SIXMILE CREEK:

A Status Report

A document prepared under the auspices of the
Sixmile Creek Partners in preparation for a channel
and watershed management plan.

MAY, 2007

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SIXMILE CREEK: A STATUS REPORT

Introduction

Sixmile Creek is unique in Tompkins County: it serves as the source of the City of Ithaca's drinking water and is geomorphically very active. For these reasons, the number of studies, data collection efforts, and management projects occurring along Sixmile Creek, and within the watershed, is proportionally greater than that in most other creeks and watersheds in the County and even in the Cayuga Lake watershed.

An increasing awareness of watershed issues among many stakeholders in the Sixmile Creek watershed, with the leadership of Tompkins County, yielded questions about the effectiveness and outcomes of the many highly localized and often uncoordinated channel management efforts scattered throughout the watershed. In 2002, the Tompkins County Planning Department retained Milone and MacBroom, Inc. (MMI) to complete a Flood Mitigation Needs Assessment for Sixmile Creek, which suggested a more holistic approach to stream management and watershed needs (MMI, 2003). The following year, the City of Ithaca invited various local agencies, municipalities and scientists to participate in the "Sixmile Creek Partnership" in fulfillment of a grant obligation and to facilitate greater information sharing and coordination of projects in the Sixmile watershed.

At a Sixmile Creek Partners meeting in 2005, several participants noted that most management practices in Sixmile Creek and its watershed are planned and constructed largely on a site-by-site basis and without the benefit of a watershed-wide management plan as recommended in the MMI report (MMI, 2003). After some discussion, the Partners agreed that the data necessary for the generation of a channel management plan were not yet available. In recognition of this data gap, a committee of the Partners proposed a technical meeting to review the status of existing data and information and to identify major data gaps. Acquisition of these missing data would then lead to formulation of a management plan.

This technical meeting was held on August 4, 2005 and the participants included:

Ed Bugliosi, Office Chief, U.S. Geological Survey, Ithaca, NY
Scott Gibson; Environmental Engineer, City of Ithaca
Kate Hackett; Senior Planner, Tompkins County Planning Department
Ruthanna Hawkins, Watershed Educator, Cayuga Lake Watershed Network
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Todd Miller, Hydrologist, U.S. Geological Survey, Ithaca, NY
Liz Moran; Principal, EcoLogic LLC Consulting Services
Craig Schutt; District Manager, Tompkins County Soil & Water Conservation District
Carl Schwartz, Fish and Wildlife Biologist, U.S. Fish and Wildlife Service

Topics discussed at the meeting included a review of channel behavior, in particular that of Sixmile Creek, followed by discussion of the role of large woody debris and by identification of major data gaps. This report includes discussion points and conclusions from that meeting, though not in the order discussed, as well as supplementary information added by Partners during the writing of the report.

Late Quaternary History of Sixmile Creek Valley

The geologic history of the Sixmile Creek valley that is relevant to this report begins in the late Pleistocene Epoch (about 130,000 yrs ago), when glaciers advanced and retreated several times through the Sixmile valley and continues through the period of deglaciation and establishment of the present drainage system. The Quaternary history of the valley is not well understood, but there is clear evidence that ice advanced up and retreated from the Sixmile Creek valley at least three times. These advances are documented by the cutting of three gorges known to exist from Ithaca to the 60-foot dam (which impounds the present City water supply reservoir) (Rich and Filmer, 1915). Each of these gorges represents a period of postglacial downcutting by a Sixmile Creek that was left "hanging" above a glacially deepened Cayuga Valley trough.

During the maximum advance of the last major late Quaternary glacier (~24-28,000 years ago), which extended into Pennsylvania, all of Tompkins County was covered by ice. During this last glacial episode the ice in the Sixmile trough overrode existing deposits, eroding most, and deforming and reworking others into till. Much of this material consisted of fine-grained lake sediments that were deposited in proglacial lakes trapped south of earlier retreating and advancing ice margins.

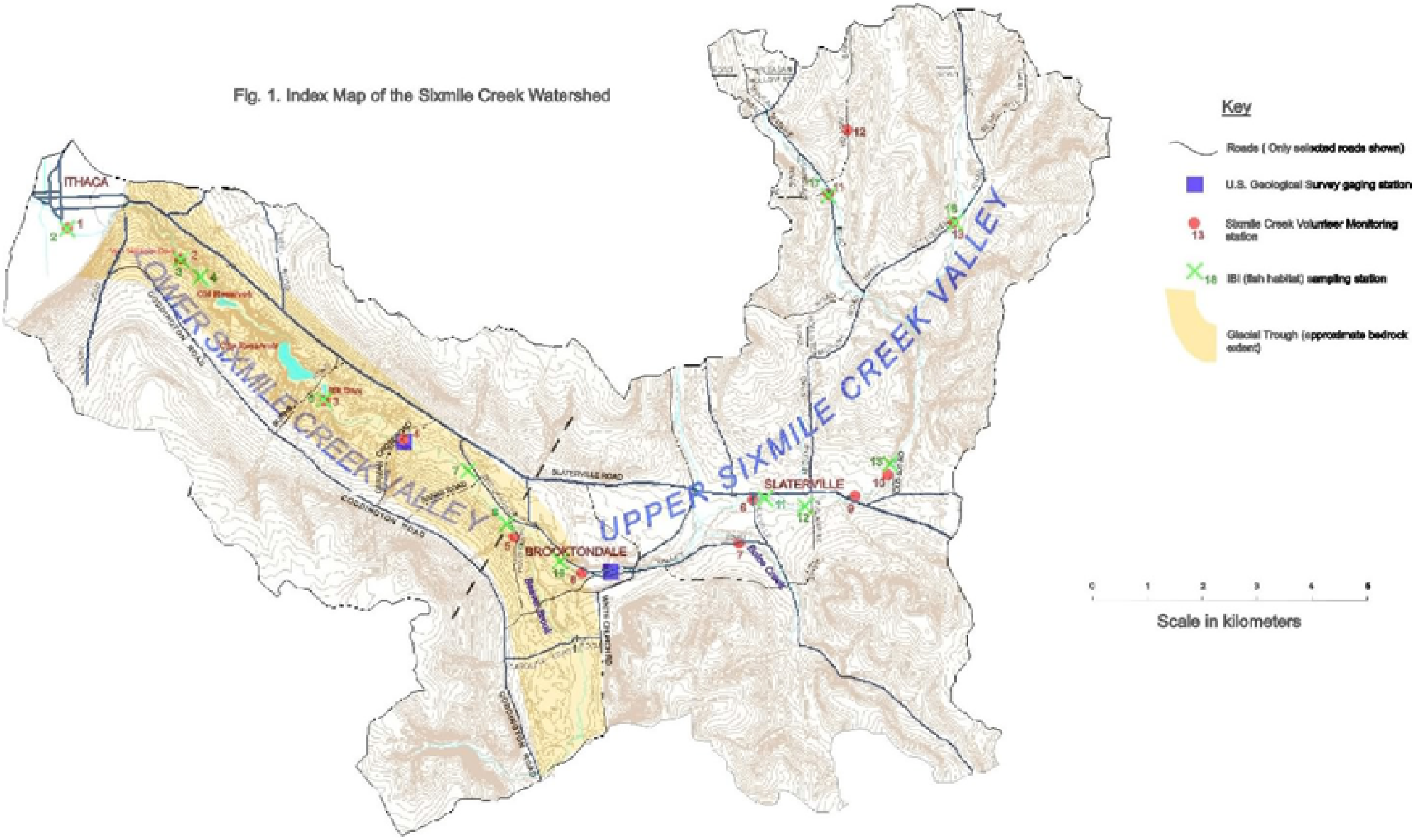
Lower Sixmile valley trends northwest-southeast, which was oblique to the southerly flow of the ice. It is likely that the erosional forces of the ice in this valley were not as intensive as those valleys aligned more nearly parallel with the direction of ice flow (north-south) such as the Cayuga trough. This is probably the reason why the Sixmile trough was not cut down to the level of the Cayuga trough as well as why a thick section of till formed beneath the ice.

The last glacial stade to affect the Sixmile trough (the Valley Heads stade) occurred about 17,500 years ago and was restricted to ice tongues in the major valleys. Although details of this event are debated, and may have involved several oscillations, the front of the ice tongue that filled the trough paused for a time just north of Willseyville, where large amounts of glaciofluvial sediments were deposited. The meltwater from this glacial front carried sediments southward into the Susquehanna River drainage, forming an extensive outwash plain. After the Valley Heads stade, about 16,000 years ago, the ice retreated rapidly from the Sixmile Creek valley, leaving a partially drift filled U-shaped trough, which lay well above the bedrock trough floor (Fig. 2)

The main glacial tongues advanced up the Sixmile Creek valley almost to Brooktondale, but there they continued southward through the Willseyville "through valley", whereas the present Sixmile Creek continues eastward to Slaterville and then northward (Fig. 1). This divergence between the paths of the ice and the stream resulted in a Sixmile Creek valley that is divided into lower and upper sections, each with quite a different history and character.

During the last glacial stades, the main ice tongues that flowed into the Sixmile Creek valley split into two near Brooktondale, with the major flow continuing southward into the Sixmile-Willseyville "through valley" and another, smaller tongue extending eastward into upper Sixmile Creek valley, terminating just east of Slaterville Springs (Fig. 1). The divergent paths of ice into valleys of different orientations resulted in significant differences in the depositional processes that occurred during deglaciation in the two valleys. These differences resulted in some significant distinct differences in the characteristics of the hydrogeology of upper and lower Sixmile Creek valleys, Because of these differences, in this report, Sixmile Creek valley is divided into lower Sixmile and upper Sixmile valleys (Fig. 1). The following discussion describes the history of only lower

Fig. 1. Index Map of the Sixmile Creek Watershed



Sixmile Creek valley and concentrates on that period during and after the final glacial episode to affect the valley.

The type of glacial deposits found in the lower Sixmile valley indicate that, during the last ice advance, the advancing ice eroded or overrode older sediments in the valley and filled any gorges that existed at that time with till.

When the present Sixmile Creek was re-established following the last ice retreat, the channel initially flowed on a new till surface, without regard for its pre-glacial location. As downcutting proceeded from near Ithaca to the 60-foot dam, the stream re-occupied older (interstadial) gorges in some reaches, whereas in other reaches it cut down into bedrock and formed new, post-glacial gorges.

Because the interstadial periods were generally longer than the time since the last glacier left the Ithaca area, the older gorges are wider than the post-glacial gorges. Where Sixmile Creek is re-excavating former gorges filled with unconsolidated sediment, the stream erodes a wide channel, whereas where it is cutting a new channel into bedrock it is confined to a narrow gorge This gives the stream valley below the silt dam (a sediment trap above the 60-foot dam) the appearance of beads on a string; the fat beads being the re-excavated gorges and the narrow strings being post-glacial gorges. All three water supply dams (Van Natta's dam, the "30-foot dam" and the "60-foot dam) were constructed in the "strings" and the reservoirs behind are in "beads".

Upstream from the silt dam, and below Brooktondale, Sixmile Creek and its tributaries have eroded deeply into the till and in places into older unconsolidated deposits that underlie

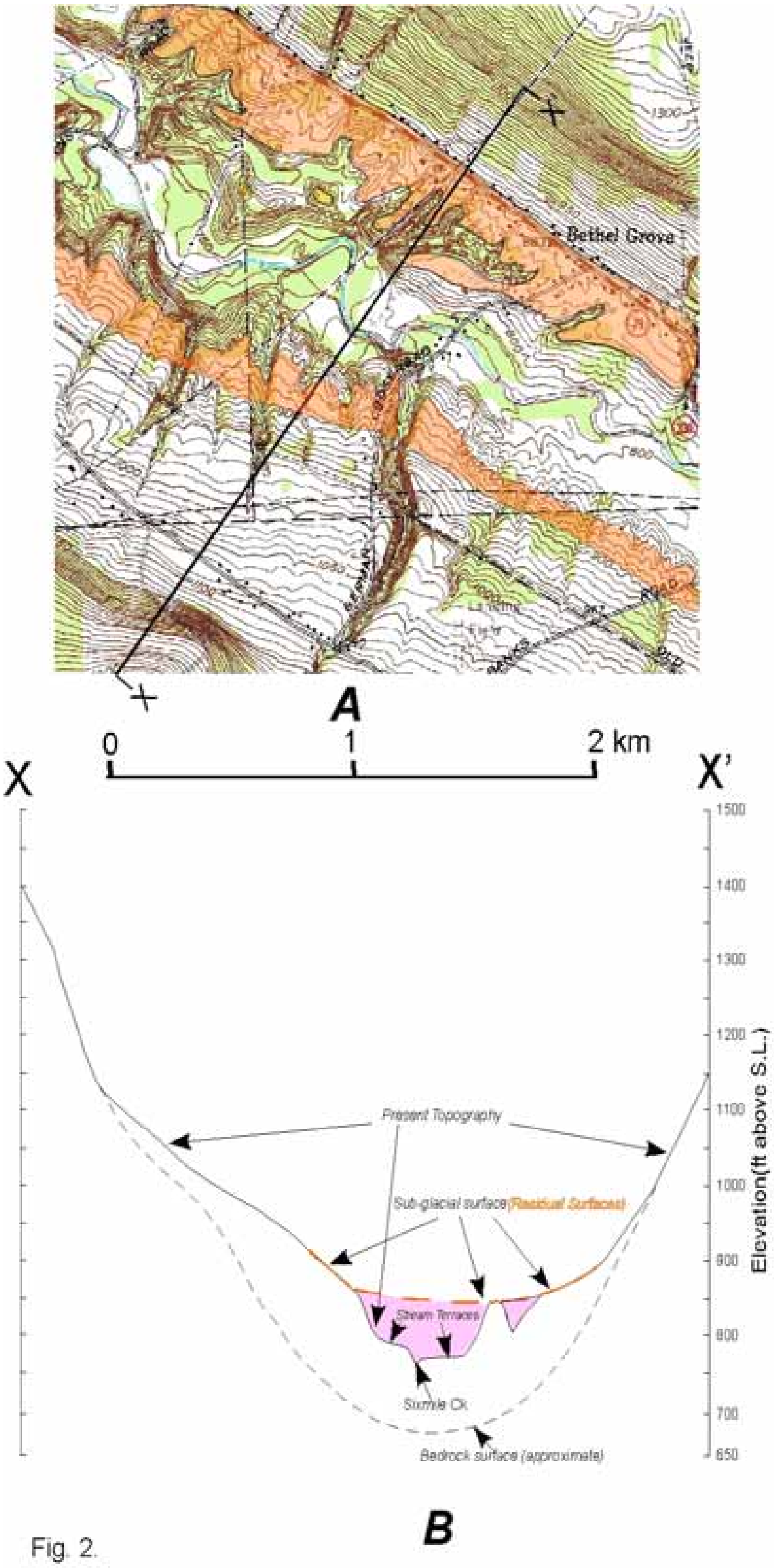


Fig. 2.
A. Map of Sixmile valley near German Crossroad, showing terrace-like remnants of the glacial trough fill (orange).
B. Cross section X-X' illustrating the trough fill.

the till. In this reach, Sixmile Creek has not incised into bedrock, which is last exposed in the channel just upstream from the sediment control basin behind the silt dam. This bedrock forms the local natural base level for the stream channel up to Brooktondale.

The shape of the Sixmile valley just after deglaciation can be reconstructed, and the amount of sediment removed by channel degradation determined can be estimated through construction of geologic cross sections. Because remnants of the original till surface are preserved along the valley flanks, that surface can be reconstructed by extrapolating between the remnants on both sides of the valley (Fig. 2). Along the north side of the valley, these remnants are nearly flat and terrace-like, but on the south side the surfaces are gently sloping.

In a geologic cross-section of the valley near German Crossroad (Fig. 2), where well records and other sub-surface data are available to constrain the depth to bedrock, the unconsolidated Quaternary sediments were at least 200’ thick, into which the creek has eroded about 100 feet. Well data in this area indicate that beneath the till are older fluvial sediments of unknown origin, which serve as an artesian aquifer along much of the valley.

The remnant surface elevations show that the floor of the post-glacial valley rises upstream with a lower gradient than that of the present-day stream. Thus, the depth that the stream channel has incised into the underlying till decreases upstream and disappears in the wetlands of the Sixmile-Willseyville “through valley”.

Above the bedrock gorge in Brooktondale in upper Sixmile Creek valley, the incision into the valley-fill deposits has been relatively minor. The bedrock gorge at Brooktondale is the base level, or controlling threshold of the development of the stream profile the upper Sixmile Creek valley. That base level effectively makes this reach a separate geologic regime with its own set of geohydrologic characteristics. North of the abandoned bridge over Sixmile Creek at Six Hundred Rd, the stream once again is incised, as much as 100 ft, into a deep bedrock gorge, and is yet another geohydrologic regime. Knowledge of the geologic history of Sixmile provides perspective concerning the basic nature and proclivities of the system, but its shorter term, anthropogenic history is more relevant to its current behavior and to stream channel management.

General Behavior of Sixmile Creek Channel

Stream channels are natural systems that transport both water and sediment from higher to lower elevations. The characteristics of stream channels are not random and depend on the amounts of, and relationships between, water and sediment transported by the stream. Extensive observations have shown that parameters such as the slope of the stream channel and the amount of sediment relative to the volume of water in the stream determine the nature of the channel, whether it be meandering or braided. Characteristics such as channel width and meander wavelength show a systematic relationship with the bankfull flow.

Research about and discussion of these relationships is extensive and far beyond the scope of this report, but a general understanding of the topic can be found in any modern textbook on environmental geology. A particularly good explanation of the concepts in moderate technical detail is “A View of the River” by L. B. Leopold (1994). The following discussion assumes that the reader has a general familiarity with the subject or will rely on one of these references. It is now generally accepted that the channel of Sixmile Creek is currently downcutting (degrading) in many or most sections, as documented by Karig (2000) and MMI (2003). The cause of this channel degradation is most likely the return of the channel toward equilibrium with a lower sediment yield from the uplands than there had been during an earlier period of intensive agriculture there. The large amount of sediment eroded during this period of intensive agriculture, mostly during the late 19th and early 20th century, caused channel aggradation and storage of large amounts of alluvium along the major channels.

Since the early 20th century, agricultural intensity has declined and that stored sediment is being removed by channel degradation and by increased channel sinuosity. Such behavior has been recognized in other streams in the eastern United States where similar cultural histories have occurred (Fig. 3).

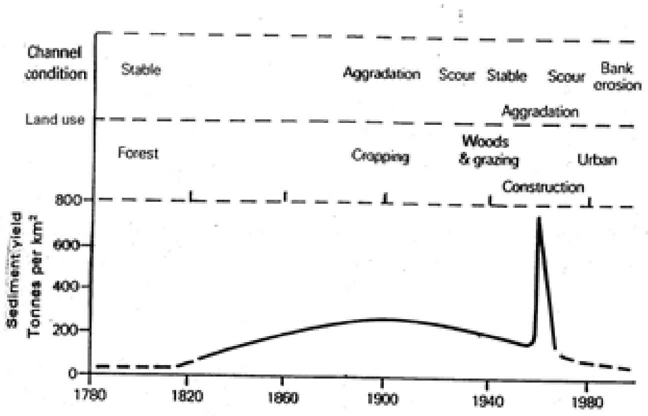


FIG. 6.13 Models of river-channel adjustment. Changes of sediment yield since 1780 in the north-east USA associated with man-induced alterations of land use and induced alterations in river-channel stability (from Wolman, 1967)

Figure 3

Figure 3 -- Models of river channel adjustment

This process by which the channel is re-equilibrating with the present watershed conditions is not occurring uniformly along the Sixmile channel, in part because the post-glacial period has been too short (14,000 –16,000 yrs) to allow different reaches of the stream to come to equilibrium with each other (MMI, 2003). Only the very lowest section of the creek is graded to its Cayuga Lake base level. The section with gorges is incompletely graded to this base level, and the sections above the 60-foot dam are graded to local bedrock base levels, as described earlier.

In the lower Sixmile Creek valley, above the 60-foot dam, there has been a large amount of degradation since ice withdrawal (Fig. 2) and a significant amount (5’ or more) of degradation over the past few decades (Fig. 4). Degradation in the upper Sixmile Creek valley on a geologic time scale has been minimal, but exposures of till along the channel bed (e.g. Milone and McBroom, 2003) indicate that there is also at least some historic degradation occurring along this section.

From the silt dam to Burns Road (segment 3 of MMI), the stream channel is actively both degrading and migrating laterally. This activity is associated with active or recent landslides, some of considerable size, triggered by lateral channel migration. Degradation, as measured at the German Crossroad bridge (Fig. 2), appeared to be decreasing after about 1985, with the channel reaching an equilibrium elevation, but after the April, 2005, flood, the channel at the bridge degraded more than 3 feet. This was associated with the upstream migration of a pronounced knickpoint, which caused the channel to downcut into till and to leave the former point bar well above the channel (Fig. 5). This was surprising, because of the previous stability of the channel elevation (Fig. 4) and the fact that the massive stonework at the gas pipeline crossing a few hundred meters downstream had created a local base level, about 4' higher than the pre-existing channel elevation. Both these factors suggested that the channel should have finished degrading in this reach.

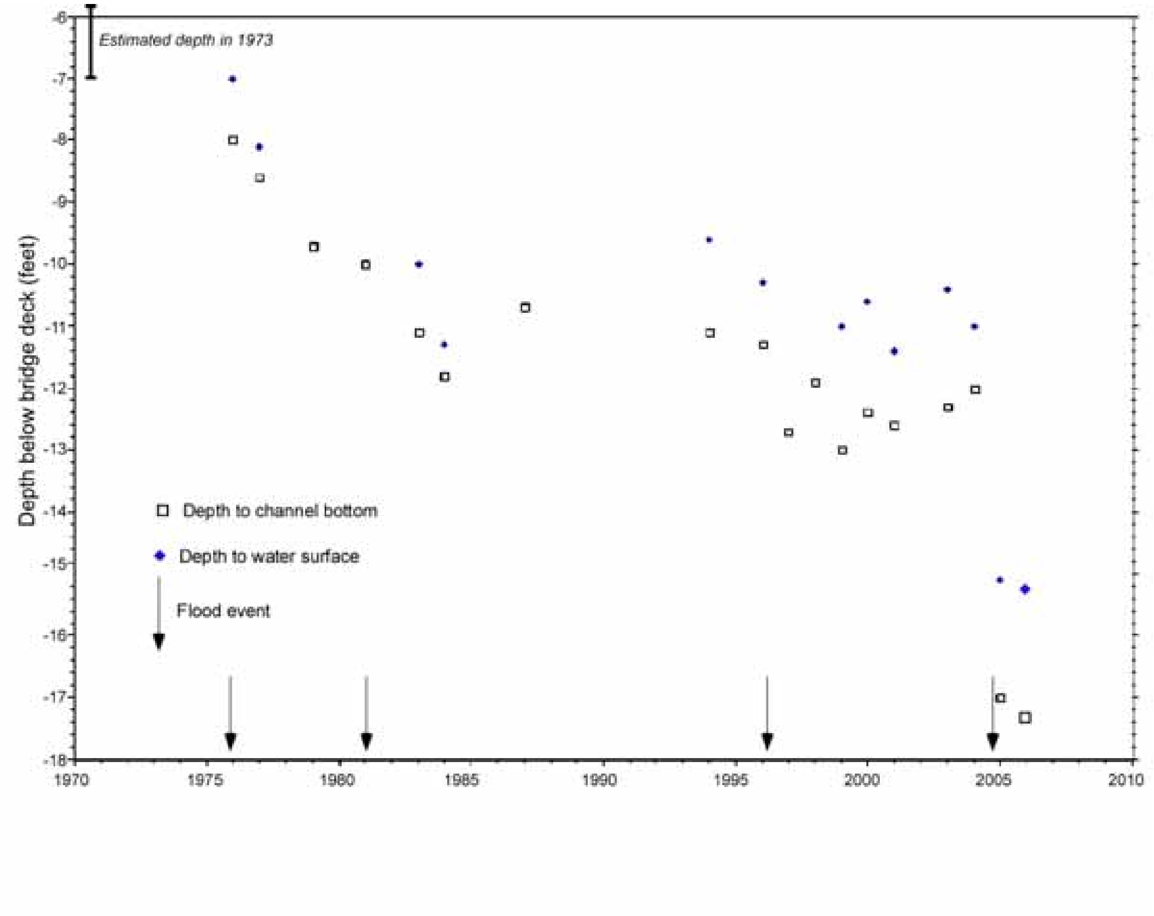


Figure 4. Channel degradation at the German Crossroad bridge

The channel reaches between Banks Rd and Middaugh Rd (MMI segment 4) and from Middaugh Rd to Valley Rd (MMI segment 5) are also degrading, but probably at a rate that decreases upstream. MMI identified these sections as having several knickpoints, which also mark upstream steps of channel degradation.

Sinuosity also decreases upstream through these reaches. Channel sinuosity (length of stream/length of valley) and slope were measured by MMI (table 2-2, 2003) from topographic maps. Because the sinuosity shown for segment 3 is anomalously high (1.48), sinuosities were remeasured using the most recent orthoimages (Karig, 2006, unpublished). This study showed that sinuosity decreased from 1.35 between the silt dam and German Crossroad, 1.28 from German Crossroad to Banks Rd, 1.27 from

Banks Rd. to Middaugh Rd., and 1.13 from Middaugh to Valley Roads, which is at the upper end of the lower Sixmile valley.

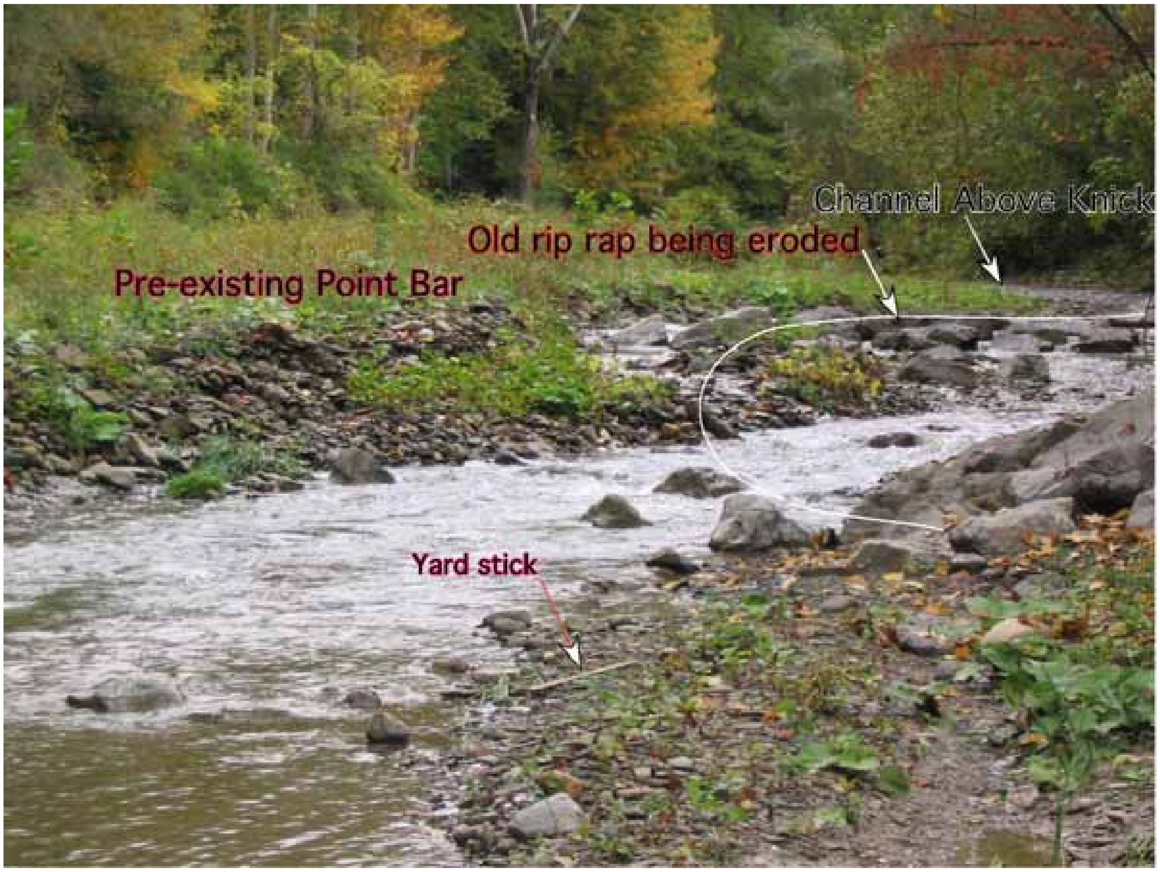


Figure 5. Knickpoint just upstream from German Crossroad bridge. Channel elevation drops over 3 ft from background to foreground. Channel is incising through old riprap that had already been breached.

The upstream decrease of sinuosity and degree of degradation as well as the upstream increase in slope are cited by MMI as evidence of an upstream decrease in channel maturity, although some of the upstream slope increase is a normal characteristic of a stream. Another possible line of evidence for upstream decrease in maturity comes from the comparison of sinuosity in 1936, based on the oldest aerial photos available, with that at present, based on the 2002 orthoimages (Karig,2006, unpublished data). This study showed only a slight increase in sinuosity between the silt dam and German Crossroad from 1.30 to 1.35, but an increase from 1.03 to 1.28 over that same period from German Crossroad to Banks Road. This increase in channel maturation could be a long-term (post glacial) effect, but more likely reflects the attempt of the channel to approach a new equilibrium state, reflecting the reduced sediment yield, following the period of intensive agriculture.

To some extent this pattern of maturation follows models in which channel incision is followed by bank slumping, channel widening and meander migration, and formation of a new and lower flood plain. Using MMI's segment 3 as an example, however, the channel appears to be concurrently degrading and migrating. It is also questionable whether the channel is anywhere incised, in the sense that there is a condition where both channel banks are very steep. The recent situation, at least, is one in which the channel is almost everywhere bounded on at least one side by recent bar material.

Nature and Quantity of Sediment Load

Sediment is transported down the channel as both suspended and bedload (dissolved load is here ignored). The suspended load consists of fine-grained sediment that is distributed through the water column, although not with uniform concentration. Bedload includes the larger sized material that slides, rolls, or bounces along the channel bottom.

The grain size at the division between suspended load and bedload undoubtedly increases with increasing power (velocity) of the flow, but seems to lie in the medium sand range (diameter (d) = 0.25 to 0.5mm). The relatively small range of this boundary probably reflects the fact that the grain weight, resisting suspension, increases as r^3 (where r is radius) whereas the surface area, related to shear between water and grain, increases only as r^2. Support for a break near 0.5 mm is found in Leopold (1994) and by observation at the silt dam, where coarse sand deposits show current bedding and the finest sand showed evidence of having settled from suspension. With this assumption, some estimate of the suspended load and bedload carried by the creek at the 60-foot dam can be made.

All bedload is trapped in the settling basin behind the silt dam. A qualitative survey was made after the water was drained in August 2005, using 14 sample pits distributed around the basin. This study showed that, for the sediments deposited by and since the April 2005 flood, sediment coarser than sand was restricted to a small delta at the upstream end of the basin and that a ridge of coarse sand extends beyond the delta, almost to the dam. Except for a localized deposit of coarse material where a tributary entered from the south, the remainder of the basin was covered with a thin layer of finer sediment (very fine sand, silt and clay), deposited from suspension. Quantitative analysis of the grain-size distribution of the basin as a whole proved impossible because of striking vertical heterogeneity in grain size of the sediment infill. Between high flow events, when all the bedload is transported, only suspended sediments are deposited in the basin.

A reliable ratio of suspended sediment to bedload in the basin would require analyses of very large bulk samples, but a “guessimate” made during the study suggests that 2/3 to 3/4 of the material in the basin consists of bedload, based on grain-size and the nature of sediment deposition.

The only estimates of total sediment loads trapped behind the silt dam are from records of the number of truckloads of material removed by the City of Ithaca over the period from 1963 to 1976. Two values of 10,000 yds^3/yr by Roberts (1978) and 14,000 yds^3/yr by Karig (2000) represent crude averages.

These load data are in terms of volume per year whereas the data from discrete samples and from the automatic sampler at the gaging stations are in terms of weight per year. A conversion from volume to weight requires knowledge of the porosities of the sediment deposits, which must be estimated from general relationships. The approach to this conversion is shown in the sidebar figure, but if an average porosity of 0.5 is assumed for the sediment behind the silt dam, the 12,000 yds^3/yr of that material is equivalent of about 13,000-14,000 tons/yr.

Because all bedload is trapped in the silt dam, only suspended sediment is deposited in the reservoir behind the 60-foot dam (except for a minor load of coarser sediment entering the reservoir directly from several tributaries). Repeated surveys of this reservoir, last done in 2002, show a near-linear accumulation of sediment infilling, of 11,200 yds^3/yr (Fig.6). Assuming a porosity of 0.6 for the yearly volume addition, this is equivalent to bit over 10,000 tons/yr.

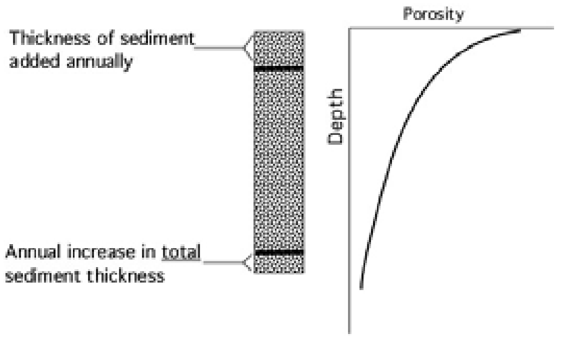
There has been a wide range of opinion as to the amount of suspended sediment that passes the 60-foot dam. It has often been claimed that much of the suspended sediment in Sixmile Creek is transported to the Cayuga Lake inlet. On the other hand, an estimate in Karig (2000), based on yearly mean flow and average concentration of sediment at the drinking water intake at the face of the dam, indicated a load of only about 500 yds^3/yr. A recent study (Karig, 2006, unpublished) was made to improve this estimate.

CUBIC YARDS TO TONS

Sediment loads in the reservoir were measured in cubic yards, whereas loads from gaging stations and sampling were in tons, which are preferable. How are cubic yards converted to tons?

If we assume that the sedimentation rate and the sediment type stay constant over time, which seems true in the reservoir, then there will be a constant porosity-depth curve over time. An element of sediment moves downward along this curve as it consolidates. The element added yearly at the surface is thicker than yearly elements at greater depths, but the shape of the porosity-depth curve stays the same, as sediment elements move down it. Thus, the annual increase in total sediment thickness is an increase at the base of that curve.

The estimated porosity of the basal sediment layer is a function of the total thickness of the sediment fill and is here based on typical porosity depth curves. With a given curve and the know specific gravity of silty clay. the conversion can be made.



In this recent study, daily values of total suspended solids (TSS) at the water intake and the daily mean flow from the gaging station at German Crossroad for water year 2003(October 1, 2002 to September 30, 2003) were used as an estimate for the amount of suspended sediment passing the dam. The additional flow from several small tributaries between the gaging station and the dam are assumed to be insignificant, and the approximately 4 cubic feet per second (cfs) of drinking water withdrawn by the City compensates for much of this. The TSS at the water intake represents primarily sediment, and is assumed to represent the concentration of suspended sediment flowing over the dam.

The drinking water intake is about 20 ft below the surface on the face of the dam and it could be questioned whether the concentration of suspended sediment there is the same as that of the surface water, which flows over the dam. There is no evidence in continuous bathymetric profiles across the reservoir for turbidite deposits, which result from high density, sediment-laden plumes. However, the suspended sediment content of a water mass renders it denser than clear water of the same temperature and salinity, so it is difficult to see how the surface water could have a higher TSS content than that at 20’ unless it was much warmer. It seems reasonable to assume a fairly well mixed water body in the reservoir, at least during high flow events.

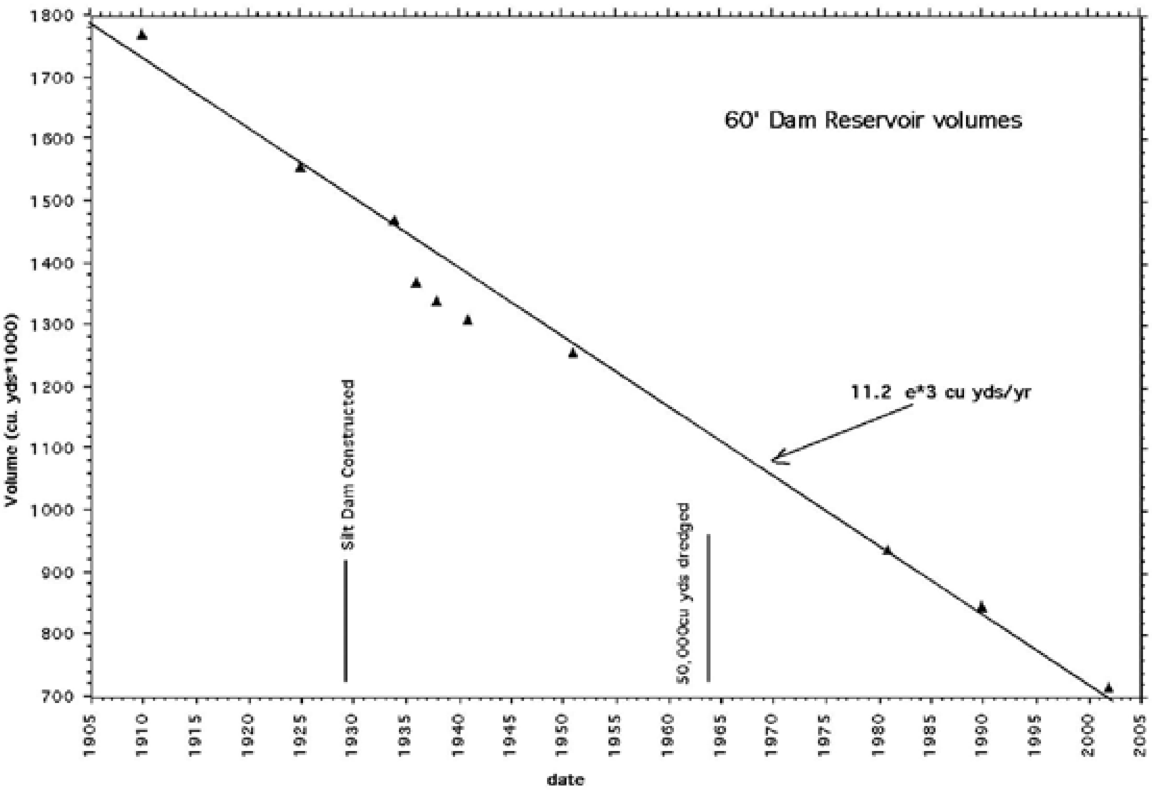


Figure 6. Volume of the City Water Supply Reservoir over its lifetime

The sum of all the daily products of the mean flow and the TSS gave an annual load of sediment passing the 60-foot dam of about 3500 tons/yr. This indicates that about 20% of the suspended sediment load and about 13% of the total sediment load reaching the silt dam impoundment passes the 60-foot dam. Because the settling rate of sediment particles decreases with decreasing grain size, the suspending sediment passing the 60-foot dam is dominated by the clay fraction.

The 4 dams along Sixmile Creek are or have been effective sediment traps, but engender significant erosion in the Mulholland Wildflower Preserve downstream. This process, which occurs when a stream has excess energy because of a sediment deficit, is termed clear water erosion, and was noted in the MMI report. Because of the bedrock-floored channel in much of this gorge section, this erosion is necessarily lateral rather than degradational. This process leads to channel avulsion, which supplies additional sediment to Cayuga Inlet and Cayuga Lake. Yet another increment of sediment is supplied to this section of Sixmile Creek by several tributaries that drain areas underlain by clay-rich sediment. To date almost no attention has been focused on this erosion/sedimentation problem.

The annual total estimated suspended sediment load that is trapped upstream from the 60-foot dam, using the preceding calculations is 14,000 tons/yr (10,000 in reservoir, 4000 in silt dam). Inaccuracies in this value stem primarily from lack of knowledge of the sediment deposition behind the silt dam and in the conversion of volumes to tonnages of trapped sediment.

Table 1. Estimated annual sediment transport at the 60-foot dam

Depositional Site	Silt Dam	Reservoir	Downstream
Suspended load (tons/yr)	4000	10,000	3500
Bedload (tons/yr)	9500±	minor (local tributaries)	0
Total suspended load		17,500 tons/yr	
Total bedload (rough)		9,500 tons/yr	
Total sediment load		27,000 tons/yr	

This estimate compares favorably with the average yearly values for the suspended sediment measured at the German Crossroad gaging station since water year 1999. Over this period the collection system was inoperative for half of 2003 and a portion of 1999, but values can be obtained for 5 of these years. Yearly totals range from 10,600 tons to 22,700 tons, with a 5-year average of 16,600 tons/yr. This is in reasonable agreement with the data derived from entrapment calculations (Table 1). Data from the USGS gaging station at German Crossroad do not include sediment added downstream, which is probably significant, but there are significant sources of inaccuracy in both data sets.

With caution, these sediment transport data can be used to estimate average rates of denudation in the watershed. In many watersheds denudation rates exceed transport rates because some of the denuded sediment is deposited along the stream channel and riparian zone. Because Sixmile Creek is degrading and removing stored sediment, the opposite is more likely true. Nevertheless, the sediment transport data in Sixmile Creek, measured at the 60’ dam, where the watershed area is about 45 mi^2, convert to a denudation rate of about 600 $\text{tons/mi}^2\text{/yr}$, or .94 tons/acre/yr, using the total sediment load. The denudation rate related to the suspended sediment load alone is 390 $\text{tons/mi}^2\text{/yr}$, or .61 tons/acre/yr. The latter value can be compared with data from other streams, where only suspended sediment data are usually available, and show that the denudation rate in the Sixmile Creek watershed is far higher than the 250 $\text{tons/mi}^2\text{/yr}$ average value for mid-Atlantic streams (e.g. Leopold, 1994, tables 11.1 and 2). Again, because the Sixmile Creek watershed is relatively undeveloped, it is very likely that this high denudation value reflects removal of stored sediment associated with channel degradation rather than from a debased watershed.

Sources of Sediment

Before a management plan can be developed for Sixmile Creek, it is critical that the major sources of both bedload and suspended load be determined. While some bedload and suspended load are derived from the main channel, the tributaries, and the watershed, the sediment contribution from each of these sources is almost certainly not equal. Little data exist concerning the sources of bed and suspended load, and almost all that is available concerns suspended load. Sources of existing data include surveys involving discrete water samples (both grab samples and depth integrated samples), data from the automatic sediment samplers in the USGS gaging stations, and indirect methods such as a cesium tracer study.

Suspended Load

Discrete suspended sediment samples have been collected by Fabbri (1996), Hawkins (Ecologic. 2005), and by the Sixmile Volunteer Monitoring Group (unpublished). All these synoptic surveys show that the concentration of suspended sediment generally increases in sediment load downstream to the silt dam and more importantly, that there is a pronounced increase starting somewhere downstream from Boiceville Road. However, each of the 3 surveys used different sampling sites, or had different objectives, so that the combined results provide additional constraints concerning the source of the sediment. Because of the lack of reliable flow data during most of this sampling, only sediment concentrations are considered here, but these still lead to valuable conclusions. To compare the magnitude of events during which sampling occurred, the flow at the USGS gage at German Crossroad is cited.

Fabbri(1996) collected depth-integrated samples with a USGS sediment sampler during two high-flow events (Fig. 7). One event (April, 1996) resulted from snowmelt and reached a peak of 900 cfs, or over half of the estimated 1200-1300 cfs bank full value at German Crossroad. The earlier event (October, 1995) followed a long dry spell and reached a peak of 400 cfs. The sampling sites for this survey were chosen to investigate the relative sediment contribution from the different sub-watersheds.

The unique contribution of Fabbri's study was that, despite the higher flow during the April event, sediment influx to the main stem was much greater during the October event, especially in the section downstream from Brooktondale. This was attributed to loose, dry sediment that accumulated in the tributary channels during the summer, which was flushed out during the first significant storm after the dry period. The Beaver Creek sub-watershed, which contains the wetlands of the White Church valley, showed no such effect, nor was it apparent during the spring event, which was preceded by a wet period with the tributaries flowing continuously.

Hawkins (Ecologic, 2005) collected grab samples along the main channel during 4 events, 3 of which had flows during the sampling of 200-300 cfs and the fourth (7/14/05) of less than 100 cfs (Fig. 8). The 3 higher flow events were far below bankfull, but showed similar, irregular downstream increases in sediment concentration. An initial increase in the rate of the downstream increase in sediment concentration occurred between Creamery and Boiceville roads, with a relative drop at Banks Road, followed by a very sharp increase between that site and German Crossroad. Concentrations decreased or only slightly increased downstream to Burns Road and beyond, an effect logically attributed to sediment retention behind the several impoundments.

The sediment sampling of the Volunteer Monitoring Group is done in conjunction with other chemical and biological sampling. These are also grab samples but of smaller sample size than in the other studies. To date most of the sampling has been done at low flows and generally shows very low suspended sediment concentrations. Exceptions are the values at Burns Road where resuspension of material in the silt dam is suspected and in the upper reaches of Sixmile Creek where construction or other in-stream activity has resuspended material.

A single high flow (~400 cfs) event in late March showed a very sharp increase in sediment concentration downstream from Brooktondale (site 6 on Fig. 9). Similar but much muted increases in this sector were also noted during most of the low flow sampling surveys. Downstream from the dams (sites 1 and 2), the TSS shows the expected decrease, or lack of continued increase. The automatic sediment samplers in the USGS gaging stations at Brooktondale and German Crossroad (Bethel Grove) provide suspended sediment data of quite a different type. Daily mean flows are combined with the sediment data to produce a record of daily suspended sediment load (in tons/day) over time. Data for the water year 2004 (10/1/04 to 9/30/04), which was wetter than average, are the most complete available and are used in this report. This is also the only year for which complete data sets are available for both gaging stations.

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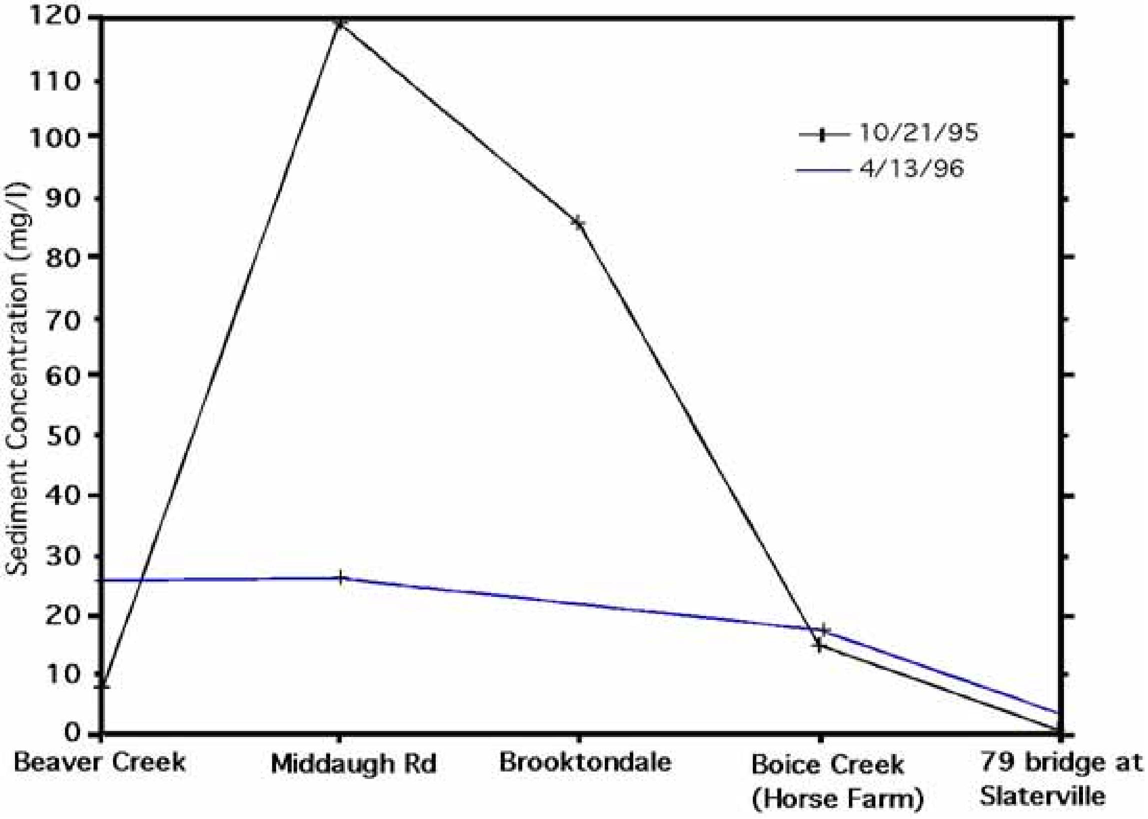

Figure 7. Values of suspended sediment concentrations along Sixmile Creek, and in the tributaries Boise Creek and Beaver Creek from Fabbri (1996). .

Although a simple plot of load <u>versus</u> time for the two stations shows a significant increase in sediment load downstream from Brooktondale, a much clearer picture is gained by comparing the suspended sediment load/mi^2 for the watershed area above Brooktondale with that for the stream section between Brooktondale and German Crossroad (Fig. 10). This “differential load” was obtained by dividing the difference in daily sediment loads by the difference in watershed areas at the two gaging stations (Fig 8). This plot illustrates the rates at which suspended sediment enters the creek from the two areas, either from the off-channel watershed or from tributaries.

These data indicate that the sediment load contribution from the area between Brooktondale and German Crossroad in terms of load per mi^2, becomes increasingly larger than that upstream from Brooktondale as the flow increases. There are only a few exceptions, which may be due to inaccuracies in the data, but the overall correlation is generally consistent.. During very low summer base flow (e.g. less than 30cfs at German Crossroad) the sediment load at both stations is less than 0.1 tons/day. Even during relatively small rainfall events the differential load and especially the differential load per square mile rise sharply to several tens of tons/mi^2. This quantifies the observation that, downstream from

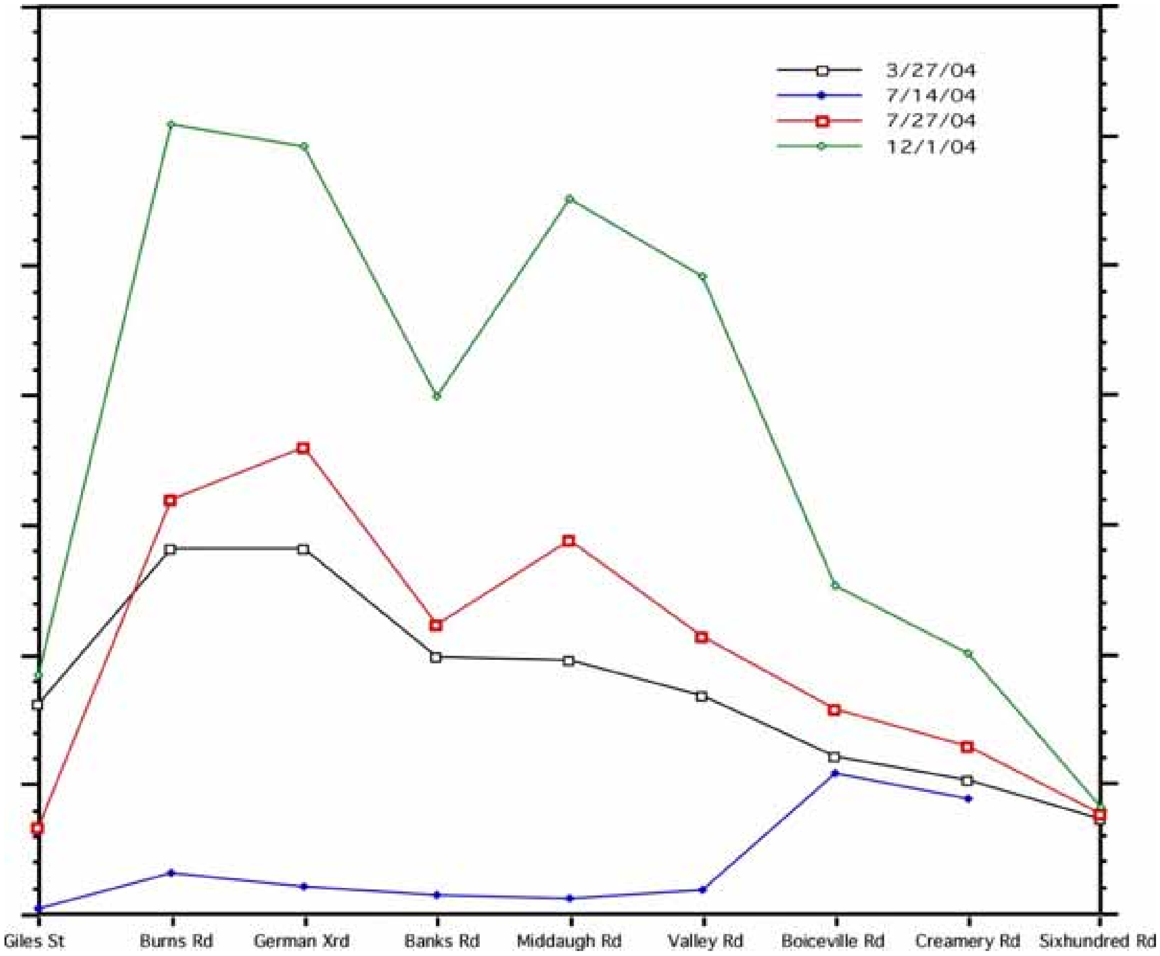

Figure 8. Suspended sediment concentrations along Sixmile Creek during four sampling days in 2004, from Hawkins (Ecologic, 2005).

Brooktondale, Sixmile Creek becomes more turbid than other local streams after even minor rainfall events. As flow events increase in size, the differential load/area reaches hundreds of tons/mi^2

The conclusion that can be drawn from the suspended sediment data is that a disproportionate fraction of the suspended sediment load is added to the stream below Brooktondale. A closer definition of the source distribution is not presently possible because there are no monitoring sites between German Crossroad and the silt dam. Nor is it at all obvious whether the source is primarily the bed and banks of the main channel, those of the tributaries, or from the off-channel watershed.

Some very valuable data that help determine the distribution of sources of the suspended sediment load has been provided by Nagle et al (in press), who used cesium from nuclear testing as a tracer. During the period of atmospheric tests, the isotope ^{137}Cs accumulated in the upper foot or so of the soil profile. Erosion and transport of this soil to the stream produces higher ^{137}Cs concentrations in suspended sediment samples from the stream than will material derived from the channel bed and banks, which are beneath the “contaminated” zone. Nagle et al. collected samples of the fine fraction (clay and silt) from 18 sites along the Sixmile channel (Fig. 11), which show that the suspended sediment has a bimodal source distribution.

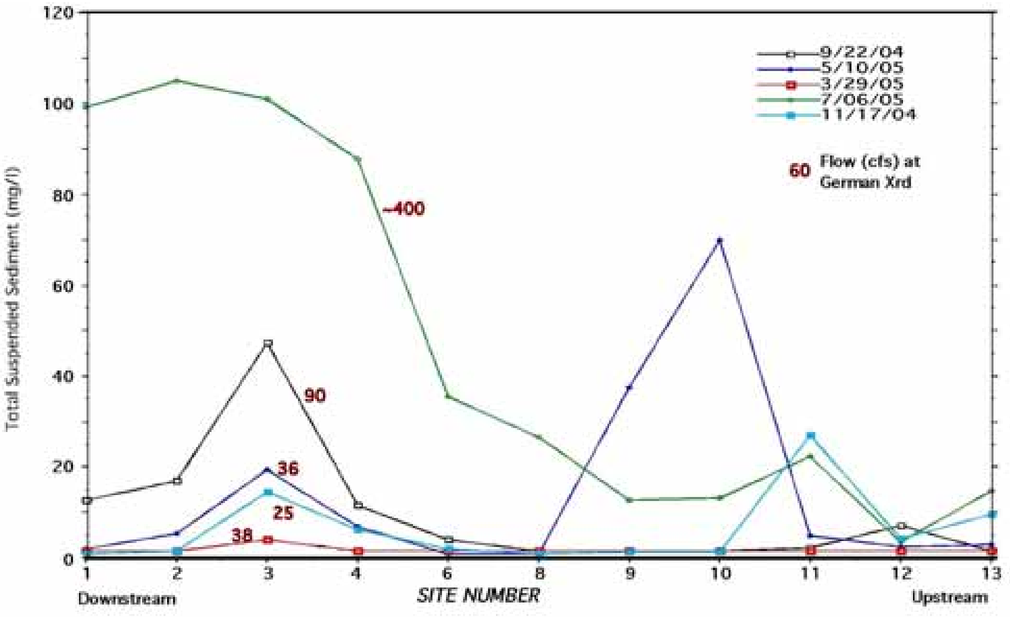

Figure 9. Suspended sediment concentrations along Sixmile Creek in 2004-05; data from Volunteer Monitoring Group (tributary sampling sites were omitted). Site locations are shown on Fig. 1.

In the uppermost reaches of the watershed, ^{137}Cs values are very high (10 to 25 millibequerels/gram (mBq/g)), indicating that most of the relatively low load of suspended sediment entering this section of the stream is derived from off-channel sources. In contrast, samples taken from Slaterville and downstream have values less than 5 mBq/g, indicating that the bulk of the suspended sediment in this section is derived from channel bed and banks. However, these data cannot discriminate whether these beds and banks are from the main channel or from tributaries

The question remains as to how large a role the tributaries downstream from Brooktondale play in supplying suspended sediment to Sixmile Creek. This section of the stream occupies the glacial trough of the through-valley and the tributaries drain mostly clay-rich till within this trough. It was commonly assumed that this till was overlain by a thick, relatively unconsolidated post-glacial lacustrine clay unit (e.g.Karig, 2000), but recent geological mapping (Karig, in progress) shows clearly that these lacustrine deposits have been folded and are mixed with other till facies. They are also quite highly consolidated when unweathered (porosities are 30-35%). There is little doubt that this clay-rich till was originally lacustrine but was mixed with other lithologies and reworked during the last ice advance through the valley

MacBroom (MMI, 2003) suggested that many of the tributaries to Sixmile Creek had reached bedrock, but this is not the case, except downstream of the 60-foot dam, where the gorges of the main channel have degraded to bedrock. Mapping along the tributaries shows that they reach the bedrock edges of the glacial trough roughly along the old railroad grade to the south and just upslope from Slaterville Road to the north. Inside these boundaries Quaternary sediment fills the trough to depths of up to 100’ or more, based on drill records and a seismic refraction line near German Crossroad.

Many of the tributaries between Brooktondale and the 60-foot dam are confined to the trough, but the larger have headwaters in bedrock outside the trough. Within the trough, the tributary channels lie over one sort of till or another, but most seem clay- rich. Although quite consolidated and fairly resistant to erosion when unweathered and undisturbed, the till is prone to slumping and swelling during freeze-thaw and wet-dry cycles. Many small to medium sized slumps were observed along the tributary channels, which, after initiation of movement, become very soft and easily mobilized

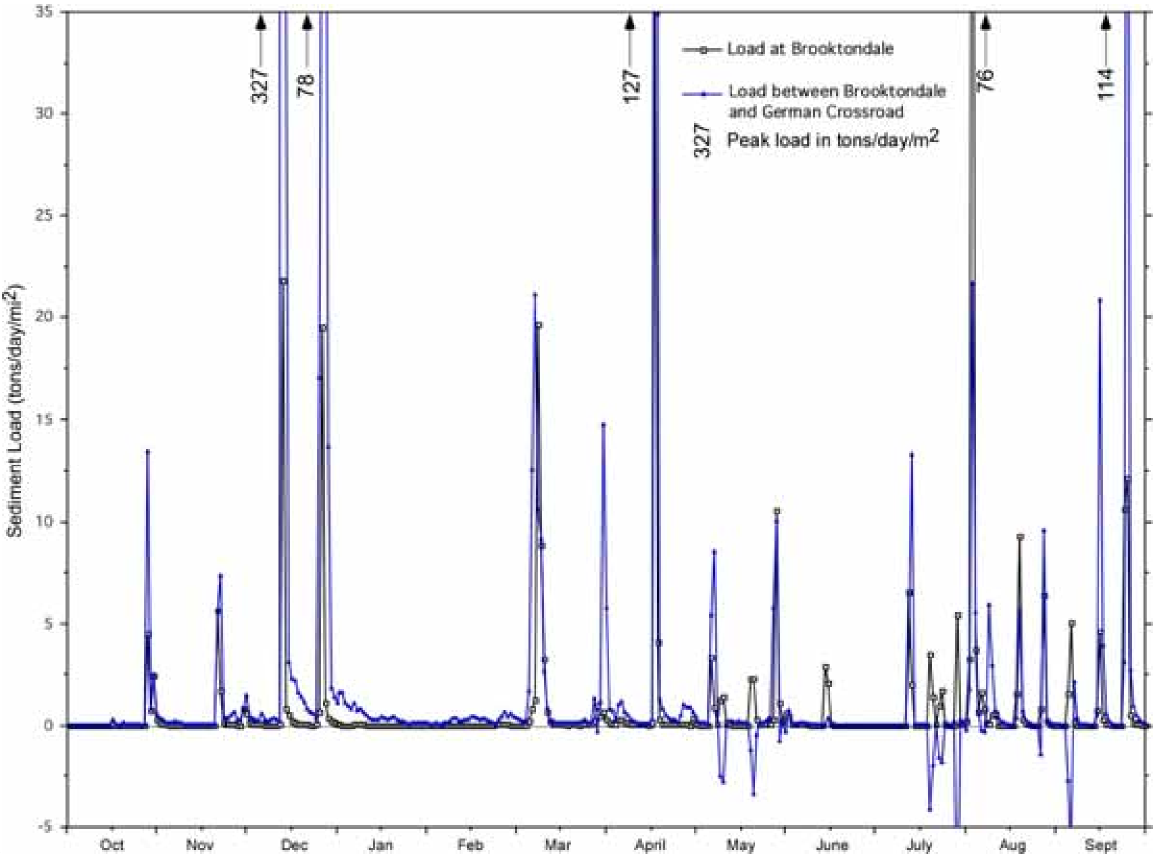

Figure 10. Sediment loading for the watersheds upstream of Brooktondale and that between Brooktondale and German Crossroad. Data are for Water Year 2004 *(starting in October 2003)*. Negative load values probably result from subtraction of large total load values that have significant errors. The till includes clasts of all sizes and of both local and exotic (distant) origin. The largest are boulders, dominantly exotic, with diameters of over 3', which resist transport and accumulate in the channels. The smaller, intra-trough tributaries carry relatively little of this clast component to the main channel and do not create alluvial fans where they join Sixmile Creek. Some of the larger tributaries that have a significant portion of their watershed outside the trough do form such fans (e.g. the tributary that flows from the north and joins Sixmile Creek south of Crispell's truck repair shop) in which a major clast component consists of angular local bedrock.

The relative paucity of suspended sediment load originating from the watershed above Brooktondale is most likely due to differences in Quaternary geology and history between the upper and lower Sixmile Creek valleys. The post-glacial fluvial history in lower Sixmile Creek valley has resulted in a main channel and a network of tributaries deeply incised into till. In contrast, in the upper Sixmile Creek valley there has been much less channel incision by the main channel and tributaries and more lateral

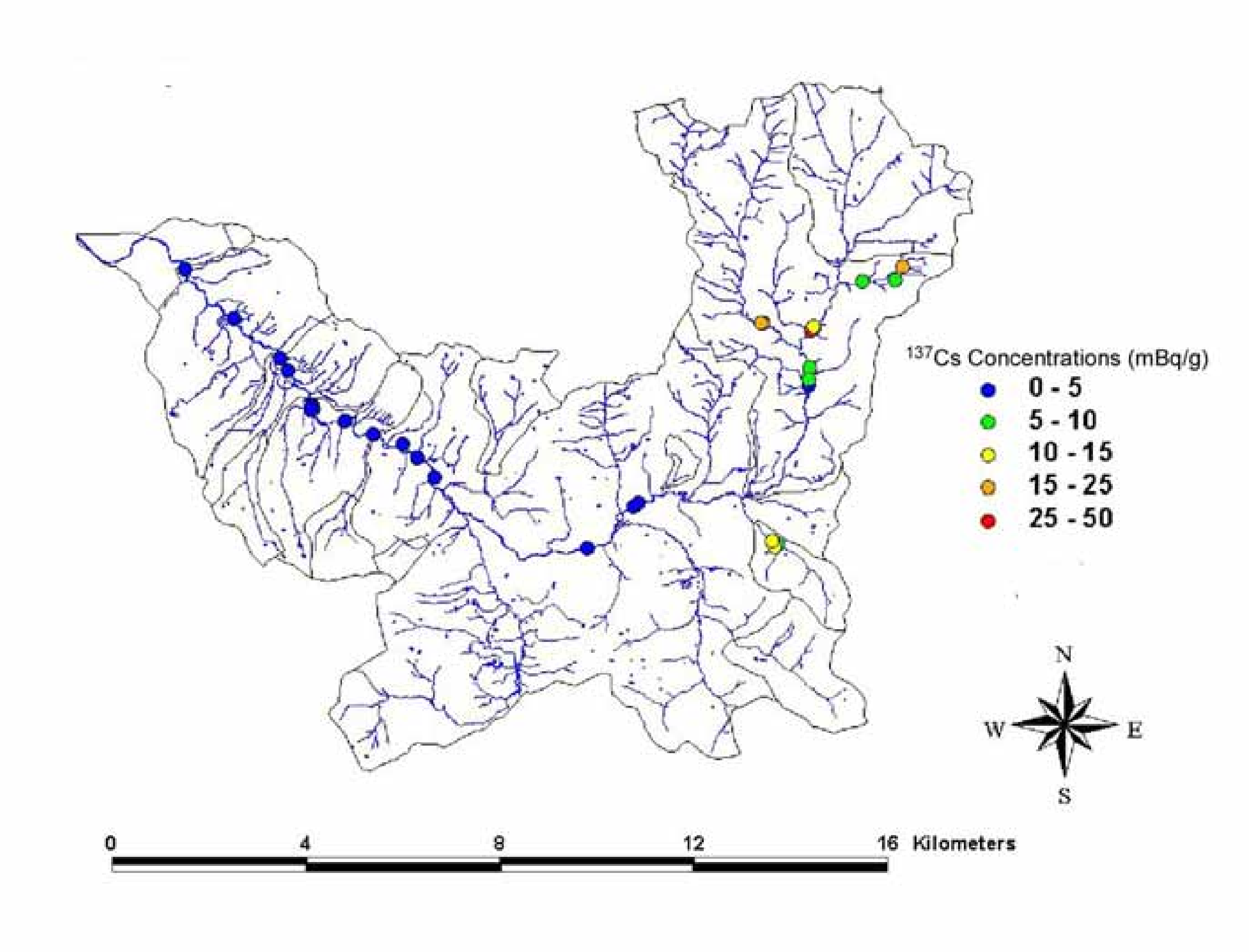

Figure 11. Bomb-derived Cesium concentrations in fine-grained sediments along Sixmile Creek (from Nagle et al, in press)

channel migration. Also, in contrast to the thick clayey till that is exposed nearly everywhere at or near land surface in the glacial trough of the lower Sixmile Creek valley, the types of sediments exposed in upper Sixmile Creek valley are more diverse- but notably with much less fine-grained material exposed at land surface. In many places in the upper Sixmile Creek valley surficial alluvial (cobble-sized gravel) deposits mantle the till and lacustrine deposits. Clay matrix till is exposed in many places along the main stream channel but this channel is not as deeply incised as in the lower valley and this leads to tributaries that have not sympathetically incised through the alluvial cover.

Bedload

Even less is known about the source of the bedload than is known for suspended sediment. The bedload in Sixmile Creek consists of both local and exotic clasts. The clasts of local derivation are almost all siltstone and sandstone, not shale as commonly stated (e.g. MMI, 2003). While these clasts are tabular, sometimes even platy, they do not easily shatter or disintegrate, as does shale. The larger the size, the greater is the percentage of clasts of exotic origin. In addition, the exotic clasts are more equant and rounded in all sizes. The penultimate source of the exotic clasts and of some of the local clasts in the bedload is the till. These enter the main channel both through the tributaries and from bankside till exposures. Exposures of till supply a mixture of suspended and bedload sediment to the main channel.

Another large reservoir of bedload is the older alluvium stored along the main channel and tributaries and exposed in their banks. For example, above German Crossroad an eroding cutbank exposes about 6 ft of older alluvium overlying 3 to 4 ft of till. (Fig. 12). In contrast to till exposures, this stored alluvium consists almost entirely of older bedload material and, when supplied to the channel, adds little suspended sediment.

Figure 12. Cutbank with thick deposit of older (300-400yrs b.p.) alluvium overlying till just upstream from German Crossroad.

Some of the bankside exposures along Sixmile Creek are very high and create a significant point source of bedload to the channel. The ”high bank” just downstream from the bridge on the Old Sixhundred Road. is a good example of such. It has often been claimed that it and similar sources add to the total bedload that moves downstream to the silt dam, but this is highly questionable.

The amount of bedload that is carried in a channel is primarily a function of the flow (Q) and the water velocity (v). Any excess bedload causes deposition to compensate for the addition, generally in a bar immediately downstream. With time, bedload moves slowly downstream, from one bar to the next.

One other factor that affects the amount of bedload transported is the character of the channel bed. Bedload moves more easily where clast size is small and/or uniform. In a stream such as Sixmile Creek, with a broad assortment of clast size and shape available, the bed develops a “lag deposit”, in which smaller clasts lodge in the interstices between larger clasts and tabular clasts become tilted (imbricated) downstream.

At the August 2005 technical meeting, questions arose about the effect of disturbance to such lag deposits and about the length of time that these effects last. It would seem logical that a lag deposit reforms after a flood event large enough to move the larger clasts in such a deposit. In any case, it does seem important to preserve and develop these lag deposits to reduce bedload transport.

The data available provide an incomplete picture of the quantity and sources of suspended and bedload sediment in Sixmile Creek. Of the roughly 15,000 tons of suspended sediment that moves down the channel during an average year, much or most of that enters the creek downstream from Brooktondale. The big question is whether the suspended load is primarily from the bed and banks of the main channel or from the tributaries. Indirect evidence suggests the latter. But more and better data are needed.

Although less constrained, the average bedload seems to be about 6000 ±1000 tons/year. Most of this probably is derived from the bed and banks of the main channel and lower reaches of the tributaries. Both alluvium stored in these reservoirs during the period of channel aggradation and till are sources, but the former is a more likely source for most.

Aquatic Health of Sixmile Creek

The overall condition or quality of the creek depends on more than the amount of sediment transported along the channel. Biological diversity and water quality are also major factors in what might be called the aquatic health of the creek. Surveys of biotic components (benthic invertebrates and fish) provide direct assessments of biotic health and diversity, whereas measurements of water quality (physical, chemical and bacteriological) provide information on factors that affect the biotic health. A section about large woody debris (LWD) is included in this report because it was a topic of discussion at the technical meeting.

Benthic Macroinvertebrate Inventories (BMIs)[1]

Sampling for BMI’s involves the collection of small invertebrates, primarily insect larva, from riffles along the stream channel. These surveys supply a time-integrated measure of water quality in that these invertebrates spend all or a significant portion of their life cycle in the stream channel and have varying degrees of tolerance for degraded water quality. For this reason BMI’s are used by agencies such as the New York State Department of Environmental Conservation (DEC) as an initial, efficient method of assessing stream health and water quality.

The Sixmile Volunteer Monitoring Group has conducted three BMI surveys to date. The first survey, done in 2004 was analyzed to order (tier 1) whereas the next two, in 2005 and 2006 were analyzed to family (tier 3). The tier 1 survey was largely a pilot project, but found little to no negative impacts on or variation in water quality from Plain Street to the headwaters.

The two tier 3 surveys, conducted in July, 2005 and September, 2006, provided a more quantitative and sensitive estimate of water quality, but further refinements of the sampling locations and methodologies are projected for future surveys.

The 2004 survey included sample sites at Plain St (Site 1), Burns Rd, German Crossroad (Site 4) and Beaver Brook (Site 5). In 2006, sites 1 and 4 were resampled, the Burns Rd site was moved upstream to

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[1] This information was provided by Nick Schipanski, Sixmile Creek Volunteer Monitoring Group.

the gasline site (Site 3), and a site in the headwaters, near Site 13 was sampled (See Fig. 1 for sample locations). In the future the group plans to sample once each summer at 4 to 5 sites that best characterize the stream system.

The mean of the analytical metrics for the 2004 and 2005 surveys showed no significant impacts to water quality at any of the sampling sites, but individual metrics did show some variations.

The metrics used to calculate the mean were:

Family Richness: the total number of families found in the sample

Family EPT Richness: (the number of families of mayflies (**E**phemeroptera), stoneflies (**P**lecoptera), and caddisflies (**T**trichoptera), which are relatively pollution-sensitive

Family Biotic Index (FBI): similar to Family Richness except that pollution-tolerance values are assigned to families. This is thought to be the metric that maximizes the impairment in streams that show no or only slight impacts.

Percent Modal Affinity (PMA): Percent composition of the sample compared to a model community in an un-impacted stream.

For the 2006 survey, EPT and PMA increased continuously upstream whereas FBI showed no such trend (Fig. 13). In fact FBI was lowest, indicating a slight water quality impact at German Crossroad because of the identification of a relatively pollution tolerant mayfly family (Caenidae). Unfortunately, the possibility of misidentification there has not been fully explored.

According to DEC research, combining the metrics into the multimetric Biological Assessment Profile (the "mean" on Fig. 13) does consistently predict the level of impact to water quality 92% of the time when identifications are done to family level. In the 2006 survey, the mean is constant from Plain St. to German Crossroad, but rises significantly in the headwaters.
[2]

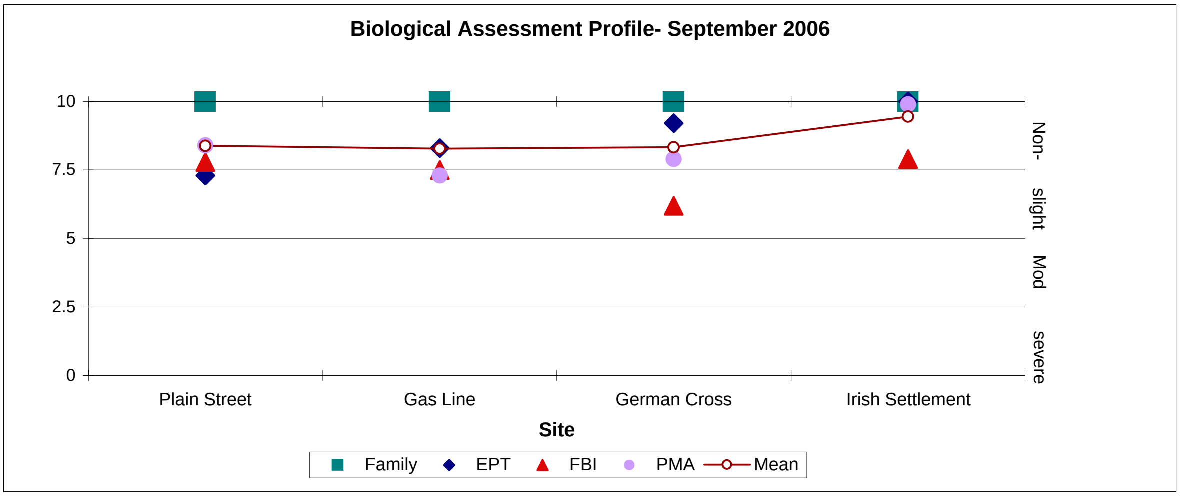

Figure 13. Results of biological assessment profile of Sixmile Creek (Metric for the 2006 BMI survey, see text for details)

Biodiversity (Fish)

There have been several suggestions that the biodiversity of fish in Sixmile Creek is relatively low. McBroom (personal communication, 2006) cites “below average habitat and limited fish observations”

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and attributes this to “a relatively “plane” bed with weak pools and riffles”. However, this conclusion seems to relate more to abundance than to diversity of fish. A more direct approach to the abundance and diversity of the fish population in Sixmile Creek was made during a fish survey carried out by the U. S. Fish and Wildlife Service from Cortland, N. Y. during September and October, 2004 (U.S. Geological Survey and U.S. Fish and Wildlife Service, 2005).

This fish survey involved “electrofishing” at 12 sites along Sixmile creek from Plain St to the headwaters along Irish Settlement Rd[3]. The results of this survey indicated that the diversity index generally decreases upstream, despite the decrease in water temperature and turbidity in that direction. Fish species also changed upstream from a warm water assemblage (e.g. bass and pumpkinseeds) below Burns Rd to a cold water assemblage (e.g. brook trout) in the headwaters (above the Slaterville Rd bridge in Slaterville). The reaches between contained a transitional assemblage. Clearly the situation is more complex than can be described by a simple diversity index. It is important to differentiate between “biodiversity” and “abundance” and consider both in the overall context of the health of the aquatic biota in Sixmile Creek relative to other streams in the region and to the pre-disturbed condition of this creek. Some insight was given by Jim McKenna, who was the lead investigator for this survey (see Appendix A).

Site #	N	# Species	Diversity	Evenness
2	468	19	1.95	0.63
3	484	13	1.56	0.51
4	343	11	1.80	0.58
6	814	10	1.50	0.48
7	664	11	1.36	0.44
8	678	13	1.30	0.42
10	394	8	0.96	0.31
11	439	6	0.91	0.29
12	528	6	0.84	0.27
13	1,070	5	0.56	0.18
17	107	5	0.77	0.25
18	148	5	1.26	0.41

Table 2. Summary of fish captured by site (see Fig. 1) and fish diversity for Sixmile Creek, September - October, 2004 (U.S. Geological Survey and U.S. Fish and Wildlife Service, 2005). N = total number of fish captured. See citation for explanation of diversity and evenness.

Data presented in the report indicate that the increase in suspended sediment downstream from Brooktondale, documented earlier, does not correlate well with either the transition from coldwater to transitional or from transitional to warm water fish populations. The relationship, or lack thereof, may be attributable to many factors, such as the downstream increase in water temperature during base flow and the general character of the stream channel (such as the lack of pools and/or shade), which may also be important in controlling fish populations.

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[3] The electrofishing sites differ from the Sixmile Volunteer Monitoring sites

Water Quality

Chemical, physical and bacteriological parameters of the water in Sixmile Creek have been measured since 2004 by the Sixmile Volunteer Monitoring Group and less completely or less often by several other entities. Total coliform, E. coli, pH, temperature, alkalinity, and turbidity are measured at the intake to the City Water Treatment Plant at least once per day and soluble Fe is measured weekly.

At present total coliform, E. coli, total phosphorus (TP) and soluble reactive phosphorus (SRP) are collected once a month from the USGS gaging station at German Cross Rd. Total coliform and E. coli are measured by Roxanna Johnston in the City Water Treatment Plant lab while TP and SRP are measured in the Community Science Institute lab. Suspended sediment or TSS samples are also collected during most of these surveys, but those data were reviewed earlier in this document.

The Volunteer Monitoring Group collects samples at 13 sites along the stream (Fig. 1) five times per year; three at base flow from spring to fall and two high water flows. After consideration of usefulness and cost effectiveness, the parameters now measured are physical (temperature, turbidity, conductivity), chemical (pH, alkalinity, total hardness, chloride, sulfate, SRP, TP, nitrate, Kjeldahl nitrogen, total nitrogen (Note: Total nitrogen is the sum of nitrate plus Kjeldahl nitrogen and is not measured separately)) and bacteriological (total coliform, E. coli). All samples are analyzed at the Community Science Institute; summary data are found on their website: *www.communityscience.org/SixMile/SixMileCreek.* The results of these surveys vary with respect to location, season and flow level, but a few preliminary conclusions can be drawn from the combined sources.

Some parameters, such as temperature, chloride and alkalinity show a definite but often irregular progressive change along the stream from the lake to the headwaters Temperature increases downstream, as might be expected, but the specific cause is not obvious. Percent shade probably influences local variations, but it is not an obvious cause for the overall trend. Other confounding factors could include the amount of stormwater runoff, number of roadside ditches discharging to the creek, effect of groundwater recharge, heating by energy dissipation, or differences in air temperature.

Chloride concentration is generally low (10-15mg/L) in the headwaters of Sixmile Creek, but rises rapidly downstream from above the Slaterville Rd bridge in Slaterville (Site 9) to Brooktondale (Site 6). Between Brooktondale and the wildflower garden (Site 2) mean chloride values are near 20 mg/L but rise significantly at Plain St (Site 1). Chloride concentrations are most reasonably associated with road salt, as there is a good correlation between the chloride values and the number of roads that cross the stream.

Alkalinity is due mainly to CaCO3 in groundwater entering the stream as base flow. Alkalinity increases quite regularly downstream during both high and low flow conditions, although values become lower at all sites as flow increases. The downstream increase during base flow conditions might be attributed to the effect of evaporation along the stream, which would increase CaCO3 concentration downstream. The decreased concentration with increased flow is most likely a dilution effect by surface runoff, which is strongly controlled by rainwater chemistry.

Phosphorus concentrations are measured both as total phosphorus (TP) and soluble reactive phosphorus (SRP). TP correlates strongly with suspended sediment and flow because most phosphorus is bound to mineral grains. In that form it is not readily bioavailable and is largely removed from the aqueous system when the sediment is deposited. SRP concentrations are fairly constant along the stream and correlate poorly with flow. Mean values are 10 to 15 μg/L, similar to that in Cayuga Lake, implying that Sixmile Creek is not a significant source of SRP to the lake.

Bacteriological parameters show some of the most serious impacts to water quality in Sixmile Creek. Regulatory guidelines for E. coli and coliforms are geared towards contact recreation and consumption. Consumption guidelines are not relevant to Six Mile Creek as all surface waters are deemed to require treatment prior to consumption. Recreation (swimming beach) guidelines are also not directly relevant as none of Six Mile Creek is designated for public swimming. However there is some logic in using these guidelines to give context to the volunteer monitoring data as swimming does certainly occur in the stream. The EPA recommends that the geometric mean of a series of E. coli measurements (five or more per month) not exceed 126 colonies/100 ml for a heavily used swimming area*. The geometric means of E. coli concentrations in Six Mile Creek, based on eight monitoring events over 20 months, are near or below the recommended EPA level at most sampling locations. However, concentrations of E. coli in single samples range as high as 6,900 colonies/100 ml (Fig. 14).

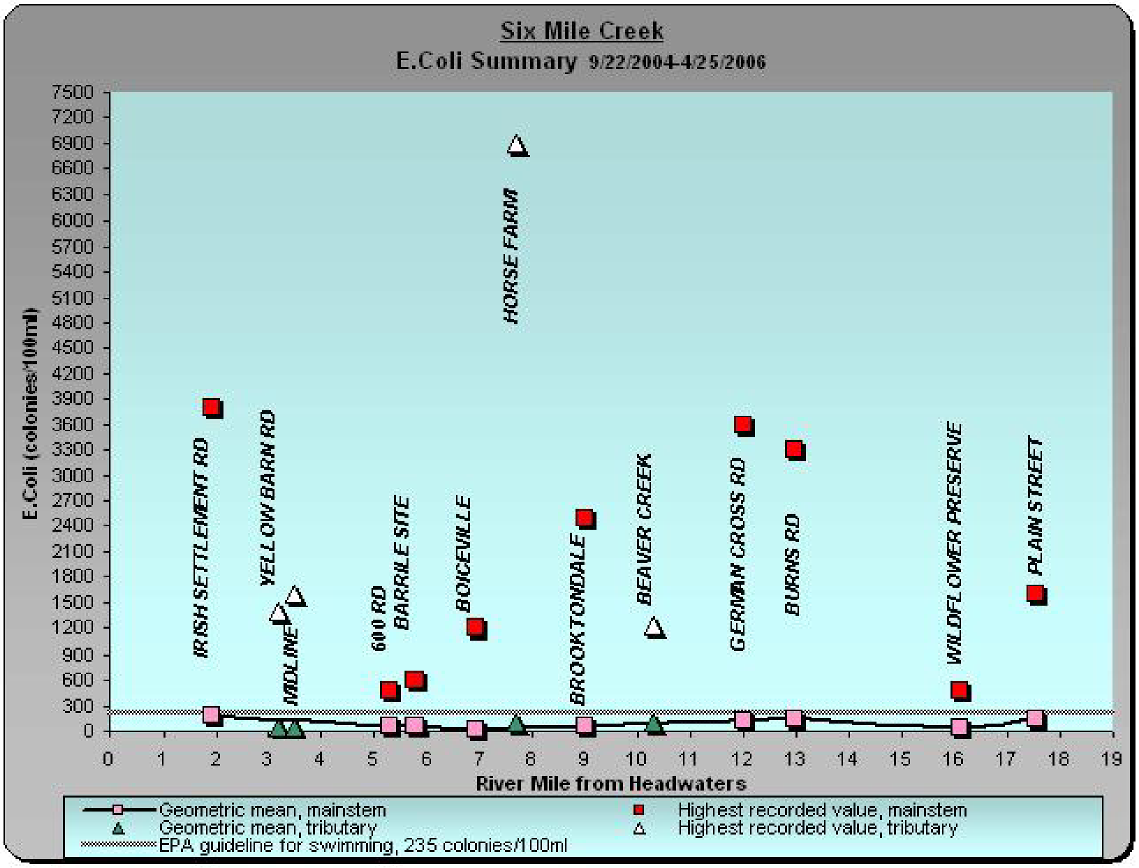

Figure 14. Concentrations of E. Coli measured by the Sixmile Creek Volunteer Monitoring Group (from www.communityscience.org/SixMile/SixMileCreek)

There are unusually high (relative to nearby sites) concentrations of E. Coli at sites 7 (Boice Creek or “horse farm”) and 13 (Irish Settlement Rd.). Both these sites are just downstream from properties on which livestock (primarily horses) are kept.

It is often assumed that bacteria levels are low when the water is low in a stream, and that they rise when the water level is high following rain or snowmelt. Surprisingly, flow appears to have had little if any effect on bacteria concentrations during the 19-month period from September 2004 to April 2006. It is possible that the high values during high flows is a flushing effect and perhaps that, during low flow and high water temperature, bacteria in the water actually multiply.

Large Woody Debris (LWD)

The role of LWD in streams such as Sixmile Creek is complex and even controversial. LWD is a normal component of natural streams, but was long viewed as just material obstructing the channel and was, consequently, removed. LWD serves as cover, habitat and food for a wide spectrum of aquatic biota. LWD also serves to reduce water velocities, leading to local sediment deposition and formation of downstream pools. LWD can also lead to effects that are or can be perceived to be deleterious. An unambiguous problem is the lodging of LWD on bridge piers and other structures in the stream channel, leading to upstream flooding. More ambiguous are the effects of large masses of LWD, or logjams.

Wagenet and Pfeffer (2005) note that *"a logjam may redirect the flow in small streams….disper(sing) floodwaters and creat(ing) more habitat"*. This may be the general opinion of aquatic biologists, but not necessarily that of fluvial geomorphologists. According to Jim MacBroom (personal communication, 2006), *"log jams on already disturbed or unstable rivers can be detrimental to channel equilibrium. Portions of Six Mile Creek have had excessive slope due to previous aggradation after forest clearing, leading to subsequent incision into erodable post settlement valley bottom sediments as sediment loads later decreased. The modern valley bottom sediments that I saw have limited bed material armor and do not seem to resist lateral channel migration well, thus LWD with high velocity (creates) side channels and erosion occurs. If this is valid, then LWD should be more stable and beneficial as the channel gradient flattens, velocities are reduced, and lateral movement slows."*

Karig has observed several log jams in Creek that did "redirect" the channel. In one case, clumps of trees caused serious erosion downstream along a new channel, which had a geometry that was far from equilibrium. The return to an equilibrium channel geometry caused rapid channel migration and bank erosion.

Observation of the section of Sixmile Creek just upstream of German Crossroad during the period (1972-1980), when the channel was migrating rapidly (Karig, 2000), led to several conclusions. Most of the LWD consisted of trees eroded from cutbanks during the associated flood event. Very few appeared to be refloated from point bars, possibly because bars are depositional areas and trees grounded there are quickly buried. In fact, these grounded trees reduce flood water velocities and engender sedimentation on the point bars. As the rate of channel migration and cutbank erosion decreased, the quantity of LWD during floods has diminished. Several log jams formed during the first half of this period, some causing significant channel realignment. No logjams have formed in this section since 1978, when the overall channel geometry approached an equilibrium state

Identification of Problems

The data summarized in the preceding sections of this report go far toward reaching conclusions concerning the condition of Sixmile Creek and in laying the foundation for the construction of a watershed management plan. However, before any such plan can be generated, watershed managers and stakeholders must identify the issues and problems of greatest concern, as well as acquiring any additional data needed to adequately define these problems.

Flooding

Floods are defined as flows that exceed a bankful stage and are commonly rated by their recurrence interval (RI). For example, a 50-year flood is one that statistically occurs once every 50 years or one that has a 2% probability of occurring during any one year. The size of a flood can be determined, at a given point along a stream, if a flood frequency curve (FFC) has been generated, either with past flow data or with some combination of data and assumptions based on the behavior of similar streams having adequate data.

At this time, no observationally based FFC is available for Sixmile Creek because data from the USGS gaging stations have not been collected for a sufficiently long period. As well, most large peak flows during the lifetime of the German Crossroad gage (1995 to present) have had to be estimated because the gage was rendered inoperable during those events.

In 1999, the USGS generated an “estimated” FFC based on annual peak flows at the German Crossroad gage as well as annual peak flows estimated at the silt dam going back to 1967. This FFC, as well as one generated in 1984, with unknown inputs, suggested that the 100 year (yr) flood in Sixmile Creek near German Crossroad has a magnitude of about 14,000 cfs, but with admittedly widely diverging 95% confidence limits.

Another estimated FFC has been generated by Thomas Suro of the USGS for this report (Lynn Szabo, 2006, written communication). This analysis used annual peak flows from 1996 to 2005 at the German Crossroad gage and resulted in slightly lower flows at the same RI’s in the earlier analyses; the 100 yr flood is now estimated at about 10,000 cfs (Fig. 15).

This analysis also determines the mean annual flood (RI = 2.33 yrs) as having a flow of 2400 cfs and estimates bankfull flow (RI ~ 1.5 yrs) at 1750 cfs. This latter flow value is only slightly greater than a bankfull flow of 1400 ±100 cfs estimated by comparing gage readings with observed channel conditions.

The magnitudes of most historical flood events (from 1905 forward) have been estimated at locations along the stream where the channel shape is regular enough to permit calculations (e.g. the silt dam). These estimates were from different locations, from the 60-foot dam to the City of Ithaca, and are not exactly comparable, but even taking those differences in account, there has been no event in the past century with a flow that exceeded approximately 8000 cfs. On the other hand, there have been several floods in the range of 6,000 to 8000 cfs over this period.

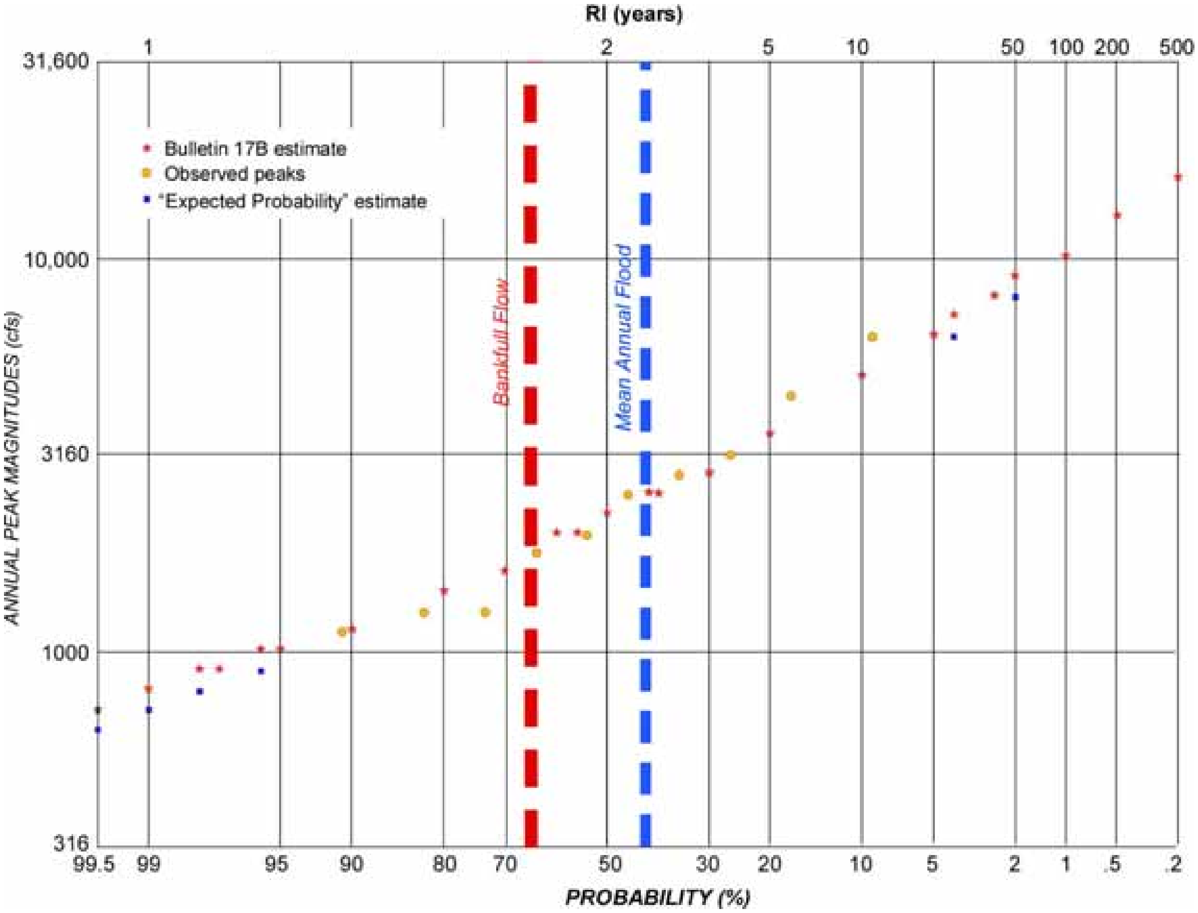

Figure 15. Flood frequency analysis at the German Crossroad gage estimated from annual peak flows and extrapolated to higher flows using USGS Program peakfq

The question then arises as to whether there has been any flood in Sixmile Creek approaching even a 50 yr RI, let alone a 100 yr RI, as suggested by the FFC, or whether there have been gross inaccuracies in the estimates of flood magnitudes or in the FFC's. This finding is extremely significant and will have important implications for watershed management in Sixmile Creek.

The perceived intensity of a flood is often based on the resultant damage rather than on the magnitude (RI) of the event. Flood damage in the lower Sixmile valley has been decreasing because channel degradation and increasing sinuosity are creating a new, lower flood plain that can accommodate greater flows. In the upper Sixmile Creek valley, flooding may be of greater concern socially because channel degradation there may be of less magnitude and the density of development in and adjacent to the floodplain is greater. However, the watershed in the upper valley section is in relatively good shape, with the area of woodland still increasing. Because the condition of the watershed affects the intensity of flooding more than does that of flood plain or channel, the upper Sixmile Creek valley should have a relatively low flood risk, as long as the watershed is adequately protected.

Erosion

Erosion is a problem where structures are threatened, but most of Sixmile Creek has relatively few structures along its channel. The channel erosion that is occurring in Sixmile Creek is generally associated with increasing sinuosity, which is a natural and desired process. Erosion in Sixmile Creek is high, relative to that in other local streams and probably relative to the erosion before European settlement. This in large part is due to the attempt of the stream to come into equilibrium with a watershed supplying less sediment than was supplied during the earlier period of more intensive agriculture. This process includes both channel degradation and increased sinuosity, which in turn leads to lower water velocities and reduced erosion. Unfortunately, the duration of this re-equilibration process is of the order of decades, possibly more than a century. Unwise development and other forms of degradation in the watershed will prolong or even reverse this re-equilibration process.

Deposition

Sediment deposition is directly related to erosion, but occurs in different areas and causes different problems. Sedimentation in the City of Ithaca water supply reservoir is the most serious economic problem in the watershed. Data in Fig. 6 show that if the linear rate of infilling of that reservoir continues, it will be completely filled in about 60 years. Because the drinking water intake is 20’ below the reservoir surface, it would be useless as a water supply well before then. It is an important and unanswered question whether it is more economical to attempt to reduce erosion and sediment transport in the channel above the reservoir or to remove sediment from the silt dam and dredge the reservoir periodically.

Sedimentation in Cayuga Lake from the reaches of Sixmile Creek above the dams is minor, but is augmented by erosion in the system below the 60-foot dam. The sediment load reaching the Cayuga Inlet has not been measured, but is obviously significant, based on the TSS measurements at Plain St. (Site 1) and from visual observations in the Inlet. A significant part of that load likely originates from the tributaries that enter Sixmile Creek downstream of the 60-foot dam.

Habitat Protection

In previous sections of this report, BMI and fish populations were discussed primarily as criteria for water quality, but they are also elements in the larger stream-related habitat. This habitat, termed the riparian corridor, includes not only the stream channel but also the flood plain and bordering zone of riparian vegetation.

Protection of the riparian corridor along Sixmile Creek is necessary for more reasons than preservation of habitat. A vegetated and undeveloped riparian corridor helps reduce flood peaks and, equally important, eliminates structures from the area that tends to be flooded. Such corridors act as pathways for wildlife movement and enhance possibilities for recreation, especially where public access is permitted.

The state of the riparian corridor along Sixmile Creek has not yet been assessed. An adequate, undeveloped corridor exists along most of the stream; the exceptions being in the vicinities of Slaterville and Brooktondale. Little is known about the terrestrial fauna (e.g. mink, beaver, muskrat, amphibians) or flora. One obvious observation is that exotic and often invasive flora is abundant, in large part because of the ease of migration along (down) the corridor.

Remaining Data Gaps

Much information has been gathered concerning the hydrology of Sixmile Creek, but some additional data are needed before a unified watershed management scheme can be generated and implemented. Perhaps the greatest need is to determine the source of suspended sediment below Brooktondale; specifically, to what extent it is derived from the bed and banks of the main channel and to what extent from the tributaries in this reach. The best way to make such a determination would be with a synoptic survey of sediment loads from all tributaries and from the main channel using data from the two USGS gaging stations. Such a survey would be effort-intensive and would require the measurement of both flow (Q) and the concentration of suspended sediment. The measurement of just sediment concentrations would not provide sediment load data, but would give a good idea as to where the most turbid water is entering the stream, and would be significantly easier to accomplish.

The current amount of stream degradation in the upper Sixmile Creek valley must also be determined, but could easily be done with annual measurements of the depth to the channel bottom at a number of bridge decks along this section.

Suggestions of other data that might be useful included:

1. synoptic measurement of flow and suspended sediment in tributaries along Sixmile Creek to substantiate the assumption that most of the suspended sediment is derived from tributaries downstream of Brooktondale
2. conditions during which most of the suspended sediment is transported (i.e. during the dominant periods of base flow or during the infrequent storms). This could be done with a careful analysis of USGS flow and suspended sediment data
3. more detailed information about the load trapped in basin behind the silt dam; both the total load and the fractions comprised by bedload and suspended load. If a contractor were again to process the material removed from the basin, an agreement might be made with that entity(party) to tabulate that information.
4. assessment of the health of the riparian corridor and identification of areas in need of protection.

Next Steps

The purpose of this report, as noted in the introduction, is to lay the necessary groundwork for the development of a Sixmile Creek watershed management plan. The report is certainly not an end unto itself. It is absolutely critical that momentum generated by the report be viewed only as the first step in the development and implementation of an intermunicipal management plan. The next steps in developing such a plan might include:

1. Brief stakeholders on report findings and issue charge to develop watershed management plan
2. Gather additional data to support technical report and identified data needs as well as to initiate development of watershed management plan. Data needs for initiation of a watershed management plan might include identification of stakeholders and stakeholder representatives, assessment of stakeholder capacity to develop and implement a plan, identification of an

appropriate mechanism to develop and initiate a plan, inventory of potential sources of funding, etc.

3. Convene stakeholder representatives to initiate development of an integrated watershed management plan that includes considerations such as flood plain management, land use, and channel management techniques. This plan should include information about and recommendations for management priorities and available resources (grant funds, sources of technical assistance, etc.). Sources of support for such an initiative might be available from university students or interns

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Glossary of Technical Terms

Aggradation-- The upbuilding of a stream channel by deposition when it is supplied with more sediment than it is capable of transporting.

Alluvium-- Unconsolidated clay, silt, sand and gravel deposited in relatively recent time by a stream or other body of running water.

Alluvial Fan-- A low, gently sloping mass of alluvium, shaped like an open fan at the place where a stream is near or at its junction with the main stream.

Artesian Aquifer-- An aquifer bounded above and below by impermeable beds. The water level in a well drilled into an artesian aquifer rises above the aquifer (sometimes to above the surface).

Avulsion-- A sudden change in course of a stream during a flood, whereby the stream deserts its old channel for a new one.

Base Level-- The lowest level toward which erosion along a section of stream can reach, or the level below which that section cannot erode its bed. Ultimate base level is sea level, but locally (and temporarily) base level can be a lake, a resistant rock floor or a man-made structure.

Clasts And Exotic Clasts-- A clast is an individual grain or fragment produced by the disintegration of a larger rock mass. Exotic clast here refers to a clast originating from a rock mass far from the present location of that clast.

Facies-- The aspect, appearance and characteristics of a rock unit, usually reflecting the conditions of its origin; esp. as differentiating that unit from adjacent or associated units.

Fluvial-- Of or pertaining to a river.

Glaciofluvial-- Pertaining to the meltwater streams flowing from wasting glacier ice.

Glacial Drift-- A general term for sediment transported by a glacier and deposited directly by or from the ice or by running water emanating from a glacier.

Glacial Stade-- A substage of a glacial stage marked by a glacial readvance or a climatic episode within a glaciation during which a secondary advance of glaciers took place.

Hanging Valleys--Many east-west trending valleys that are tributary to deep troughs were not parallel to the direction of ice movement, and, thus, were less deeply eroded. These tributary valleys end at the main valley wall, high above the floor of the trough valley, and are known as “hanging valleys”.

Knickpoint-- A point or short length along a stream where there is an abrupt change or inflection in the longitudinal profile. This can be a steeper slope or a distinct drop.

Lacustrine-- Pertaining to, produced by, or formed in a lake.

Outwash Plain-- A broad, gently sloping sheet of clastic sediment deposited by meltwater streams flowing in front or beyond a glacier.

Proglacial-- mmediately in front of or just beyond the outer limits of a glacier, generally at or near its lower end.

Quaternary Period-- The Quaternary Period covers the span of time from about 1.8 million years ago to present day. The Quaternary includes 2 geologic subdivisions—the Pleistocene and the Holocene Epochs. The Pliestocene epoch of the Quaternary period contains the period from about 1.8 million to 10,000 years ago when the earth underwent periods of cooling and repeated glacial cycles. The Holocene epoch of the Quaternary period from about 10,000 years ago to present represents a period of climatic warming that is probably an interstadial period (warm period between glaciations) and is distinguished by being the age in which human activities have had a significant effect on the environment.

Synoptic (Survey)-- A set of measurements that are made in a short time interval (ex. one day)

Through Valley-- Some segments of the Finger Lakes and other north-south-trending troughs, such as the lower Sixmile trough, contain a “through valley,” which is described by Tarr (1905) as follows: “Along a number of valleys it is possible to pass from one drainage system to the other through open valleys in which the present divides are determined not by rock, but by drift deposits”. A through valley occurs at the drainage divide near Willseyville.

Troughs-- The most notable evidence of glacial erosion is the large bedrock valleys (troughs) that were carved by ice flowing through pre- and interglacial river valleys. The flow of ice in valleys oriented parallel to the direction of ice movement scoured the walls and floor of these valleys, widening and deepening them while truncating bedrock hillsides (spurs) that extended into these valleys. The result was the creation of nearly straight, U-shaped bedrock troughs. Bedrock erosion occurred mainly through quarrying and abrasion by the ice mass, but the material carried by torrents of sediment-laden meltwater under the ice probably eroded bedrock in some areas also. The most notable bedrock troughs in New York are the many other north-south trending valleys within the northern rim of the Appalachian Plateau, many of which now contain the Finger Lakes.

Turbidite-- A sediment or rock deposited from a turbidity current. A turbidity current is a mass of water and suspended sediment that moves downslope in a standing body of water due to its density (greater than the surrounding water).

Appendix A

Response by James McKenna of the US Fish and Wildlife Service to a query concerning the IBI survey of 2004.

I'm sorry there is not an easy answer to your quest. The magic single number is what you see for "diversity" in our document, but that is a summary index of all the factors that contribute to the balance of number of different species (richness) and relative abundances among those species. Total fish abundance does not equate to diversity and rarely is there a direct correspondence. In fact, some of the most abundant areas are dominated by one or two very tolerant invasive species that are indicative of poor ecological conditions. The diversity number is an index of one aspect of community conditions and is interpreted relative to potential or past conditions, neither of which we really know. So, the best we can probably do is to look at the spatial changes in diversity. This is not a simple matter either, because natural diversity values span a wide range; some waters can be expected to be quite diverse, while others are NATURALLY low in diversity. Part of this is associated with the hydrologic changes inherent to a stream system as it traverses the landscape from small head waters to the mouth. One simplistic view of this effect is that larger sections of stream have more types of habitat and greater volumes of those habitats, and thus, diversity is higher than in small streams. Thermal conditions also enter into it; coldwater systems generally have low diversity (at least for fish).

So, it is not a simple situation and cannot be accurately described in a paragraph or two. Here's what I think we can do. We looked at the relative change in the stream community, longitudinally. That showed us that the head waters are cold and have low diversity fish assemblages. There is a transition zone starting at about site 6 (just above Burns Rd.) where the system progressively changes into a warm-water system. There is a dip in diversity (but a gradual decrease in species richness) in this transition zone. The warm water community at the lower end of the Six-mile Creek system is the most diverse. Much of this is as should be expected simply from the increasing size of the fish habitat (i.e., stream size) and the warming of the water. This could be a natural situation for some stream systems. However, if historically (this is speculation now), Six-mile Creek was a cold-water trout-dominated system from headwaters to mouth, then human influences have converted a large portion (roughly from near Burns Rd. on down) into a warm-water system dominated by species that would otherwise not be present in any significant numbers. This kind of degradation (from the "natural" condition) is extremely common and wide spread in this country and a symptom of large-scale loss (or at least conversion) of fish habitat.

We would have to look much harder at historic records to determine IF this is the scenario for Six-mile Creek. Some of those records exist. It is unclear to me how comparable they will be to the information we have recently collected.

I know this isn't the cut and dried answer you were hoping for, but I hope it does help in some way to fill in the biodiversity aspects of your report. In a nutshell biodiversity is high in the lower end of the creek, low in the headwaters, and intermediate in the middle, but we don't know why for sure or if that is the natural (or desirable) condition -- given the effects of the dams, modification to riparian cover, groundwater pollution and diversions, etc. this is probably not the natural condition.