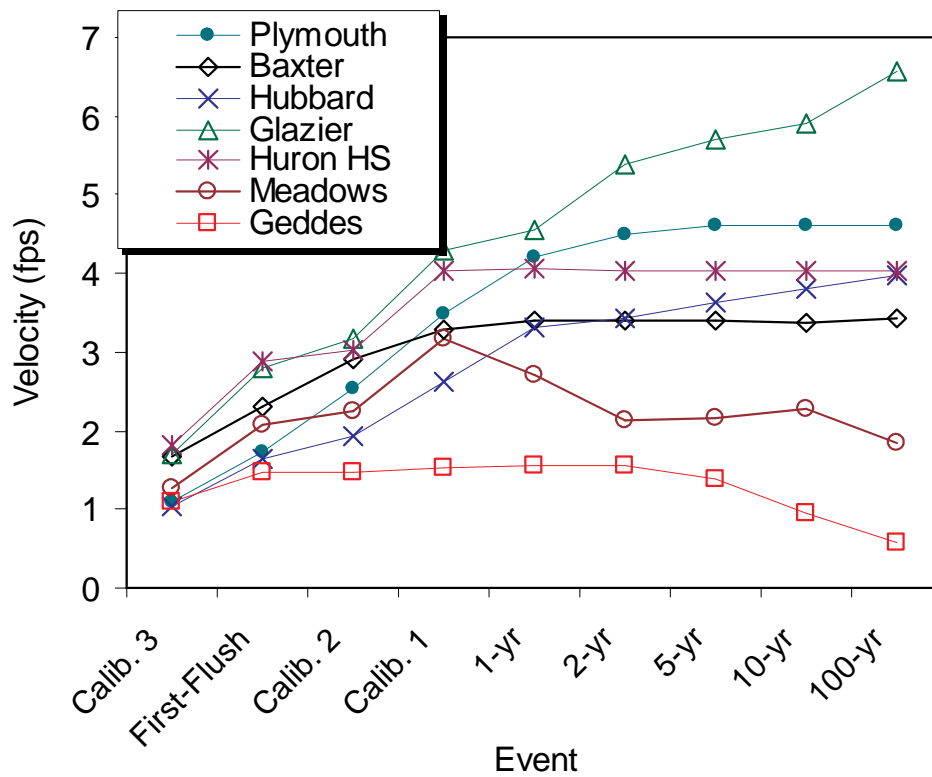


Figure 4.7 Model-Estimated Peak Velocities\* for all Existing Conditions Events (model velocity defined as the average across the channel)

### 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.

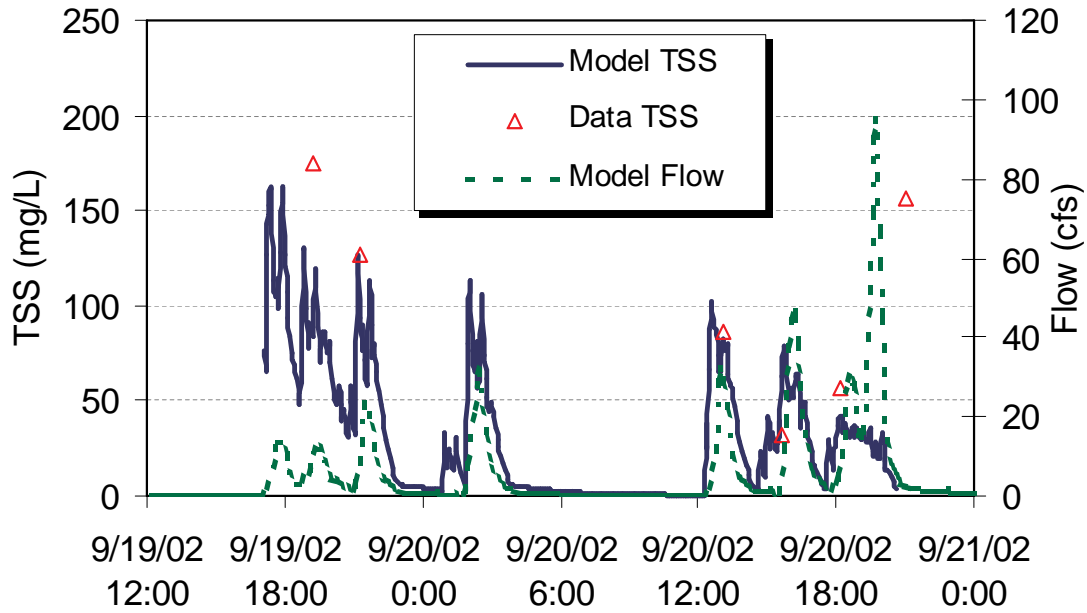
SWMM simulates washoff at each time step by making the washoff load proportional to the runoff rate raised to a power. The pollutant build-up rates on land surfaces were taken from the Generalized Watershed Loading Functions (GWLF) model (Hath, et al., 1992) along with some correction factors based on 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**

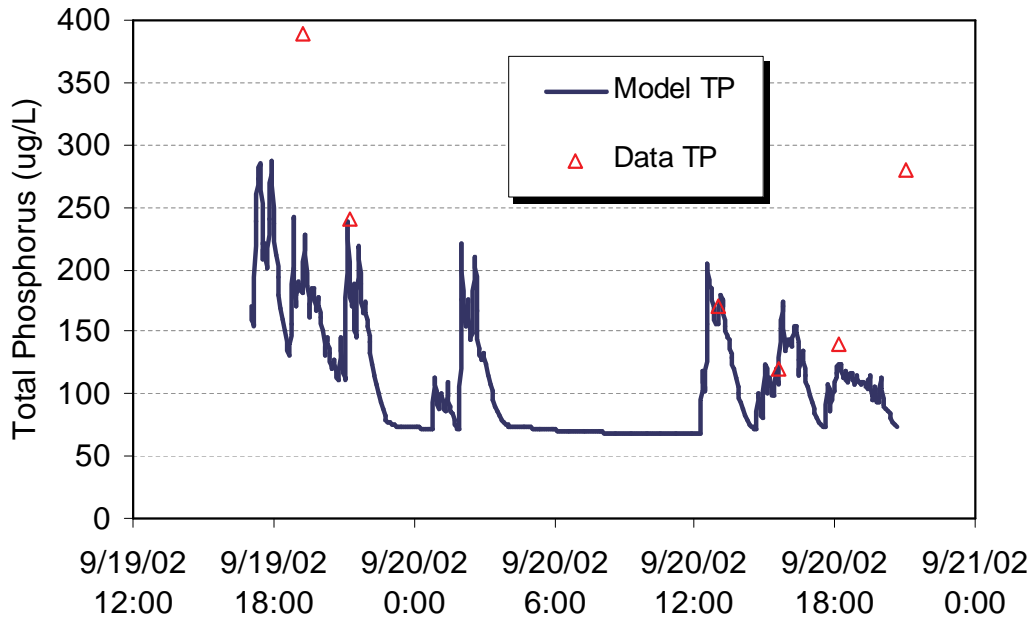
Land Use Category	Area (ac)	Solid Load Build Up (lbs/ac/day)
Wetland	47.1	0.1
Forest/Open Shrub	418.3	1.2
Commerc/Instit.	377.0	2.5
Med/High Resid.	467.3	3.5
Low Resid.	221.2	5.5
<b>Total</b>	<b>1530.8</b>	<b>2.81</b>

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  $TP \text{ (in ug/L)} = 1.34 * [TSS \text{ in mg/L}] + 67.6$  ( $r^2 = 0.58$ ). 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  $TP \text{ (in ug/L)} = 0.96 * [TSS \text{ in mg/L}] + 145.3$  ( $r^2=0.85$ ) (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**



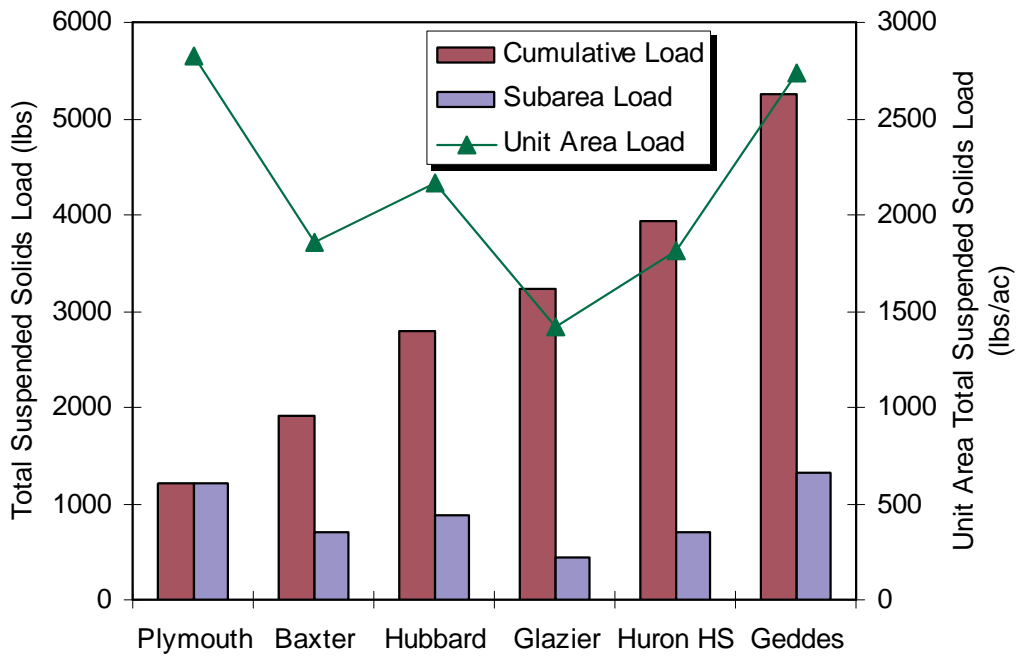
**Figure 4.9 Comparison of Model-Calculated and Filed Data Total Phosphorus Concentration at the Hubbard Station for Event 1, Sept.19-21, 2002**

### 4.3.2 Water Quality Model Results Summary

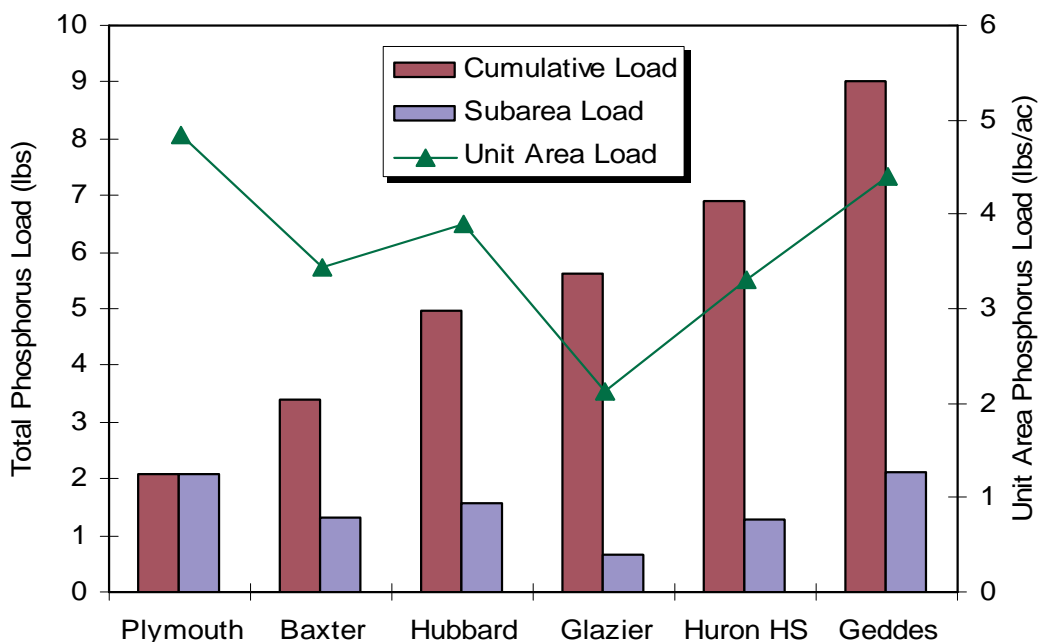
#### Individual Event Loads

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.

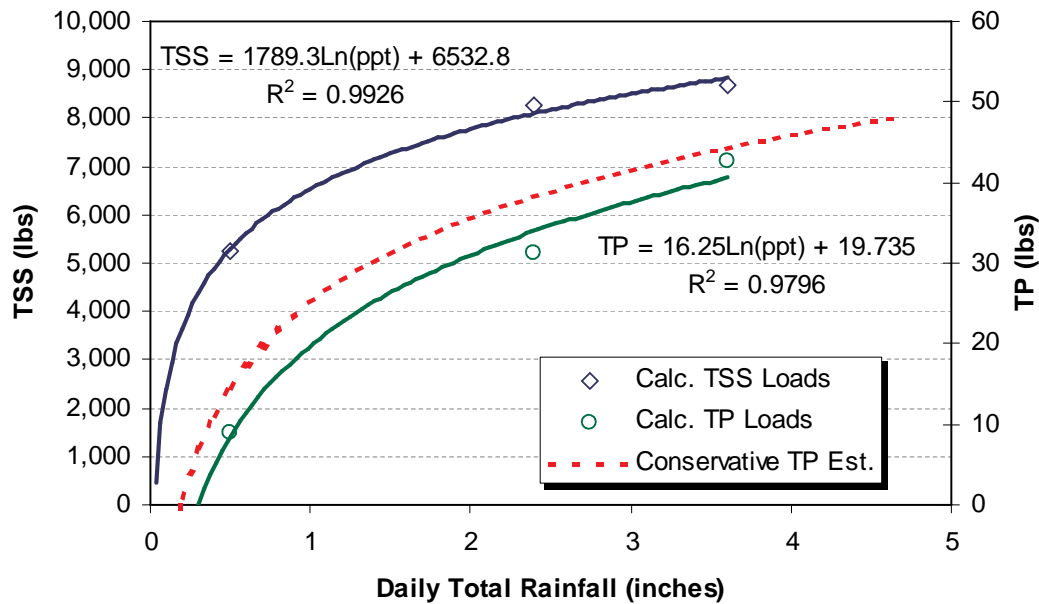
The total model-estimated loads at the Geddes station (the creek outlet) were then plotted against the design storm event size and a best-fit curve was fit to the points (see **Figure 4.12**

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**