STREAM CHANNELIZATION IN THE SARATOGA LAKE WATERSHED

By

Allison Gillum and Allison K. Stafford

A SENIOR CAPSTONE PROJECT IN ENVIRONMENTAL STUDIES

Environmental Studies Program
Skidmore College

May 8, 2006

Karen A. Kellogg and Michael C. Ennis-McMillan, senior project advisors

ABSTRACT

STREAM CHANNELIZATION IN THE SARATOGA LAKE WATERSHED

By

Allison Gillum and Allison K. Stafford

Stream alteration in the form of straightening, deepening, widening, clearing, diking, or lining existing streams with concrete, riprap or stones is known as stream channelization. Channelization is a common practice throughout the world for purposes such as flood control, urban development, and navigation. The current study examined how, where, and for what reasons humans have modified or altered stream banks and channels within the Saratoga Lake watershed. Using a Geographical Information System computer program and field measurements, the total length of streams in the Saratoga Lake watershed that have been channelized was determined to be 21.3 km. Approximately 5.5% of the stream system has been channelized for transportation and industrial use. Though a relatively small percent, the possible positive and negative effects of this stream alteration on the local ecosystem, as well as the possible effects on water quality—an important issue for a potential future drinking water resource—are discussed. It is recommended that the Saratoga Lake watershed develop a management plan in which future channelization is monitored and controlled.

STREAM CHANNELIZATION IN THE SARATOGA LAKE WATERSHED

As the human population continues to grow, marginal lands are increasingly inhabited, causing the alteration of the natural environment. This especially holds true for bodies of water; humans alter streams and rivers for many reasons such as controlling flooding and erosion, draining wetlands for human habitation and irrigation, improving navigation (Keller 2002), and for highway construction (Hahn 1982). Stream alteration in the form of straightening, deepening, widening, clearing, diking, or lining existing streams with concrete, riprap or stones is known as stream channelization (Keller 2002; Brookes 1985). There are two different scales of channelization found throughout the world. Large scale modification, which includes building levees and dams along large stretches of rivers or streams, is mainly done to control flooding. Smaller alterations are done for reasons such as industrial uses of rivers and building of bridges and roadways.

Channelization is a common practice throughout the world. By the year 1997, it was estimated that Army Corps of Engineers alone had channelized 33,000 km (20,510 miles) of streams in the United States (Leopold 1997). There are both benefits and costs of implementing channelization.

Benefits

Stream channelization is often designed to overcome a specific problem, such as to prepare land for human habitation or increase agricultural productivity (EPA February 2006). Channelization is also often used in flood control to increase channel capacity, as well as stream velocity, so that high amounts of precipitation and other forms of flooding can be moved along the stream without spilling into the stream's floodplain (Brookes 1985). Channelizing a stream also reduces curves or meanders in streams, resulting in an easier navigable channel. Lining a stream can also reduce the amount of abrasion and bank slip, lessening detrimental erosion along the stream bank (Brookes 1985). Additionally, streams may be altered to accommodate transportation, such as roads and railroads, through bridge building, straightening, or relocating a stream. Channelization may also be performed in urban areas to aid in storm-water runoff drainage (EPA March 2006).

Costs

Unfortunately, the costs of channelization are often not fully considered before construction (EPA February 2006). Streams are constantly changing bodies of water that meander, or curve, adding variety to the stream velocities and depths found throughout the channel (Hahn 1982). These natural changes that take place in a stream depend on the weather, climate, and geology of its watershed (Hahn 1982). Channelization construction restricts streams from their natural movements, which may result in detrimental effects, since creating a uniform stream path allows more water to pass through the channel than a natural stream channel would previously permit (Hahn 1982). Stream channelization may negatively impact both aquatic organisms and water quality in many ways, two important environmental issues in the Saratoga Lake watershed.

Increased Current Velocity

To begin with, channelization often results in an increase in stream velocity. Velocity increases because the area of channel is decreased, yet the discharge, or the quantity of water flowing past a particular point of a stream (Keller 2002), remains the same. Current velocity may also increase due to possible increased steepness of the river bed as well as a decrease in flow resistance because of the removal of stream obstructions during channelization construction (Hahn 1982).

Increased Current Velocity: Impacts on Aquatic Organisms

Increased velocity can lead to the erosion of the stream bed, which in turn affects the benthic vertebrate population and thereby the amount of food available for fish (Hahn 1982). The increased velocity may also negatively impact fish populations because spawning and survival of eggs are hindered by the faster currents (Hahn 1982). Channelization also decreases the variability of pool and riffle habitats in the stream (Hahn 1982). Pools are characterized as deep areas that were created by erosion with slow moving water (Keller 2002). Riffles are defined as shallow areas that were produced by the deposition of obstructions and are characterized by relatively shallow, fast-moving water (Keller 2002). Natural variation in the pool and riffle habitats allows for many types of ecological niches to accommodate a wide variety of macro-invertebrates and fish. A decrease in the diversity of flow patterns lowers the number of feeding and breeding grounds, as well as habitats, available (Keller 2002). A decrease in variability of habitats caused by channelization can lead to a decrease in fish population. Higher velocity leads to few to no resting places for organisms in pool environments, and makes riffle environments too shallow for many fish and other organisms during the dry season (Keller 2002). A decreased diversity of substrate sizes in riffle environments further decreases the number and types of microhabitats for benthic invertebrates (Hahn 1982).

Increased Current Velocity: Impacts on Water Quality

The increased current velocity may also affect how quickly pollutants can be transported throughout the watershed (EPA February 2006). A faster current could be beneficial, since pollutants may be more rapidly flushed through the stream system, not having time to affect the ecosystems of the stream. However, these pollutants may not be filtered before reaching the final discharge point, thereby degrading the body of water into which the stream flows. Pollutants from various land uses, such as toxins from commercial use or fertilizers from agricultural land, can have negative impacts on water quality in the watershed, and can be carried downstream and dispersed throughout the watershed at a quicker rate.

Destruction of Riparian Zone

Channelization may cause permanent destruction of riparian zones (Leopold 1997), or strips of lush vegetation along streams (Miller 2002). In fact, the Center for Conservation Biology has estimated that over 90 percent of riparian forests in the western United States have been deforested or degraded as a result of channelization (Leopold 1997). These vegetated areas have several important functions that include promoting stream bank stability and providing habitat for many species of fauna and flora (Miller 2002).

The riparian zone can be damaged by channelization in two major ways. First, when channelization is implemented, hardwood trees and other vegetation are sometimes cleared to construct the channelized section of the stream (Hupp 1992). Secondly, the stream itself sustains the riparian zone by providing it with both underground and surface water. When a stream is channelized, the riparian zone may be completely cut off from its water source by concrete or other alterations, which can destroy the riparian zone (Leopold 1997). Another possible impact is that the increased velocity of the stream no longer allows water to infiltrate the banks of the stream as far as it did before. This lack of infiltration leads to a narrowing of the riparian zone as the vegetation father away from the stream is no longer able to get enough water to survive (Leopold 1997).

Destruction of Riparian Zone: Impacts on Aquatic Organisms

The narrowing of the riparian zone causes a loss of habitat for organisms that live along the stream. This loss of habitat can make organisms much more vulnerable to predation, parasitism, and human disturbance (Leopold 1997). Furthermore the trees, brush, grass, and sedges that are found in the riparian zone provide important shade to the stream and help control water temperature (Leopold 1997). When channelization causes the destruction or narrowing of the vegetation along a stream, the stream becomes vulnerable to rises in temperature and rapid daily and seasonal temperature fluctuations (Keller 2002). Changes in water temperature can have negative effects on fish, plants, and other organisms that live in the stream. As the temperature of the water rises, less oxygen is able to dissolve into the water causing fish and other organisms to potentially asphyxiate (Gordon et al. 1992).

Channelization also potentially leads to a loss of leaf material input (Keller 2002), especially in the headwaters of the stream (Hahn 1982). Aquatic invertebrates rely on leaf litter as an important source of nutrients and the removal of leaf litter can reduce the overall productivity of the stream ecosystem (Hahn 1982). Fish rely on the population of aquatic benthic invertebrates as their source of food, therefore a decrease in the number of invertebrates in the water may also lead to a decrease in the fish population. Fish populations may also decrease with the removal of riparian vegetation because the amount of terrestrial insects, another important food source, also decreases near the river after channelization (Hahn 1982).

The narrowing or destruction of the riparian zone can also cause a decrease in bank stability (Leopold 1997), as stabilizing plant and tree roots are removed. A decrease in bank stability, in combination with an increased velocity, may lead to increased rates of erosion. Erosion brings excess nutrients into the stream, and, combined with an increase in sunlight due to less shade, an increase in organisms such as algae occurs (Miller 2002). When this algae dies and is decomposed on the bottom of the stream, dissolved oxygen, necessary for fish, is depleted (Miller 2002).

Erosion may also cause an increase in sedimentation and turbidity, a measure of the cloudiness of water (FFC 2006; EPA February 2006). An increase in turbidity has negative affects on fish health and vision, impairing both feeding and reproduction (Hahn 1982). Increased turbidity also decreases the benthic vertebrate survival rate, further increasing the negative affects on the fish population (Hahn 1982). Turbidity causes streams to become warmer, as particles absorb sunlight, leading to a further decrease in dissolved oxygen levels (FFC 2006). Increased turbidity can also lead to a decrease in photosynthesis in streams, as less light can penetrate to the same depth as previous to channelization (FFC 2006; Hahn 1982). The lack of aquatic plants results in even less dissolved oxygen for fish (FFC 2006).

Removal of Riparian Zone: Impacts on Water Quality

A decrease in the riparian zone surrounding a river may negatively impact the water quality of the stream (Klapproth and Johnson 2000). Riparian buffers serve as important filtration zones, reducing the amount of sediment, nutrients, and other pollutants that can enter streams (Klapproth and Johnson 2000). When the riparian zone is removed, more toxins and other pollutants can be carried into the stream through subsurface or groundwater flow. When a stream is channelized, the banks may no longer serve as buffer systems (Klapproth and Johnson 2000).

Destruction of Wetlands

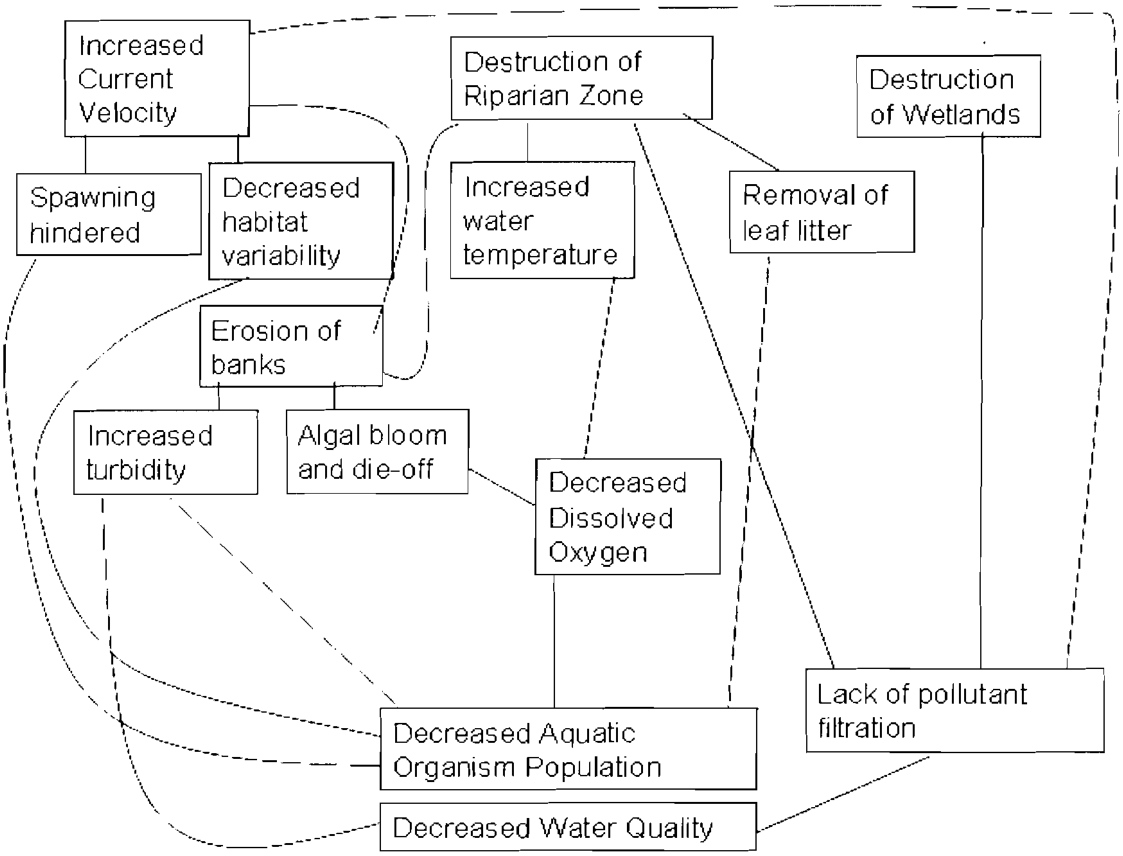
Wetlands serve as an important buffer zone for stream systems, both for pollutants as well as excessive discharge. Channelization can affect wetlands at the area of channelization as well as upstream or downstream in much the same way that the riparian zone can be affected. This results in the loss of marshes, swamps, and floodplains and their ecological diversity, as well as their important environmental functions (Gordon et al. 1992). Wetlands provide food and habitat for many different types of wildlife (Miller 2002); the destruction of wetlands lowers the ecological productivity of an area.

Wetlands, like riparian zones, filter pollutants, nutrients, and sediments from subsurface flow into the stream (Miller 2002). The loss of wetlands can cause degradation in water quality; in fact, the Audubon Society has estimated that wetlands in the United States provide at least $1.6 billion worth of water quality protection (Miller 2002).

Wetlands also help manage higher flows associated with flooding. With the reduction of wetlands, excess water cannot infiltrate the stream channel and be stored or redirected, which increases flooding magnitude downstream (Gordon et al. 1992).

The complexly integrated possible negative effects of channelization are outlined in Figure 1.

Figure 1. Possible Negative effects of channelization.



Current Study: Saratoga Lake Watershed

The City of Saratoga Springs in upstate New York is currently examining the use of Saratoga Lake as the primary drinking water source for the City. The Saratoga Lake watershed spans 543 square kilometers (Wiles-Skeeles and Nichols 2004), including a total of twelve municipalities. Development has been on the rise in the Saratoga Lake watershed over the past twenty years and is projected to continue to increase (Wiles-Skeeles and Nichols 2004), which may lead to more channelization as more of the watershed is occupied by humans (Wiles-Skeeles and Nichols 2004). Extensive channelization within the Saratoga Lake watershed could potentially have a negative impact on the aquatic organisms in the streams and lake, as well as cause water quality problems.

The goal of the current study was to examine how, where, and for what reasons humans have modified or altered stream banks and channels within the Saratoga Lake watershed as well as quantify the amount of channelization in the watershed. The type of modification, in combination with why it was implemented, was examined in order to determine whether channelization in the watershed is potentially having detrimental effects on the watershed and the lake itself. This study will also examine possible correlations between increased development and channelization in the Saratoga Lake watershed.

METHODS

In order to gather information on channelization within the Saratoga Lake Watershed, an accurate and complete map of the delineated watershed was created using ArcHydro Tools in the ArcMap 9.1 GIS program. The Saratoga Lake Watershed was delineated using digital elevation maps from the U.S. Geological Survey website. The point of drainage, used to define the watershed, was the outflow of Saratoga Lake at Fish Creek. Shape files containing streams from CUGIR NY Data (2000), roads and railroads from ESRI (2000), land use from the US Geological Survey (USGS) (2001) and an aerial photo from NY State Orthoimagery (2004) were added to the watershed map.

Road Intersections

The first type of channelization, that which occurs at the intersection of streams and roads, was examined by clipping the shape files of streams and roads to the watershed map. Using ET Geowizard to locate these intersections, a total of 270 sites were found. An Excel spread sheet containing latitude and longitude as found in ArcMap 9.1, an ID number, and a street location for each of the sites was created.

Three of these sites were randomly chosen to obtain a sample length estimate. The total length of altered streambed due to a road intersecting the stream was measured in the field. The standard deviation of the lengths measured at the three sites was calculated. This standard deviation, along with a max error of 20 feet and a 95% confidence interval, was used in the Sample Size Selection for Limiting Error Equation found in Kachigan, 1986. Using this equation, we calculated that 51 sample sites were needed to estimate the average length of channelization found at every intersection. Using Excel, 51 of the 270 sites were randomly selected. Map 1 is a map of the road-stream intersections in the watershed, with the sites that were visited and measured displayed in red. As Map 1 shows, the sample sites were fairly evenly spread throughout the watershed, including the headwaters, the main stem of the Kayaderosseras, and the lake area itself. The average length of channelization for the sample of sites was calculated and multiplied by the total number of sites (270) to obtain an estimate of the total length of channelization due to the intersection of roads and streams.

Using GIS, we found a total of 18 intersections between railroads and streams. We attempted to visit all of the 18 sites, and found that a total of five were accessible. Map 2 is a map of the railroad-stream intersections in the watershed, with the sites that were visited and measured displayed in red. The total length of channelization at each of the five sites was measured. This average was multiplied by the total number of railroad-stream intersections (18) to find an estimate of the total length of channelization due to railroad-stream intersections.

Industrial and Commercial Use

The second type of channelization, that which occurs at industrial or commercial sites next to a stream, was examined by locating any NPDES Permit holders or EPA TRI

Facilities in the watershed (Caris and Wittman 2005). A total of five sites were located. Other possible industrial or commercial uses of the river were found by examining the land use map in GIS. An additional 9 sites were located, for a total of 14 industrial sites. Map 3 is a map of the industrial sites with potential channelization located in the watershed. Though each site was visited, channelization was only found and hence measured at three sites. These three sites are indicated in red in Map 3. The estimated length of channelization due to commercial or industrial use was calculated by summing the lengths from each site.

Other Visible Channelization

An aerial photo of the watershed was examined to determine any channelization that does not occur at industrial sites or road intersections. Portions of streams that have been visibly straightened alongside roads or visibly altered were marked and measured using ArcMap 9.1. Map 4 is a map of the straightened sections in the watershed indicated in red. The estimated total length of this type of channelization was calculated by summing the lengths of each site.

Total Channelization

An estimate of the total length of channelization in the watershed was calculated by summing the total lengths of the three types of channelization. The total length of stream system was measured using CUGIR NY Data within ArcMap 9.1. By dividing the total length of channelization by the total length of stream system in the watershed, the estimated percentage of channelized stream was calculated.

RESULTS

Road Intersections

A total of 270 intersections of roads and streams are contained within the watershed and 51 of these sites were sampled (Map 1). The length of channelization at each sample site ranged from 6 meters to 133 meters with an average length of 25 meters (Appendix A). Since the total amount of channelization due to road/stream intersections is equal to the average length per sample site multiplied by the total number of sites, the total length of channelization due to road/stream intersections is estimated to be 6750 meters. The types of channelization at these intersections includes cement banks, one to three metal corrugated pipes at a site, plastic corrugated pipes, and cement pipes.

Railroad Intersections

A total of 18 railroad-stream intersections were found in the watershed (Map 2). The lengths of each sample site are given in Appendix B. Of these 18 sites, 5 were accessible and measured, with a range of 8 meters to 41 meters and an average length of 25 meters. The estimated total amount of channelization due to railroad/stream intersections is equal to the average length per measured intersection multiplied by the total number of sites, or 450 meters. The types of channelization found at these intersections were typically cement or stone banks.

Industrial and Commercial Use

Though a total of 14 industrial sites were detected through GIS, only 13 were accessible, and of these 13 only 3 actually proved to have channelization present at the site (Map 3). The length of channelization at each industrial site is given in Appendix C. The estimated total length of channelization due to industrial use equals the sum of the lengths measured at the three channelized sites, for a estimated total of 446 meters.

Other Visible Channelization

Using GIS and aerial photos, a total of 29 sections of the river were found to be channelized due to close proximity to a road or railroad (Map 4). The length of each segment is given in Appendix D. The estimated total length of channelization due to straightening is 13,699 meters.

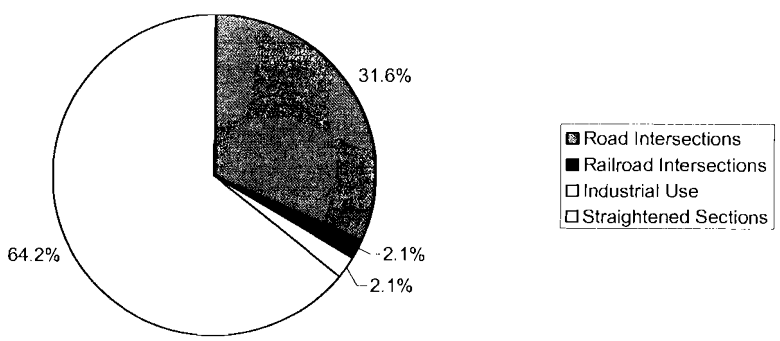
Total Channelization

The estimated total length of channelization in the watershed is equal to the sum of the lengths channelized by intersections, industrial use, and straightening (Table 1, Figure 2). The estimated total length of channelization in the Saratoga Lake watershed was found to be 21,345 meters. The total length of stream in the watershed was found to be 390,512 meters. Therefore, the estimated percent of stream that is channelized in the watershed is 5.5%.

Table 1. Estimated Channelized Lengths per Type and Estimated Total Channelized Length

	Road Intersections	Railroad Intersections	Industrial Use	Straightened Sections	Total
Average Length (m)	25	25			
Number of Sites	270	18	14	29	331
Total (m)	6,750	450	446	13,699	21,345

Figure 2
Percent of Different Types of Channelization in the Saratoga Lake Watershed



DISCUSSION

It was found that approximately 5.5% of the Saratoga Lake watershed has been channelized, largely due to proximity to and intersections with roadways, railroads, and industrial use (Table 1). Compared to other watershed studies, this is a relatively small percent of channelization for a watershed (Elliot 2003; Williamson and Todd 2005). Studies conducted on watershed of similar size found channelization percents closer to 20 to 60 percent, sometimes even as high as 80 percent channelized stream (Williamson and Todd 2005; NCDENR 2003; LeJeune et al. 2000). A study conducted in three separate watersheds in the Lower Fraser Valley of British Columbia used a six indicator buffer assessment to evaluate the effectiveness of the stream system as a buffer for pollutants when different percents of channelization were present (Elliot 2003). As discussed previously, channelization increases current velocity, which disallows water to infiltrate the stream banks, so that pollutants can no longer be filtered out of the water before reaching their final discharge location, thereby negatively affecting water quality. The study concluded that a stream system with over 60% channelization is considered to be a "poor" buffer, 30-60% channelization is considered to result in a "fair" buffer, and less than 30% channelization produces a "good" buffer (Elliot 2003). According to this study, the Saratoga Lake watershed is well within the criteria for a "good" buffer in regards to channelization.

Furthermore, the type of channelization observed in the Saratoga Lake watershed is relatively small scale, primarily a result of road and railroad construction as well as industrial uses. Though this channelization is not as extensive as large scale flood control projects, which includes building levees and dams along large stretches of rivers or streams, it can still have harmful effects on aquatic organisms and water quality, especially if its extent increases.

As the population grows in the Saratoga Lake watershed, recreational fishing will become more widespread. Saratoga Lake is already one of the top fisheries in the state and is an important economic resource (Tim Blodgett, personal communication, February 2, 2006). The Kayaderosseras is one of the top fishing waters in Saratoga County for species such as brown trout and rainbow trout, while Saratoga Lake is one of the top fishing waters for smallmouth bass, northern pike, and walleye (NYSDEC 2006). Channelization has been shown to possibly negatively affect fish populations, such as trout. A reduction in the number of catchable trout has been shown to occur in channelized reaches as short as 0.40 km due to a loss of shelter and an increase in water temperature (Hahn 1982). The current study found that sixteen of the straightened sections of the stream were longer then 0.40 km, with two sections extending over a kilometer long. These channelized sections could potentially harm the trout population throughout the stream system, hindering recreational uses of the stream.

Studies have shown that urbanization within a watershed can lead to increased channelization (EPA March 2006). For example, a study in the Kaneohe Bay of Hawaii found that development within the watershed increased channelization as well as runoff flows (EPA March 2006). Because of the extensive channelization within the watershed, nutrients and other pollutants caused by urbanization were no longer filtered out of the water due to the increased stream velocity following channelization (EPA March 2006), leading to a decrease in water quality. Similarly, the Saratoga Lake watershed had a 25% increase in population from 1980 to 2000, and has a further projected increase of 10% by 2030 (Wiles-Skeeles and Nichols 2004). Due to this population increase, the amount of residential land use in the watershed increased by 24%, accompanied by an increase of 5% commercial use (Wiles-Skeeles and Nichols 2004). These two forms of urbanization are associated with channelization, and an increase in their respective percents may also lead to increased amounts of channelization in the future.

Furthermore, growth in population has increased the demand on drinking water in the area, forcing Saratoga Springs to consider using Saratoga Lake as a drinking water source. Therefore the water quality in Saratoga Lake is of utmost importance. As most of the channelization found in the watershed was alongside or underneath roads, the possibility of road pollutants such as oil and salt entering the stream is increased. The increased current velocity due to channelization could quickly carry these pollutants into Saratoga Lake, compromising the water quality of the lake. But, since there is a relatively small percent of small scale channelization in the watershed, channelization is most likely not effecting water quality at this time. However, an increase in development and thereby channelization may negatively impact the water quality of Saratoga Lake in the future.

CONCLUSIONS

The current study found that approximately 21.3 km, or 5.5% of the Saratoga Lake watershed stream system is channelized. This is a relatively small percent of channelization for a watershed of this size. The majority of this channelization is small scale modifications due to proximity to roadways as well as intersections with roads and railroads and industrial use. This channelization could potentially have harmful effects on the aquatic organism population and water quality of the stream system.

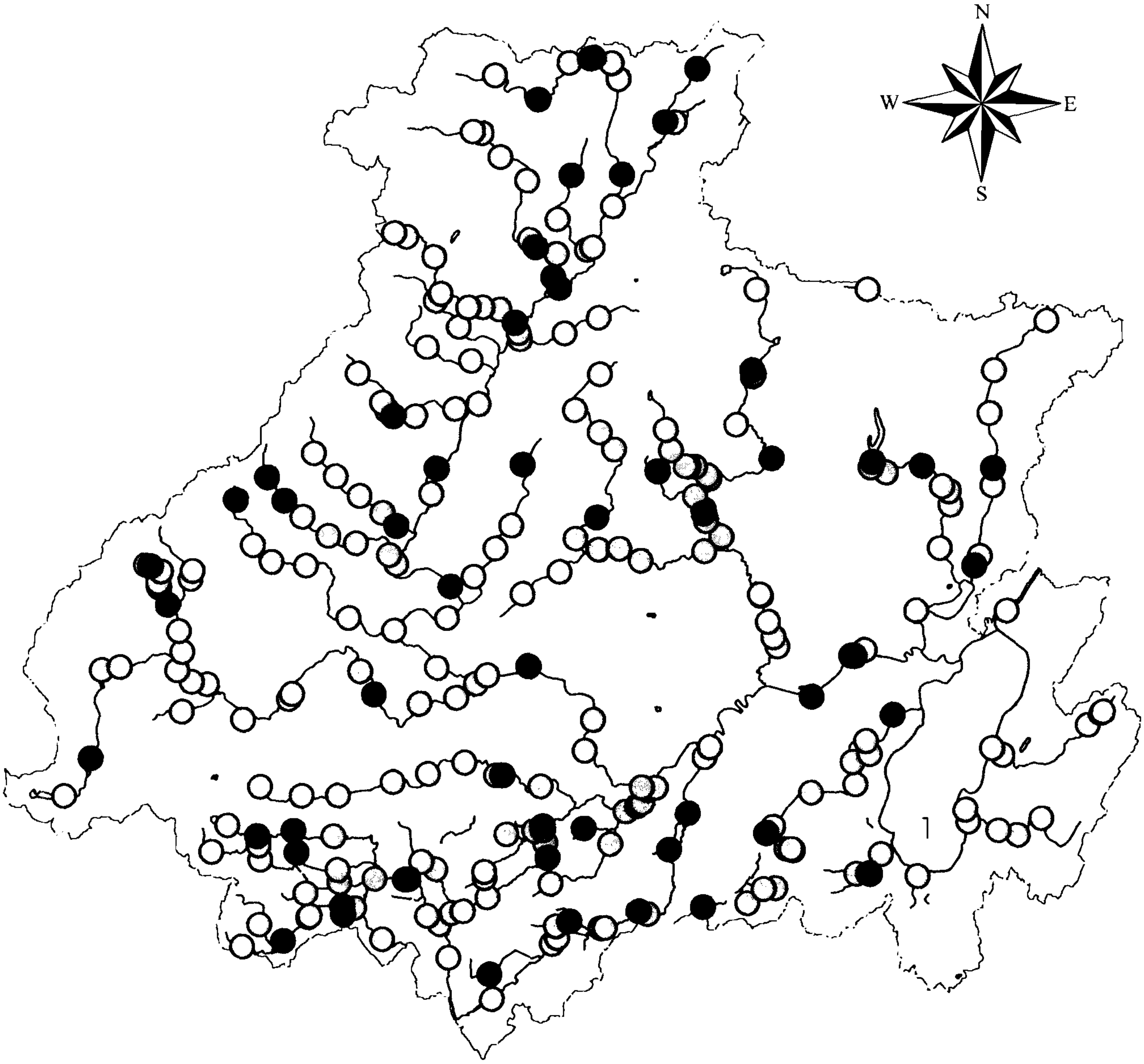
It is recommended that the Saratoga Lake watershed develop a management plan in which channelization is monitored and controlled. The percent of channelization in the watershed should be kept well under 30% to maintain the integrity of the watershed including the aquatic organism populations and water quality.

Further studies on the effects of channelization within the watershed—on issues such as recreational fishing, water quality, and flooding—should be conducted. For instance, a study that compares channelized areas and natural areas in the watershed, looking at benthic invertebrate and fish populations, should be conducted. Other studies could be conducted on the amount and types of pollutants in channelized areas. For example, the channelized sites used in this study can be further used to examine the how the proximity of roads to streams affects water quality. Another useful study may be to look at the percent of channelization within subwatersheds of the Saratoga Lake watershed, seeing if some areas are more heavily channelized than others. Studies such as these may aid Saratoga Springs in its decision to use Saratoga Lake as its drinking water source, as well as to develop a management plan that includes channelization.

ACKNOWLEDGEMENTS

We'd like to thank Nick Napoli and the student employees of the Skidmore College GIS center, as well as Dr. Karen Kellogg and Dr. Michael Ennis-McMillan and the Skidmore College Environmental Studies Program for supporting this study.

Map 1
Road-Stream Intersections in the Saratoga Lake Watershed

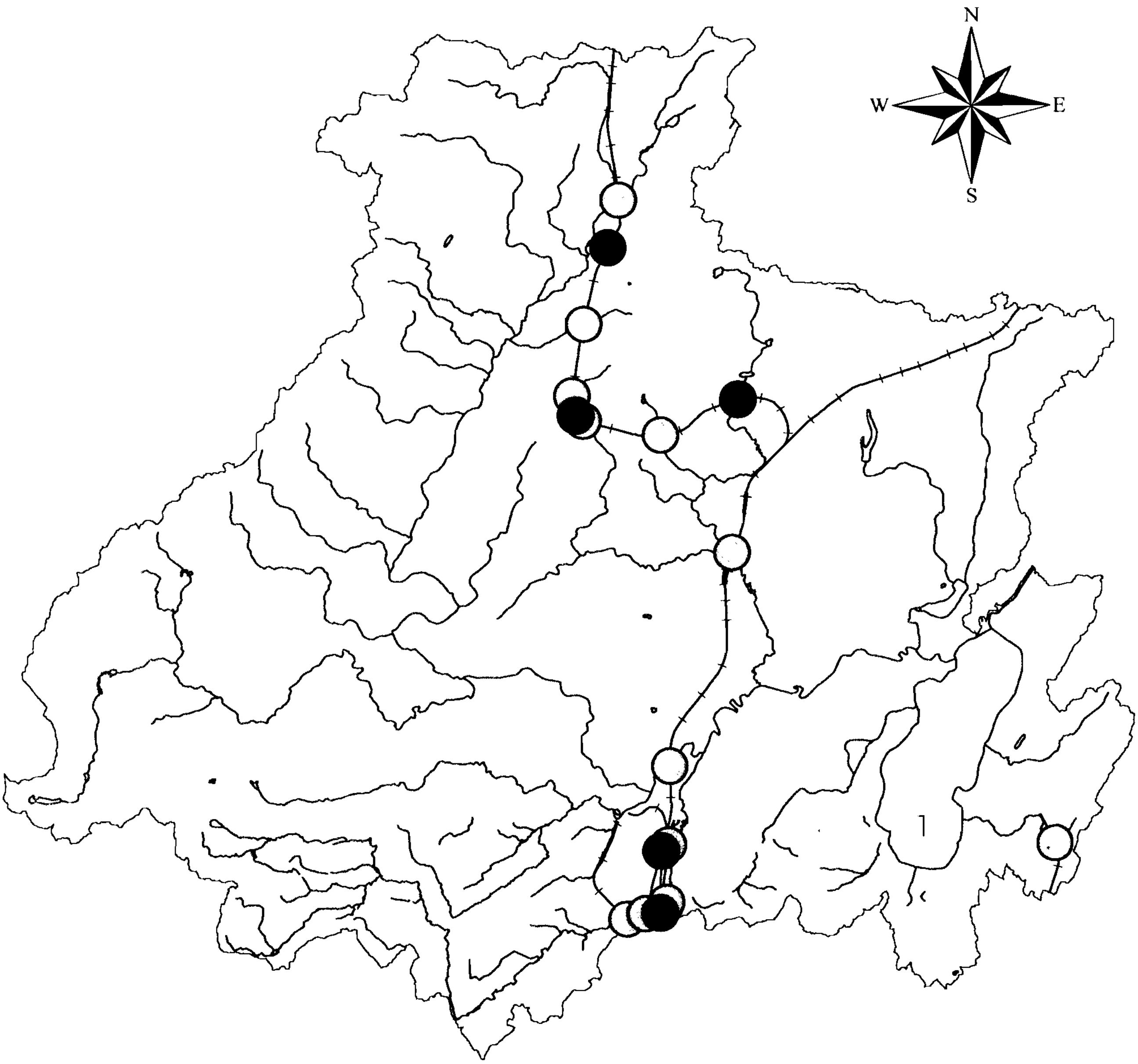


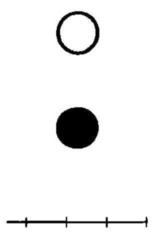
○ Road-Stream Intersections

● Sample Sites

Created by Allison Stafford & Allison Gillum
Skidmore College GIS Center 2006

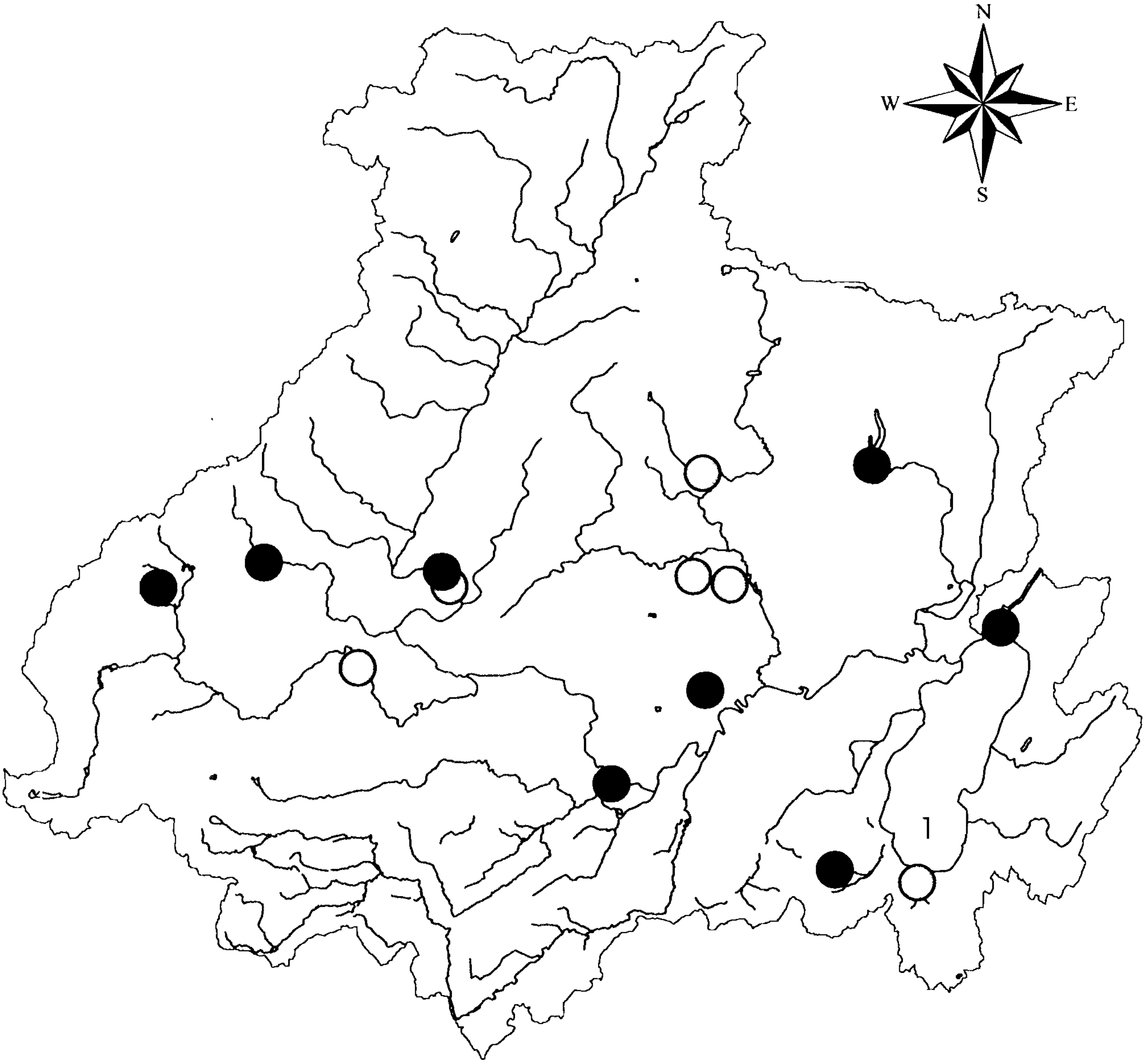
Map 2
Railroad-Stream Intersections in the Saratoga Lake Watershed





Created by Allison Stafford & Allison Gillum
Skidmore College GIS Center 2006

Map 3
Industrial Sites Near Streams in the Saratoga Lake Watershed



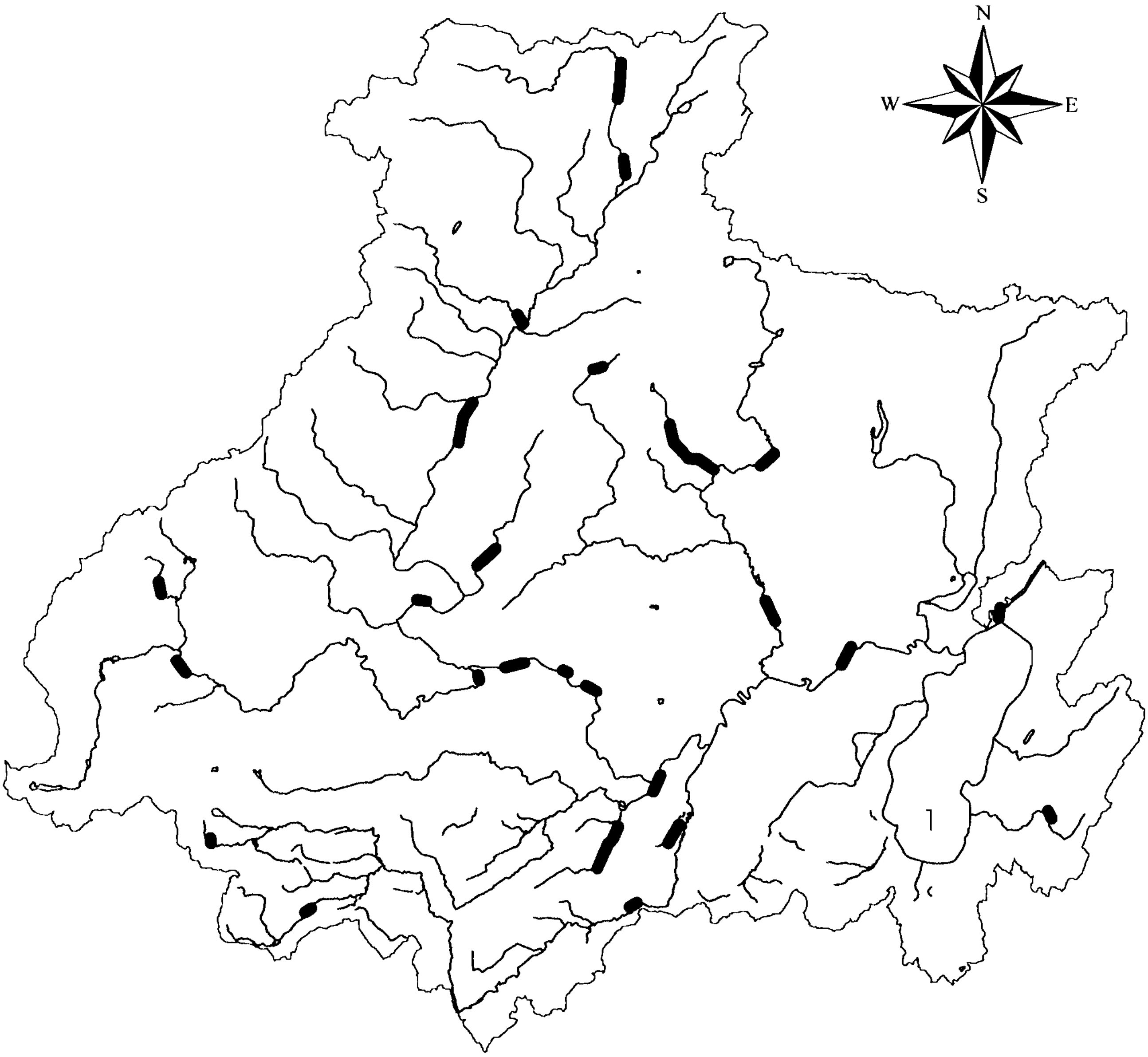
○ No Channelization Found at Industrial Site

● Channelized Industrial Sites

● No Industrial Site Found

Created by Allison Stafford & Allison Gillum
Skidmore College GIS Center 2006

Map 4
Sections of Channelization Caused by the Straightening of Streams Along Roads and Railroads in the Saratoga Lake Watershed



Straightened Sections

Saratoga Lake Stream System

Created by Allison Stafford & Allison Gillum
Skidmore College GIS Center 2006

REFERENCES CITED

Brookes, A. 1985. River channelization: traditional engineering method, physical consequences and alternative practices. Progress in physical geography **9(1)**:44-73.

Caris, J. and L. Wittman. 2005. *Kayaderosseras Creek Watershed: An Examination of Land Use Patterns & Point and Nonpoint Pollution.* ES375 Case Studies in Sustainability, Skidmore College, NY.

Cornell University Geospatial Information Repository. 2000. Hydrography (Census 2000) [shapefile]. <http://cugir.mannlib.cornell.edu/> Accessed February 1, 2006.

Elliot, L. 2003. A new approach to quantifying riparian buffers in the rural-urban fringe in the lower Fraser valley. Georgia Basin /Puget Sound Research Conference.

ESRI. 2000. Line Features-Rails [shapefile]. <http://arcdata.esri.com/data/tiger2000/tiger_download.cfm> Accessed February 1, 2006.

ESRI. 2000. Line Features-Roads [shapefile]. <http://arcdata.esri.com/data/tiger2000/tiger_download.cfm> Accessed February 1, 2006.

Friends of Five Creek (FFC). 2006. Water Quality Monitoring: Turbidity. <http://www.fivecreeks.org/monitor/turbidity.html> Accessed February 23, 2006.

Gordon, N. D., T. A. McMahon, and B. L Finlayson. 1992. Stream Hydrology: An Introduction for Ecologists. John Wiley & Sons, New York, New York, U.S.A.

Hahn, S. 1982. Stream channelization: Effects on stream fauna. Geological Survey Cicular **C0848-A:** 43-49.

Hupp, C. R. 1992. Riparian vegetation recovery patterns following stream channelization: A geomorphic perspective. Ecology **73(4)**:1209-1226.

Kachigan, S. 1986. *Statistical Analysis: An Interdisciplinary Introduction to Univariate & Multivariate Methods.* Radius Press, New York, NY.

Keller, E.A. 2002. *Introduction to Environmental Geology.* Second Edition. Prentice Hall, Upper Saddle River, New Jersey, U.S.A.

Klapproth, J.C. & J. E. Johnson. 2000. *Understanding the science behind riparian forest buffers: Effects on water quality.* Virginia Cooperative Extension Service Publication Number 420-151.

LeJeune, K., T. Podrabsky, J. Lipton, D. Cacela, A. Maest, D. Beltman. 2000. Report of the injury assessment and injury determination: Coeur d'Alene basin natural resource damage assessment. < http://www.fws.gov/filedownloads/ftp_r1contaminants/00i-Chapter_7_Fish_Resources.pdf> Accessed April 15, 2006.

Leopold, L. 1997. *Water, Rivers and Creeks*. University Science Books, Sausalito, California, U.S.A.

Miller, G. T. 2002. *Sustaining the Earth*. Fifth Edition. Brooks/Cole, Belmont, California, U.S.A.

New York State Department of Environmental Conservation (NYSDEC). 2006. Region 5 fisheries: Fishing spots in Saratoga County. <http://www.dec.state.ny.us/website/reg5/r5fish/topfish/stfishsara.html> Accessed May 7, 2006.

New York State Orthoimagery. 2001. New York State Plane NAD 83, US Survey Feet [image file]. < http://www.nysgis.state.ny.us/gateway/mg/2001/saratoga/> Accessed February 1, 2006.

North Carolina Department of Environmental and Natural Resources (NCDENR). 2003. Basinwide assessment report: French broad river basin. <http://wire.enr.state.nc.us/esb/Basinwide/French%20Broad%202003%20Report.pdf> Accessed April 15, 2006.

U.S. Environmental Protection Agency (EPA). February 2006. Polluted runoff (nonpoint source pollution): Management measure for physical and chemical characteristics of surface waters-II: channelization and channel modification management measures. <http://www.epa.gov/OWOW/NPS/MMGI/Chapter6/ch6-2a.html> Accessed February 23, 2006.

U.S. Environmental Protection Agency (EPA). March 2006. Mid-Atlantic integrated assessment: State of the Streams: 1995-1997 Maryland Biological Stream Survey Results. < http://www.epa.gov/maia/html/mbss-ch7.html> Accessed April 15, 2006.

U.S. Geological Survey. 2001. National Land Cover Dataset 2001 - Land Cover [shapefile]. <http://gisdata.usgs.net/Website/Seamless/> Accessed February 1, 2006.

Wiles-Skeels, R. H., and K.K. Nichols. 2004. Evaluating the effect of land use on peak discharge and runoff in the Saratoga Lake watershed. Geological Society of America Abstracts with Programs **36(2):** 127.

Williamson, C. and B. Todd. 2005. Wyaconda River: Watershed inventory and assessment. Conservation Commission of Missouri. <http://mdc.mo.gov/fish/watershed/wyaconda/hardcopy/400lotxt.pdf> Accessed April 15, 2006.

Appendixes

Appendix A. Road-Stream Intersection Sample Sites

Random Order	Id	Latitude	Longitude	Length (ft)	Length (m)	Random Order	Id	Latitude	Longitude	Length (ft)	Length (m)
1	72	43.00177	-73.83336	65	20	**29**	51	42.99242	-73.84002	No Site Found	
2	45	42.99066	-73.88281	58	18	**30**	266	43.19416	-73.82860	32	10
3	35	42.98541	-73.93180	99	30	**31**	204	43.09215	-73.89075	54	16
4	174	43.07842	-73.86487	169	52	**32**	67	42.99827	-73.97187	21	6
5	122	43.04009	-73.88910	39	12	**33**	19	42.97646	-73.95462	41	12
6	113	43.03324	-73.94358	Restricted Area		**34**	205	43.09303	-73.80335	60	18
7	62	42.99708	-73.98464	59	18	**35**	203	43.09202	-73.76800	423	129
8	192	43.08972	-73.98065	39	12	**36**	26	42.97872	-73.95498	40	12
9	202	43.09145	-73.92109	44	13	**37**	248	43.14848	-73.88569	123	37
10	243	43.14069	-73.87968	64	20	**38**	181	43.08369	-73.97470	40	12
11	52	42.99260	-73.97089	31	9	**39**	172	43.07675	-73.93528	40	12
12	66	42.99807	-73.87002	44	13	**40**	142	43.06103	-73.91654	80	24
13	198	43.09082	-73.75067	436	133	**41**	14	42.97420	-73.87502	52	16
14	89	43.01208	-73.89831	49	15	**42**	125	43.04181	-73.77497	325	99
15	256	43.16693	-73.85522	30	9	**43**	257	43.16699	-73.87317	45	14
16	175	43.07911	-73.82725	Restricted Area		**44**	150	43.06490	-73.73262	80	24
17	214	43.10497	-73.93616	50	15	**45**	105	43.02666	-73.76143	43	13
18	156	43.06714	-74.02170	138	42	**46**	269	43.19721	-73.86612	40	12
19	138	43.05697	-74.01578	42	13	**47**	110	43.03143	-73.79000	344	105
20	195	43.09002	-73.72574	55	17	**48**	2	42.96057	-73.90327	51	16
21	224	43.11586	-73.80997	51	16	**49**	233	43.12894	-73.89317	65	20
22	242	43.13783	-73.87762	26	8	**50**	263	43.18673	-73.88464	No Site Found	
23	194	43.08999	-73.84323	37	11	**51**	40	42.98582	-73.77015	40	12
24	20	42.97665	-73.85075	102	31	**52**	6	42.96987	-73.97573	33	10
25	58	42.99638	-73.80602	100	30	**53**	196	43.09015	-73.84350	31	9
26	69	42.99889	-73.88437	52	16	**54**	262	43.18052	-73.84016	50	15
27	97	43.01763	-74.04309	64	20	**55**	183	43.08397	-73.99177	37	11
28	23	42.97744	-73.82812	57	17						

Appendix B. Railroad-Stream Intersection Sample Sites

Id	Latitidue	Longitude	Length (ft.)	Length (m)
1	42.97457	-73.85426	Inaccessible	
2	42.97591	-73.84768	102	31
3	42.97595	-73.84248	Inaccessible	
4	42.99213	-73.84147	52	16
5	42.99214	-73.84200	Inaccessible	
6	42.97873	-73.84020	Inaccessible	
7	42.99236	-73.70333	No Site Found	
8	42.99374	-73.83935	Inaccessible	
9	43.01405	-73.83842	Inaccessible	
10	43.06921	-73.81552	Inaccessible	
11	43.10017	-73.84020	Inaccessible	
12	43.10421	-73.86741	Inaccessible	
13	43.10561	-73.87007	26	8
14	43.10894	-73.81264	136	41
15	43.11067	-73.87128	Inaccessible	
16	43.12922	-73.86679	Inaccessible	
17	43.16144	-73.85379	Inaccessible	
18	43.14912	73.85786	92	28

Appendix C. Industrial Sites

Id	Latitude	Longitude	Length (ft.)	Length (m)	Site Name
1	-73.98173	43.06763	0	0	No Site Found
2	-74.01868	43.06147	338	103	Country Store
3	-73.94880	43.04019	Inaccessible		Knolls Atomic Power Laboratory
4	-73.86034	43.00964	0	0	No Site Found
5	-73.78217	42.98672	0	0	No Site Found
6	-73.72375	43.04891	0	0	No Site Found
7	-73.75355	42.98337	No Channelization Found		Mobile Home Complex
8	-73.82780	43.08946	No Channelization Found		Stewarts Factory
9	-73.76851	43.09108	725	221	Water Treatment Facility
10	-73.91656	43.06105	No Channelization Found		Cottrell Paper
11	-73.83123	43.06285	No Channelization Found		Quad Graphics
12	-73.81841	43.06085	No Channelization Found		Industrial Park
13	-73.82721	43.03340	0	0	No Site Found
14	-73.91870	43.06452	400	122	Old Cottrell

Appendix D. Straightened Channelized Sections along Roads and Railroads

Id	Length (m)
1	1047
2	314
3	739
4	375
5	445
6	560
7	1342
8	503
9	608
10	302
11	524
12	540
13	622
14	260
15	543
16	282
17	725
18	676
19	591
20	244
21	228
22	197
23	143
24	155
25	152
26	342
27	274
28	499
29	466