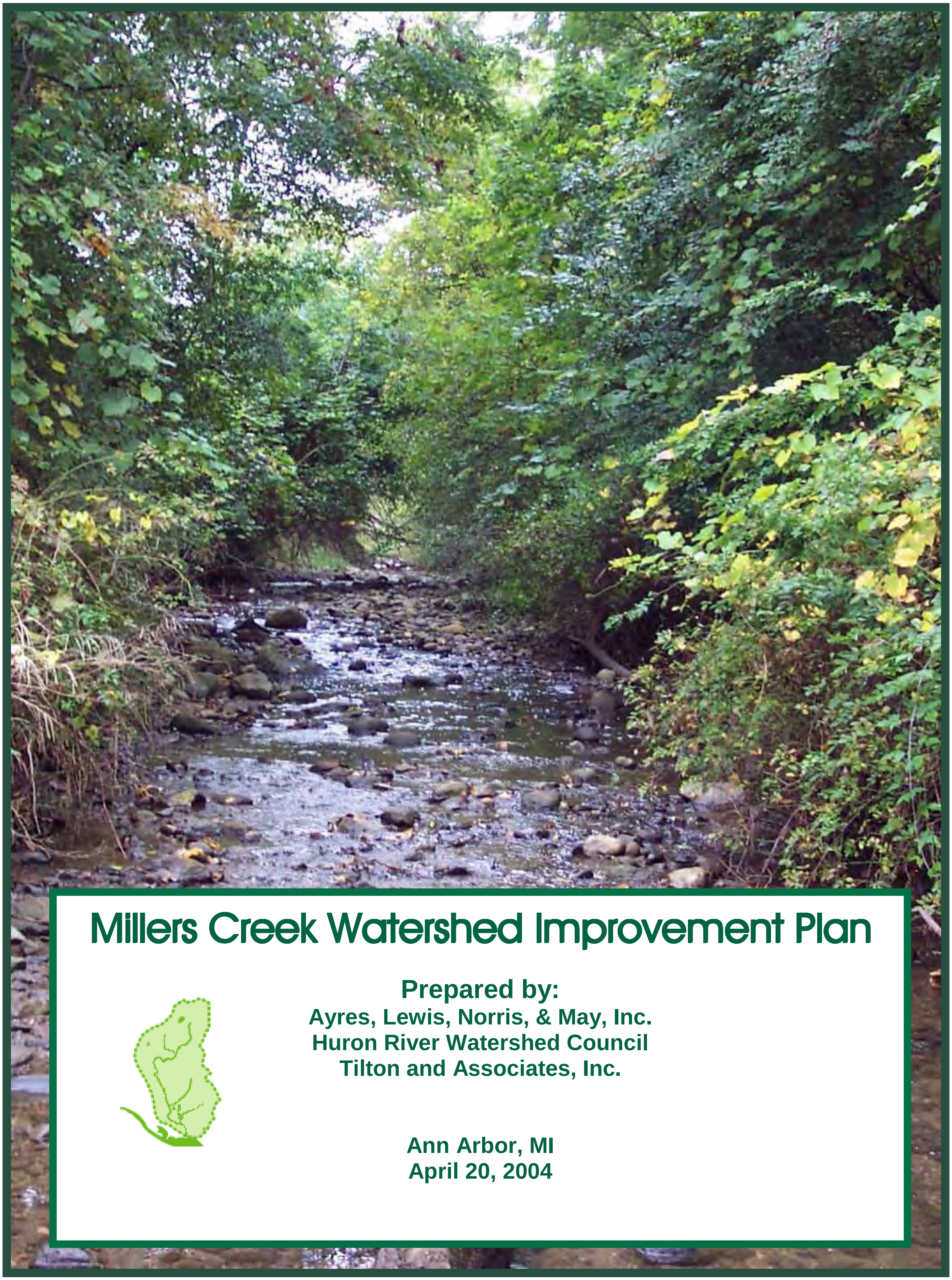

Millers Creek Watershed Improvement Plan

Prepared by:

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Ann Arbor, MI
April 20, 2004

ACKNOWLEDGEMENTS

This project was made possible by the foresight and generosity of **Pfizer Global Research and Development, Inc**. The individuals representing Pfizer for this project were Michael Lemon and Steve Kapeller.

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City of Ann Arbor (AAB) Building Department
City of Ann Arbor (AAU) Utilities Department (now Systems Planning, Public Services)
Huron River Watershed Council (HRWC)
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For their contributions to this plan, the following individuals are acknowledged. For the rest, please keep reading.

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1. EXECUTIVE SUMMARY

1.1 Project Background

Millers Creek
Improvement Plan

This document is a comprehensive watershed improvement plan for Millers Creek, an urban tributary of the Huron River located on the northeast side of the City of Ann Arbor in Washtenaw County, Michigan. This project originated as a unique public and private sector partnership funded by Pfizer Global Research and Development, Inc. (Pfizer), the second largest landowner in the watershed. Plan development oversight was provided by the Millers Creek Action Team (MCAT), a voluntary group of watershed stakeholders including businesses, community representatives, and local and state entities.

This project was prompted by flooding and bank erosion on Pfizer's Ann Arbor campus (See **Figure 1.1**). Pfizer decided to investigate the problems and develop a solution by looking at their campus in the context of the entire Miller Creek watershed. With assistance from the Washtenaw County Drain Commissioner (WCDC) and the Huron River Watershed Council (HRWC), Pfizer initiated MCAT and this project. Concern for the creek coalesced in the middle to early 1990s when an earlier version of MCAT, led by the Environmental Research Institute of Michigan (ERIM), the HRWC and the WCDC began investigating possible watershed-wide improvements.

Figure 1.1 Damage on Pfizer Campus Along Millers Creek

The creek has little to no existing institutional support. It is not a county drain and is considered a receiving water for the City of Ann Arbor and the University of Michigan North Campus storm water drainage. The creek is also identified as a contributing source in the Ford and Belleville Lakes Total Maximum Daily Load (TMDL) for phosphorus and the Geddes Pond TMDL for *E. coli*.

On-going planning efforts consulted for this project include the Northeast Area Plan (NAP), the Ann Arbor Parks and Recreation Department Open Space Plan 2000-2005 (PROS Plan), and the *E. coli* implementation plan (2003). The NAP and PROS plans provided recommendations of forecasted land use for a fully built-out Millers Creek watershed.

1.2 MCAT Mission and Project Goals

The mission of MCAT is to establish and implement socially, environmentally, and economically sustainable watershed management standards and practices that will improve the quality of the Millers Creek watershed. The goals of this plan are to develop a set of recommendations that will improve stream habitat and watershed hydrology, improve recreational opportunities in and around the creek and help local stakeholders achieve the objectives of the Ford and Belleville Lakes total phosphorus TMDL and the Gallup (Geddes) Pond *E. coli* TMDL. Implementation of these recommendations will also help foster activities that perpetuate urban watershed and stream stewardship, and create a healthier balance between the local community and its ecosystems.

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.

2. BACKGROUND

Millers Creek has a 2.4 square mile watershed and is the smallest named tributary to the Huron River (**Figure 2.1a and 2.1b**). The 125-mile Huron River, from its origin in Springfield Township in Oakland County to its outlet on Lake Erie, is a critical natural resource. It supplies drinking water to 140,000 people, and with two-thirds of the public recreational land of southeast Michigan, is one of the major recreational features in the region. The Huron River is also recognized as one of the premier smallmouth bass fisheries in Michigan. Thirty-seven miles of the Huron River and three of its tributaries have Michigan Department of Natural Resources Country Scenic River designation under the State's Natural Rivers Act (Act 231, PA 1970).

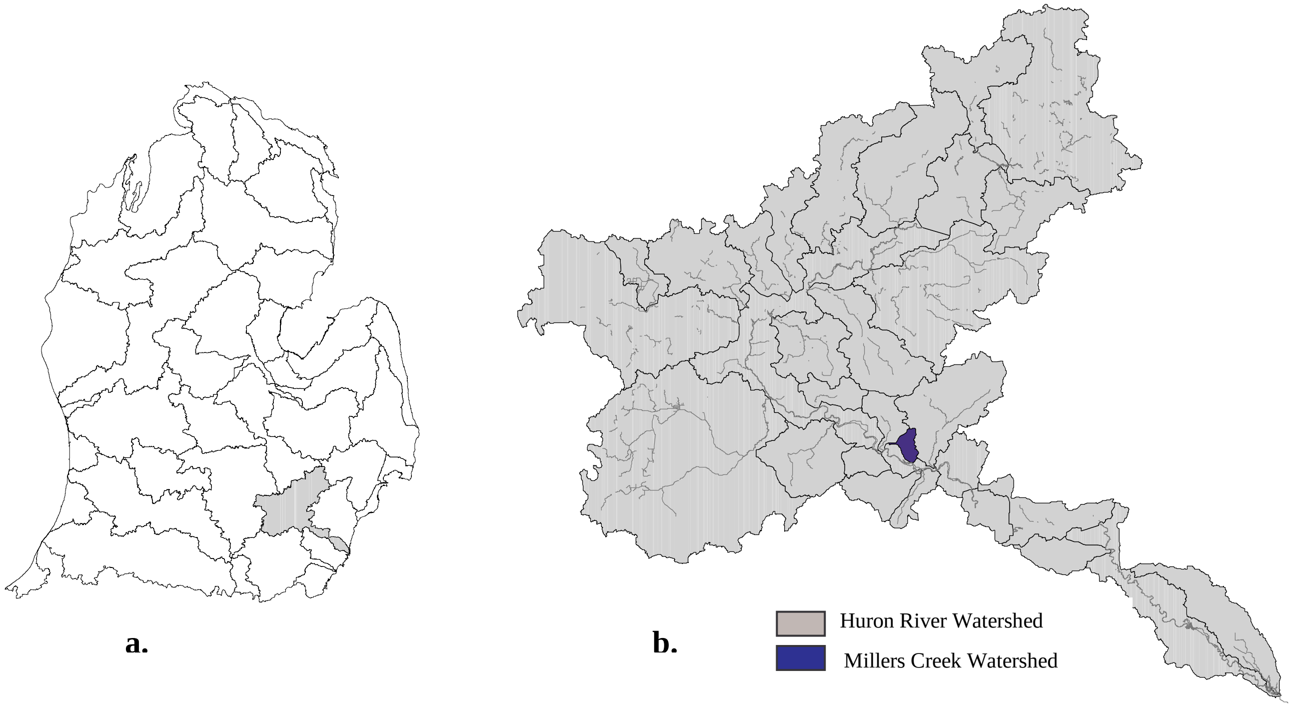

Figure 2.1 a. Location of Huron River Watershed within the State of Michigan. b. Location of the Millers Creek Watershed within the Huron River Watershed.

The main branch of Millers Creek (formerly known as the North Campus Drain) originates on Pfizer's 1600 Huron Parkway campus and flows under Baxter Road, through UM north campus, under Huron Parkway and Pfizer's 2800 Plymouth Road campus and then back again under the Parkway and Hubbard Road (See **Figure 2.2**). The creek crosses under the Parkway twice then cuts through Ruthven Nature Area to meet up with the Huron River at Gallup Park. The northeastern tributary (or Green Road tributary) originates at the wetland on the current campus of the Ave Maria Law School and drains a significant area near the intersection of Green and Plymouth Roads. The southwestern tributary, referred to here as the Lakehaven tributary, drains several hundred acres north of Glazier Way and along Green Road.

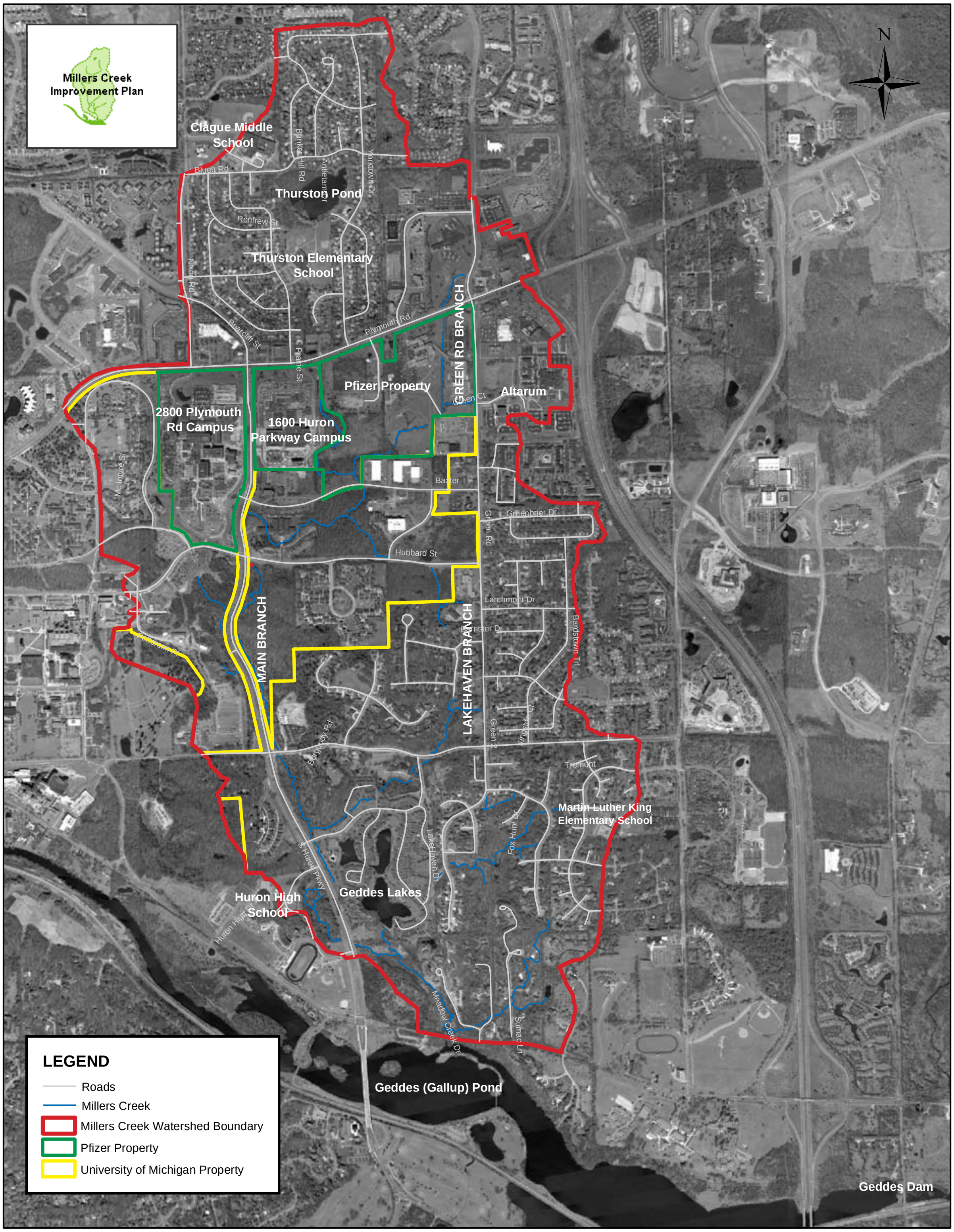

Figure 2.2 Millers Creek Watershed Map

The name “Millers Creek” first appears on a 1905 Huron River Atlas prepared by Gardner S. Williams for the Detroit Edison Company. A portion of the creek appears on the original surveyors plat for Ann Arbor Township prepared by Joseph Wampler in 1818. The entire stream system appears on the first USGS quadrangle produced by the USGS in 1902.

Millers Creek is located in the planning region for the Northeast Area Plan of the City of Ann Arbor (CPC, 2003). The population of the northeast area of Ann Arbor grew by 14% between 1990 and 2000, making it the fastest growing area within the city. The Southeast Michigan Council of Governments (SEMCOG) projects 16% growth for the area between 2000 and 2020.

The conversion of open space from forest and fields to roads, rooftops, parking lots, driveways and lawns completely changes the hydrologic cycle. It is likely that before European settlement in the 1800s, most rainfall in this area was intercepted by vegetation or infiltrated into the ground and slowly recharged groundwater, lakes, rivers and streams. With the construction of impervious surfaces, rainfall was cut off from its former hydrologic pathways. Rain now strikes impervious surfaces and with nowhere else to go, must be channeled away to lakes and streams.

This channeled runoff delivers significantly higher volumes of water to lakes, rivers and streams in a much shorter period of time. Natural channels formed to transport historic flows must now cope with frequently occurring and significantly higher flows. This new flow regime literally re-shapes channels, making them deeper and wider, carrying bed and bank sediment downstream. In addition, channeled runoff flows over construction sites, lawns, driveways, roads and parking lots carrying with it sediment, nutrients (such as nitrogen and phosphorus), pesticides, oils, grease, gasoline, heavy metals (from brake pads, internal combustion engines, etc.), salts, and in the summertime, heat from sunlight-absorbing surfaces such as asphalt.

Runoff, both from urban, suburban and agricultural sources, has been identified as a primary source of water quality problems in the Huron River. The MDEQ has identified two significant water quality problems, high phosphorus and *Escherichia coli (E. coli)* concentrations, related to the impact of runoff on the Huron River.

Low dissolved oxygen levels (DO), algae blooms and fish kills in Ford and Belleville Lakes (impoundments on the Huron River downstream of Ann Arbor) prompted the MDEQ to add these reservoirs to Michigan’s Section 303(d) list (Impaired Waterbodies List) for not meeting designated recreational uses. Low DO and high phosphorus are caused by nutrient enrichment, particularly high phosphorus loading from wastewater treatment plants and runoff. The MDEQ has set summer (May through October) phosphorus concentration targets at Belleville and Ford Lakes of 30 ug/L and 50 ug/L, respectively. This requires an approximate 50% reduction in both wastewater treatment plant and runoff phosphorus loads. Millers Creek is one of six creeks in the Ann Arbor area contributing an estimated, combined total phosphorus load of 11,580 pounds annually or about 14% of the total load at Ford and Belleville Lakes (Brenner and Rentschler, 1996).

Geddes Pond is also listed as an impaired waterbody due to elevated pathogen levels. The listed segment is approximately five miles of the Huron River located in the Ann Arbor area, from Geddes Dam at Dixboro Road upstream to Argo Dam. This segment is also the receiving water for Allens Creek, Traver Creek, Millers Creek, Malletts Creek, and Swift Run Creek. Water sampling in this area indicates that Michigan Water Quality Standards (WQS) for *E. coli* are not consistently being met in the Huron River or its tributaries (See **Appendix A**).

The other major regulatory mechanism influencing storm water management is the National Pollutant Discharge Elimination System (NPDES) storm water permitting program. The City of Ann Arbor and the UM both hold Phase I stormwater NPDES permits. Ann Arbor Township and the Ann Arbor School District received certificates of coverage for Phase II NPDES permits in 2003. The NPDES permits require the permit holders to develop and implement a local stormwater management program that educates watershed residents about stormwater impacts and controls runoff within their jurisdictions.

For development of this plan, Pfizer brought together a plan oversight committee, called the Millers Creek Action Team (MCAT) with volunteer representatives from Pfizer, the WCDC, the MDEQ, the City of Ann Arbor (AA), the University of Michigan (UM), the HRWC, Altarum Institute, and Pollack Design Associates. The local (Ann Arbor vicinity) institutional stakeholder representatives in MCAT are many of the same individuals responsible for implementing the Middle Huron Phosphorus TMDL Initiative and the *E. coli* TMDL implementation plan (2003). This carry-over of representatives with long-standing relationships has helped facilitate productive and efficient information exchange for the MCAT.

2.1 Watershed History

The surface geology that determines the shape of the Millers watershed was predominantly formed during the last major deglaciation of the Great Lakes, between 16,000 and 10,000 years ago (**See Figure 2.3**). Over this period the Lake Huron-Erie and Saginaw lobes of the ice sheet retreated and then advanced, pushing up the Ft. Wayne and Defiance end moraines that underlie the western extent of Ann Arbor and some of Ypsilanti while the meltwater from the lobes formed the Huron River. As the glacier went through a series of advances and retreats, the direction and flow of the outlet changed many times (Russell and Leverett, 1915). The river's present course was set by the end of this period, and the modern topography and soils are the result of postglacial erosion and soil formation processes acting on the glacial deposits (Albert, et al., 1986).

According to Russell and Leverett (1915), the ancestral Huron River was formed during the build-up of the Ft. Wayne moraine, but successively occupied a larger portion of its basin as the ice retreated to the east. The Huron River was a glacier meltwater drainageway that entered ancient Lake Erie near what is now Ford Lake (**See Figure 2.3**). The Millers Creek watershed to the north is part of the Defiance end moraine. Post-glacial alluvium suggests that the Huron River bed may have been located further north and once occupied what is now the southern half of Millers Creek watershed.

The European pre-settlement vegetation within the Millers Creek watershed was primarily oak-hickory and mixed oak forest (**Figure 2.4**). Oak-hickory forest covered the watershed east of the creek while mixed oak forest occupied the western half of the watershed. A large area of wet prairie once existed in the area that is now Thurston Pond and Nature Area. Another linear area of wet prairie once extended along Millers Creek from the mouth to Glazier Way (Cormer, et al., 1995).

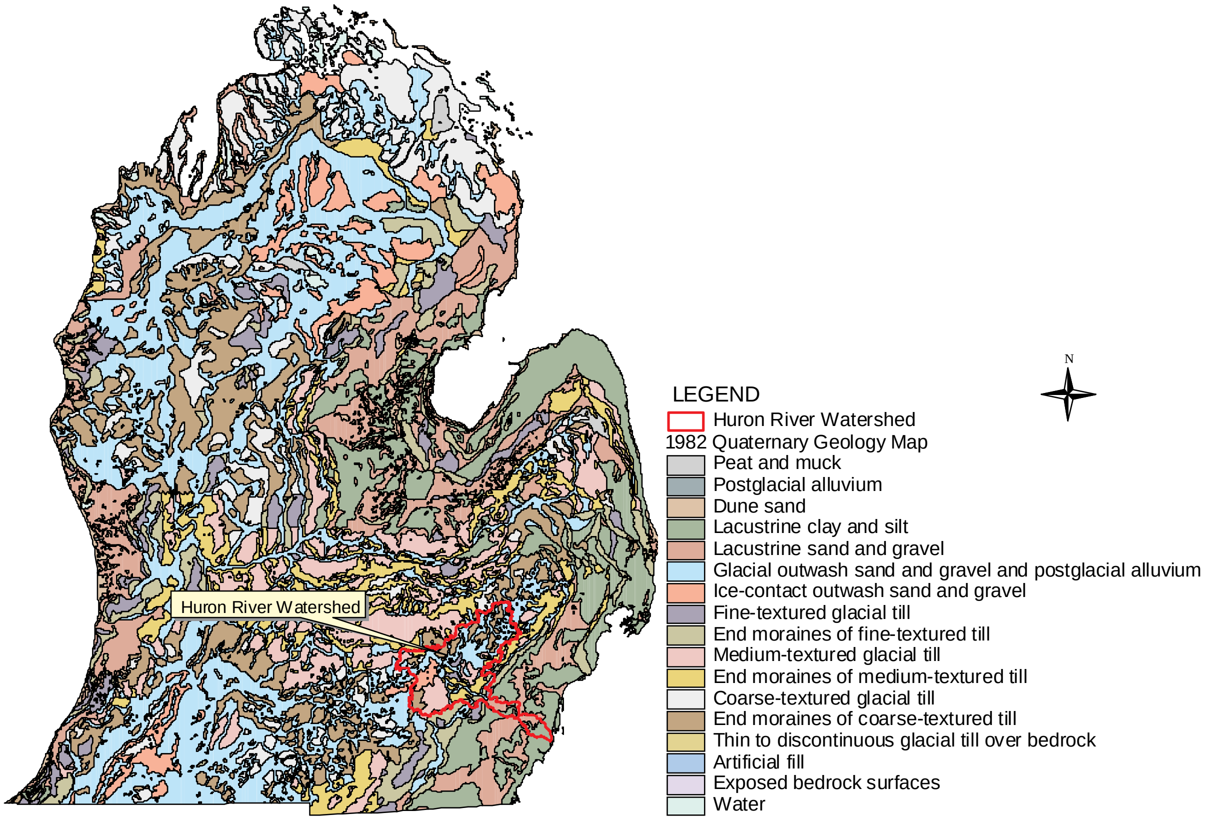

Figure 2.3 Surficial Geology of the Huron River Watershed

Beginning in the late nineteenth century, the watershed was logged and farmed. In the early 1950’s, the University of Michigan purchased 800 acres of land to establish North Campus, and the Michigan Department of Transportation began acquiring land for the construction of US-23 (**See Figure 2.5**). During the late 1950's and early 1960's, research firms began locating along Plymouth Road due in part, to the proximity of University of Michigan’s North Campus and US-23. The 1960's and 1970's saw a tremendous amount of growth in the Northeast Area, including single-family subdivisions, apartment communities, new employment centers, Plymouth-Green shopping center and numerous North Campus student housing projects. M-14 was constructed in the 1960's. Between 1964 and 1967, Huron Parkway, a broad four-lane boulevard, was constructed through much of the middle and lower valley of the creek.

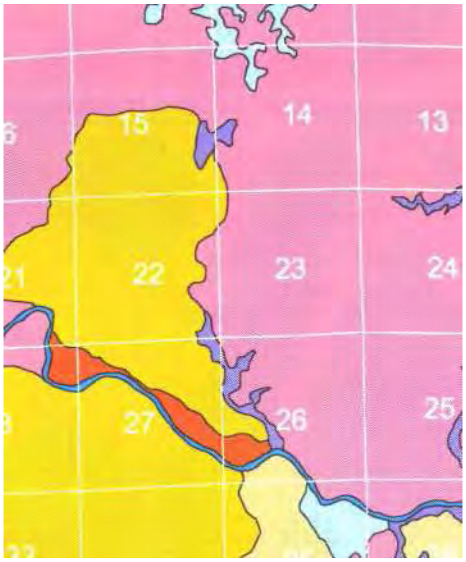

Figure 2.4. Presettlement Vegetation (pink area represents oak-hickory forest)

During the 1990's, strong growth pressures in Ann Arbor resulted in the development of additional hotels, commercial centers, office buildings and residential projects in the Northeast Area of the city. A significant amount of City parkland also was acquired in the 1980's and 1990's (NAP, 2002). At the same time, concern for the creek coalesced into a working group led by representatives from ERIM, the HRWC and the WCDC. Some of the original members of this group are now MCAT members.

Figure 2.5. 1947 Aerial Photograph of the Millers Creek Channel

2.2 Existing Area Plans

2.2.1 Northeast Area Plan

The City of Ann Arbor's Planning Department is currently updating the master plan for the Northeast Area. The Northeast Area Plan (NAP) covers the entire northeast quadrant of Ann Arbor, including the entire Millers Creek watershed. The NAP mission statement aims for a Northeast Area, "…where planning decisions are based, in part, on the interconnectedness of natural, transportation and land use systems. Natural systems, including air and water, natural features, native flora and wildlife habitats, will be improved and protected. It will be a place where the Huron River is a cherished part of the community and a focal point for recreation," (NAP, 2003). The NAP draft contains a series of relevant planning principles related to the Millers Creek Watershed, including:

1. High quality natural systems should be preserved as much as possible as development occurs.
2. Fragile lands should be protected.
3. Development should be clustered to preserve natural systems.
4. Impervious surfaces should be minimized.
5. The scenic integrity of Huron Parkway should be preserved.
6. Landscaping should be improved along major streets.
7. Native landscaping should be encouraged to reduce storm water runoff.
8. Underground, understructure and structured parking should be encouraged to minimize imperviousness.
9. On-site stormwater management systems should be encouraged to reduce storm water runoff.
10. Native landscaping should be encouraged where feasible.
11. Surface water quality should be improved and protected.

These principles align with the goals and objectives of this plan. In addition, the assumptions of watershed build-out conditions for this plan were based on NAP recommendations.

2.2.2 PROS Plan

The 2000-2005 PROS plan is the current five-year vision of the City of Ann Arbor Parks and Recreation Department for planning, development, and property acquisition of current and proposed parks. Recommendations in the plan relevant to the Millers Creek Project include:

1. A need to preserve some of the environmentally sensitive natural resources along Green Road extension, plus along US-23, to enhance and preserve the perimeter image of Ann Arbor.

2. Huron Parkway imagery and right-of-way preservation/enhancement and improvements to the linear bike path are needed. As a portion of the Huron Parkway has been acquired, the development of a trail system must carefully weigh impacts on the golf course, Black Pond Woods access/linkage to parks and bike path opportunities.

3. Examine the use of private open space in research or industrial sites for public use. This could help solve problems caused by a shortage of active recreation area and facilities in the northeast area of the City and provide space for softball, soccer and even tennis. Some additional parking may be necessary.

4. The wetland and hillside along Huron River Drive, across from the South Pond of the Huron River, has been identified as an important natural area related to the Huron River that needs protection.

5. Linkages along watercourses between natural areas, such as Traver Creek in the now undeveloped portions of the northeast area, are essential to allow public access to natural areas and to minimize the impact of development on the natural systems. Specific wetlands and woodland throughout the northeast area will need some sort of protection as they come under development pressure, for example, the northwest corner of Plymouth and Green Road, on the old National Sanitation Foundation site.

6. The North Campus area of the University of Michigan probably has sufficient open space for its residents but should have special attention given to programming of recreational activities for families with young children and lower than average incomes.

7. Enhance Thurston and Clague Schools' active recreation facilities for school and neighborhood use through improved access, visibility and educational programming of the natural area including Thurston Nature Center.

8. Future acquisitions in this area should consider properties along the river and creeks, retirement communities, school properties, greenbelt connections.

9. Renovations of playgrounds should include Windemeer, Greenbrier, Glacier Highlands, Island, Riverside, Plymouth, Gallup and Placid Way.

2.3 Significant Watershed Stakeholders and Activities

With approximately 302 acres, the University of Michigan owns 20% of the land in the watershed. Pfizer owns 175 acres, approximately 11% of the land in the watershed. The City of Ann Arbor and Ann Arbor Township jurisdictional boundaries cover approximately 862 (56.3%) and 192 acres (12.5%), respectively (refer to **Figure 2.6**). Other notable stakeholders include Altarum (formerly the Michigan Environmental Research Institute (ERIM)) and the United States Geological Survey.

2.3.1 Pfizer

Pfizer's land holdings in the watershed nearly doubled with the purchase of 54 acres of UM land along Plymouth Road in 2001. In 2002, Pfizer purchased 29 acres of the former Environmental Research Institute of Michigan (ERIM) and Veridian campuses at the corner of Plymouth Road and Green Road. This increased Pfizer land holdings to 175 acres, making it the second largest landowner in the watershed.

In addition to Pfizer's participation in community watershed programs such as initiating the development of MCAT and this plan in Fall 2001 and participating in the "Community Partners for Clean Streams" program since August 1997, Pfizer has implemented several watershed improvement projects at its facility over the last few years. These projects include upgrading the facilities storm water management system, replacing some manicured lawn areas with native prairies, restoring a wetland, and implementing a phosphorus-free fertilizing program. Future projects may include storm water improvement projects along Millers Creek on Pfizer's property, continued annual monitoring of Pfizer's onsite wetland, a study documenting water pollutant

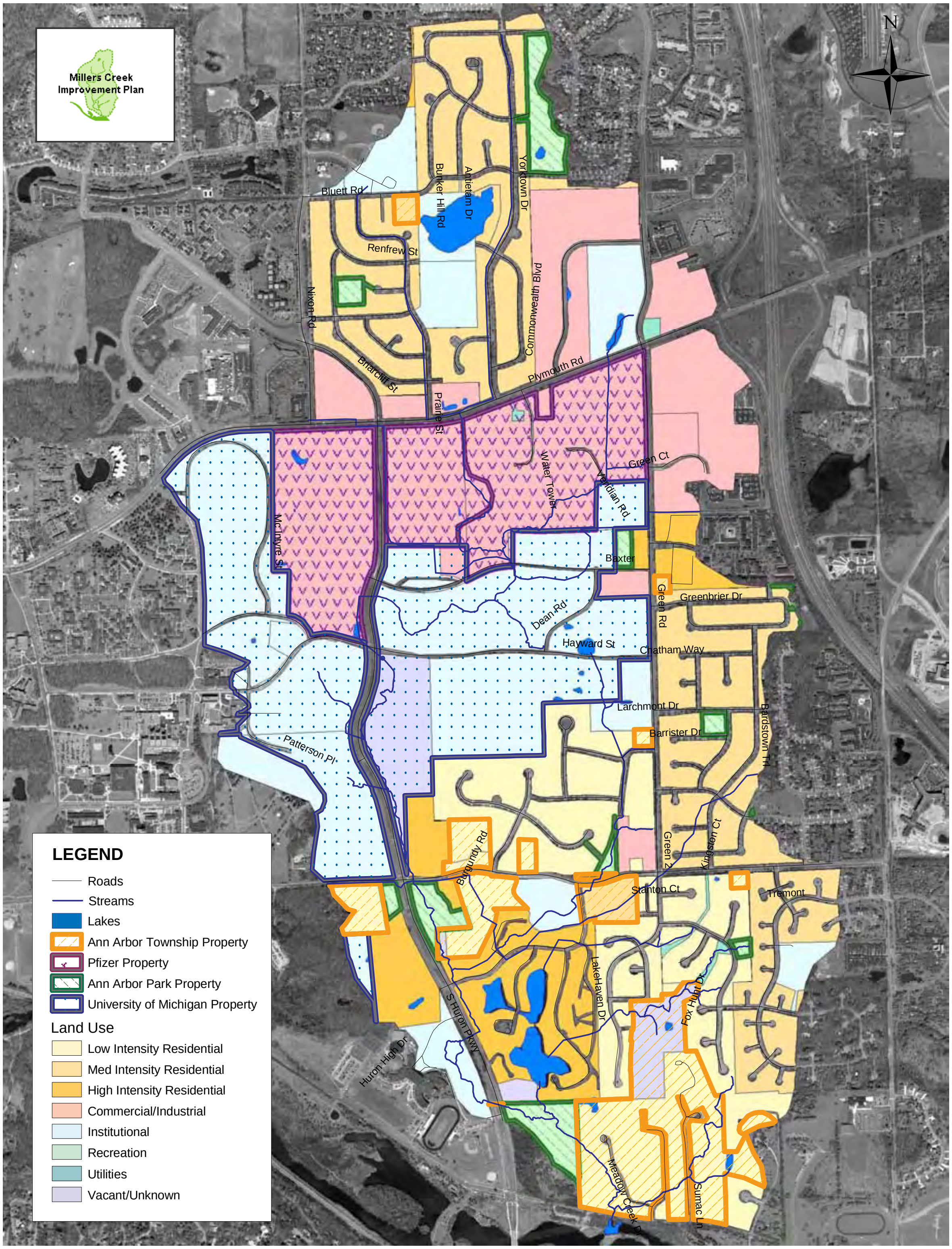

Figure 2.6 Jurisdictions and Land Holdings of Major Millers Creek Stakeholders

removal efficiency of the wetland, and installation of additional native prairies or wildflower meadows.

Pfizer also has a strong internal storm water management program. As part of Pfizer's ISO 14001 certification, Pfizer seeks continuous improvement in all environmental aspects at the site - including storm water management. The facility's Storm Water Pollution Prevention Plan is reviewed annually to identify areas for improvement in the facility's storm water management program. Any improvements identified become goals that are endorsed by site management. Pfizer environmental affairs colleagues are also involved in the early stages of all facility design projects to ensure that the proposed design will not adversely affect the storm water system at the facility. Pfizer routinely conducts general facility inspections and construction inspections to ensure complete compliance with all storm water and spill prevention regulations.

2.3.2 University of Michigan

The largest landowner in the creekshed is the University of Michigan (UM). A portion of the UM Ann Arbor North Campus is in the creekshed. As a state entity, UM regulates and manages its own separate storm water drainage system. In 1995, UM voluntarily entered into the Phase I National Pollutant Discharge Elimination System municipal storm water permit program. UM has a Storm Water Management Program, which was updated in March 2003 and includes permit requirements, public education, public involvement and participation, illicit discharge elimination, construction runoff controls, post construction storm water management, and pollution prevention & good housekeeping. Storm water education is an important focus of UM programs and takes a variety of forms, including storm water awareness announcements at football games, resources on the web (http://www.umich.edu/~oseh/stormwater/), video on UM cable television, and presentations geared to departments and their particular operations. UM also has a phosphorus-free fertilizer program and has created 'no mow' areas, which allow for more extensive root systems to establish and increase storm water infiltration. Other maintenance activities include a twice a year cleaning of all storm water drainage system lines and catch basins as well as routine street sweeping.

UM has several small storm water detention basins in the Millers Creek watershed at the Glazier Way commuter lot, the North Campus Grounds Service Facility, and 2901 Hubbard. Future plans include reviewing these basins for potential improvements in capacity and quality. UM recently implemented three pilot projects for innovative storm water management in parking lots, including porous pavement, a Rainsaver system, and bioretention islands. A study of flooding issues on campus has resulted in the construction of a one-million gallon storm water detention basin on Central Campus and the start of construction of a storm water detention basin and wetland on North Campus (just outside of the Millers Creek watershed). Other areas of campus are also being identified for potential future storm water management projects.

2.3.3 Altarum Institute

The Altarum Institute, formerly known as ERIM, has historically been a major landowner in the watershed. Since the 1970's when ERIM moved to its location on the corner of Plymouth and Green, several employees have worked to improve the landscape by planting trees and encouraging the Institute to practice good land stewardship. In the early 1990's, several ERIM employees began the first Millers Creek Action Team, the seeds of which are still active. Most recently, ERIM has worked on development of the land to the east of Green Road in a conscientious way to mitigate the effects of impervious surface runoff with naturalized biofiltration swales and planting of native species in the retention basins. Their new four-story building was conceived to fit with the landscape, preserving existing trees and planting native vegetation. Currently, Altarum is in the process of creating a set of signs to point out the ways the site adheres to "Best Management Practices." It is hoped that other landowners in the watershed will use similar signage to educate and promote good land stewardship throughout the creekshed.

2.3.4 Ann Arbor Parks

City of Ann Arbor parks in the Millers Creek watershed include the Ruthven Nature Area (20.57 acres) (see **Figure 2.7**), Oakridge Nature Area (7.67 acres), Earhart and Earhart West Parks (2.23 and 0.9 acres), Glazier Hill Park (1.72 acres), Windmere Park (3.96 acres), Glacier Highlands Park (1.67 acres), Green Brier Park (3.18 acres), Folkstone Park (3.17 acres), Baxter Park (2.0 acres), Sugarbush Park (30.14 acres) and Bromley Park (2.33 acres).

2.3.5 Ann Arbor Public Schools

Ann Arbor public schools in the watershed include Huron High School (52.89 acres with approximately 5 acres in the Millers Creek watershed), Clague Middle School (23.20 acres with approximately 11 acres in the watershed), Thurston Elementary School (11.95 acres) and King Elementary School (10.08 acres). Ann Arbor public schools also own the Thurston Nature Area (16.53 acres).

Figure 2.7 Upstream of Ruthven Nature Area

Ann Arbor public Schools has a certificate of coverage for the Phase II NPDES program and is working to improve storm water management at its facilities.

2.3.6 Geddes Lake Cooperative Homes

Geddes Lake Cooperative Homes is a 360-unit residential community on 56.8 acres near the intersection of Huron Parkway and Glazier Way. A focal point of the community are three small (8.41 acres total) interconnected lakes that are remnants of a mining operation on the site during the 1950's (JJR, 1990). These lakes take the storm water runoff from the cooperative as well as approximately 152 additional acres upstream of the development. The lakes discharge through a control structure to a small open channel that outlets to Millers Creek in Ruthven Nature Area.

In 2003, the lakes' outlet structure was upgraded to meet the Washtenaw County Drain Commissioner extended detention requirements. In addition, bioengineering erosion control measures were implemented along the shorelines of the ponds to reduce sediment loading. However, a recent limnology study (Jude, 2003) indicated that water quality conditions in the lakes are relatively poor. Summer sampling found anoxic zones at the bottom of the two largest lakes and high soluble phosphorus concentrations (0.21 mg/L) suggesting that sediment phosphorus was being released into the water column. Bottom contour maps and sediment sampling from 1990 and 2002 suggest that at least one of the lakes (the northwest lake) has experienced quantifiable sedimentation over that period.

2.3.7 Thurston Pond Nature Center

Prior to 1965, Thurston Pond was a wet prairie or marsh system with poor drainage. The superintendent of the Ann Arbor Parks and Recreation Department at the time noted that water levels fluctuated throughout the year and that sometimes the area held considerable amounts of water while at other times appeared as a mud flat (Ennett, et al., 1997).

With the development of the Orchard Hills and Bromley subdivisions, the hydrology of the marsh was so altered that it was transformed into a pond. This property, originally bought by the Ann Arbor Schools Department in 1955, was deemed unsuitable for development. In 1965, the Thurston School Parent-Teacher Organization (PTO) voted to set aside the marsh/pond as a nature study area. In 1967, the Smokler Company, developer of the Orchard Hills and Bromley neighborhoods, deeded their portion of the pond (about 1/3 the area) to the Orchard Hills Homeowners Association (OHHA). The OHHA deeded a portion of the land to the Thurston Nature Center, and the remainder eventually became the Orchard Hills Athletic Club.

In 1968, the Thurston Nature Area was officially designated a Conservation Education Reserve by the Michigan Department of Natural Resources, only the second such area in Michigan to receive this designation. Since that time, the nature area has been managed by a sub-committee of PTO volunteers.

After severe flooding in the Bromley and Orchard Hills neighborhoods in the summer of 1968, City planners decided to build a berm around the southern edge of the pond to hold excess runoff when surrounding storm sewer was at capacity. In 1972, an overflow structure was built to connect the 48-inch storm sewer main in Georgetown Boulevard to the northeast side of the pond. Another 24-inch overflow drain carries a portion of the Clague Middle School runoff into the pond on the northwest side. Two outlets on the southwest side of the pond, one inside the berm and the other outside the berm carry overflow to storm sewer on Renfrew Street that eventually empties into Millers Creek south of Plymouth Road.

In 1996, the Thurston Pond Nature Area PTO sub-committee requested assistance from the UM School of Natural Resources and Environment to enhance the pond, woodland, upland oak woodlot, tall grass prairie and old field ecosystems. Recently, after several years of lower-than-average rainfall, much of the pond was converting back into marsh. It is not clear how much of this conversion is due to natural succession, solids loading from the storm sewer or adverse, sustained weather conditions. In 2002, the PTO sub-committee decided to initiate development of a pond restoration plan. The Millers Creek Project Team began working with the sub-committee in the fall of 2002 to provide technical assistance with the restoration plan.

2.4 Stream Stability and Rehabilitation

In this plan the term ‘stream rehabilitation’ is used to distinguish between full restoration to some pre-development state and an intermediate end point that lies between a completely degraded resource and a completely restored one. The intent of the plan is to partially compensate for human damage to biodiversity and ecosystem dynamics by working with natural regenerative processes in ways that lead to the re-establishment of more sustainable relationships between nature and culture.

Natural stream stability is achieved when the dimensions, pattern and profile of a channel are maintained and the stream neither aggrades nor degrades. A generalized stable channel balance for flow and sediment discharge was first proposed by Lane (1955) as:

$(Q_s)(D_{50})$ is proportional to $(Q)(S)$

where,
Q_s = sediment discharge
D_{50} = mean particle size
Q = flow
S = bed slope

A change in any one variable will be offset by a change in the companion variables and characteristics of the river. For instance, wholesale increases in the magnitude and frequency of peak flows will result in sediment load increases and likely lead to channel degradation. This channel degradation means the channel “cuts down” and becomes incised.

Several decades of research on stream shape have found that there are distinct relational patterns between channel shape and bankfull flows. In natural rivers, bankfull flow is, as the name implies, the discharge that just fills the stream to the top of its banks. Bankfull flow has also been defined as the flow that does the most work to determine channel shape. Although extreme floods can radically alter a channel, the basis for the average channel characteristics, size, bars, bends, and meander shape is bankfull flow. This discharge moves the most sediment over time due to its size and relative frequency of occurrence.

Bankfull flow has been shown to occur on average once every 1.5 years; however, a wide range, between 1 and 25-year occurrence rates, has been reported in the literature (Rosgen, 1996). For incised streams, such as Millers Creek, bankfull flow is not necessarily descriptive of existing conditions because incised, deeper channels flood much less frequently, if ever. However, the idea that a certain size event of a given frequency does most of the work to shape the stream is still meaningful. In this regard, we will refer to the theoretical idea of a channel-forming event as the “effective discharge” and will assume that it is somewhere in the vicinity of the 2-year recurrence interval design storm for this region. Where the stream cuts through the Ruthven Nature Area, flooding occurs between the 1-year and 2-year design storms. This is probably indicative of the flooding frequency along most or all of the stream before the watershed was built out.

The relationships between effective discharge and channel shape are related to the regional climate, lithology, depositional and erosional history and vegetative cover. In this area, a broad database relating shape and discharge is not available. In order to have a fluvial geomorphological basis for management decisions on Millers Creek, the Project Team applied Rosgen’s hierarchical stream classification system (Rosgen, 1994). This system was developed with several decades of quantitative research on rivers across the country as a systematic way to understand river behavior. Rosgen’s analysis found that parameters used to describe stream morphology tend to cluster into definable groups and have predictable patterns of variation [*See **Appendix I** for a PDF version of Rosgen’s original paper on his stream classification system*]. Most importantly, Rosgen has demonstrated that the stream response to management actions can generally be predicted in relation to the stream type (Rosgen, 1996).

2.4.1 Incised Channel Evolution Model

Schumm, et al. (1984) used a location-for-time substitution to develop a model of incised channel development. The assumption of this substitution technique is that reaches in different states of development reflect differences in the local channel reaction along the same trajectory in time. In other words, channels undergoing incision have to pass through the same stages of channel morphology, and at any given time, reaches in the channel can be found at different stages along that continuum.

Rosgen has characterized a similar series of stages that channels pass through in reaction to changing conditions in the watershed. Rosgen has defined sequences of channel adjustments by use of his stream classification system. **Figure 2.8** demonstrates one possible evolutionary sequence for a type E4 stream undergoing incision that correlates well with the five-stage channel evolution model of Schumm. The Rosgen classification system offers the utility of expressing a series of field parameters as an identifiable stream type or stage in the evolutionary cycle of stream development.

Most importantly, Rosgen and others have been able to associate a stream’s overall capacity for rehabilitation and the effectiveness of specific rehabilitation measures with specific stream types (Rosgen, 1996). This project will rely upon the Rosgen stream classification method to corroborate hypotheses of underlying problems and to help judge potential success of restoration measures in relation to the classification results.

Below are the descriptions (a-f) of the channel types shown in order from top to bottom in **Figure 2.8**. On the left of **Figure 2.8** are representative channel cross-sections along Millers Creek, with the bankfull water surface elevation shown. On the right of **Figure 2.8** are the theoretical set of adjustments one particular channel section would go through over time as it adjusts to a new and more intense hydrologic regime. This comparison highlights the location-for-time substitution idea proposed by Schumm; i.e., different reaches in a stream will make adjustments to hydrologic changes at different times (e.g., the representative cross-sections in Millers Creek on the left side of **Figure 2.8**), while each impacted cross-section eventually passes through the same trajectory of channel morphological changes over time (e.g., the right side of **Figure 2.8**).

Figure 2.8 Description

a. An existing E-stream type experiences higher and more frequently occurring peak flows that widen the channel to a C-stream type. The E-stream type is a very stable stream type unless the banks are disturbed and there are significant changes in hydrology and sediment supply (Note: dashed lines on the Rosgen figure represent the future trajectory of the same cross-section at each stage).

b. The C-stream type continues to experience disturbance. Increased shear stress at the toe deepens the low point of the channel. The C-type stream is more susceptible to shifts in both lateral and vertical stability caused by channel disturbance and hydrologic changes than the E-type stream. Rates of lateral adjustment are influenced by the presence and condition of riparian vegetation.

c. The C-stream type is still out of equilibrium with existing conditions and converts to a G-stream type. The G-stream type is moderately to extremely incised and has lost its connection to the floodplain. This process of incision increases velocities and shear stresses because all flows are now confined within the banks. The channel rarely if ever experiences overbank flow. G-type channels tend to have high bank erosion and bedload transport rates. These stream types are very sensitive to disturbance (inherently unstable) and tend to make significant adverse channel adjustments to changes in hydrology and sediment supply.

d. The G-stream type eventually widens to an F-stream type. Velocities begin to slow down and the stream begins to meander. Sediment supply in an F-stream type can be moderately high. Depositional features are common and tend to promote the creation of a new floodplain within the channel.

e. Meandering creates a C-type stream within the confines of the original channel.

f. Additional settling out of solids builds up a new, active floodplain, and a new E-stream type within the original channel. The old floodplain is perched above the active stream and is now referred to as a terrace.

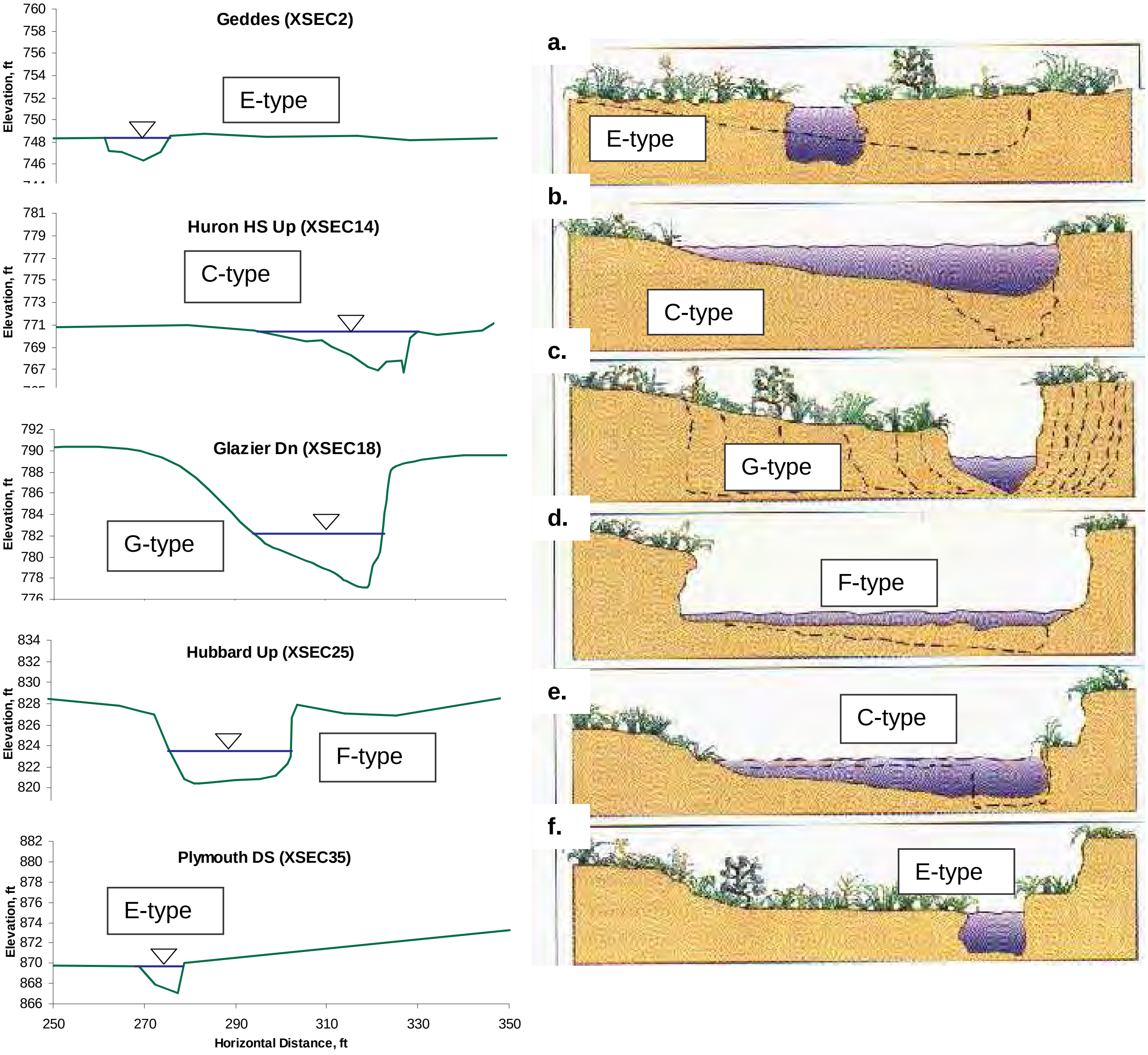

Figure 2.8 Millers Creek Cross-sections (left) and an Example of Channel Evolution (right), modified from Rosgen (1996)

3. METHODS

3.1 General Summary

The watershed plan was prepared by the Project Team, including Ayres, Lewis, Norris & May, Inc. (ALNM), Tilton and Associates, Inc. (TAI) and the Huron River Watershed Council (HRWC). Oversight for plan development was provided by the Millers Creek Action Team (MCAT). On a monthly basis the Project Team met with the MCAT and reviewed progress to date, projected future progress, resolved project issues and discussed plan development.

One unique aspect of this project was the highly detailed field work, including the efforts and involvement of volunteer groups to measure macroinvertebrate diversity, habitat conditions, temperature, conductivity, channel dimensions, flow and velocity. HRWC taught volunteers basic surveying and flow gaging techniques. In addition, as a class project for a University of Michigan undergraduate chemistry class, continuous recording temperature, conductivity and dissolved oxygen probes were installed at the Glazier site for Fall 2002.

The efforts of MCAT and the Project Team were communicated and discussed with public participants in three direct mailings, a meeting of watershed businesses, three public meetings, two stream tours and through a regularly updated web page (http://www.aamillerscreek.org).

3.2 Existing Data Sources

Existing sources of data compiled for this project include:

Planning Documents

- Complete City of Ann Arbor (AA) Storm Water Master Plan, including all associated NPDES storm water monitoring data
- University of Michigan NPDES monitoring data and facilities planning information
- Ordinances (AA, AAT) and regulations (WCDC)
- City of Ann Arbor Northeast Area Plan

Spatial Data

- Natural Features Information
- City of Ann Arbor Stormwater Management Model (XP-SWMM) input and output data in electronic format
- City of Ann Arbor storm sewer maps
- UM storm sewer maps
- Soils, topography, and land use from state, county, city and UM sources
- Historic and current aerials for review of watershed and stream changes to provide context for impacts of urbanization on the stream corridor
- Zoning/tax assessor maps
- Existing National Flood Insurance Program (NFIP) FEMA maps and studies for Ann Arbor City and Township, including Geddes Dam water surface elevations

Construction Drawings

- Pfizer site data, including topography, wetland delineation, natural features inventory and as-built drawings for storm water features
- As-built drawings for storm water features from all major developments in the watershed
- Geddes Lake Condominium lower lake outlet structure retrofit

Existing Gauges

- Pfizer rain gauge and mitigation wetland pressure transducer (water level)
- University of Michigan (UM) rain gauge

Water Quality Data

- Michigan Department of Environmental Quality E. coli sampling data to support the *E. coli* TMDL (summer of 2002 – See **Appendix A** of this report)

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.

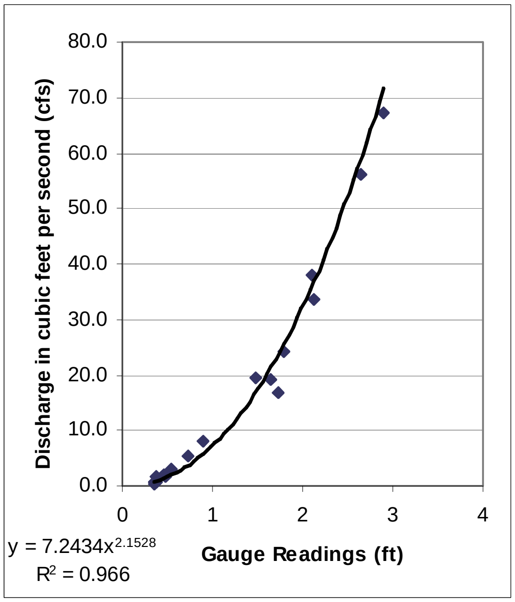

Figure 3.3. Rating Curve for Millers Creek near the Huron High School.

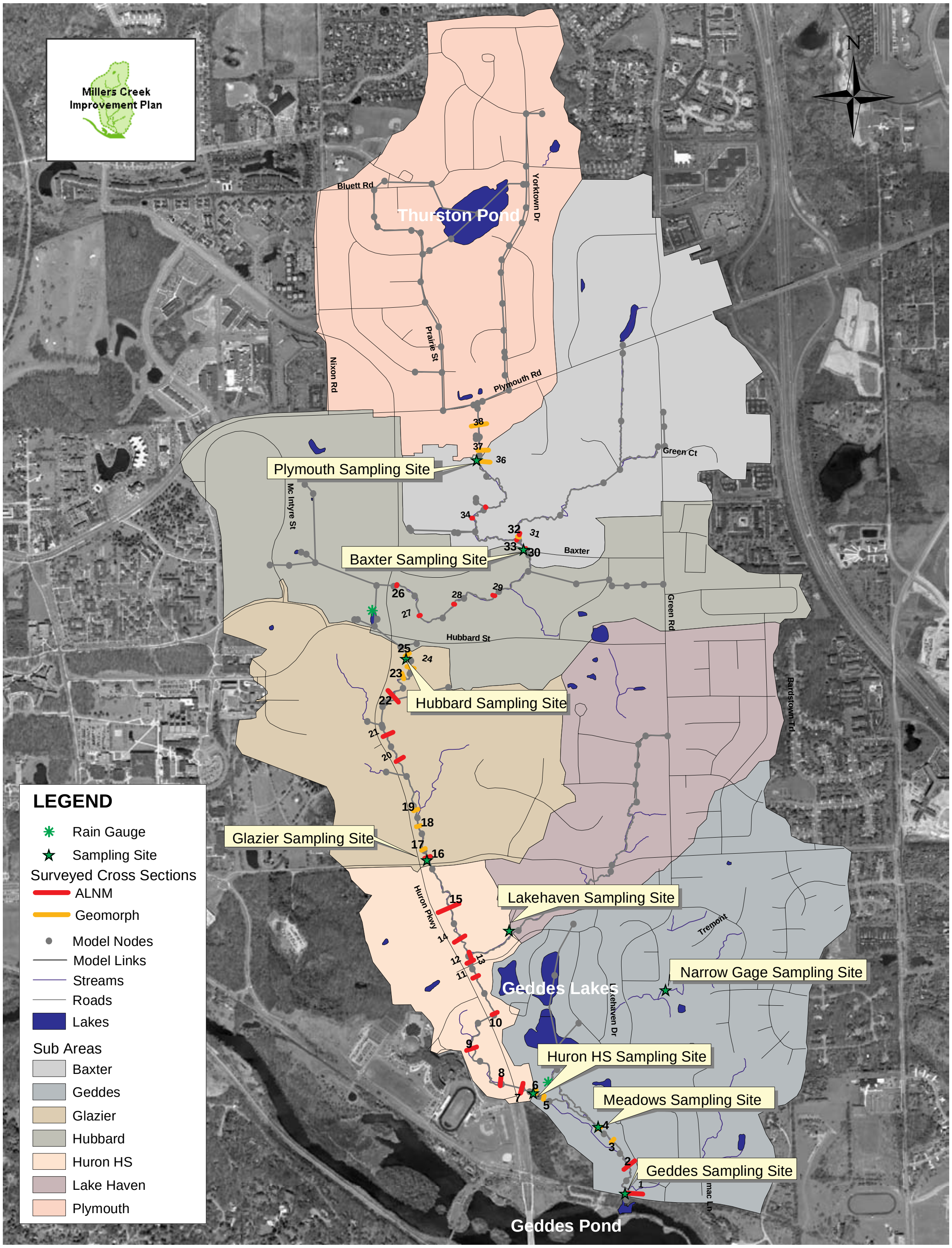

Figure 3.1 Subarea, Sampling Site, and Cross Section Locations

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

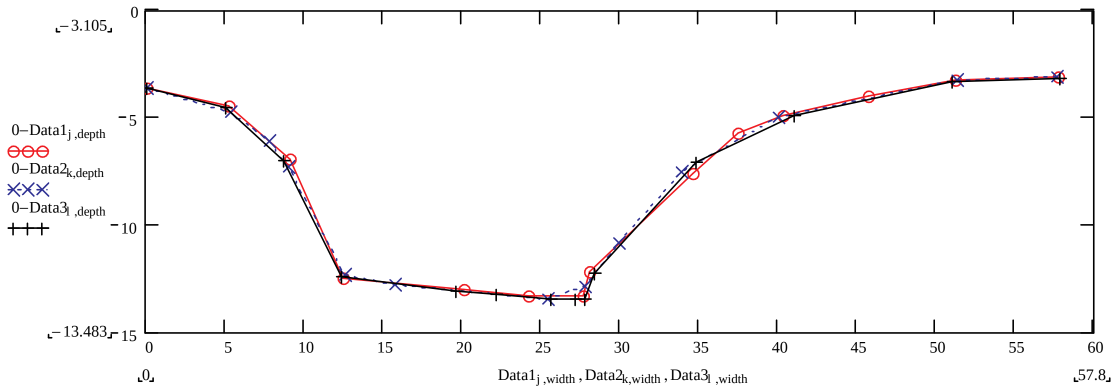

Figure 3.6. The shape of the channel at the upstream transect at the Glazier study site.

(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.

	Erosion Potential & Severity			
Criteria	**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.

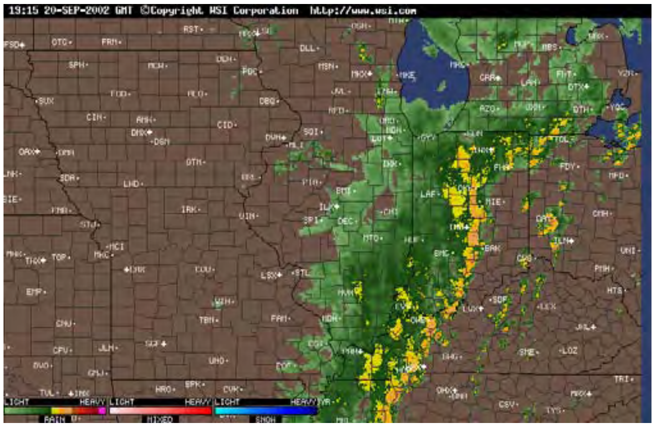

Figure 3.10 Radar Image of 9-20-02 Rainfall

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).

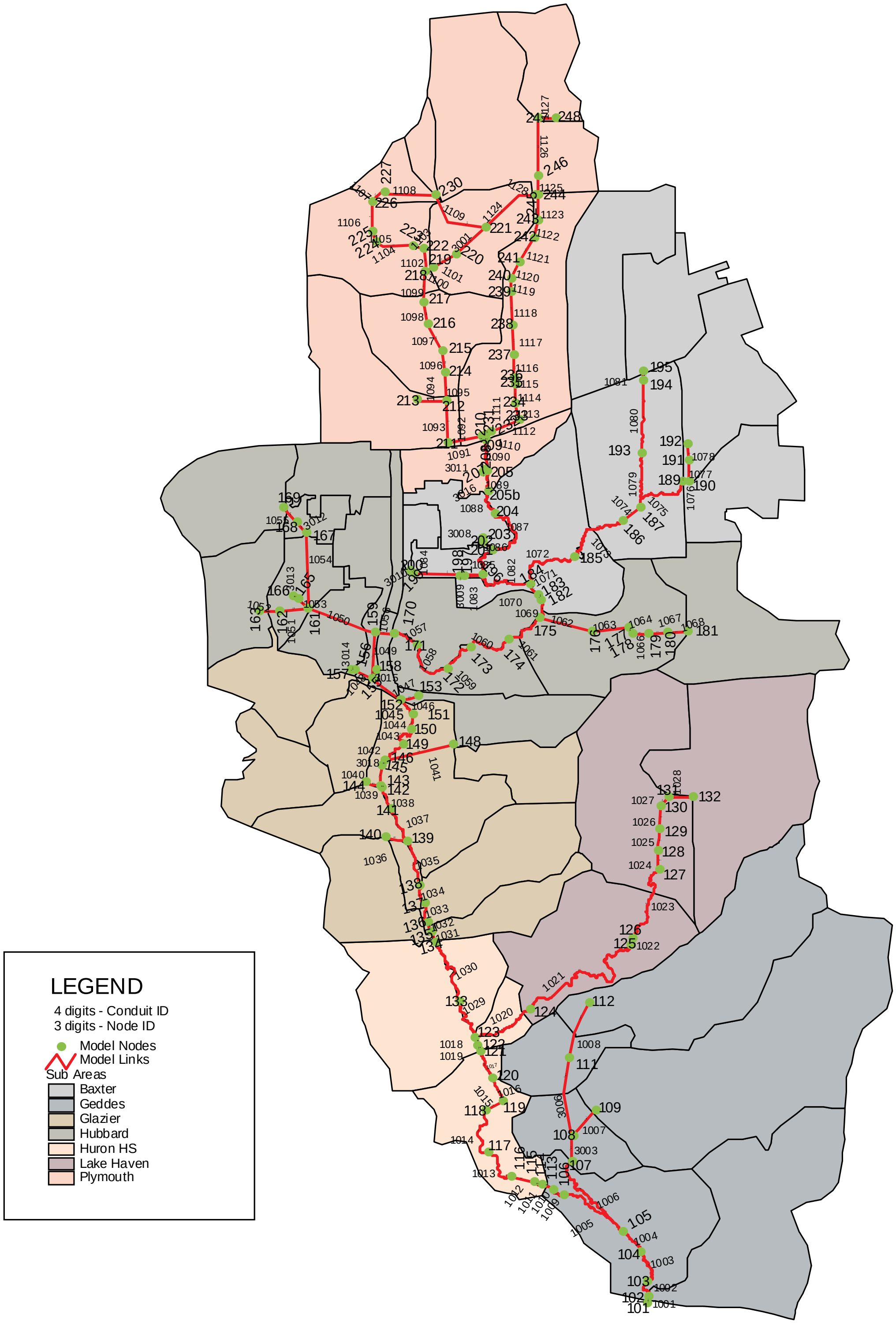

Figure 4.1 SWMM Model Schematic (with sub areas shown)

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.

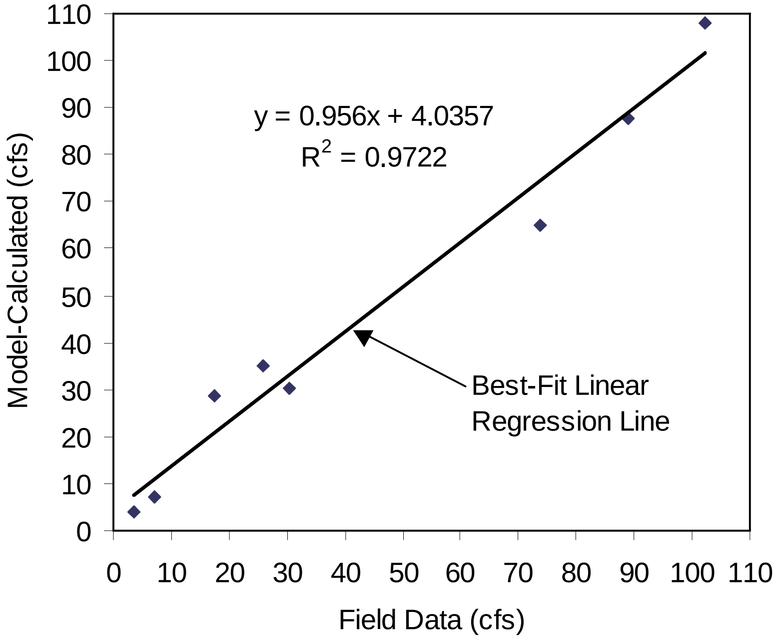

Figure 4.2 Comparison of Model-Calculated and Measured (by transducer) Peak Flow Rates for the three calibration events at the Plymouth, Glazier and Meadows Sites

Note: Meadows flow estimated for comparison purposes using Huron HS site stage-discharge relationship

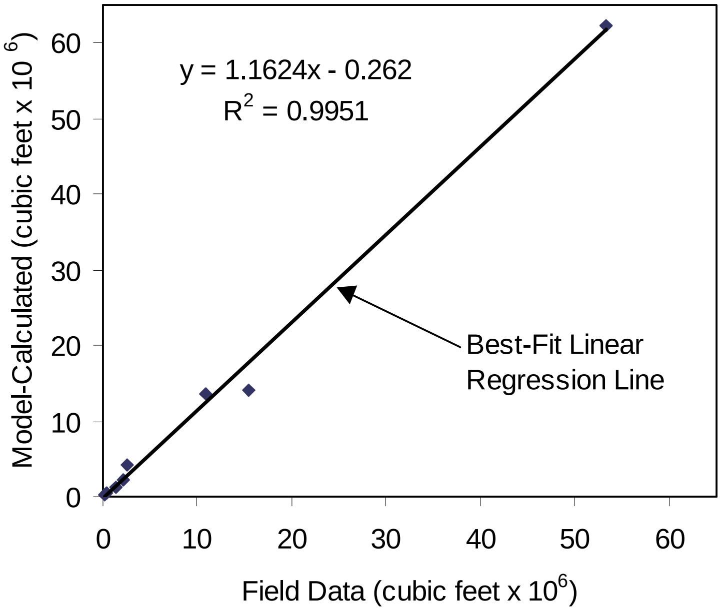

Figure 4.3 Comparison of Model-Calculated and Measured (by Transducer) Total Event Volume for the three calibration events at the Plymouth, Glazier and Meadows Sites
Note: Meadows total event volume estimated for comparison purposes using Huron HS site stage-discharge relationship

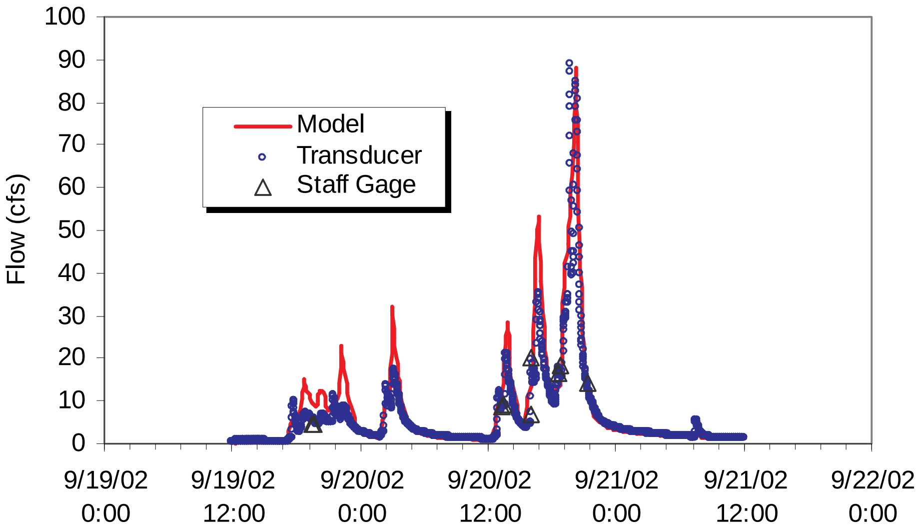

Figure 4.4 Example Flow Calibration Fit, Event 1 (Sept.19-21, 2002) at the Glazier Site

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.

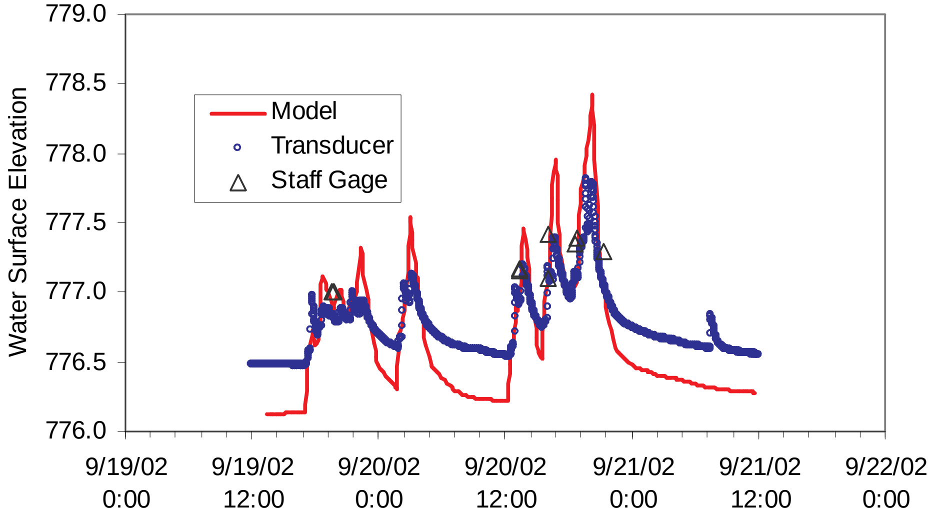

Figure 4.5 Example Water Surface Elevation Calibration Fit Event 1 (Sept.19-21, 2002) at the Glazier Site

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.

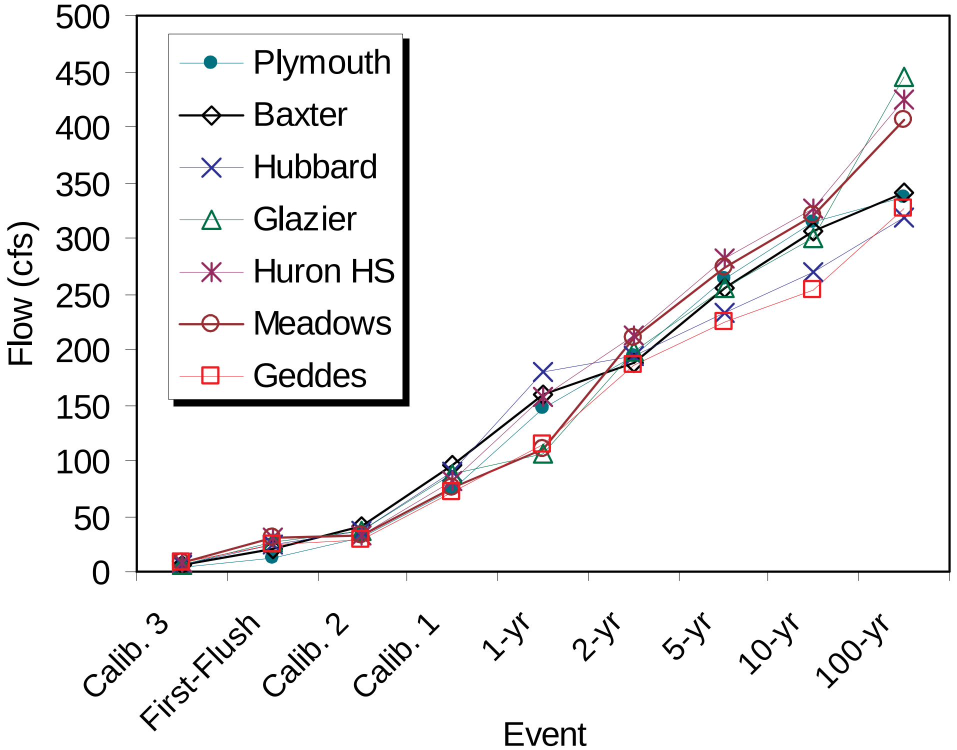

Figure 4.6 Model-Estimated Peak Flow Rates for All Existing Conditions Events

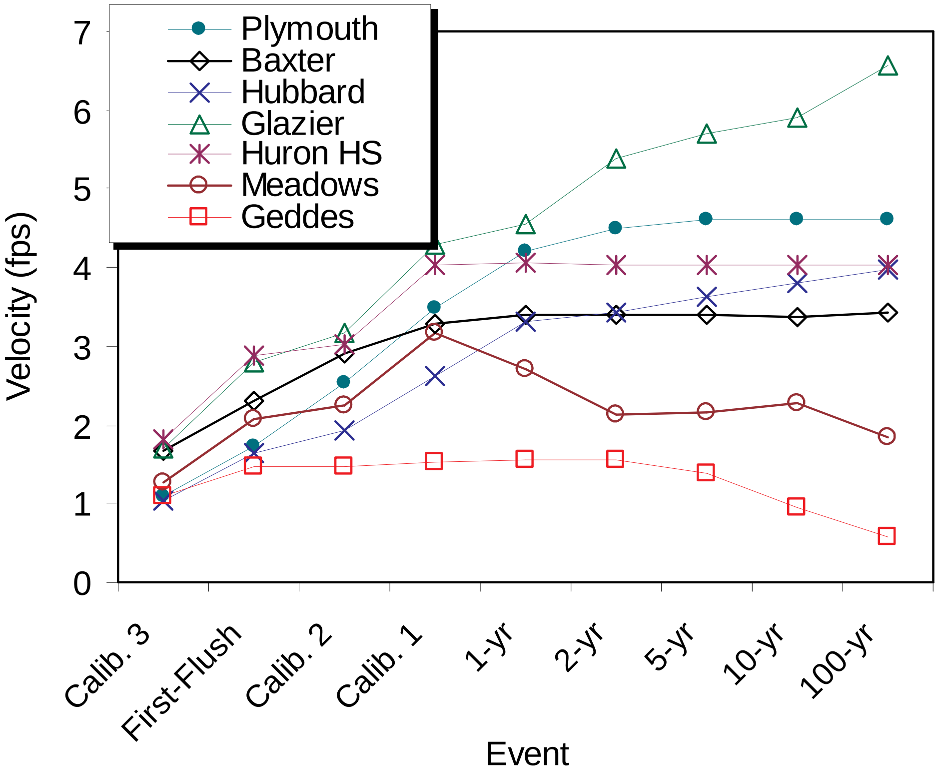

Figure 4.7 Model-Estimated Peak Velocities* for all Existing Conditions Events
(model velocity defined as the average across the channel)

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.

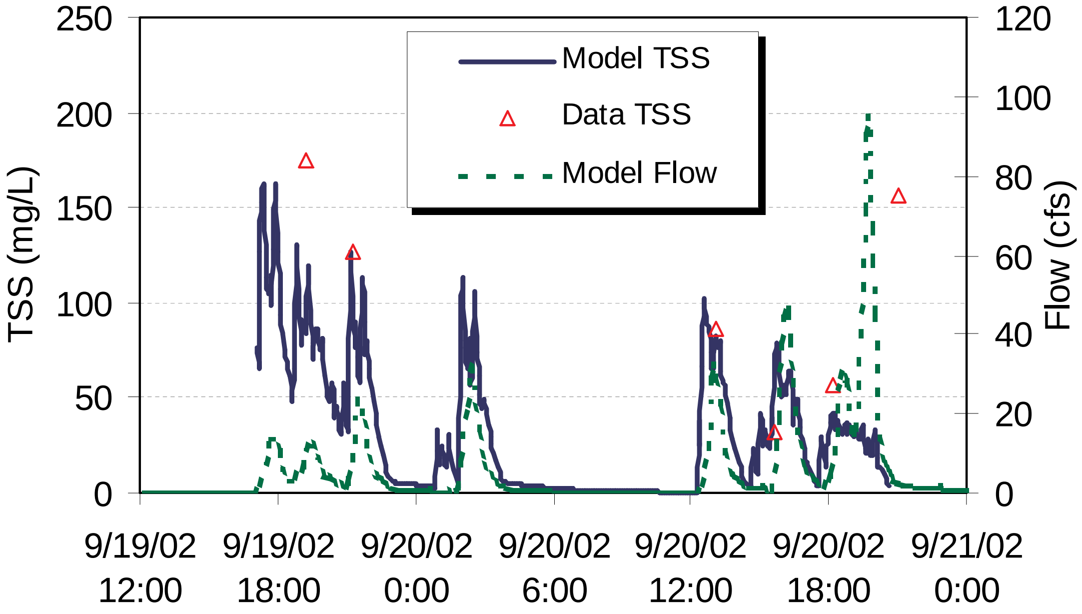

Figure 4.8 Comparison of Model-Calculated and Field Data Total Suspended Solids Concentration at the Hubbard Station for Event 1, Sept.19-21, 2002

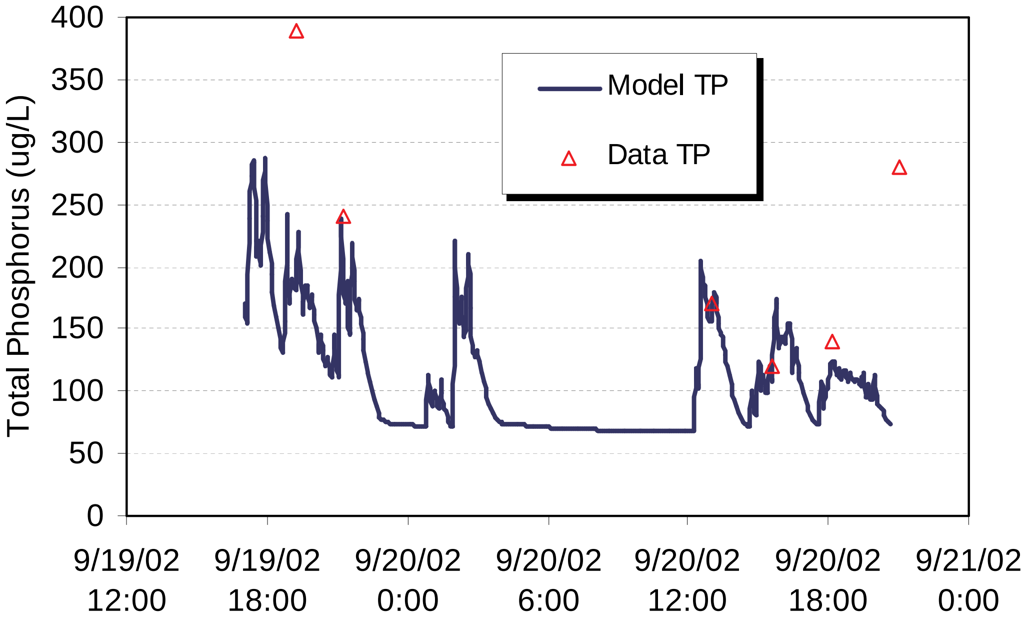

Figure 4.9 Comparison of Model-Calculated and Filed Data Total Phosphorus Concentration at the Hubbard Station for Event 1, Sept.19-21, 2002

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.

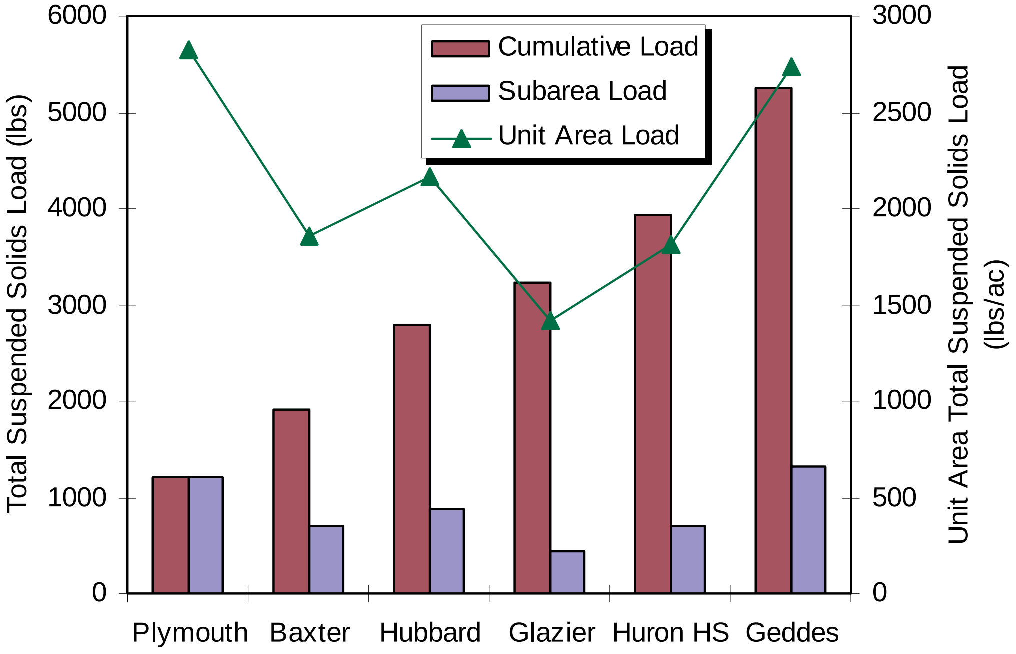

Figure 4.10 Model-Estimated Total Suspended Solids Loads for the First Flush Event (0.5 inches of rain in six hours)

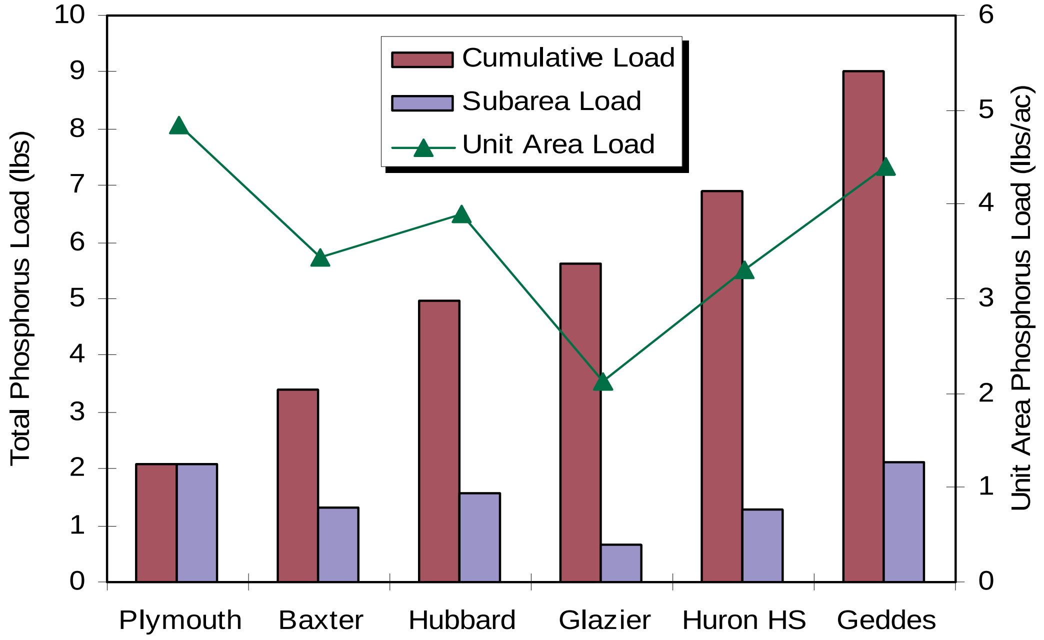

Figure 4.11 Model-Estimated Total Phosphorus Loads for the First Flush Event (0.5 inches of rain in six hours)

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.

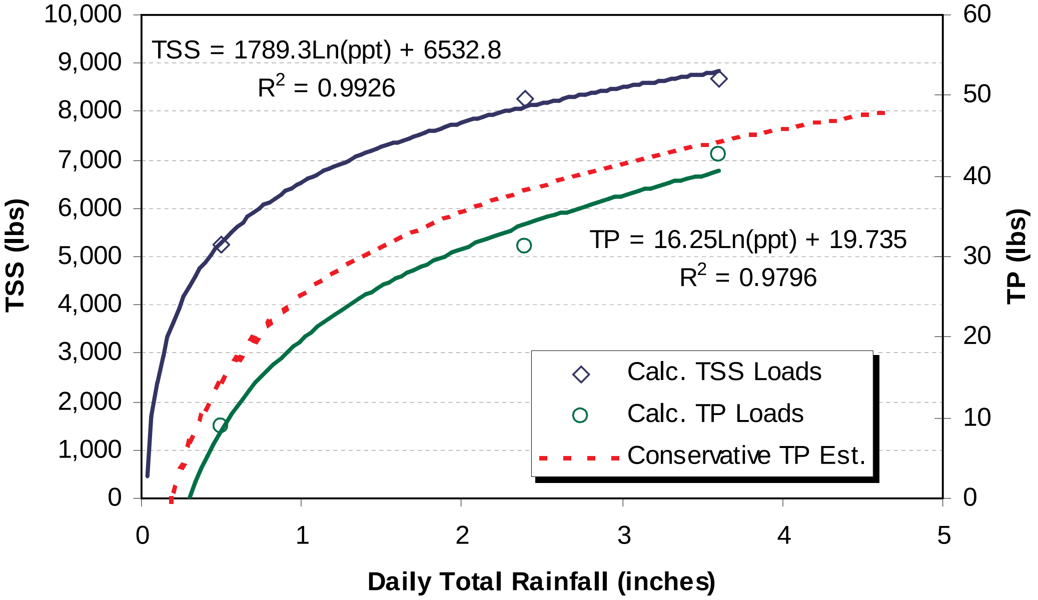

Figure 4.12 Relationships of TSS and TP Total Event Loads to Design Event Rainfall Totals