Flood Mitigation Needs Assessment

Six Mile Creek
Tompkins County, New York

October 2003

MMI #2343-01

Prepared for:

Tompkins County Planning Department
121 East Court Street
Ithaca, NY 14850

Edward Marx, Commissioner of Planning
Kate Hackett, Water Resources Planner
Katie Borgella, Land Programs Manager

Prepared by:

Milone & MacBroom, Inc.
716 South Main Street
Cheshire, CT 06410

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDED FIGURES

Executive Summary

Study Purpose and Need

The Tompkins County Planning Department has retained Milone & MacBroom, Inc. (MMI) to conduct a Flood Mitigation Needs Assessment for numerous watersheds in the County as part of an ongoing planning and mitigation effort. The intent is to restructure the *Flood Hazard Mitigation Program* to address a more holistic watershed approach. This will enable individual projects to be assessed and evaluated based on their merit and function within the framework of the overall watershed needs. The following objectives have been identified for the subject planning initiative:

- to evaluate effective flood mitigation in Tompkins County;
- to re-emphasize watershed approaches through the development of a strategy to address watershed needs;
- to consider cumulative flood mitigation measures; and
- to identify watershed management and flood mitigation priorities.

Six Mile Creek is one of the largest tributaries to Cayuga Lake and has been selected as the pilot watershed to undergo the first needs assessment. Based on discussions and interviews with watershed stakeholders, as well as a review of the history of actions within the watershed, the highest priority concerns in Six Mile Creek center around the following issues:

- protection of property and infrastructure (i.e. roadways, bridges, pipelines, etc.);
- protection of drinking water quality;
- elimination of "unsightly" erosion occurring within the watershed; and
- elimination of the sediment plume in Cayuga Lake during and following precipitation.

Other secondary issues involve the practices of road sanding, aquifer protection, and the overall ecological health of the creek. In addition to addressing the aforementioned concerns, a common goal of establishing riparian buffers along the creek has been identified by numerous watershed stakeholders.

Summary of Existing Conditions

Existing conditions in the Six Mile Creek watershed have been evaluated based on a review of available data, mapping, and information, coupled with a week-long intensive field investigation. The following summary of existing conditions is based upon that collective effort.

From a broad perspective, Six Mile Creek has been found to be alternately stable and degrading, depending on location within the watershed. The most notable degradation occurs in the middle of the upper and lower halves of the creek. In recent history, the watershed has been revegetated, with an overall reduction in sediment as compared to past land uses. The lack of sediment loading has left Six Mile Creek with a sediment deficit. In other words, the sediment transport capacity of the creek now exceeds its supply of sediment. The degradation that is occurring in Six Mile Creek is indicative of a stream that is attempting to reach a new equilibrium. In essence, the creek's lack of external sediment loading and excess energy is causing it to migrate laterally in some reaches, while degrading vertically in other reaches.

Specific observations of existing conditions within Six Mile Creek follow:

1. The Six Mile Creek Watershed has transitioned from a mature forest of 300 years ago through clear cutting for lumber and agriculture. It now supports mixed agriculture and increasing second growth woodlands. The hydrologic impact of urbanization is minor, except in and near the City of Ithaca.

2. The Six Mile Creek watershed was subject to glacial action as recently as 10,000 to 12,000 years ago, leaving it with peculiar through-valleys and erodible glacial lake bottom sedimentary soils of silt and clay.

3. Six Mile Creek has an extremely steep watershed, dropping some 1,300 feet from its headwaters in Dryden to Cayuga Lake. The creek is subject to numerous elevational controls, both natural and man-made. Cayuga Lake controls the most downstream elevation, at a normal water surface elevation 382 feet. At its headwaters, Six Mile Creek approaches elevation 1,650 feet.

4. Many of the tributary channels that flow into Six Mile Creek are incised in deep gullies. Some show signs of having had significant or dramatic erosion in the past, but many have since reached bedrock or till vertical control and are now relatively stable.

5. The Six Mile Creek channel is going through transition phases, with some segments having become incised and are now widening. Other segments are still becoming incised.

6. Bank erosion within the main channel of Six Mile Creek is evident throughout its course, and in some areas is quite severe. The channel appears to be becoming more sinuous in an attempt to decrease its slope. This is resulting in widespread lateral migration of the channel through the highly erodible lakebed deposits that characterize much of the watershed. In other locations, the creek appears to be stable, both vertically and horizontally. Vertical stability has been attained in certain instances by virtue of the fact that the creek has eroded to bedrock, creating a stable base level below which the channel cannot rapidly erode.

7. The channel along most of the Six Mile Creek from its headwaters to Cayuga Inlet is armored with cobble and does not appear to be actively down-cutting. However, evidence of historic down-cutting is readily evident, with a former floodplain terrace set above a newly forming floodplain adjacent to the incised channel.

8. The most current Federal Emergency Management Agency (FEMA) Flood Insurance Study of the area outside of the City of Ithaca was conducted sometime in the 1960's. Given the highly dynamic nature of the creek, coupled with the computational techniques used in the 1960's, the FEMA study is almost certain to be inaccurate, even for the most rudimentary of planning purposes. While flooding does occur in some areas within the Six Mile Creek watershed, given the apparent lack of *anthropogenic* related flooding problems in the watershed, flow rate management and water elevation management are not critical elements of the proposed flood mitigation strategy.

9. Channel cleaning and snagging have removed large woody debris from many of its reaches, encouraging higher velocities and scour. The bedrock fragments of gravel and cobble, along with log deposits of rocks from glacial till, are generally too light to form a natural erosion resistant riverbed.

10. Land uses within Six Mile Creek are rural in nature, with local concentrations of residential and commercial development in the town centers of Slaterville Springs, West Slaterville, Brooktondale, and along Route 79. The exception is the more intense development within the City of Ithaca, where the creek has been completely channelized.

11. Erosion and sedimentation problems in Six Mile Creek are clearly not the result of poor watershed management practices. Little evidence has been observed of unnatural erosion as a result of irresponsible agricultural practices or construction activities. The humid climate, till soils, and high vegetative cover result in low sediment yields. It is likely that road sand and unvegetated roadside ditches produce some sediment loading in the watershed, however, this is not believed to be a major source. No seasonal trends in sediment load in U.S. Geological Survey data are evident.

12. Even without urbanization, land use changes can lead to broad changes in runoff rates and sediment loads. However, there is little evidence of significant erosion from the Six Mile Creek watershed's land surface.

Summary of Recommendations

Many techniques are available for managing channel incision and its adverse consequences. The project team recommends a broad approach that has three components. First is accepting that inevitable degradation will occur; second is reducing sediment loads from the largest sources; and third is improved downstream sediment trapping, specifically in the area near the City of Ithaca's existing siltation dam. As a mechanism for implementation, the County and watershed member towns are encouraged to adopt stream corridor protection mechanisms and certain land use controls for the future protection of the creek and its watershed. Programmatic changes in the *Flood Hazard Mitigation Program* are also recommended to steer mitigation toward a watershed-wide approach.

The following overall recommendations are offered:

1. It is not practical or economically feasible to stabilize Six Mile Creek through conventional means. Traditional approaches to river management are often limited in scope, prohibitively expensive, and environmentally unsound. The concept of managing the watershed and corridor as well as the river channel itself provides an alternate approach that allows each river function to be managed at the appropriate level. As such, bank stabilization techniques should be judiciously applied in priority areas to protect existing structures, private property, and infrastructure (i.e. bridges, gas mains, water mains, etc.).

2. At channel bank erosion problem sites, the project team recommends placing a priority on the creation of synthetic floodways to disperse flow and reduce velocity rather than construction of large scale structural bank protection measures. Highest priority should be given to hazard mitigation projects that utilize natural stabilization methods, such as the use of conventional plantings or bio-technical methods (i.e. strategic placement of boulders, root wads, hemlock revetments, etc.).

3. Most of the inspected channel reaches along Six Mile Creek have unusually low levels of channel roughness with which to reduce flow velocities and provide structural habitat. The project team recommends that a comprehensive program be undertaken to increase channel roughness that would include the following measures:

    - anchor or bury large woody debris in the banks;
    - create boulder and log sills in the riverbed to form rapids and pools;
    - install individual boulders and boulder clusters in the channel; and
    - redefine the channel's thalweg.

4. The Six Mile Creek watershed appears to have an unusually low amount of wetlands and ponds that would help delay storm runoff and trap sediment. It is recommended that additional upland ponds and wetlands be created in the tributary watersheds to help control peak runoff rates.

5. The application of the geomorphic-based design is a powerful tool, but the methodology is not appropriate in many areas of instability.

6. The priorities outlined in the table below are recommended along the Six Mile Creek: The highest priority reaches include Segment 4 (from Banks Road to Middaugh Road) and Segment 8 (from Creamery Road to Six Hundred Road). Moderate priority reaches include Segment 3 (from Burns Road to Banks Road) and Segment 5 (from Middaugh Road to Valley Road near Route 330 in Brooktondale).

Segment Restoration Priorities

Segment	*Description of Geographic Limits*	*Priority*
1	Cayuga Inlet to Van Natta's Dam	Low
2	Van Natta's Dam to Burns Road	Low
3	Burns Road to Banks Road	Moderate
4	Banks Road to Middaugh Road	High
5	Middaugh Road to Valley Road near Route 330 in Brooktondale	Moderate
6	Valley Road near Route 330 in Brooktondale to Boiceville Road	Low
7	Boiceville Road to Creamery Road	Low to Moderate
8	Creamery Road to Six Hundred Road	High
9	Six Hundred Road to Headwaters in Dryden	Low

The following programmatic recommendations are offered:

1. Urbanization does not appear to be a significant factor in the runoff and sediment problems within the Six Mile Creek watershed. However, there are few mechanisms in place to minimize the impact of future land use changes. The project team recommends that the County and watershed member towns closely follow the New York Department of Environmental Conservation's Stormwater Management Manual and consider local regulation changes to support its application.

2. The project team strongly recommends that the County and watershed member towns create a conservation corridor along both stream banks to encourage riparian vegetation for channel and floodplain stabilization and wildlife habitat. Vegetated floodplains also help to reduce flow velocities, prevent scour and trap sediment.

3. High quality hydrologic data is essential for managing watersheds and understanding geophysical processes. It is essential that the U.S. Geological Survey stream flow gauge continue to operate.

4. Specific changes in the *Flood Hazard Mitigation Program* application process for funding are recommended that would give priority to sustainable restoration alternatives, watershed approaches, and restoration projects that are aimed at preventing damage to the natural environment. Development of minimum requirements for funding eligibility is also recommended.

Finally, the following site-specific recommendations are offered:

1. Both past and future mitigation efforts in the form of structural walls and other vertical barriers are likely to require continued maintenance and experience repeated failures. Rigid riverbank retaining walls should be designed by a qualified licensed Professional Engineer and should include a hydraulic analysis of velocity and scour impacts, as well as a

stability analysis that considers active earth pressures, hydrostatic pressure, surcharge loads, and foundation conditions.

2. The Ithaca Water Department siltation basin at Burns Road should be modified to improve its efficiency, including a forebay, flow by-pass system, and a floating boom/silt curtain. The apparent increase in turbidity as water flows through the siltation basin is a peculiar situation that should be monitored to determine its cause.

3. A gas pipe crossing the river about 600 feet upstream of the siltation basin is reported to have been previously exposed by degradation and was observed to have been armored with riprap and a grade control sill. A second gas pipe crossing was found approximately 2,000 feet downstream of German Cross Road and the pipe is exposed. It is a hazard and should be stabilized immediately.

4. The existing Six Mile Creek "knick points" between Banks Road and Brooktondale should be stabilized in-place as an interim measure to minimize further upstream incision.

5. The bifurcated flow upstream of Banks Road at the property of Scott Whitham (reach #3505) should be redirected into the left channel and the right channel should be converted to a riparian wetland floodplain.

6. The eroding river bank and stacked rock retaining wall failure at the Tutton property (reach #3487) in Slaterville Springs should be addressed by creating a floodway on the left bank and backfilling the channel near the wall to increase the waterway area and reduce velocities.

The Needs Assessment for Six Mile Creek has been conducted on a "macro-scale" level. While this assessment has enabled development of a broad scale watershed management strategy, establishment of a hierarchy of specific projects, with cost estimates and implementation schedules will require more in-depth investigations of the moderate and high priority stream reaches along Six Mile Creek.

With regard to implementation, the site-specific recommendations described above are all excellent short-term implementation candidates that should be pursued as funding allows. The programmatic recommendations should be initiated as soon as practical. However, given the depth of coordination that will be required among the member municipalities, along with the complexities of the public process to implement any regulatory changes, will likely take several years.

The County can begin to work towards the long-term goals and objectives of a holistic watershed approach by initiating changes to its current funding program. However, many of the long-term watershed measures presented in the overall recommendations described above, will require funding that significantly exceeds the annual allocation of $25,000 or the combined contribution of $75,000 per year with "matching" funds.

Small projects, such as area-specific channel roughening with cobble, woody debris, islands, or bars that serve to freeze the elevation of the bed and slow down the flow to inhibit incisement would be expected to cost in the tens of thousands of dollars range, depending upon the extent of the area of application. By comparison, larger-scale projects such as channel relocation or creation of an artificial floodplain would be expected to cost in the hundreds of thousands of dollars range. Wetland creation costs are typically on the order of $45,000 per acre.

1.0 *Introduction*

1.1 Background and Purpose

The Tompkins County Planning Department has retained Milone & MacBroom, Inc. (MMI) to conduct a Flood Mitigation Needs Assessment for numerous watersheds in the county as part of an ongoing planning and mitigation effort.

Figure 1-1 is a location plan of Tompkins County. It encompasses the City of Ithaca as well as the Towns of Ithaca, Lansing, Groton, Dryden, Caroline, Danby, Newfield, Enfield, and Ulysses.

The Tompkins County Planning Department provides planning and related services to both County government and local municipalities. The Department is charged with preparing a comprehensive development plan; collecting and distributing data and information on population, land use, housing, environment and community facilities; preparing planning studies and analyses; and acting as a resource for other County agencies as well as the member communities in seeking outside funding.

In 1997, the Planning Department initiated its *Flood Hazard Mitigation Program*, funded through the County tax base. The program set up a system whereby a total of $25,000 was made available each year for flood hazard mitigation projects within Tompkins County. Funding was contingent upon a one-third County grant, with one-third matching requirements by the project proponent (typically the property owner) and one third match by the municipality in which the project was located. In instances where the municipality was the project proponent, their share was two-thirds. In-kind services were eligible to meet all or a portion of the matching requirements, for individuals as well as municipalities.

Figure 1-1

In the past, the County solicited *Flood Hazard Mitigation Program* project proposals on an annual basis. Application forms were developed on which project proposals were submitted by interested parties. These proposals were then reviewed and funding awards were made accordingly. The program was administered in coordination with the Tompkins County Soil and Water Conservation District (TCSWCD). During the time that the program was active (1999 through 2001), project awards were typically in the $5,000 range, with total project costs in the $15,000 range.

Coincident with the inception of the *Flood Hazard Mitigation Program*, a five-member Flood Hazard Advisory Committee was established, with representation by County Planning, Engineering, and Environmental Management Departments, a Water Resources Council, and the Soil and Water Conservation District. The Advisory Committee last met in late 2001, at which time funding was put on hold pending reorganization and reassessment of the flood hazard mitigation needs within Tompkins County. The intent was, and remains, to restructure the *Flood Hazard Mitigation Program* to address a more holistic watershed approach. This will enable individual projects to be assessed and evaluated based upon their merit and function within the framework of the overall watershed needs.

The following objectives have been identified for the subject planning initiative:

- to evaluate effective flood mitigation in Tompkins County;
- to re-emphasize watershed approaches through the development of a strategy to address watershed needs;
- to consider cumulative flood mitigation measures; and
- to identify watershed management and flood mitigation priorities.

In all, ten watersheds drain into Cayuga Lake within Tompkins County. These watersheds are depicted in Figure 1-2. In clockwise order, they are:

Figure 1-2

- East Cayuga Lakeshore South Watershed;
- Fall Creek Watershed;
- Cascadilla Creek Watershed;
- Six Mile Creek Watershed;
- Cayuga Inlet Watershed; and
- West Cayuga Lakeshore South Watershed.

Six Mile Creek is one of the largest tributaries to Cayuga Lake and was selected by the Planning Department as the pilot watershed to undergo the first needs assessment.

1.2 Six Mile Creek Pilot Watershed

Before the arrival of the Europeans, the Six Mile Creek valley served as a transportation route to and from Ithaca. An important travelway crossed the creek at Brooktondale, six miles from Cayuga Lake, serving as a landmark to travelers and giving the creek its name (Reidenbach, et. al., 1996).

Figure 1-3 is a location map of the Six Mile Creek watershed. The creek flows through the Towns of Dryden, Caroline, and Ithaca, and finally through the City of Ithaca into Cayuga Lake via the Cayuga Inlet. The contributing watershed to Six Mile Creek is approximately 52 square miles, portions of which lie within the Towns of Caroline, Dryden, Danby, and Ithaca, as well as the City of Ithaca.

The headwaters of Six Mile Creek are located in the Town of Dryden near the intersection of Irish Settlement Road and Card Road. The headwaters of the creek are nestled between Yellow Barn State Forest to the northwest and Hammond Hill State Forest to the southeast. The creek flows in a southerly direction and crosses beneath Irish Settlement Road before flowing into the Town of Caroline.

Figure 1-3

Six Mile Creek flows parallel to Six Hundred Road in northern Caroline and then crosses beneath Route 79 and Buffalo Road in Slaterville Springs. It turns to the west and flows beneath Creamery Road, Boiceville Road, and then parallels Valley Road behind the Caroline Elementary School into Brooktondale. At Brooktondale, Six Mile Creek turns in a northwesterly direction and runs parallel to Brooktondale Road and Route 79. It crosses beneath Middaugh Road and Banks Road within the Town of Caroline and then skirts the southwest corner of Dryden near German Cross Road before flowing into the Town of Ithaca.

Downstream (and northwest) of German Cross Road, Six Mile Creek flows into an impoundment known as the siltation dam, constructed circa 1930. This impoundment is located just upstream of the City of Ithaca's drinking water supply reservoir, located in the Town of Ithaca. The siltation dam was installed in an effort to capture suspended sediment upstream of the drinking water supply. The area is actively managed for sediment control, and stockpiles of previously dredged material have been placed adjacent to the impoundment.

Downstream of the siltation dam, Six Mile Creek crosses beneath Burns Road, located within the Town of Ithaca and then it flows into Ithaca Reservoir, where ±5.5 million gallons of water is withdrawn each day to supply drinking water to the residents and businesses within the City of Ithaca as well as portions of the Town of Ithaca. Cornell University, portions of which are located within the City limits and the limits of the Town of Ithaca, is supplied by its own system.

Ithaca Reservoir has been a water supply source since 1892, when the Ithaca Light & Power Company purchased the mill and dam at the Van Natta's Dam complex. In 1902, the utility constructed an upstream 30-foot high dam and laid a 24-inch aqueduct along the creek. Shortly thereafter, they built a water filtration plant. In 1904, the City of Ithaca purchased the dam and filtration plant, and by 1911, construction of a 60-foot dam was completed upstream of the initial dam. The reservoir continues to provide potable water to the City and portions of the Town of Ithaca.

The overflow from the 60-foot reservoir dam is directed downstream, where it is impounded by the 30-foot high dam. The surrounding area is known as the Wildflower Preserve and is heavily utilized by hikers, walkers, and joggers. The creek flows through a largely bedrock channel downstream of the lower reservoir and then onto Van Natta's Dam within the City of Ithaca.

Downstream of the impoundments, Six Mile Creek flows into Cayuga Inlet. The inlet is approximately one mile in length and is located between the mouth of Six Mile Creek and Cayuga Lake. The creek is channelized in the downstream reaches, beginning at the Aurora Street bridge.

1.3 Project Stakeholders

Numerous stakeholders have been identified for the Six Mile Creek, including the individuals and organizations summarized in Table 1-1.

TABLE 1-1
Partial List of Project Stakeholders

Organization	*Principal Contact*
Tompkins County Planning Department	Kate Hackett
Tompkins County Engineering Department	John Lampman, Sr. Civil Engineer
Tompkins County Soil & Water Conservation District	Craig Schutt, District Manager
Town of Caroline Watersheds Committee	Todd Schmit, Chair
Town of Ithaca Planning Department	Sue Ritter
U.S. Geological Survey	Todd Miller
City of Ithaca Drinking Water Treatment Plant	Roxy Jonston
City of Ithaca Public Works Department	Larry Fabbroni, Assistant Supt.
Town of Dryden Conservation Advisory Council	Dan Karig
Cayuga Lake Watershed Network	Sharon Anderson

The most notable issue raised by the stakeholders of the Six Mile Creek watershed is ongoing erosion that is occurring in the watershed, along with the resulting turbidity of the water. Based on discussions and interviews with watershed stakeholders, as well as a review of the history of actions within the watershed, the highest priority concerns in Six Mile Creek center around the following issues:

Protection of property and infrastructure (i.e. roadways, bridges, pipelines, etc.). Widespread concern has been voiced from private property owners along the creek with regard to the loss of land and, in some cases, vulnerability of structures.

Protection of drinking water quality. Ongoing erosion in the creek and in the watershed regularly results in elevated sediment and turbidity in Ithaca Reservoir. This has management, treatment, and water quality implications.

Elimination of "unsightly" erosion occurring within the watershed. There is a general level of discomfort associated with the stark eroding banks along the Six Mile Creek.

Elimination of the sediment plume in Cayuga Lake during and following storm events. Water quality impairment has been documented in Cayuga Lake, resulting in its placement on the 303(d) list of water quality impaired waterbodies. The impairment is associated with the sediment plume into Cayuga Lake from the Cayuga Inlet, which is also a visual eyesore during periods of rain.

Other secondary issues include the practices of road sanding, aquifer protection, and the overall ecological health of the creek. In addition to addressing the aforementioned concerns, a common goal of establishing riparian buffers along the creek has been identified by numerous watershed stakeholders.

1.4 Principles of Watershed Management

Many factors require that river management efforts extend far beyond the banks that contain flowing water. Some management issues result from upstream land use, runoff, and sources of pollution. Others arise because of floodplain encroachments, inadequate riparian buffers, or loss of wetlands. The evolving methods of river management emphasize a holistic approach, addressing the watershed and stream corridor in addition to the actual channel. Traditional approaches to river management are often limited in scope, prohibitively expensive, and environmentally unsound. The concept of managing the watershed and corridor as well as the river channel itself provides an alternate approach that allows each river function to be managed at the appropriate level.

Watershed management has evolved in response to the need for a broad approach that considers rivers to be important natural resources with many, often competing uses. It is essential to recognize that, besides conveying storm runoff, streams serve many other ecological, economic and social functions, and the planning and design of management systems must consider water supply needs, recreational uses, wildlife, aesthetics, and the cost and maintenance of the management measures that are implemented.

The concept of watershed management has been in existence for many years. The practical application of the watershed management approach is constantly evolving as new technologies are developed. An effective watershed management program should be based on scientific and engineering guidance, but also needs to be communicated to and implemented by the stakeholders of the watershed in a complementary and coordinated effort.

Effective watershed protection involves a multi-faceted approach that encompasses land use (past, present, and future); stream and wetland buffers; responsible development through adequate site selection, design, and maintenance; stormwater best management practices; control of non-stormwater discharges; control of destructive and unnatural erosion and sedimentation; and watershed stewardship programs that have the ability to span corporate boundaries and governmental divides.

The process of watershed management begins with a watershed needs assessment, wherein the following basic tasks are conducted:

- identification of the study area;
- identification and notification of interested individuals, organizations, and public agencies;
- establishment of an advisory or coordinating board;
- collection of existing data and evaluation of existing natural and cultural features;
- collection of new data as needed;
- identification of watershed and stream issues and problems;
- identification of highest priority issues;
- evaluation of alternative solutions to problems;
- researching of funding sources and needed regulatory programs;
- development of a final strategy;
- adoption of a management plan; and finally
- implementation of the plan.

The flood hazard mitigation needs assessment for Six Mile Creek is designed to follow the above approach. The subject document is organized accordingly:

- Section 1.0 of this needs assessment identifies the study area, project stakeholders, and project goals and objectives.

- Section 2.0 presents an inventory of existing conditions based upon available data and information.

- Section 3.0 presents new data collection associated with the subject study and presents an assessment of the watershed and stream;

- Section 4.0 presents a detailed review of priority issues and recommendations; and

- Section 5.0 presents an implementation strategy, including an evaluation of the funding mechanisms for future flood hazard mitigation efforts.

1.5 Watershed Delineation and Nomenclature

In 1998, the Center for Watershed Protection published the *Rapid Watershed Planning Handbook*, which presents a rapid eight-point program for developing effective watershed plans. The handbook details various methodologies used in watershed planning, such as impervious cover measurement and estimation, subwatershed mapping, cost projections, and rapid monitoring techniques.

More recently, the *Watershed Vulnerability Analysis* was created, primarily as a rapid planning tool for application to larger watersheds. The analysis also contains a refinement of the techniques used to delineate subwatersheds and estimate impervious cover. Additionally, the analysis provides guidance on factors that would alter the initial classification or diagnosis of individual subwatersheds. Application of the *Watershed Vulnerability Analysis* is appropriate in instances where more than 15 or 20 subwatersheds exist and it is necessary to group and prioritize subwatersheds for implementation and protection. This method yields the following primary outcomes:

1. A defensible rationale for classifying subwatersheds. Typically these classifications are used to develop specific management criteria for each subwatershed class within the framework of an overall watershed overlay district;

2. An effective framework to organize and integrate mapping and monitoring data that are currently being collected in the subwatershed assessments to make final classifications;

3. A rapid forecast of which specific watersheds are most vulnerable to future watershed growth and warrant immediate subwatershed planning efforts; and

4. A priority ranking identifying subwatersheds that merit prompt restoration actions.

Subwatershed-scale is preferred for assessment studies, stream classification, and management planning for several reasons. First, the influence of impervious cover on hydrology, water quality, and biodiversity is readily apparent at the subwatershed level. Second, subwatersheds are small enough that there is less chance of confounding problem sources, thus confusing management decisions. Third, subwatershed boundaries tend to be located within just a few political jurisdictions where it is easier to establish a clear regulatory authority and incorporate the stakeholders into the management process. Finally, the size of a subwatershed allows monitoring, mapping, and other watershed assessment steps in a rapid time frame.

For analysis purposes, Six Mile Creek has been subdivided into 17 sub-watersheds as depicted on Figure 1-4 and on appended Figure I. These were selected based upon drainage basin divides and are numbered WS-10 through WS-170, moving from west to east within Six Mile Creek watershed. Table 1-2 presents a listing of the subwatersheds.

Within the watersheds, the *State Hydrologic Unit Mapping* nomenclature developed by the U.S. Department of the Interior/Geologic Survey has been used. The nomenclature is a series of uniform, nationally consistent codes that delineate the hydrographic boundaries of major U.S. river basins. The numbering system provides a standard geographical framework for more detailed water- and related land-resources planning.

Figure 1-4

Each mapping unit is comprised of an 8-digit number. The first two digits represent the region; the third and fourth digits represent the subregion; the fifth and sixth digits represent the unit code (which is simply an accounting unit); and the last two digits represent the cataloguing unit. Since all of the Six Mile Creek watershed has the same first four digits, only the latter four are referenced in this assessment.

TABLE 1-2
Summary of Subwatershed Areas

Watershed Designation	*Watershed Area (ac)*	*Watershed Area (sq. mi)*
WS-10	1,704 acres	2.66 sq. mi.
WS-20	1,364 acres	2.13 sq. mi.
WS-30	3,194 acres	4.99 sq. mi.
WS-40	2,350 acres	3.67 sq. mi.
WS-50	3 029 acres	4.73 sq. mi.
WS-60	1,201 acres	1.88 sq. mi.
WS-70	1,608 acres	2.51 sq. mi.
WS-80	2,785 acres	4.35 sq. mi.
WS-90	993 acres	1.55 sq. mi.
WS-100	2,320 acres	3.63 sq. mi.
WS-110	3,723 acres	5.82 sq. mi.
WS-120	607 acres	0.95 sq. mi.
WS-130	982 acres	1.53 sq. mi.
WS-140	1,238 acres	1.93 sq. mi.
WS-150	3,369 acres	5.26 sq. mi.
WS-160	548 acres	0.86 sq. mi.
WS-170	2,377 acres	3.71 sq. mi.

For analysis purposes, in addition to the stream reach references and subwatershed delineations, reach segments were defined along the length of Six Mile Creek. These are summarized in Tables 1-3 and 1-4 below. Figure 1-5 presents a schematic diagram of the sub-watershed structure.

TABLE 1-3
Summary of Stream Segment Designations

Segment	*Description of Geographic Limits*	*Length*	*Description of Conditions*
1	Cayuga Inlet to Van Natta's Dam	1.95 mi	Highly channelized stable urban stream.
2	Van Natta's Dam to Burns Road	2.65 mi	Fairly stable area due to impounded water.
3	Burns Road to Banks Road	2.80 mi	High degree of lateral migration and erosion.
4	Banks Road to Middaugh Road	0.76 mi	Highly unstable with active headcut.
5	Middaugh Road to Valley Road near Route 330 in Brooktondale	1.36 mi	Stable channel segment u/s of headcut.
6	Valley Road near Route 330 in Brooktondale to Boiceville Road	2.08 mi	Stable bedrock channel with falls.
7	Boiceville Road to Creamery Road	0.77 mi	Stable low-gradient reach.
8	Creamery Road to Six Hundred Road	1.32 mi	Excessively steep segment with structural issues.
9	Six Hundred Road to Headwaters in Dryden	4.83 mi	Stable channel headwaters.

TABLE 1-4
Correlations of Subwatersheds to Stream Segments

Segment Number	*Description of Geographic Limits*	*Incremental Contributing Subwatersheds*
1	Cayuga Inlet to Van Natta's Dam	WS-10, WS-20
2	Van Natta's Dam to Burns Road	WS-30*
3	Burns Road to Banks Road	WS-30*, WS-40, WS-50*
4	Banks Road to Middaugh Road	WS-50*
5	Middaugh Road to Valley Road near Route 330 in Brooktondale	WS-50*, WS-60, WS-70*, WS-80
6	Valley Road near Route 330 in Brooktondale to Boiceville Road	WS-70*, WS-90, WS-100*, WS-110
7	Boiceville Road to Creamery Road	WS-100, WS-120, WS-130
8	Creamery Road to Six Hundred Road	WS-100*
9	Six Hundred Road to Headwaters in Dryden	WS-140, WS-150, WS-160, WS-170

*Indicates that only a portion of the watershed drains into the stream reach.

Figure 1-5

2.0 Inventory of Existing Conditions

2.1 Geologic and Geomorphic Background

The Finger Lakes region of New York is often cited for its classic examples of "U-shaped" valleys carved by the advancing glaciers of the most recent ice ages. Indeed, these valleys are the prominent characteristic of the area, but many geologic forces have shaped the landscape of Tompkins County, and these must be addressed to understand the natural processes in the Six Mile Creek basin. Figure 2-1 presents a summary of regional channel evolution.

Most of the consolidated sedimentary rocks in the Ithaca area were formed 375 million years ago during the Devonian period. At least 1.2 miles (vertical) of sedimentary rock have been removed from the Ithaca region by erosion over several million years, including erosion that occurred over several glacial periods.

The cycle between glacial periods is estimated at 100,000 years to 150,000 years (Bloom, 1990). The most recent glaciers (known as the Wisconsin advance) were completely retreated from New York about 11,000 years ago. Between 13,500 years ago and 11,000 years ago, while the glaciers were melting, several ancient lakes existed in the Ithaca region, each with different elevations and outlets. Each ancient lake is associated with ancient beaches, ancient deltas, outlet stream deposits, and lake-bottom deposits that currently exist as landforms and subsurface deposits.

Specifically within the Six Mile Creek basin, the following lakes likely existed between 12,950 and 12,800 years ago:

- Lake Freeville/Dryden drained to the south at elevation of 1,060 feet;

Figure 2-1

- Lakes Brookton, West Danby, and Slaterville drained to the south at elevations ranging from 980 feet to 1,070 feet; these lakes covered most of the Town of Ithaca with water;

- Early Lake Ithaca drained to the south at an elevation of 980 feet (with the overflow located two miles south of Brooktondale and the east edge located east near Game Farm Road); and

- Late Lake Ithaca drained to the west at an elevation of 940 feet.

One of the ancient southerly drainage outlets occurred in the Six Mile Creek watershed near Ellis, at the headwaters of a Six Mile Creek tributary. Lake Freeville/Dryden drained through this area and then to the south and east, demonstrating that ancient outlet rivers may have flowed in the Six Mile Creek valley, but in the opposite direction. By 12,200 years ago, Cayuga Lake was at approximately 395 feet to 400 feet, near its current level.

As ancient lake levels formed and were replaced by lower lake levels, ancient deltas formed at different elevations in stream valleys. The net result is a series of ancient deltas that lie along the valley main stems, found along several of the major streams draining toward Cayuga Lake. Existing streams have eroded and cut into some of the ancient deltas that were deposited by their ancestral streams, with the result being the downstream transport of sediment.

Some of the boundaries of the ancient lakes can be approximately located based on the locations on landforms. For example, an ancient beach deposit marks the uppermost elevation of Lake Ithaca (1,020 feet) far to the east of the Cornell University campus. An ancient delta located beyond the eastern edge of the Cornell University campus (elevation 970 to 975 feet) marks another position of ancient Lake Ithaca. Southwest of Ithaca, three small ancient deltas lie along Coy Glen, at elevations of 980 feet, 1,040 feet, and 1,060 feet.

Many are familiar with the classic profile of rivers and streams, beginning in high-gradient areas with many riffles, flowing through intermediate areas with pools and riffles, and eventually flowing through large, low-gradient floodplain areas that may be characterized by meanders and wide channels. Although these types of streams are found in the northeastern United States, most rivers in the Ithaca area are not in equilibrium with their landscape due to the glacial cycles.

Fall Creek, flowing through the largest watershed to the north of Six Mile Creek, is a good example of a stream that is not in equilibrium due to recent glacial forces. The upstream reaches of Fall Creek have an artificial base level control due to the presence of bedrock at "flat rock." The midstream reaches of Fall Creek have inherited large meanders that were formed under previous flow conditions, and the downstream reach of Fall Creek (in the vicinity of the Cornell University campus) is characterized by deep gorges with near-vertical walls.

Fall Creek is an example of a river that can not easily adjust to its down-valley slope. Because the regional base level control (Cayuga Lake) is so much lower in elevation than the upper portions of the watershed, and because the Cayuga Lake valley is U-shaped, Fall Creek must fall through a very large change in elevation in a relatively short distance. Fall Creek has naturally worked toward cutting a more gradual profile, resulting in gorges in the downstream reaches, while constrained by other bedrock base level control at flat rock.

The elevation change in the Ithaca portion of the Six Mile Creek drainage basin is less drastic than the Ithaca portion of Fall Creek. As a result, Six Mile Creek is more aligned with its down-valley slope than is Fall Creek. However, Six Mile Creek does have evidence of non-equilibrium, such as the lack of a wide floodplain in its lower reaches and the presence of a wide floodplain closer to its headwaters. This is the result of the natural geology of the watershed and is atypical for the rest of the United States.

Because rivers in the Ithaca region are not in equilibrium with the current landscape due to glacial processes, they are actively eroding many of the sediments that were deposited directly by glaciers and their melt water, or that formed beneath the ancient lakes, at the edges of the ancient lakes (the ancient deltas), or during outflow from the ancient lakes. This is a natural process that has occurred in many other watersheds that have already reached equilibrium conditions. In Six Mile Creek, this process is ongoing. In geomorphic terms, the term for erosion over an expansive area is "denudation." Rates of denudation typically indicate a vertical loss of material averaged over a wide area.

Denudation rates for glaciated areas have been estimated at 3.0 centimeters (cm) per thousand years, and there is evidence that the Ithaca region has lost an average of 4.5 meters (vertical) since the beginning of the last glacial cycle (Bloom, 1990). Denudation rates are higher for intense agricultural areas, such as the Mississippi valley (estimate of 5.0 cm per thousand years), and for mountainous areas (as much as 13.0 cm per thousand years in the Sierra Nevada). Nonetheless, the estimate for glaciated areas indicates that the Ithaca region may continue to experience erosion and downstream sedimentation at an overall vertical rate of 3.0 cm per thousand years, at a minimum.

If left alone, Six Mile Creek will continue in its dynamic nature towards eventual equilibrium in the environment. The challenge, however, is the integration of this natural process with existing development and the management of the City's source of drinking water supply.

2.2 Terrain

Six Mile Creek flows in a U-shape from its headwaters in a southwest, west, and then northwesterly direction into the south end of Cayuga Lake via Cayuga Inlet. The terrain in the watershed that contributes to approximately 19 miles of the main channel of Six Mile Creek is quite diverse, ranging from broad flat expanses in the Slaterville Springs area, to markedly steep side slopes with a non-existent floodplain in portions of Ithaca. In some reaches, the creek has downcut through the former clay and silt lake deposits down to the underlying till and bedrock.

The highest elevations in the watershed occur at around elevation 1600 to 1900 feet NGVD along the northern and southern perimeters. Cayuga Lake is the low point in the watershed, with normal water surface at elevation 382 feet.

2.3 Existing Land Uses within the Six Mile Creek Watershed

A great deal of information and insight can be gained from evaluating existing land uses in a watershed, comparing them with historic land uses, and projecting possible future land use changes. The latter can become a complex issue when dealing with multiple forms of zoning (or lack thereof) within different governmental and jurisdictional territories. Ideally, future land use should be governed and guided by effective land use planning along with the adoption and adherence to complementary regulations.

In many instances, land use has evolved based upon topography, terrain, and proximity to water resources. For instance, existing and historic agricultural uses tend to occur in areas with fertile soil types, relatively flat land, and proximity to irrigation supplies. In steeply sloped areas, one would expect a different type of development, perhaps sporadic single homes set amidst large forested areas.

The history of land use in the Six Mile Creek area is typical of many other areas in the northeast United States. The first land use activities of European settlers consisted of clearing the forests for fields and pastures on small farms. Agricultural land use increases runoff by removing the natural vegetation and its resulting forest litter and porous humus soils that help retain water. Further, surface water storage is reduced by repeated plowing and smoothing of the land. Farmers also built ditches to drain wetlands and dry out their fields.

Current land use in the Six Mile Creek watershed is largely forest cover, including three areas of protected state forest land, and moderate amounts of agricultural and residential uses. Overall, the density of development is quite low, and severe impacts caused by urbanization have not occurred in the watershed.

Figure 2-2 presents land use within the Six Mile Creek watershed based upon 1995 GIS mapping.

Urban Areas – The only significant urban area is sub-basin WS-10, representing the City of Ithaca. This basin is intensely developed with residential, commercial, and industrial uses as well as transportation facilities. Slopes range from mild in downtown areas and along Route 13, to very steep to the east. Portions of sub-basins WS-20 (Ithaca College area) and WS-30 (Route 79, Route 366) south of Cornell University are also urban. Urban areas have a high impervious cover, catch basins with storm drains, and high surface runoff rates.

Moderate Development – Portions of watersheds WS-20, WS-30, WS-40, and WS-50 have what can be described as moderate development with low density residential areas. WS-70 has a compact developed village at Brooktondale in the Town of Caroline, centered around a series of 19th century water powered mills.

Figure 2-2

Secondary villages of limited size are located within WS-100 along Route 79 at West Slaterville and Slaterville Springs. All of the moderately developed zones are relatively low density and of limited land area.

Rural – Large areas of WS-50, 60, 70, 100, 110, and 130 are dominated by open cornfield, pasture, and cropland. During the May 2003 inspection, relatively few tilled fields were observed, and most had temporary or permanent (grass) ground cover. Few areas of surface erosion, rills, or gullies were observed. Extensive forest (mostly second growth hardwoods) exist in watersheds WS-90, 120, 140, 150, 160, and 170. The overall pattern is stable forestland on the steeper slopes around the perimeter of the Six Mile Creek watershed, with agricultural land in the valley bottoms and flatter uplands such as in WS-150 and 170. Watershed WS-90 is noteworthy because it follows a very low gradient glacial "thru valley" with significant wetlands.

The watershed's hydrologic regime is reflective of rural land uses with limited impervious cover and formal drainage systems. The landscape has been previously cleared and is currently returning to hardwood forest as farm land is abandoned. The watershed has good to excellent ground cover with minimal exposed soils. The few exceptions are active fields that are being tilled in preparation for spring planting and the large sand and gravel mining operation in WS-70 as well as an area near Middaugh Road and Route 330 at a self-storage facility, where fill (comprised of earthen material as well as tires, concrete blocks, etc.) has been placed directly adjacent to the streambank.

2.4 Water Quality

The southern basin of Cayuga Lake is included on New York State's *Priority Water Bodies List*, primarily because of the prevalence of silt and sediment. Southern Cayuga Lake is also included on the 303(d) list of impaired water bodies requiring a watershed approach to restoration. Six Mile Creek, located within the southern Cayuga basin, is noted for its extensive deposits of fine grained glacial drift that are actively and, in some cases dramatically eroding. However, there are no known permitted wastewater discharges to Six Mile Creek.

2.5 A Review of Past Studies on Six Mile Creek

Six Mile Creek has been the subject of numerous study efforts, including academic studies affiliated with Cornell University. One such study (Nagle and Fahey) analyzed the proportional contributions of stream bank and surface sources to define sediment loads in streams of the southern Cayuga Lake Basin and other nearby watersheds. The study notes that many stretches of the stream below Brooktondale are characterized by slumping hillslopes and large eroding banks above the channel. Even forested slopes with minimal human impact exhibit this instability. In fact, extensive radionuclide testing indicates that the sediment load from bank erosion along Six Mile Creek is 82% of the total load, whereas surface erosion load accounts for only 18%.

Nagle and Fahey report that sediment loads in streams of the southern Cayuga watershed are not unusually high compared to the rest of the Northeast. However, high levels of bank erosion are occurring in response to channel incision, valley filling, and changes in stream channel morphology.

The Six Mile Creek channel is laterally unstable in some areas, particularly upstream of German Cross Road in the Bethel Grove section of Dryden, with rapid channel migration and re-establishment of meanders. This instability is coupled with channel degradation or down-cutting by several feet in some areas, resulting in an incised channel. A new floodplain has developed that is several hundred yards wide and significantly lower than what is thought to be the original floodplain elevation (Karig, et. al., 1995). The ground water table has been reported to have declined proportionally.

Field conditions suggest that the observed stream degradation (and subsequent aggradation) has occurred previously in Six Mile Creek, with the conversion of the watershed to agricultural uses in the 19th and early 20th centuries and the subsequent reduction in agricultural land uses through the 20th century, leading to reforestation and the associated degradation. Similar trends have been observed elsewhere in the eastern United States.

In the summer of 1994, the Tompkins County Soil and Water Conservation District conducted an inventory of the Six Mile Creek and its tributaries for the purpose of identifying areas of critical streambank erosion. Their study evaluated over 13 miles of main stem and almost 11 miles of tributaries (out of a total tributary length of approximately 39 miles). Erosion and deposition were calculated using the "*New York Procedures for Calculating Streambank Erosion*," developed by the New York State Natural Resource Conservation Service (formerly the Soil Conservation Service). The method quantifies streambank erosion and does not consider contributions from surface erosion or those from individual storm events or unnatural disturbances to banks and stream flow.

The Soil and Water Conservation District's inventory identified over 266 eroding banks on the main stem of Six Mile Creek, with an additional 676 eroding banks on the inventoried tributaries. Approximately 50 of the main channel banks and 80 of the tributary banks were classified by the District as being "critical" (i.e. those where erosion is or will affect man made structures or those that have a recession rate that is greater than 0.3 feet per year and were therefore categorized as contributing significant amounts of sediment load to the stream). The District's estimated cost to stabilize all eroding banks in the watershed totaled $848,000.

Many of the sites that were identified during the 1994 inventory are naturally occurring erosion and are due to the local geology and evolution of the watershed. It is difficult to ascertain from the 1994 inventory which type of erosion was occurring at the different sites. It is also important to look at the sub-watershed within which erosion is occurring to gain a broader perspective of the dynamics that are driving the system.

The Cayuga Lake Watershed Intermunicipal Organization also conducted a road bank and stream bank inventory from May through August 2000 wherein visual surveys were performed to obtain information to rank the erosion potential within the watershed. A visual survey was performed on all roads in the Cayuga Lake watershed (including those within the Six Mile Creek watershed) and road bank erosion was categorized as moderate, severe, or very severe.

The road banks in the Six Mile Creek watershed were identified as an area of concern. Numerous sites within the watershed were documented as moderately eroded, with many sites classified as severely eroded. Eight road ditches were classified as very severe.

Visual surveys were also performed by the Cayuga Lake Watershed Intermunicipal Organization on each tributary to Cayuga Lake to and the erosion potential of each sub-watershed was ranked. The Six Mile Creek stream inventory included 55 sites, most of which showed evidence of significant streambank erosion.

The level of detail contained in the published documentation on the road bank and stream bank inventory by the Cayuga Lake Watershed Intermunicipal Organization did not permit a direct comparison to the field investigations and findings of the subject study. However, the study findings are consistent with historic observations as well as more recent investigation of conditions within the Six Mile Creek watershed.

Past inventories of erosion along Six Mile Creek area somewhat dated, particularly in light of the maintenance schedules of roadside ditches. Many areas that were previously subject to erosion have since stabilized, while other ditches that have been more recently maintained represent new sources of erosion. Incorporation of check dams and hydroseeding in the routine maintenance of drainage ditches in the future would help to reduce maintenance related erosion.

2.6 ***Hydrology and Flooding History of Six Mile Creek***

Surface water hydrology is the quantitative study of the presence, form, and movement of water in and through the drainage basin. The primary independent variables affecting runoff are precipitation, watershed area, surficial geology, and slope. Dependent variables that change over short and intermediate time spans include vegetative cover, land use, wetland and floodplain water storage, reservoir size and volume, water diversion for irrigation or municipal use, and beaver dams.

For the purpose of studying bank erosion, sediment transport, and flooding, the primary interest is in peak stream flows due to intense precipitation, sometimes in combination with snow melt. It is the peak flood flows that shape and form the river channels, scour the banks, and carry the majority of sediment. Subsequent storm runoff events, perhaps up to the mean annual flood, also convey sediment and tend to dominate the formation of the inner channel dimensions, bars, pools, and riffles. Monthly mean stream flow rates are a good indicator of seasonal flow patterns that affect water supply, habitat, and recreation.

A watershed's stream flow rate can be obtained or estimated using several different techniques, including direct measurement, use of surrogate gauge data in nearby watersheds, physical deterministic computer models, statistical or stochastic analysis, or empirical techniques.

Within Six Mile Creek, direct measurement is possible via the U.S. Geological Survey (USGS) stream flow gauging station located at German Cross Road in Bethel Grove. This gauge was installed in cooperation with the City of Ithaca. A second gauge was installed along the creek in 2002. The Bethel Grove gauge has only been active since 1995, so only limited data is available. Consequently, longer duration regional gauges were also reviewed to learn about broad trends and patterns. Table 2-1 presents gauge data based on the published record at Bethel Grove, from 1996 through September of 2001.

TABLE 2-1
Summary of USGS Stream Gauge Data at Bethel Grove – Gauge #04233300

Year	***Average Annual Stream Flow (cfs)***	***Average August Stream Flow (cfs)***	***Peak Stream Flow (cfs)***	***Minimum Stream Flow (cfs)***
1996	102 cfs	47 cfs	2,700 cfs	8 cfs
1997	41 cfs	10 cfs	3,030 cfs	7 cfs
1998	62 cfs	10 cfs	1,180 cfs	8 cfs
1999	44 cfs	4 cfs	2,590 cfs	2 cfs
2000	66 cfs	13 cfs	2,020 cfs	8 cfs
2001*	55 cfs	8 cfs	2,950 cfs	5 cfs
Average	***57 cfs***	***14 cfs***	***2,344 cfs***	***6 cfs***

*Data spans a partial year.

The watershed area at the gauge is reported by USGS as both 39.0 and 39.3 square miles. The mean annual flood, based on just five years of record, is 2,344 cubic feet per second (cfs), which is equal to 60.1 cfs per square mile and well above average for the glaciated northeast. The highest peak flow of 3,030 cfs occurred in 1997.

The adjacent Fall Creek watershed has a long term USGS gauge with data from 1927 that helps to define trends and patterns in the region. The most notable pattern is that there is no distinct change in peak runoff rates over the period of record. Unusual peak flows occurred in 1935 (15,500 cfs), 1982 (11,900 cfs), and 1996 (9,450 cfs). All other peaks were uniformly distributed and below 6,000 cfs. The plot of the peak annual flow is quite consistent.

Low stream flow is primarily a function of precipitation patterns, land use and runoff characteristics, soil types, and geology. Six Mile Creek has a mean August flow of 0.35 cubic feet per second per square mile, which is typical for the Northeast. However, the minimum of the daily flows range from 2.0 to 8.0 cfs, which are inadequate for larger fish in the broad Six Mile Creek.

Beyond in-stream flow rates, aquatic habitat and fish are very sensitive to the corresponding stream channel depth and cross sectional area. Deep pools are necessary for fish survival during low flows. The channel structure in Six Mile Creek is wide and shallow along much of its length, with no concentration of flow. If the channel had a more well defined thalweg (i.e. the deepest portion of the channel), it would be more conducive to aquatic habitat during low flows.

3.0 Watershed Needs Assessment

3.1 Overview of Field Investigations

During the week of May 19 through May 23, 2003, Milone & MacBroom, Inc. conducted a week-long field investigation of Six Mile Creek and its contributing watershed. All seventeen sub-watersheds were inspected to visually access the properties that could influence downstream surface runoff and sediment loads. In addition, topographic maps, aerial photographs, and GIS land use/cover data were reviewed prior to the initiation of field investigations.

The investigations targeted areas of previously identified problems as well as representative stream sections, natural and man-made control points (such as dams, natural falls, and reaches flowing over bedrock), and areas of extensive lateral migration. Numerous cross sections were surveyed in the creek to enable an analysis of channel geometry in stable sections of the creek.

3.2 Stream Profile and Control Points

Appended Figure II is a profile of the Six Mile creek from its inlet at Cayuga Lake to the headwaters in Dryden. Cayuga Lake controls the most downstream elevation, at a normal water surface elevation 382 feet. Within the City of Ithaca, Six Mile Creek is channelized, with concrete vertical walls along much of this reach.

Van Natta's dam is located within WS-10 within the City of Ithaca. The spillway at Van Natta's dam is at elevation ±502 feet. Upstream of the impoundment, Six Mile Creek flows atop bedrock in a deep gorge along stream reference 3255 within WS-30. The bed elevation in this reach is estimated to rise from elevation ±500 feet up to about 550 feet, just downstream of the lower reservoir dam.

The 30-foot lower reservoir dam (at stream reference 3255 in WS-30) has a spillway elevation of 583 feet, according to USGS topographic mapping. Between the lower reservoir dam and the Ithaca Reservoir Dam (within WS-30) is an area of shallow bedrock. Approximate bed elevation in this reach ranges from 590 feet on the downstream end up to 640 feet just downstream of Ithaca Reservoir. The 60-foot Ithaca Reservoir dam (also within WS-30) has a spillway elevation of 704 feet.

The siltation dam (at stream reference 3349 in WS-40) has a spillway elevation of approximately 720 feet, based on USGS topographic mapping. Upstream of the siltation dam (downstream of German Cross Road), two natural gas pipelines crosses Six Mile Creek. The lower pipeline has been armored with rip rap, the elevation of which is unknown.

Two sets of natural falls occur in Brooktondale, referred to herein as the lower falls and the upper falls. The lower falls (at stream location reference 3581 within WS-70) are about 20 feet in height along a width of about 120 feet, with a plunge pool at the base. The upper falls are located at stream reference 3573, also within WS-70.

An old mill dam is located upstream in Brooktondale.   A set of falls are located approximately 300 yards upstream of the mill dam, and another set of falls are located near Irish Settlement Road in Dryden, near a long bedrock gorge. Six Mile Creek at its headwaters approaches elevation 1,650 feet.

3.3 *Needs Assessment by Stream Segment*

3.3.1 *Segment # 1 – Cayuga Inlet to Van Natta's Dam*

This stream segment includes all of subwatersheds WS-10 and WS-20. The stream in this reach of Six Mile Creek has been channelized between Cayuga Inlet and Aurora

Street, with a linear alignment and vertical masonry, stone, and concrete walls. It is a non-alluvial channel with a bankfull width on the order of 90 feet, and a cobble bottom. Numerous storm drain outlets discharge to the creek in this reach. A narrow buffer zone exists along South Titus Road and numerous bedrock outcrops are visible, beginning at Aurora Street. A deep bedrock gorge extends up to Van Natta's Dam at Giles Street.

This stream segment is very stable due to the bedrock gorge and the channelized reach in the City of Ithaca, and therefore does not represent a high priority with regard to flood mitigation.

3.3.2 Segment # 2 – Van Natta's Dam to Burns Road

This stream segment includes a portion of subwatershed WS30 as well as stream reaches 3255 and 3349. It is dominated by deep bedrock gorge impoundments. Reach 3255 upstream from Van Natta's Dam to the Lower Reservoir is a deep, flat bottomed bedrock gorge in the Wild Flower Preserve. Trails provide easy public access to the scenic gorge and its bedrock channel. A recent landslide is visible on the left bank (looking downstream) of the gorge, most of the debris having been washed away. The lower reservoir is inactive.

Two significant landslides along the right (north) side of the reservoir have been major sediment sources in the past. An active slide behind the *Commonland Community Condominiums* is about 200 feet wide and 210 feet high. It is estimated to have released 15,000 cubic yards of material. Reach 3349 is an upstream low gradient extension of Ithaca Reservoir to Burns Road and appears to be a modern deposition zone in the reservoir's backwater.

Landslides are very rare on mature landscapes and the cluster along Six Mile Creek is indicative of very steep slopes and a deep valley. There are no readily available or affordable preventive measures to address these, except for the preservation of existing vegetation. Aside from the historic landslides that have occurred in this reach of the creek, the stream and watershed are not actively contributing significant amounts to downstream sediment load. However, suspended sediment from further upstream does pass through this segment.

3.3.3 <u>Segment # 3 – Burns Road to Banks Road</u>

This river segment includes a portion of subwatersheds WS-30 and WS-50, and all of WS-40. The reach is of great interest because it has extensive evidence of large scale past degradation (±100 years) and now appears to be reaching an equilibrium slope. The channel bed is characterized by long runs with few riffles and pools, and no significant rapids. Several low residual knick points are still active but are atypical.

The previous degradation at the German Cross Road bridge has been well documented by Dr. Karig, a retired geology professor at Cornell University. His measurements indicate the streambed elevation declined by five feet over a period of 25 years. Measurements conducted during field investigations indicate no significant degradation since 2000. Figure 3-1 depicts a plot of the channel depth over time below the bridge at German Cross Road.

Most of the channel bed is covered with a dynamic natural armor of three- to 10-inch rock fragments, most of which are a thin strata of shale, resembling shingle or flagstone. A high percentage of the material is embedded in a gravel matrix, providing good stability but poor habitat. This material is deceptive, as it has low volume and weight in proportion to its D_{50} size. This is relevant, since volume and weight are important components in the evaluation of shear stress for stability.

Figure 3-1

In traditional "pebble count" techniques, the pebble count dimension is assumed to be equal to the width of the pebble or stone. That dimension is used to estimate sphere diameter (i.e. stone width is assumed to be equal to stone length), which is in turn used to calculate the weight of the stone. When substrate material is not uniform in diameter, the length is not representative of the diameter of the stone and the resultant computation of weight and/or volume. In Six Mile Creek, therefore, conventional pebble count techniques would be misleading.

The channel reach from Burns Road to Banks Road has a high degree of sinuosity, with large gravel and cobble point bars with sparse vegetation. Using the Brice classification system, it is an equal width sinuous channel. Using the Watson (1984) Channel Evaluation Model, it is Class V. The degradation has exposed an interesting soil profile consisting of shallow topsoil, modern alluvium, glacial lake silt and clay, and glacial till.

Inspection of this reach indicates that having already approached an equilibrium slope, it is now widening and forming a second floodplain, leaving the alluvium of the past floodplain as a terrace. The evidence includes increased width-to-depth ratios (compared to upstream reaches), wide point bars, sinuous alignment, and active bend erosion on only one bank at a time.

A gas pipe crossing the river about 600 feet upstream of the siltation basin is reported to have been previously exposed by degradation and was observed to have been armored with riprap and a grade control sill. A second gas pipe crossing was found approximately 2,000 feet downstream of German Cross Road and the pipe is exposed. It is a hazard and should be stabilized immediately.

Dr. Karig's reports (1995) and MMI inspections confirm that the channel upstream of German Cross Road migrated laterally by approximately 100 feet over 25 years, with a continuing bank erosion and point bar/floodplain development. One would expect a cessation in degradation, a continuing increase in sinuosity and bank erosion, coupled with decreasing bed load sediment transport.

3.3.4 Segment # 4 – Banks Road to Middaugh Road

This river segment includes a portion of subwatershed WS-50. The segment upstream of Banks Road is a classic Simon Class IV scenario, with very active channel degradation and is just beginning the widening phase. The steeper gradient, multiple knick points, raw banks, and multiple mass failures attest to ongoing degradation.

The narrow point bars and lower percentage of embedded material both suggest continuing instability and lack of aggradation. This segment is a sediment source, with probable increasing rates of bank erosion. An anabranched channel has formed at the Whitham property along Route 330, apparently stimulated by a beaver dam. Other headcuts lower in this reach appear to have been at least temporarily stabilized at clusters of glacial boulders, some of a non-native, unusual reddish granite. If not controlled, degradation will accelerate in the next upstream segment towards Brooktondale.

3.3.5 Segment # 5 – Middaugh Road to Valley Road near Route 330 in Brooktondale

This river segment includes a portion of subwatersheds WS-50 and WS-70, and all of WS-60 and WS-80. This fairly straight river segment has two distinct faces. The first (downstream) portion is a continuation of the active headcutting channel found below Middaugh Road, with low steep banks and large trees down. Well defined bend pools and riffles are present, unusual for this river, not yet destroyed by degradation. The largest fish observed were in this segment, along with a large water snake. This occurrence is due to the fact that this segment is providing better habitat, with less incised and less regular streambed. Low gradient wide and shallow reaches generally provide poor habitat.

The floodplain and riparian zone on the right bank is being filled near Middaugh Road, with earth, demolition debris, tires, and trash, with no erosion controls or buffer. The upstream portion of the segment is a straight equal width channel with limited encasement. The bend at River Road has been rip rapped and is stable. The channel bed has a higher sand content than elsewhere, and the lake bottom clay soil state is barely visible at the bottom of some fresh cut banks. Full exposure of the clay has not occurred yet. But it will.

3.3.6 <u>Segment # 6 – Valley Road near Route 330 in Brooktondale to Boiceville Road</u>

The Village of Brooktondale in the Town of Caroline is an 18th to 19th century industrial site with several low stone dams that powered mills. Six Mile Creek flows within a bedrock gorge with steep near vertical walls that are five to 30 feet high. This river segment includes a portion of subwatersheds WS-70 and WS-100, and all of WS-90 and WS-110. The channel is stable with minimal substrate.

A recent partial dam failure in this reach (lowered crest) released a low volume of impounded sediment, filling local downstream pools. Steel sheeting and gabions have been used to reinforce steep earth banks that back bedrock at this structure.

The small mill dams are fish blocks and they are filled with sediment. The run-of-the-river structures have a low trap efficiency and would have little if any impact on downstream suspended concentrations, even if dredged.

3.3.7 <u>Segment # 7 – Boiceville Road to Creamery Road</u>

This river segment includes a portion of subwatershed WS-100 and all of WS-120 and WS-130. The grade of this slightly sinuous, equal-width channel is controlled by bedrock at Brooktondale that stabilizes and prevents degradation. The downstream reach is influenced by backwater from a dam in Brooktondale and has some riparian wetlands, as well as weak points (i.e. point bars that are not well defined, with low amplitude meanders that would be expected to grow in time) and alternate bars. Much of the channel in this reach is remote and was not inspected on foot.

Previous bank erosion at a residential property was repaired using a vertical retaining wall consisting of five to six stacked courses of somewhat cubical rough cut stone, without mortar or tiebacks. No conventional foundation is apparent. This wall is reported to have been installed ±1997 and blew out in either 1998 or 1999. Portions of the wall have since collapsed, leaving large stones in the river and an earth slump. The rocks are working effectively as a deflector. Additional measures at this site that may be considered include excavating along the left (eastern) bank in combination with placing another course of stone on the lower wall of the right (western) bank and stepping it down with boulders downstream of the meander.

3.3.8 Segment # 8 – Creamery Road to Six Hundred Road

Proceeding farther upstream, the banks of Six Mile Creek are higher, with increased incision. This river segment includes a portion of subwatershed WS-100. The channel at Slatersville Springs at the Tutton property has increased and scoured one bank where a retaining wall has failed. This is a Simon Class IV channel and a Rosgen Type F.

The incised 60-foot wide channel is disconnected from its former floodplain, concentrating water with higher velocities. Smooth rigid bank protection will increase velocities and exacerbate degradation. A preferred solution in this reach would be to create a new larger floodplain at a lower grade and add channel roughness.

The right bank of Six Mile Creek was inspected at the Tutton property to view a previous bank erosion site that has been repaired. The top of bank width is approximately 60 feet, with a bank height of 10 feet and a typical flow depth of one to two feet. The slightly sinuous channel has a gravel and cobble bed, two feet of bend scour, and an estimated velocity of two to three feet per second.

Further upstream along Segment #8 near Slaterville Road is a site known as the Barrile site, which has also experienced bank erosion on both banks. Field conditions suggest that the stream is attempting to achieve more sinuosity to overcome its excessive energy. There is no real floodplain in this area and the channel is incised. A restoration effort is proposed for this area under coordination by the Soil & Water Conservation District. This site would be a good candidate for single wing deflectors, placement of boulders or boulder clusters, and vortex weirs. However, bank-to-bank vortex weirs are not advisable here, as they would serve to back water up on the upstream side.

The channel upstream of Route 79 parallel to Six Hundred Road has a narrower bankfull width due to its smaller watershed and steeper gradient. This reach has several active knick points that are deepening the channel. Widening is occurring here and meanders developing. This dynamic activity, probably stimulated by the 1982 and 1996 floods, appears to cause no harm other than generating moderate levels of sediment, and no nearby downstream aggradation problems are obvious. Vortex weirs or sills could be used to curtail the natural degradation if so desired.

A long precast concrete mass retaining wall along the right bank of Six Mile Creek was inspected at the Moesch property in this reach. The wall is comprised of four courses of large rectangular concrete block (approximately two-feet by two-feet by eight-feet) stacked vertically on the outside of a bend. This gravity wall is supporting the toe of a ±100-foot high slide area composed of steep un-vegetated coarse outwash soils. Repeated landslides and bank repairs have occurred at this site.

The original two-block high wall was built in 1989; damaged and repaired in 1992; failed again in 1997/98; and repaired again in 1998, with a partial planting along the bank. The undated design sketches, probably from 1997 on *International Engineering Company* paper show no foundations or tiebacks. No known hydraulic or scour computations exist for this restoration effort.

The upper slope has some cohesion, with near vertical slopes and a visible seepage plane. The mid-bank area is at the angle of repose and is barren, while the lower bank is a colluvium deposit zone with some successional and planted vegetation. Despite the stark appearance of the vertical, unvegetated cliff, this site does not appear to be a significant source of sediment. A permanent solution in lieu of continued maintenance of the wall would be to physically relocate the creek to the east, away from the cliff. However, this would be a major and costly undertaking. On a much smaller scale, the blocks in the wall could be tied together and anchored to prevent frequent blow-outs.

3.3.9 <u>Segment # 9 – Six Hundred Road to Headwaters in Dryden</u>

This river segment includes subwatersheds WS-140, WS-150, WS-160, and WS-170. It consists of the headwaters of Six Mile Creek and is a low flow stable channel. A deep bedrock gorge with water falls and flat flumes (i.e. flat bedrock with broad, shallow water) is located east of a former tree farm, while further upstream is a low gradient first and second order pastoral channel through active agricultural areas.

3.4 <u>Surveyed Cross Section Geometry</u>

Several channel cross sections were surveyed by MMI with a transit and stadia rod to help document and classify the stream and check widths and depths versus regional data. The cross sections were selected to be representative of longer stream segments and were used as a guide for visual classification of non-surveyed areas. The cross section surveys included identification of the apparent "bankfull width and depth" and the channel slope using standard USGS (Leopold) and USFS techniques. They were intentionally placed at four different types of channel classes, and then compared with literature values. Cross sections are depicted in Figures 3-2 through 3-6. Data is presented in Table 3-1.

TABLE 3-1
Hydraulic Geometry of Selected Stream Segments

Section	***Location***	***River Seg-ment***	***W_{bF} (ft)***	***D_{bf} (ft)***	***W/D Ratio***	***$2xD_{bF}$ W_{bF}***	***Entrench-ment Ratio***	***Rosgen Classifi-cation***
#1	3449 reach – Karig Site – German Cross Road	3	72	3.6	20.0	148	2.05	B3
#2	3471 reach – D/S Banks Road	3	55	2.8	19.6	94	1.71	B3
#3	3477 reach – Barille Site – Six Hundred Road	8	28	3.8	7.3	148	5.29	E3 (G3)

The substrate material was inspected at each cross section, and selective particle measurements were taken. Detailed pebble counts and sieve tests were not performed, largely because the thin flat gravel and cobbles would not be described well by the popular but inaccurate "count" method and the sands are primarily limited to interstitial voids. The resistance to movement by individual stones is primarily a function of the their weight, which is often approximated by measuring their intermediate axis to find their equivalent diameter. However, the Six Mile Creek gravels and cobbles are generally the shape of a plate, so that simple pebble counts of equivalent diameter are not appropriate.

Each of the cross sections was classified using the Rosgen system. The cross sections near German Cross Road and near Bank Road were both found to be moderately entrenched with moderate sinuosity, fitting the Rosgen B3 classification. However, the first section was unstable due to lateral migration and continual widening, while the second section was stable. A cross section was also surveyed at the active meander bend upstream of the Karig property to demonstrate the bend scour and point bar.

Figure 3-2

Figure 3-3

Figure 3-4

Figure 3-5

Figure 3-6

A cross section was surveyed between Slaterville Springs and Six Hundred Road in the Town of Caroline. This section was found to be a Rosgen F3 due to limited floodplain entrenchment. However, its true behavior characteristics are closer to a Rosgen G3 channel due to a pronounced low flow inner channel.

Recent studies in the Catskill region of New York by the NYCDEP provide the best available regional channel geometry data. While the Catskill data is not a good fit to Six Mile Creek, it is the best that is available. Those studies found that the local bankfull discharge that is assumed to dominate the channel size can be expressed as:

$$Q_{bf} = 62.96\ (DA)^{0.87}$$

Q_{bf} = bankfull discharge, CFS
DA = drainage area, square miles

Applying this to Six Mile Creek for Segment 3 at German Cross Road yields a discharge of 1,525 cfs compared to the measured mean annual flood (six years of record) of 2,344 cfs, a poor fit. This may be due to the short gauge record or different climate conditions.

The watershed area at German Cross Road is 39 square miles. The corresponding regional equilibrium channel bankfull width (W_{bf}) for this size watershed is 81.0 feet, slightly wider than the 72 feet surveyed by MMI, and much wider than the 55 feet measured near Banks Road where widening is in its earlier stages. The bankfull depth (D_{bF}) computed with the NYCDEP regional equation is 3.1 feet, compared to the 3.6 and 2.8 feet measured by MMI for Six Mile Creek.

Cross section #3 was surveyed at the Barille site north of Route 79 and west of Six Hundred Road, an area with active channel head cuts and excessive slope, in the early stages of entrenchment.

The data in Table 3-1 indicates Six Mile Creek is narrower in the measured areas than one would expect based upon regional hydraulic geometry data. The conclusion of this evaluation, although limited in extent, is that Six Mile Creek has become incised vertically faster than it is spread laterally, and that one can expect further channel widening as per the classic Watson channel evolution model.

3.5 Channel Incision

The dominant fluvial process along Six Mile Creek, and indeed much of the Finger Lakes Region, is the incision of channels into the landscape. The overall process of regional landscape degradation has been described by Von Engeln (1961) and is summarized in section 2.1 of this report.

Schumm, et. al. (1984) have described several different types of channel incision, all of which have been observed in the Six Mile Creek watershed and are described below with examples.

- *Rills* – are small intermittent channels as a result of erosion by overland flow. They are often seasonal and are "plowed" out during planting. Some examples were found on agricultural fields, and in wooded areas south of Coddington Road, but the number and density of observed rills is far lower than unglaciated terrain.

- *Valley Side Gullies* – are small to intermediate size channels, generally with relatively high steep unvegetated banks, extending down the side of steep valley walls without a defined valley or watershed. Many valley side gullies were observed in the Six Mile Creek watershed between Coddington Road, Six Mile Creek, and north of Route 79 at Bethel Grove and Besemer. Specific reaches include 3447, 3465, 3577, 3553, 3543, and 3351. Several of these reaches were inspected and found to have very steep bed slopes that have eroded through till or lake bottom clay and have generally reached bedrock or have become armored with cobbles. Their widening and upstream migration were significant sources of sediment in the past. They all appear to be post-glacier features and were probably formed, or at least grew, after colonial era forest clearing. Several are deep enough to intercept perched groundwater and convert to perennial streams.

- *Valley Bottom Gullies* – are found where intermittent or perennial flows have eroded a new steep sided channel across a valley base or floodplain to the valleys main stream. As a result of their position in the valley bottom, they often erode deeper to match the grade of an entrenched river or extend longer to reach a meandering river into which they discharge. Examples were found upstream of the siltation basin and upstream of Banks Road.

- *Entrenched Streams* – occur where a natural stream has become incised in its own valley and below the elevation of its floodplain. Entrenched channels may occur in bedrock, such as in Brooktondale, or in surficial soils, or in earlier sediment deposits. Six Mile Creek is an entrenched type of incised channel for much of its length.

Channel degradation can have mild to significant adverse impacts to both natural and cultural systems. Much depends upon the rate and magnitude of degradation and whether systems can adjust to the degradation. For example, rapid degradation can undermine bridge foundations or pipe crossings in less than the physical life span of the structure and require remedial action. Sediments transported downstream from incised channels can settle in and fill reservoirs prior to the life span of the dam.

Incised channels have significant ecological impacts. The deep channels have increased flow capacity and thus have less frequent floodplain inundation. This reduces over-bank floodwater storage, leading to higher peak flows and less sediment deposition on the floodplains. Alluvial ground water levels, dependent on river stages, will decline. This tends to "dry up" or eliminate riparian wetlands. Table 3-2 lists some of the adverse impacts of channel incision.

TABLE 3-2
Adverse Impacts Due to Channel Incision

Natural	***Anthropogenic***
creates excess sediment	undermines bridges
banks erode, trees collapse	exposes utility pipes
lowers alluvial groundwater levels	reservoir sedimentation
creates unstable bed habitat	loss of riverbank land
reduces biological diversity	downstream flood damages
higher velocities occur	poor channel access
reduces floodwater storage	degrades water quality
increased peak flood flows	
knickpoints inhibit fish passage	
sediments fill downstream lakes	

3.6 Complex Response

The recent sediment deposition observed downstream of Banks Road and entrapped at the siltation basin and reservoir are at least partly the result of the channel's "complex response" as defined by Darby and Simon (1999). It is not the result of upland sheet erosion or urbanization, with minor contributions from winter road sand and roadside ditches.

The modern incision of Six Mile Creek from the reservoirs to Banks Road, and from Brooktondale to Creamery Road is essentially complete. Field evidence includes relatively low channel bed gradients, fresh growth of emergent and shrub vegetation on alternate and point bars, channel widening, and the beginning of increased sinuosity. However, the complex response occurs in the upstream reaches from Banks Road to Valley Road, and from Creamery Road to the north end of Six Hundred Road, which are now incising as the knickpoints move upstream. In addition, some lateral tributaries that have to cross the valley bottom are also incised. The sediments from the upstream and tributary erosion are accumulating in the already degraded and widening downstream channel, slowing or halting any further downstream degradation.

3.7 Slope and Sinuosity

The bed slope and sinuosity were measured for various segments along Six Mile Creek based upon use of GIS and USGS maps as well as aerial photographs. These data are presented in Table 3-3 and in Figure 3-7. The points on the graph represent stream segments 2 through 5, 6a, 6b, and 7 through 9. For each reach, the valley length, stream length, and change in elevation were used to calculate slope and sinuosity, as plotted in Figure 3-7.

A river segment slope (i.e. change in vertical grade divided by horizontal length) is a good indicator of its velocity and sediment transport capacity, while the sinuosity is an indicator of the degree of channel meandering and maturity. Briefly, the normal trend is for river segments that are "geologically" young to be fairly steep and straight, while "mature" channels that have worn down the landscape towards an equilibrium condition have low gradients and a higher sinuosity with a curvilinear meandering pattern and fine grain sediments.

TABLE 3-3
Segment Data

Segment	*Sinuosity*	*Slope*	*Comment*
1	N.A.	N.A.	Urban channel
2	1.11	0.0198	Bedrock gorge, dams
3	1.48	0.0065	Incised, widening
4	1.26	0.0074	Active knickpoints
5	1.11	0.0083	Few knickpoints
6A	1.02	0.0218	Bedrock gorge, dams
6B	1.25	0.0065	Incised, stable
7	1.22	0.0082	Slightly incised, widening
8	1.26	0.0139	Active knickpoints
9	1.11	0.0141	Stable, some bedrock

Figure 3-7

The data and field inspections reveal a river with several distinct facets. The first segment is the largely channelized, straightened, and armored channel in the area of the original river mouth delta, now occupied by the City of Ithaca.

Segment 2 has deep bedrock gorges with steep sides subject to landslides, with three dams forming impoundments. The bedrock and dams control the elevation of upstream segments. Segments 3, 4, and 5 are related to the bedrock control in Segment 2, and show a classic increase in slope in the upstream direction, with a decrease in sinuosity.

Segment 6A at Brooktondale also has bedrock exposures, with an incised gorge. The channel repeats the sequence of completed incision just upstream of the bedrock segment, the active headcutting being further upstream above Route 79 at Six Hundred Road. In between, at the Tutton property in Caroline, the channel is partially incised and is in the widening stage of evolution where the sinuosity begins to increase. Thus the banks are being eroded and structural bank protection is of limited long-term effectiveness. As indicated in Section 3.3.8 of this document, a preferred solution in this reach would be to create a new larger floodplain at a lower grade and add channel roughness.

4.0 Priority Issues and Recommendations

4.1 <u>Priority Issue # 1 – Streambank Erosion</u>

4.1.1 <u>Stream Dynamics</u>

Recognizing the issues of erosion in Six Mile Creek, as evidenced by the amount of study and analysis that has been conducted relative to that issue, it is important to understand the basics of the sediment cycle.

The movement of sediments through a river system is a complex process, often made up of many cycles of scour, movement, transport and deposition. Sediment movement occurs when water flow exerts sufficient force to overcome the resistance produced by the weight of individual particles, their cohesion to similar particles, and their friction with the streambed. Most sediment is transported during periods of high water flows and high velocities. High flow velocities are able to erode and transport larger particles and so accelerate erosion. Similarly, long-duration floods can cause more erosion and sediment transport as compared to short-duration floods. The sediment concentrations in river water and long-term sediment loads depend on the availability of erodible soil and the ability of a river to transport it.

Aggradation is the general increase in elevation of a long reach of a riverbed over a long period. This process occurs when sediment is continually added to the riverbed, or even the floodplain, and the river does not have the necessary slope, velocity or flow rate to wash away the sediment. Therefore, the riverbed will rise, increasing the slope in relation to the segment farther downstream. This increased slope accelerates erosion, until sediment transport is equal to the sediment supply rate and equilibrium is achieved.

Modern aggradation is not occurring within Six Mile Creek; only historic aggradation is evident. This process has created double top soil layers. Additionally, the rise in land in the upstream reaches caused by historic aggradation relative to the bottom of the valley, which is on bedrock, has resulted in an increased slope within Six Mile Creek.

In contrast, degradation is the general lowering of the streambed. This occurs where the slope, discharge and flow velocity combine to transport more sediment than is supplied to a river section. As a result, the riverbed will erode until the slope and velocity are reduced to a point of equilibrium. Natural degradation can result from an uplift of the land, climatic changes, or even an increase in vegetation. Humans can cause or accelerate degradation through watershed development that increases surface runoff and flow rates. Dams on alluvial rivers (i.e. those that are dynamic, whose beds and banks can erode and change course over time) encourage degradation by trapping sediment that would normally be carried downstream.

An entrenched channel is one that has degraded so much that its flood flow is unable to spread across its floodplain. Such channels are confined by well-defined banks that are higher than the mean annual flood level, thereby preventing inundation. Entrenched meanders occur when the channel's original pattern was preserved as the channel degraded, such as in the Grand Canyon. In other words, entrenched meanders are those that have eroded vertically but not laterally. They have steep valley walls on both sides of the meander bends.

Incised meanders occur where the channel has eroded both vertically and laterally. They move downstream by eroding the outside of the bends. They are characterized by steep valley walls on the outside of bends, with mild sloping walls on the inside. Active meandering channels often occur where the river flows through highly erodible sediments, common where glacial lakes occupied the land.

4.1.2 Sediment Budget and Transport Mechanisms

Open channels with flowing water have a discrete ability to transport sediment based upon their flow velocities, shear strength, flow rates, and flow duration. The first two parameters are related to channel slope, friction, width, and water depth. Steep and smooth channels can carry more sediment as compared to low gradient or rough high friction channels.

Under equilibrium conditions, the sediment load produced by a watershed is equal to the channel's sediment transport capacity. Rivers that can transport more sediment than that which is supplied to them will tend to scour any erodible bed or bank material, while rivers with a transport capacity that is lower than the watershed yield will tend to aggrade or deposit sediment on the bed or floodplain. The basic relationship is:

$$\Delta S = \Sigma Q_s - Y$$

where:

ΔS = change in channel sediment storage;

Q_s = channels sediment transport capacity; and

Y = watershed sediment yield.

Field inspections, previous reports, and preliminary computations all indicate that the land surface in the Six Mile Creek watershed has low sediment yields, however, the low friction, relatively steep-gradient channel has a high theoretical transport capacity. As a result, the main channel and tributaries are scouring their beds and/or banks if and where erodible materials exist on their perimeters.

Channel erosion in steep gradient rivers has a vicious, self-perpetuating cycle. As shown by Schemms (1984) model, first they erode the bed where the greatest shear stress exists, concentrating even more flood water in the channel. Then they incise vertically until either the bed slope (and velocity) is reduced, or until the even higher banks collapse, (supplying fresh sediment). Eventually, (after decades or centuries) they reach a new equilibrium. In mountainous and shallow bedrock regions, including Six Mile Creek, incision may cease when bedrock is reached or the riverbed becomes armored with natural rock fragments of cobbles or gravel.

The periodic surveys and dredging of the reservoirs and siltation pond provide an unusually good record of sediment loads in Six Mile Creek. The Ithaca Reservoir constructed in the early 1900s, has been dredged to maintain its volume for water supply storage. The upstream siltation basin, constructed circa 1930, has also been dredged.

The estimated average annual rate of sediment accumulation in the reservoir from 1910 to 1925 was 14,000 cubic yards per year, while the sediment dredged from the siltation basin was at an average annual equivalent rate of 15,100 cubic yards from 1963 to 1976. (Roberts, 1978, in the Six Mile Creek Watershed Study). These sediment estimates exclude the wash load that remains in suspension and passes through the impoundments to Cayuga Lake.

4.1.3 Types of Erosion

Two types of erosion and sediment load can occur in a stream system. The first is called surface erosion and occurs in the contributing watershed to a stream. Surface erosion can occur at construction sites, where bare earth is exposed to the forces of stormwater. It can also notably occur as a result of agricultural practices. Sediment load can also be introduced to a river or stream through the application of road sand or through urbanization. The second type of erosion is bed or bank erosion, where the source of sediment is the stream bed or bank walls. While the latter form can be driven by land uses within the watershed, it cannot be controlled through best management practices applied to construction sites, road sanding practices, and the like.

In recent years, local planning and zoning ordinances, as well as state legislation, has focused on erosion control practices for land development, often accomplished through the use of haybales, silt fences, and sediment basins. Non-point pollution controls have also been the focus of much attention in recent years, with stormwater management treatment and best management practices becoming commonplace.

It is important to understand the mechanisms of erosion and sediment transport in relation to the needs assessment for Six Mile Creek. A tremendous amount of attention has been focused on this issue for decades and several ongoing studies continue to investigate the causes, impacts, and control mechanisms to protect the resources within and adjacent to the creek, its tributaries, Ithaca Reservoir, and Cayuga Lake.

Hills and uplands form as the result of tectonic forces that warp the earth's crust. Plutonic rock masses can also push up through the crust, forming mountain ranges such as the Sierra Nevada. These mountainous areas and uplands in turn are subject to degradation and wear by the twin processes of surficial erosion and mass movement. Made-made slopes are subject to the same degradation processes. In order to control or prevent this wearing or wasting away of the earth's surface, it is first necessary to understand these two processes of degradation and the factors that affect them (Gray & Sotir, 1996).

Surficial erosion is the detachment and transport of the surface layers of soil by wind, water, and ice. Common forms of surficial erosion include rainfall and wind erosion. This type of erosion is most notable at poorly managed construction sites on exposed steep slopes. However, erosion can also occur along streambanks, where high velocities erode vulnerable, particularly unvegetated, banks.

Mass movement involves the sliding, toppling, falling, or spreading of fairly large and sometimes relatively intact masses. A slide is a relatively slow slope movement in which a shear failure occurs along a specific surface or combination of surfaces in the failure mass (Gray & Sotir, 1996).

Eroding banks can contribute large volumes of sediment to downstream receiving waters. When the receiving waters are of critical value, it is important to minimize the transport of sediment to them in order to maintain water quality. This often entails using bioengineering techniques to regrade and replant the channel banks.

Stream banks may erode and/or collapse due to many different causes and may undergo various types of failures. The potential factors involved in bank failure include watershed hydrology, river flow hydraulics, sediment transport, geology, soils, groundwater hydrology, and vegetation cover. The specific factors in any particular case depend on the type of failure that is occurring.

Surface erosion along stream banks can result in soil loss and bank undercutting. That situation can result in an eventual mass failure, in which the soil slumps or slides as a unit. While bank protection can address the underlying cause of the problem (i.e. surface erosion), the potential for mass failure also needs to be addressed on a location-specific basis. In general, bank failure can be attributed to mass failure or surface erosion.

Numerous types of mass soil failures can occur on steep slopes as summarized in Table 4-1 below.

The analysis of mass bank failures is a geotechnical evaluation that compares the weight of the soil mass (usually saturated) versus the shear strength of the potential failure plane. Quantitative assessment shows that the higher and steeper banks are more failure prone and that failures decrease as the slope is reduced by past failures building up a berm of debris at the base of the bank. A stable bank may have gradual erosion of individual particles over a long period of time, while an unstable bank is one with frequent mass block failures every few years.

TABLE 4-1
Types of Mass Soil Failures

Shallow Soil Slides	Occurs on steep low cohesion soils, often-coarse grain material. Has thin slide layers parallel to the surface.
Circular Plane Failures	Deep seated circular failure planes, common on strongly cohesive soils.
Slab or Wedge Failures	Occur on steep moderately cohesive soils. The slabs crack along the top and tip outward with near vertical upper slopes.
Cantilever Failures	Due to the collapse of an undercut block of soil, often due to erosion at the base of the slope.
Granular Flow	An avalanche type failure of dry cohesionless soils on steep slopes, creating a loose layer of debris in a fan pattern.
Saturated Flow	Saturated soils loose their strength and become plastic, often follows heavy rain or high water levels.
Seepage Failure	Caused by saturation of the lower slope, creating a "semi-moon" shaped popout cavity in the lower bank.

4.1.4 __Bank Stabilization__

Many methods of stabilizing riverbanks can be employed, each with their own advantages and disadvantages. MMI has classified available methods into categories based upon two primary functions, mass failure protection and surface soil erosion protection. A single project site may often use multiple stabilization methods depending on site, soil and slope conditions. In addition, the type of treatment may vary based on its position on the slope and frequency or duration of inundation.

Two types of strategies can be applied to protect a bank undergoing surface erosion from a river. One is in-stream modification of the river's flow patterns to decrease the attack on the bank, and the other is modification of the bank itself to strengthen its ability to resist the erosive forces. In cases where the velocities of the water, rather than the alignment of the river, are causing erosion, modification of the bank is appropriate.

The approach to bank stabilization can be "soft" or "hard." The softest approach relies primarily on vegetation for bank strengthening. This type of approach typically provides instream and riparian habitat value that is superior to the harder methods; however it may not provide the level of stability required to decrease the erosion to acceptable levels. The harder approach relies primarily on structural methods, such as large riprap or concrete, to armor the riverbank. A balance of both soft and hard methods is often required, where some hard structural components are used and combined with softer habitat features to create a stable and attractive bank that provides both instream and riparian habitat.

Just as historic land uses have played a significant role in the behavior of the creek, future land uses in the watershed will also influence sediment transport in the Six Mile Creek. Additionally, controlling the proliferation and downstream deposition of eroded sediment is likely to be a complex and expensive endeavor, given the dominance of bank erosion.

4.1.5 Streambank Erosion Recommendations

With regard to streambank erosion, critical questions are:

- Should degradation be controlled?
- Would placement of bed controls in the creek to prevent down-cutting result in exacerbated lateral migration?
- Should the channel be relocated at the heavily eroding meanders?
- Should the steep tributaries be controlled?

Controlling degradation for the entire Six Mile Creek watershed through conventional means would be a daunting and cost prohibitive venture. Traditional approaches to river management are often limited in scope, prohibitively expensive, and environmentally unsound. The concept of managing the watershed and corridor as well as the river channel itself provides an alternate approach that allows each river function to be managed at the appropriate level. As such, bank stabilization techniques should be judiciously applied in priority areas to protect existing structures, private property, and infrastructure (i.e. bridges, gas mains, water mains, etc.).

Field conditions indicate that significant down-cutting has occurred along Six Mile Creek. In many locations, the creek has hit bedrock or till vertical control and the creek is now relatively stable. The exception is along Segment # 4 (Banks Road to Middaugh Road) where, if left unchecked, degradation will accelerate in the next upstream segment towards Brooktondale.

In many instances, channel relocation provides a more permanent, stable, and lower maintenance restoration alternative that provides environmental habitat benefits beyond erosion control. This approach is generally preferable over "spot repairs" such as riprap armoring or the erection of structural controls.

Both past and future mitigation efforts in the form of structural walls and other vertical barriers are likely to require continued maintenance and experience repeated failures. Rigid riverbank retaining walls should be designed by a qualified licensed Professional Engineer and should include a hydraulic analysis of velocity and scour impacts, as well as a stability analysis considering active earth pressures, hydrostatic pressure, surcharge loads, and foundation conditions.

Channel relocation in combination with creating an "artificial floodplain" can provide a highly effective fix. However, caution is warranted in designing restoration projects for sites that are not stable. For instance, the application of a geomorphic-based design such as Rosgen is a powerful tool. However, the methodology is not appropriate in many areas of instability.

The tributaries that feed Six Mile Creek traverse notably steep slopes and many show evidence of past down-cutting. However, the majority of those tributaries inspected by MMI had reached vertical control points and did not appear to be migrating laterally. Initial indications would therefore favor concentrating restoration efforts on the main channel of the creek.

The following priorities are recommended along the Six Mile Creek: The highest priority reaches include Segment 4 (from Banks Road to Middaugh Road) and Segment 8 (from Creamery Road to Six Hundred Road). Moderate priority reaches include Segment 3 (from Burns Road to Banks Road) and Segment 5 (from Middaugh Road to Valley Road near Route 330 in Brooktondale).

TABLE 4-2
Segment Restoration Priorities

Segment	***Description of Geographic Limits***	***Description of Conditions***	***Priority***
1	Cayuga Inlet to Van Natta's Dam	Highly channelized stable urban stream.	Low
2	Van Natta's Dam to Burns Road	Fairly stable area due to impounded water.	Low
3	Burns Road to Banks Road	High degree of lateral migration and erosion.	Moderate
4	Banks Road to Middaugh Road	Highly unstable with active headcut.	High
5	Middaugh Road to Valley Road near Route 330 in Brooktondale	Stable channel segment u/s of headcut.	Moderate
6	Valley Road near Route 330 in Brooktondale to Boiceville Road	Stable bedrock channel with falls.	Low
7	Boiceville Road to Creamery Road	Stable low-gradient reach.	Low to Moderate
8	Creamery Road to Six Hundred Road	Excessively steep segment with structural issues.	High
9	Six Hundred Road to Headwaters in Dryden	Stable channel headwaters.	Low

Most of the inspected channel reaches along Six Mile Creek had unusually low levels of channel roughness with which to reduce flow velocities and provide structural habitat. A comprehensive program is recommended to increase channel roughness that would include the following measures:

- anchor or bury large woody debris in the banks;
- create boulder and log sills in the riverbed to form rapids and pools;

- install individual boulders and boulder clusters in the channel; and
- redefine the channel's thalweg.

Finally, the following site-specific recommendations are offered:

- The existing Six Mile Creek "knick points" between Banks Road and Brooktondale should be stabilized in-place as an interim measure to minimize further upstream incision.

- The bifurcated flow upstream of Banks Road at the property of Scott Whitham (reach #3505) should be redirected into the left channel and the right channel converted to a riparian wetland floodplain.

- The eroding river bank and stacked rock retaining wall failure at the Tutton property (reach #3487) in Slaterville Springs should be addressed by creating a floodway on the left bank and backfilling the channel near the wall to increase the waterway area and reduce velocities.

4.2 Priority Issue #2 – Water Quality

The water quality of Ithaca Reservoir and Cayuga Lake will continue to be a high priority. However, discrete stabilization "patches" are not likely to prove successful. A management strategy will be necessary to actively deal with sediment loads in the siltation pond and possibly with other detention/settling mechanisms at particularly problematic points within the watershed. In the long run, expenditure of resources on sediment management (i.e. collection and dredging) is likely to produce higher water quality in both Ithaca Reservoir and in Cayuga Lake as compared to spot fixes of streambank erosion.

The Ithaca Water Department has constructed and operates a large impoundment just upstream of Burns Road to trap sediment prior to its reaching Ithaca Reservoir. During two inspections of this area, the basins were observed to be discharging water that was more turbid than its inflow. This could be due to either high flows that resuspend and transport previous sediment deposits, in-basin algae blooms in nutrient rich water, or sediment laden runoff from adjacent processing and screening of previously dredged spoil material.

The efficiency of this basin could be improved in order to further help reduce sediment loads at the downstream reservoir. Specific recommendations are:

- Construct a forebay at the basins inflow point to trap coarse sediment in an area that can be accessed for annually cleaning.

- Add a series of internal groins or dikes to minimize resuspension of previous sediment deposits, and to avoid having direct through flows.

- Install a seasonal floating boom to trap surface debris and to support a turbidity curtain.

- Evaluate the frequency and magnitude of algae blooms to determine whether biological controls are warranted.

4.3 <u>Priority Issue #3 – Need for Coordinated Planning Efforts</u>

The increased industrialization and urban growth after the Civil War was followed in this century by the rapid growth of suburbs dependent on automobile transportation. Urban and suburban areas both increase the area of impervious surfaces and use artificial drainage systems to collect runoff. The prevailing philosophy for 100 years, which only recently began to change, was to convey the runoff to rivers as rapidly as possible. This reduces infiltration and evapotranspiration, increasing the volume of runoff and raising peak flow rates in the rivers.

In addition to raising peak flows, urbanization reduces the base flows necessary for aquatic life, recreation, and water supply in dry weather. The percentage of a watershed that is covered with impervious surfaces is one of the key parameters affecting urban runoff. Increased runoff into a river's channel and floodplain affect the river's hydraulics, altering its flow depth, velocities, flood frequency, scour, and sediments. Channel and floodplain encroachments, such as fill material, buildings, bridges, and culverts, can also reduce flow capacity of a river and increase peak flow rates and velocities.

The hydrologic effects of land use changes affect the shape, size, and form of stream channels. The higher flow velocities and more frequent floods scour the channel, enlarging the flow area. Unless lateral erosion is contained by soil and vegetative conditions, urban rivers will generally erode their banks and increase in width. Lateral erosion leads to steeper, less stable banks that tend to be undercut and then collapse into the channel, adding more sediment directly to the river. Urban streams are also known to erode their channel beds, causing degradation, especially in uniform soils, such as silts and clays.

Land use can have a marked impact on stream water quality, temperatures, and sedimentation and erosion. With increased impervious surfaces come higher peak rates of stormwater runoff, greater transport of contaminants, higher stream velocities, and often degraded water quality due to increased temperatures and an influx of pollutants. Generally speaking, water quality impacts begin to occur above 10% impervious area coverage in a watershed, wherein the most sensitive stream elements are lost from the system. Above 25%, water quality is often impaired, where most indicators of stream quality consistently shift to a poor condition, including diminished aquatic diversity, water quality, and habitat scores.

Detailed studies of numerous watersheds have shown that the physical, biological, and chemical (water conditions) usually deteriorate as the watershed becomes developed. The percentage of the watershed covered with impervious material such as rooftops, parking lots, roadways, and driveways is often used as an indication of urbanization. Research has demonstrated the following relationships between watersheds impervious cover and the streams condition. (Center for Watershed Protection, 1998) This information provides an initial method to rapidly assess watersheds susceptible to change.

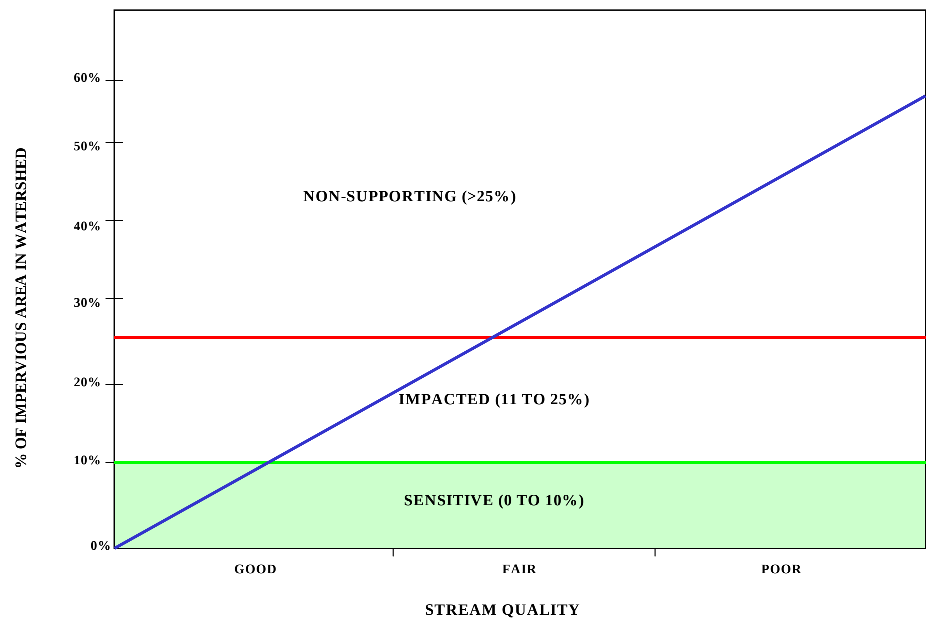
Table 4-3
Relationship of Imperviousness to Water Quality

Watershed Impervious Cover	*Stream Quality*
0-10%	Good
10-25%	Fair, probable impacts
7-25%	Low, significant impacts

Streams with 10 to 25 percent impervious cover usually are impacted with erosion channel deterioration, unstable banks, reduced habitat, reduced biodiversity, and declining water quality. Streams within watersheds of over 25 percent impervious cover tend to be flood prone, highly unstable, with poor water quality and limited aquatic life. Figure 4-1 illustrates the relationship between impervious cover and stream quality, information that can be used to categorize streams as sensitive, impacted, or non-supporting.

The water quality of the sub-watersheds within Six Mile Creek as observed in the field and indirectly assessed using the impervious cover metric, is generally quite good. The only sub-area with high impervious cover and extensive storm drainage is WS-10, and to a lesser extent WS-20 and 30. Consequently, except in the City of Ithaca, watershed urbanization is not a significant factor in the health of Six Mile Creek.

Figure 4-1
Relationship of Imperviousness to Water Quality



Source: Schueler & Claytor, 1996 ASCE

However, future land uses and development practices and trends have the potential to have a marked negative impact on Six Mile Creek and its contributing tributaries. If unchecked, land use development could have profound and unwanted impacts. Zoning and wetlands regulations at the local level are not consistent within the County and, in some instances, are non-existent. Where they are in place, these regulations do not provide adequate controls for the maintenance of riparian buffers or protection against increases in peak stormwater runoff rate and/or volume that is generated by the creation of impervious surfaces (i.e. parking areas, buildings, sidewalks, etc.).

Development of a consortium or task force among the local Six Mile Creek member towns is strongly encouraged, wherein the framework can be developed for a watershed approach to future land use planning and reasonable controls. Of particular concern would be mechanisms to protect the hydrology and water quality within the watershed and to develop a riparian corridor within which development would not occur. Controls on encroachment will serve to protect the stream corridor as well as future structures.

4.4 Management Practices

Milone & MacBroom, Inc. inspected and reviewed various watershed management practices that have been applied, or could be applied, to minimize flooding, erosion, and sediment problems in the Six Mile Creek watershed. The specific interest was to identify the performance of individual practices with regard to short- and long-term objectives.

Watershed management measures can be classified by primary functional groups as listed in Table 4-3. Typical measures are tabulated below by primary function.

TABLE 4-4
Primary Watershed Management Functional Groups

Hydrology	*Hydraulics*	*Surface Erosion Control*
detention basins	channel clearing	vegetation ground cover
infiltration systems	channel enlargement	rill/gully controls
created wetlands	bridge improvements	Mulch
flood control dams	channel alignment	bio-fabrics
low impact development	floodways	silt fence barriers
Channel Stabilization	*Sediment Control*	*Water Quality*
vegetation	upland sediment basins	catch basins sumps
bio-technical	in-stream silt basins	hooded outlets
stone riprap	vegetative buffers	vegetated buffers
log revetments	diversions	oil traps
geomorphic design	bio-filters	grit chambers
retaining walls		

Hydrologic measures are intended to reduce the volume or peak rate of runoff and ideally attempt to mimic natural conditions. Hydraulic measures are traditionally used to lower flood water levels, reduce flood damages to natural or community assets, or modify flow velocities. Surface erosion controls are used to limit upland erosion on the ground surface to reduce production of sediment, such as at construction sites and agricultural fields.

Many types of channel stabilization are in use throughout the country, ranging from simple use of vegetation and stone to geomorphic design process to reshape channels.

In some cases, a reactive strategy is implemented to control sediments that have already been eroded from the earth. In these instances, suspended sediment is captured downstream of its source and is subsequently settled by gravity or is treated through other physical or mechanical mechanisms.

All of the management measures that were inspected by MMI in Six Mile Creek consisted of channel stabilization projects or channel modifications. Several problem areas being considered for management due to bank or bed erosion were also inspected. Several of these, such as the Karig (Segment 3), Whitham (Segment 4), Tutton (Segment 8), Barille (Segment 8), and Moesch (Segment 8) properties, were referenced in the stream segment assessments.

Additionally, conventional stone riprap on graded stream banks were observed at several sites, including north of German Cross Road, south of German Cross Road, and at the gas pipeline crossing downstream of Banks Road. At all three sites, the riprap bank protection was effective in terms of resisting erosion. However none of the observed rip rapped areas has any vegetative cover and the exposed hot banks offer poor habitat.

Several bridges over Six Mile Creek have abutments and or wingwalls composed of vertically driven steel sheeting. This is a rapid and cost effective method of supporting bridge superstructures where deep or scour prone soils exist. The use of concrete pile caps or tie backs are common practice for this type of construction, but could not be visually verified. The vertical steel abutments can provide good scour protection if they are deep enough. However, these do not concentrate low flows and lack floodplain linkages.

There has been some discussion in Tomkins County related to use of the hydraulic geometry method of channel analysis for application in developing restoration plans for distressed sections of Six Mile Creek. A brief description and comments are noted below.

Channels located in alluvial soils that were placed as fluvial sediments have the ability to modify and form their channel widths, depths, and slope in proportion to their dominant discharge. Channels that are initially undersized will be subject to scour that increases their widths and depths in proportion to a channel forming flow rate, while channels that are excessively large will tend to be subject to sediment deposition that decreases width and depth. Over long time periods, alluvial channels thus approach an equilibrium condition.

This concept is the basis of the "natural" design approach to evaluating self-stable alluvial channels. It originated over 100 years ago in India and Pakistan and evolved in the United States beginning in the 1950s, becoming a popular alternative to earlier rigid boundary hydraulic engineering procedures and being much simpler than modern sediment transport techniques. It is only valid for channels at near equilibrium conditions in alluvial material.

Hydraulic geometry relations may be applied by either copying the dimensions of a stable cross section of a similar channel classification, or by using statistical analysis of regional channels to find their bankfull width and depth as a function of the watershed area or preferably their dominant discharge.

There are many alternative techniques available to address channel incision and minimize its adverse impacts. The specific management techniques and design details for individual sites is beyond the scope of this study. However, the broad alternatives that are available are described below:

Do Nothing – This no action alternative allows the renewed channel degradation to continue towards a natural self-imposed equilibrium. The long process (on the order of ten to 100 years) has several consequences, including downstream sediment loading, bank collapses, channel widening and land loss, and ground water recession. In rural areas, this is often acceptable and unavoidable.

Channel Linings – A traditional technique for minimizing channel incision is the use of continuous linings on the bed and/or banks to stop erosion. Common linings include use of concrete, stone riprap, stone filled gabions, precast concrete blocks, and revetments, as well as bio-mechanical plantings such as root wads, fascines, brush layers, and use of dormant cuttings or stakes. Channel linings usually have significant ecologic and hydrologic impacts due to vegetation removal to regrade the bank, loss of habitat diversity, and aesthetics.

Watershed Scale Measures – These are applied in selective situations where broad cultural land use activities are contributing to channel incision. Activities that stimulate incision could include deforestation, over-grazing by cattle, goats or sheep, gravel mining or mineral extraction, channelization, wetland destruction or urbanization. MMI did not observe significant watershed scale activities that would accelerate natural channel incision. Previous activity, such as deforestation, may have contributed to present incisement.

Flow Control – In watersheds subject to deforestation or urbanization, control of peak flood flows is essential to minimize downstream impacts. Higher or more frequent peak flows increase flow velocities and sediment transport that lead to channel bed or bank scour. Specific control techniques include dry storage dams, detention basins, and created wetlands.

Channel Slope Control – Incision can be minimized or contained by use of grade controls or drop structures. Various types of grade controls can be used, including low weirs, flush sills, boulder clusters, anchored logs, gabions, check dams, and rock ramps. It is important to recognize that some grade control structures on perennial streams obstruct fish passage. Site inspections along Six Mile Creek revealed that clusters of glacier erratics (boulders of non-native rock) were very effective in stopping knickpoints.

Velocity Control – Providing increased channel roughness with boulders and anchored logs or bank vegetation reduces flow velocity and subsequent bed erosion. However, extensive roughness may increase flood water levels and the frequency of overbank flows. This is in conflict with many regulatory programs.

Floodplain Connectivity – A fundamental problem with incised channels is that their increasing depth and flow capacity reduces the frequency and magnitude of overbank flow on their floodplains. As they erode and deepen, more and more of the flood flow is trapped in the channel, increasing velocity and shear stress that creates even more erosion. A very effective approach is to mimic a natural system by recreating a new floodplain at a lower grade to increase its usage and reduce velocities via a larger cross sectional area. These compound channels (low flow channel plus floodway) are complex to design, but are very effective if sufficient land is available.

Channel Fill – Occasional suggestions in the literature refer to refilling incised channels to raise the bed elevation and allow floodplain flow again. However, in developed areas, this increases flood levels as well as hazards and is a regulated activity with significant ecological impact. MMI discourages this alternative.

Sediment Load – Channels become incised when sediment transport capacity exceeds their supply of sediment. The Colorado River is a classic example where construction of large dams that trap sediment reduce downstream loads, leading to severe channel incision. Some European rivers are managed by increasing sediment loads to create an equilibrium condition. This is not desirable in many areas due to water supply intakes, water quality, and ecological concerns. Examples of measures to increase sediment loads include removing abandoned dams that remove trees and woody debris and ceasing gravel mining in rivers. In Six Mile Creek, intentionally increasing the supply of sediment is inconsistent with downstream water quality concerns in Ithaca Reservoir.

<u>*Bank Protection*</u> – Armoring the banks with retaining walls helps to protect private property by reducing channel widening. However, it does not address the source of the problem and can accelerate further incision that would undermine the walls as knickpoints migrate upstream. Similarly, the use of conventional plantings or bio-technical methods to reduce bank erosion is most effective if the channel width is already adequate for flood flows and the banks are regraded below the angle of repose.

It is noted that channel clearing operations that remove trees and debris for local flood protection tend to increase flow velocities and increase erosion by reducing channel roughness. Similarly, channel straightening will shorten the river's length and increase velocity and scour, contributing to more channel erosion.

While the areas targeted for restoration within Six Mile Creek focus on the upstream reaches that largely drive sediment loading and water quality, many of the remaining reaches, including the channelized segment in the lower watershed, can also benefit from restoration efforts. Of particular interest would be improving the ecological and recreational function of the lower watershed by acquiring a riparian zone along the channel. Concrete walls could be replaced with natural sloped banks. This would improve habitat function as well as public access opportunities.

5.0 Implementation Strategy

5.1 Management Practices, Program Operation and Coordination

The current Flood Hazard Mitigation Program funding is geared towards the protection of structures and facilities to minimize flood damages. However there is no stated goal or criteria in the funding guidelines that would place emphasis on or give priority to sustainable restoration alternatives, watershed approaches, or restoration projects that would prevent damage to the natural environment, as opposed to existing structures or property. Additionally, the current program does not account for a hierarchy of priorities that are consistent with a regional watershed approach.

The County is to be commended for its foresight in suspending its funding program pending a comprehensive watershed needs assessment. The current funding mechanism is a good one and the existing framework serves as an excellent starting point from which to develop a watershed-based approach. It is recommended that the County's current funding application and supporting guidelines be modified to incorporate a priority ranking system by which future projects can be evaluated. A ranking system can be numerical, weighted numerical, or simply utilize a "high" "moderate" "low" system to assign priority among competing projects. A suggested set of criteria elements is provided below:

- Location of the project within one of the identified priority stream segments;
- Use of natural stabilization techniques over spot treatments;
- Consistency with a watershed approach;
- Potential for ill-effects of upstream and downstream reaches;
- Level of technical analysis and design documentation provided;
- Future maintenance requirements;
- Ability to provide hydrologic benefits through detention or infiltration of runoff;

- Ability to provide water quality renovation;
- Consistency of the proposal with establishment of a riparian corridor.

Minimum requirements of eligibility should also be developed for application to project review and funding award, as well as criteria for rejection of proposals. This would include inconsistency with the stated watershed goals or local regulations, lack of technical documentation, and the like.

In the past, the total annual funding under the Flood Hazard Mitigation Program has been limited to $25,000 per year, with a requirement of equal matches from the project proponent and the municipality wherein the project would occur. This equates to a maximum potential annual pool of $75,000. A mechanism that would enable multi-year projects of larger magnitude would also be of interest. Additionally, the program would benefit from having the flexibility to roll unused funding from one year into the next, in the event that the number and/or scope of eligible projects is not sufficient to expend the available funding in a given year.

Consistent with the recommendations contained in Section 4.3 of this assessment, additional coordination among the host municipalities within the Six Mile Creek watershed would be beneficial to a watershed restoration approach. The role of the Tompkins County Planning Department as a central hub for planning activities among the municipal governments of Dryden, Caroline, Ithaca, and Danby is both appropriate and desirable.

5.2 Funding Considerations

The County is encouraged to monitor funding trends at the state and federal levels. Since September 11, 2001, the focus of federal funding has shifted to homeland security and is not heavily weighted towards stream restoration or flood hazard mitigation. Some possible sources of funding may include the National Oceanic and Atmospheric

Administration (NOAA), the Environmental Protection Agency (EPA), and the State of New York Department of Environmental Conservation (DEC).

5.3 ***Implementation and Future Needs***

The site-specific recommendations described in Sections 3.3, 4.1.5, and 4.2 are all excellent short-term implementation candidates that should be pursued as funding allows. The programmatic recommendations described in Section 4.3 should be initiated as soon as practical. However, given the depth of coordination that will be required among the member municipalities, along with the complexities of the public process to implement any regulatory changes, will likely take several years.

The County can begin to work towards the long-term goals and objectives of a holistic watershed approach by initiating changes to its current funding program. However, many of the long-term watershed measures presented in the overall recommendations described above, will require funding that significantly exceeds the annual allocation of $25,000 or the combined contribution of $75,000 per year with "matching" funds.

The Needs Assessment for Six Mile Creek has been conducted on a "macro-scale" level. While this assessment has enabled development of a broad scale watershed management strategy, establishment of a hierarchy of specific projects, with cost estimates and implementation schedules will require more in-depth investigations of the moderate and high priority stream reaches along Six Mile Creek.

Reference Inventory

"Applied River Morphology"
Rosgen, David
Wildland Hydrology, Pagosa Springs, Colorado, 1996

"Cayuga Lake Watershed Roadbank and Streambank Inventory"
Cayuga Lake Watershed Intermunicipal Organization
http://www.cayugawatershed.org
May through August, 2000

"Channelization and Stream Erosion, Six Mile Creek" in the "Six Mile Creek Watershed Study
Roberts, Lynn, Hamilton, Lawrence S.
Department of Natural Resources, Cornell University, Ithaca, New York, 1978

"Incised Channels, Morphology, Dynamics, and Control"
Schumm, Stanley A., Harvey, Michael D., and Watson, Chester C.
Water Resources Publications, Littleton, Colorado, 1984

"Incised River Channels"
Darby, Steven E. and Simon, Andrew, Editors
John Wiley, Chichester, Great Britain, 1999

Lecture notes from Geology 441, Geomorphology, Cornell University
Bloom, Arthur, 1990,

Lecture notes from Geology 202, Environmental Geology, Cornell University
Karig, Daniel, 1990

Moesch Project: Pre History
Molly Adams, June 2001

NYSDEC Division of Water Priority Water Problem List Worksheet
Prepared by Tompkins County Department of Planning, October 1993

Recent Channel Degradation in Six Mile Creek
D.E. Karig, A.L. Bloom, M.R. Bauer, and S.A. Griffen
Department of Geological Sciences, Cornell University, May 19, 1995

Sediment Sources in the Finger Lakes Region and Western Catskills of New York
Greg Nagle and Tim Fahey
Cornell University, Department of Natural Resources, Fernow Hall, Ithaca, NY 14853
Abstract (undated)

Six Mile Creek Streambank Erosion Inventory Report
A. Barber and J. Russell-Anelli
Tompkins County Soil and Water Conservation District
Summer 1994

Six Mile Creek Watershed Study
Department of Natural Resources, Cornell University

"The Finger Lakes Region, Its Origin and Nature"
Van Engeln, O.D., Cornell University Press, Ithaca, New York, 1961

U.S. Geologic Survey Topographic Maps of Ithaca East, Dryden, and Willseyville Quadrangles
Scale 1:24,000
Photo Revised 1978

Water Quality Study of Six Mile Creek
Matt Reidenbach, Tatiana Botelho - School of Civil and Environmental Engineering
D.E. Karig – Department of Geological Sciences, June 1996

Final Watershed Needs Assessment.doc