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GIS BASED ASSESSMENT OF THE IMPACT OF URBAN LAND USE TO SUSPENDED SEDIMENT AND WATER QUALITY IN THE CAZENOVIA CREEK WATERSHED, NEW YORK

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ABSTRACT: *The Buffalo River in Western New York was designated as one of the Areas of Concern by the Great Lakes Water Quality Board of the International Joint Commission due to its poor water quality and contaminated sediments. Cazenovia Creek is one of the three major tributaries of the Buffalo River. This research utilized remote sensing data and Geographic Information Systems (GIS) capability to analyze land use patterns in the Cazenovia Creek watershed and to relate land use patterns to the suspended sediment and water quality data along the creek. The results indicated: (1) Farm and forest mainly occupy the upper reach, mixed urban residential, commercial, and farmland occupy the middle reach, and urban, commercial, and industrial land dominate the lower reach of the watershed; (2) Urban residential, commercial, and industrial areas in the lower part of the watershed generate more suspended sediment than that of the rural farmland and forest areas during the high intensity rainfall events; (3) The higher the intensity of a rainfall event, the higher the difference of suspended sediment concentration between the upper and lower reaches; (4) Low Water Quality Index (WQI) sites for both rainfall events and dry weather periods were located in the urban areas close to the public transportation routes and industries. The distribution pattern suggests that low WQI is related to urban, business, industrial, and transportation type of land uses.*

INTRODUCTION

Cazenovia Creek is one of the three major tributaries of the Buffalo River. Owing to the poor water quality and contaminated sediments, the Great Lakes Water Quality Board of the International Joint Commission (IJC) has designated the Buffalo River as one of the Areas of Concern (AOC) in the Great Lakes Region (International Joint Commission, 1988; New York State Department of Environmental Conservation, 1989). Previous studies (Atkinson et al., 1994; Erie and Niagara Counties Regional Planning Board, 1978; Irvine and Pettibone, 1993, 1996; Irvine, 1996; Pettibone and Irvine, 1994; Wills and Irvine, 1996) have identified the levels of pollutant loading both for the Buffalo River and its tributaries. Research on sediment levels and loads to the Buffalo River and its tributaries has also been conducted (Erie County Department of Environment and Planning, 1978; Meredith and Rumer, 1987; Monahan et al., 1995). A great amount of hydrologic, sedimentary, and chemical pollutant data have been collected and the New York State Department of Environmental Conservation (NYSDEC) also completed a Stage 1 Remedial Action Plan (RAP) for the Buffalo River (NYDEC, 1989).

The ultimate goal of the RAP was to restore the chemical, physical, and biological integrity of the Buffalo River drainage system using the criteria established by IJC in the U.S. – Canada Great Lakes Water Quality Agreement. In order to achieve the objective of the RAP, it is important to continue the effort of identifying and monitoring the pollutant and sediment levels and loads of the river on one hand. On the other hand, it is necessary to identify the impacts of land use, in particular urban land use in the drainage basin, to the water quality and sediment concentration in the river.

Water in a river system, such as the Cazenovia Creek, may be used for variety of purposes, for example, primary contact recreation and fishing. In the mean time, the land in the drainage basin may be used for different purposes such as agriculture, commercial, industrial, residential, and recreation. Each of these land uses will exert a certain amount of stress on the drainage system and impact the surface water quality. For instance, farmland runoff may contribute nutrients, bacteria, and pesticides. While, urban land uses may increase metals, bacteria, and suspended sediment level in the river. This research utilized remote sensing data and Geographic Information Systems (GIS) capability to analyze land use patterns in the watershed and to relate land use patterns to the suspended sediment levels and water quality data along the river. The objective of this research was to analyze the impact of different types of land use in the drainage basin to the pollutant and sediment contents in the river.

According to Robbins et al. (1991), six major components are involved in effective watershed management programs: (1) inventory and characterize the watershed in terms of its physical characteristics, land use, ownership, and water quality; (2) identify the contaminants of concern and the sources of these contaminants; (3) establish the goals of the management program; (4) select appropriate control measures to protect water quality; (5) implement the program through the appropriate channels; (6) monitor and evaluate the effectiveness of the program. This research addresses the components (1) and (2) of the above effective watershed management approaches in the Cazenovia Creek Watershed. In order to improve the water quality, the Erie County Department of Environment and Planning initiated and facilitated the Cazenovia Creek Watershed Management Project (CCWMP). Six major objectives were identified in this project. They were:

(1) Introduce the Cazenovia Creek watershed communities to integrated watershed management.
(2) Develop a Cazenovia Creek watershed land use profile using Geographic Information System (GIS) data layering capabilities.
(3) Conduct a limited sampling program to determine existing pollutant levels and provide information on the creek's hydrology.
(4) Prepare a watershed pollutant loading model, based on data from items 1, 2, and 3, that will help determine existing pollutant loads and predict the effects of remediation efforts.
(5) Develop a Cazenovia Creek Watershed Management Plan, guided by the work of the Cazenovia Creek watershed communities.
(6) Work with the watershed communities to develop and implement nonpoint source pollution prevention strategies (Irvine, 1996; DePinto and Sibiga, 1998).

In particular, this study addresses objective 2 of the CCWMP and makes the connections of objective 2 with objective 3 using GIS capabilities and the field sampling data from this study as well as from previous research (Irvine, 1996).

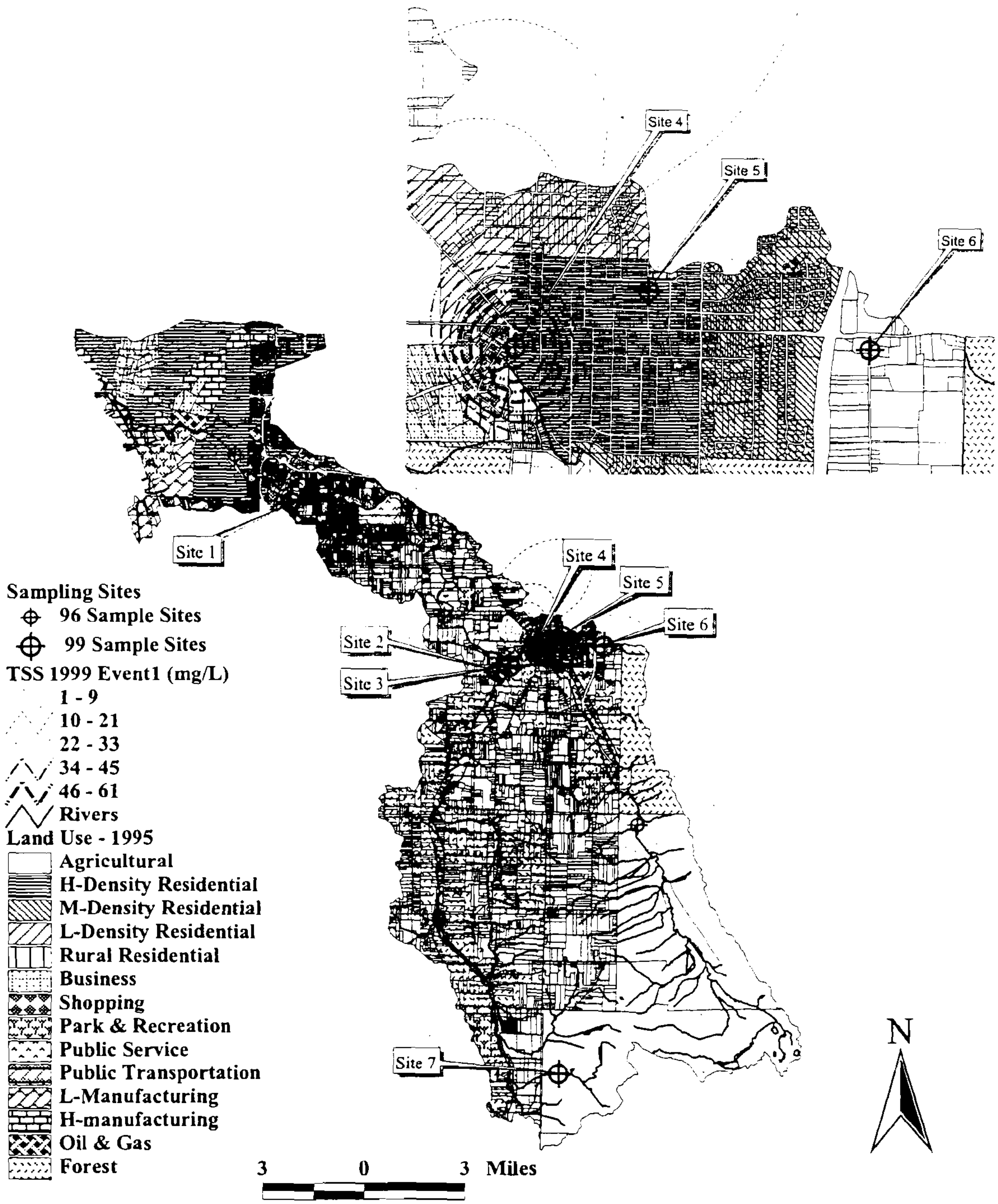
THE STUDY METHODS

Sample Site Selection and Sample Collection

The water sampling of the current research inherited four sampling sites used in previous studies (Irvine and Pettibone, 1996; Irvine, 1996) and established three additional specific sampling sites in the Village of East Aurora to identify possible pollutant and sediment sources to the Cazenovia Creek. One of the sampling sites of the previous study (Irvine, 1996) was also selected for sediment concentration analysis. The previous studies (Irvine and Pettibone, 1996; Irvine, 1996) had suggested that the village had a significant impact on water quality in the Cazenovia Creek. The sampling locations are presented in Figure 1.

The major criteria of the site selection were: (1) accessibility, (2) representation of upper, middle, and lower reaches of the river system, and (3) sample locations from previous studies. Sampling was done by two teams during the 1996 field season. All the water samples were collected by one team during the field sampling of this study in 1999. The method of collecting the water samples is to grab samples

Figure 1. Overlay of sediment concentration of 1999 event #1 and land use



manually from the mid-channel and at the 60% depth of river from the surface. All the water samples were collected individually at each sample site for each sample date.

Remote Sensing, GIS, and GPS Data Acquisition

In order to establish the Cazenovia Creek GIS database for land use analysis, land parcel level data were obtained from the Erie County Water Authority. Soils and drainage basin boundaries data were obtained from the USDA Natural Resources Conservation, East Aurora office. The different map layers were compiled into the State Plane Coordinate system with NAD (North American Datum) 83 datum.

The map layer of the boundary of the Cazenovia Creek watershed as well as lower part of the Buffalo River drainage basin was used to "cookie cut" through various layers to create the database for analysis. The Erie County Water Authority parcel data does not cover the City of Buffalo and part of the upper reach area of the Cazenovia Creek watershed. The US Census block groups in those areas were merged with the parcel data to fill the gap.

The GeoExplorer II GPS unit from Trimble Navigation Inc. was used to collect position data of the sampling sites in the field. The latitude and longitude coordinates measured in the field were translated into the State Plane NAD 83 coordinate system by the Pathfinder Office software and exported to ArcView GIS to create an event theme. Water quality data were input into the database as attributes to each of the sampling points. Hardcopies of the USDA/USGS 1995 NAPP air photos were used to interpret the current land use, and the 1978 round of air photos were used to interpret land use of 1970s. This paper will focus on the current land use.

Analyses of Land Use, Total Suspended Sediment (TSS), and Water Quality Index

Many land use classifications have been published from previous studies for different purposes. Generally speaking, these land use classification schemes can be identified into two categories: (1) Urban land use planning and property tax assessment, such as land use classification from the Erie County Real Property Information System (Erie County of Environment and Planning, 1997); (2) Natural resource inventory and environmental conservation, such as LUNR-New York State Land Use and Natural Resource Inventory (Hardy et al., 1971). Based on the review of various land use classifications, the following scheme was proposed for this study. The major characteristic of this classification scheme is to group urban land use and tax assessors parcel level information to fulfill the requirements of environmental impact assessments. The land use classification is as follows (Table 1). Types of land use were visually identified from the air photos and coded into the parcel polygon database. The result was re-evaluated using the 1995 digital orthographic air-photo quadrangles (DOQQ) that were published in August of 1999. The digital format can be loaded into ArcView GIS and can zoom in with up to five meters ground resolution. The land use within the drainage basin was then thematically mapped using type as the unique value.

Total suspended sediment (TSS), parameters of water quality, and two metals (total lead and iron) were analyzed from the water samples collected along the river. Total suspended sediment (TSS) was analyzed using the filtration method (Standard Method 2540D) that is outlined in the Standard Methods for the Examination of Water and Wastewater (American Public Health Association et al., 1989). Samples were stored in room temperature prior to filtration and each sample collected for TSS was passed through a 0.45 µm Millipore filter.

Water quality factors were summarized using the National Sanitation Foundation Water Quality Index (WQI) developed by Brown et al. (1970). Wills and Irvine (1996) conducted detailed WQI evaluations and analyses for the Cazenovia Creek. There are nine WQI components: dissolved oxygen, fecal coliform density, pH, BOD5 (biochemical oxygen demand), nitrates, total phosphates, Δt °C from equilibrium, turbidity, and total solids. Dissolved oxygen was measured in the field using a Dissolved Oxygen Meter (Model 508, YSI, Inc., Ohio, 45387). Fecal coliform density of water samples was analyzed by membrane filtration method following the Standard Methods 9222D (APHA, 1989). pH and water temperature (°C) were measured in the field using a pH meter (Model 5985-80, Cole-Parmer Instrument, Inc., Chicago, IL 60648). BOD5 of each water sample was determined

Table 1. Land use classification scheme

Land Use	Code
Agricultural Land	100
Residential Land	200
a. High Density Residential	210
b. Medium Density Residential	220
c. Low Density Residential	230
d. Rural Residential	240
Mixed Land Use Types	300
a. Transition Land from Rural to Urban	310
b. Transition Land from Forest to Agriculture	320
Commercial Land Use	400
a. Business Center	410
b. Shopping Center	420
Parks and Urban Recreation Land	500
Public Services	600
a. Public Service Institutions	610
b. Transportation	620
Industrial Land	700
a. Light Manufacturing	710
b. Heavy Manufacturing	720
c. Mining	730
d. Oil and Gas Industry	740
Forest Land	800

using the oxygen depletion approach following Standard Method 5210 B (APHA, 1992). Nitrate/nitrite for each sample was done using the Cadmium Reduction method listed by Standard Methods 4500-NO3-E (APHA 1992). Total phosphate of each sample was analyzed using the combined ascorbic reagent method, Standard Method 4500-PE (PHA1992). Turbidity for each of the water samples was measured using a Turbidity Meter (H. F. Scientific, Inc., Model DRT-15B) for the current research (1999 sampling). Turbidity data of 1996 water samples were estimated based on previous studies (Atkinson et al., 1994). The descriptions of water quality with WQI value ranges were proposed by Mitchell and Stapp (1995) and are listed in Table 2.

Results of TSS and WQI were input into ArcView GIS as a database file. A point event theme was created using the stand alone database file. Isolines of TSS concentration data were created using Spatial Analyst of ArcView GIS to identify the trend of TSS generation and possible relations of TSS distribution with different types of land use in the watershed.

Low water quality sites along the river were queried for each of the sampling rounds according to the criteria listed in Table 2. Statistical analysis of WQI for all the sites indicated that there is no significant difference of WQI between rainfall events and dry weather periods during the 1999 sampling season, while significant difference was found from the results of 1996 sampling season (Wills and Irvine, 1996). Therefore, the sites with a WQI value ≤ 70 were selected for both event and non-event samples in this analysis. A distance theme was created for the selected sites using the distance analysis function in Spatial Analyst of ArcView GIS. The distance theme was then reclassified using 0.25 miles (1320 feet) as the first zone and 0.5 miles (2640 feet) as the second zone surrounding the selected sites. The land use theme was converted to a grid theme. The selected 0.25 mile and 0.5 mile zones were overlaid onto the land use grid theme to identify the land use types within the above ranges. The final results were presented as histograms. The ranges of 0.25 miles

Table 2. Water quality description by WQI value range.

Water Quality Description	WQI Value Range
Very Bad	0-25
Bad	26-50
Medium	51-70
Good	71-90
Excellent	91-100

(1320 feet) and 0.5 miles (2640 feet) were arbitrarily selected as the primary concern of impact areas because the land use activities in adjacent areas to the sampling site usually make the largest impact. The further away from the site, the less influence due to more land mass media to absorb, trap, and filter pollutants and sediment.

RESULTS AND DISCUSSION

It was found through land use analysis that (1) farmland and forest mainly occupy the upper reach of the Cazenovia Creek watershed; (2) the mixed urban and sub-urban residential, commercial, and farmland mainly occupy the middle reach of the watershed; (3) the urban residential, commercial, and industrial land uses mainly occupy the lower reach of the watershed (Figure1).

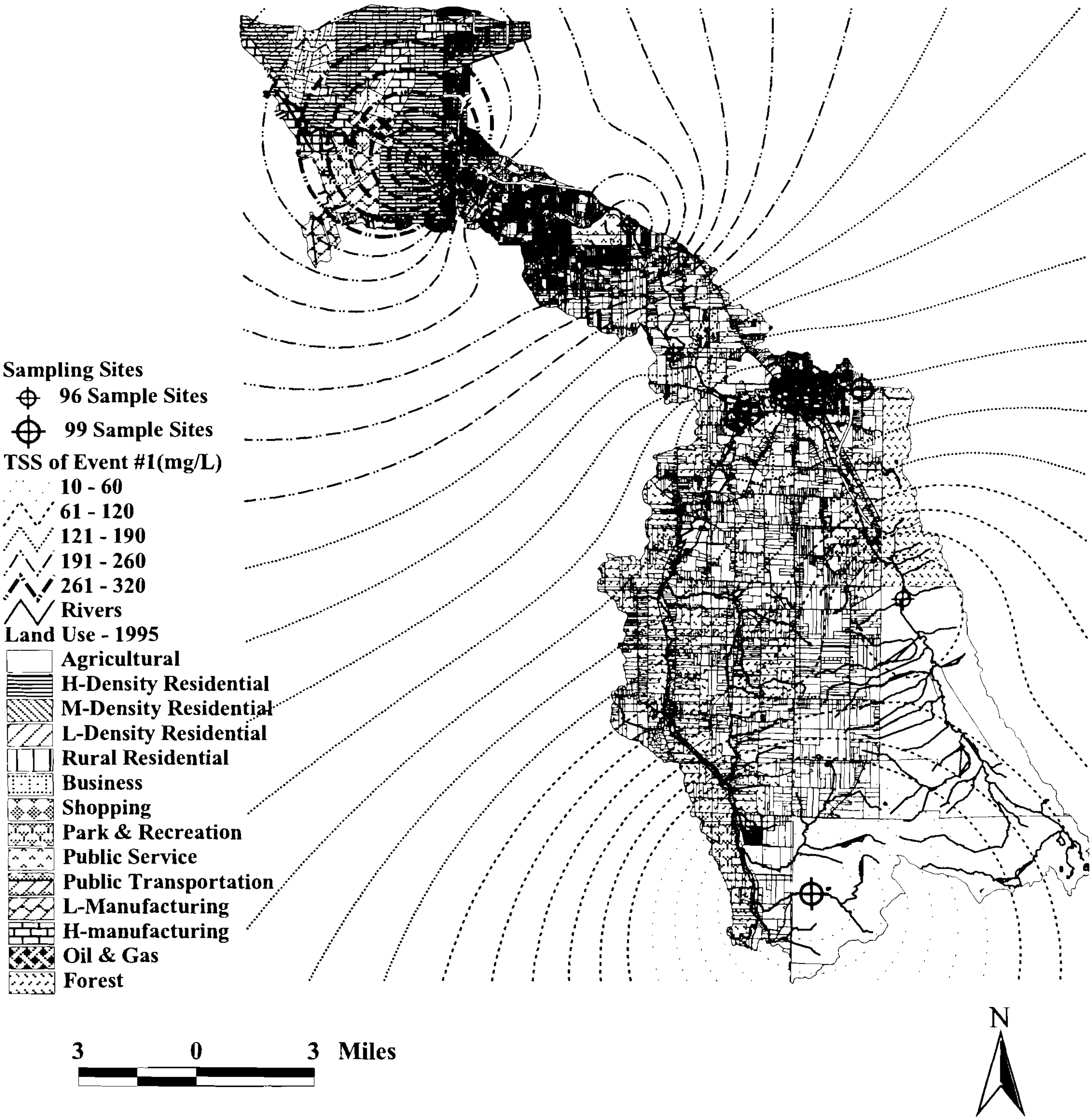
Daily and annual stream flow analysis for the three tributaries of the Buffalo River with 45-year flow data (Meredith and Rumer, 1987) indicated that the probability of daily flow equaling or exceeding 2,000 cfs (56.6 cms) is 1% at the Site 1. The study also indicated that the probability of daily flow to exceed 500 cfs (14.1 cms) is around 20% at the same location. These criteria were used to identify high intensity and low intensity rainfall events. A high intensity rainfall event is defined as a flow > 2,000 cfs (56.6 cms). A low intensity rainfall event is an event when daily flow falls in between 500 cfs (14.1 cms) and 2,000 cfs (56.6 cms).

Overlaying the trend of suspended sediment concentration of the low intensity rainfall events along the river, such as event #1 of 1999 (Figure 1), onto the land use, it suggests that middle reach mixed farmland and urban areas may generate more suspended sediment than the lower reach areas. Overlaying the trend of suspended sediment concentration of the high intensity rainfall events along the river, such as event #1 of 1996 (Figure 2), onto the land use in the watershed, it was found that total suspended sediment (TSS, mg/L) increases from upper reach to lower reach. The trend also suggests that urban residential, commercial, and industrial areas in the lower part of the watershed generate higher suspended sediment concentrations than the rural farmland and forest areas during major storm events. The results also indicted that the higher the daily flow intensity, the higher the difference of sediment concentration between the upper reach and lower reach.

During the non-event or dry periods, the magnitude of suspended sediment concentration was much lower than that during the event or rainfall periods throughout the whole drainage basin. There is no clear pattern of the suspended sediment concentration along the river during the dry weather. The mean suspended sediment concentration during rainfall events is 63 mg/L and that during the dry weather periods is 4 mg/L.

Results of sediment concentration analysis coincide with a previous study of sediment dynamics (Meredith and Rumer, 1987) which indicated that there is no clear pattern of sediment trend from upper reach to lower reach in the non-event periods. This suggests that the Buffalo River is a possible trap to sediment inflow along the system with the discharges less than 500 cfs (20% probability). While, the range of sediment concentration from upper reach to lower reach is relatively high during the high intensity rainfall storm and some proportion of the sediment may possibly be discharged to the Lake Erie. In consideration of distribution pattern of sediment concentration along the river during the high intensity rainfall event, the results indicate that most of the sediment transported to the Buffalo River Harbor in the Lake Erie was generated from lower watershed

Figure 2. Overlay of sediment concentration of 1996 event#1 and land use



areas. This suggests further that urban and industrial type of land use activities in the lower watershed area might contribute a large impact on the accumulation of contaminated sediment in the harbor.

Results of the water quality index (WQI) analysis indicated that WQI of four sampling sites were equal or less than 70 during the rainfall event #1 of 1996 (Wills and Irvine, 1996). Three of the sites are located in the lower reach area and one of them is located in the middle reach area just below the Village of East Aurora. The results of the grid theme and distance analysis showed that the distribution of land use within the 0.25 mile range from highest to lowest by relative areas are high density residential, mid-density residential, business, parks and recreation, public transportation, and shopping centers for the four sites identified (Figure 3).

The land use pattern of the 0.5mile range is similar to that of 0.25 mile range (Figure 3). The site with a WQI less than 70 during both dry weather sampling #2 and #3 of 1999 is the site in the middle reach of the Tannery Brook in the Village of East Aurora. The pattern of land use in the 0.25 mile and 0.5 mile ranges of this site is similar to that of the rainfall event #1 of 1996. WQI of three sampling sites was equal or below 70 during rainfall event #1 of 1999. All these sites are located along the Tannery Brook in the Village of East Aurora, which is a major tributary of the Cazenovia Creek. The distribution of land use from highest to lowest occupations within the 0.25mile range are mid-density residential, high density residential, rural residential, parks and recreation, oil and gas related industries, and business centers for the three identified sites (Figure 4). The land use distribution within the 0.5mile range decreases from mid-density residential to high density residential and to business, shopping centers, and parks for the three sites (Figure 4). In general, the results of WQI analysis suggest some local industrial and commercial types of land use might contribute to the low water quality of these sites.

In summary, the results of analysis for the relations of suspended sediment and land use patterns in the Cazenovia Creek watershed suggest: (1) during the major or high-intensity rainfall events, urban residential, commercial, and industrial areas in the lower watershed generate higher suspended sediment than that of rural farmland and forest regions in the upper watershed; (2) the higher the rainfall event intensity, the higher the difference of suspended sediment concentration between the upper reach and the lower reach of the river; (3) suspended sediment concentration is much higher during the event period than that in the non-event period; (4) farmland may yield more suspended sediment than that of urban areas during low intensity rainfall events. The high suspended sediment concentration from urbanized regions during the major rainfall events could result from low infiltration and high runoff. However, further studies are needed before any conclusion and prediction can be made.

Relational analysis of WQI and land use in the drainage basin indicates that:

(1) The low water quality sites are either located in the lower reach urban area or middle reach Village of East Aurora area.
(2) There was no significant statistical difference (t tests) of WQI of all sites between rainfall events and dry weather periods during the 1999 sampling season. The low WQI sites of dry weather periods generally coincide with those of rainfall events. However, more low WQI sites usually occur during the rainfall events than the dry weather periods. This is coincident with the WQI results of 1996 (Wills and Irvine, 1996).
(3) The distribution pattern suggests that low WQI sites of both rainfall events and dry weather periods are located in the urban residential and business or shopping center areas close to the public transportation routes or industries.

This study characterized the land use pattern in the Cazenovia Creek watershed and identified some relationships of land use in the watershed and water quality along the river. The results suggested that a variety of urban land use, in particular industry type of land use, make clear impact to the river system. The study also demonstrated that GIS and remote sensing methods can be used as an effective "tool" for collecting, managing, and analyzing the influential factors of water quality in the drainage basin wide scale. It is important and essential to collect data of the major parameters of water quality in a drainage basin in order to set up a base for modeling and predicting the water quality change of the river.

Figure 3. Land Use within 0.25 and 0.5 Mile of Low WQI Sites of 96 Event#1

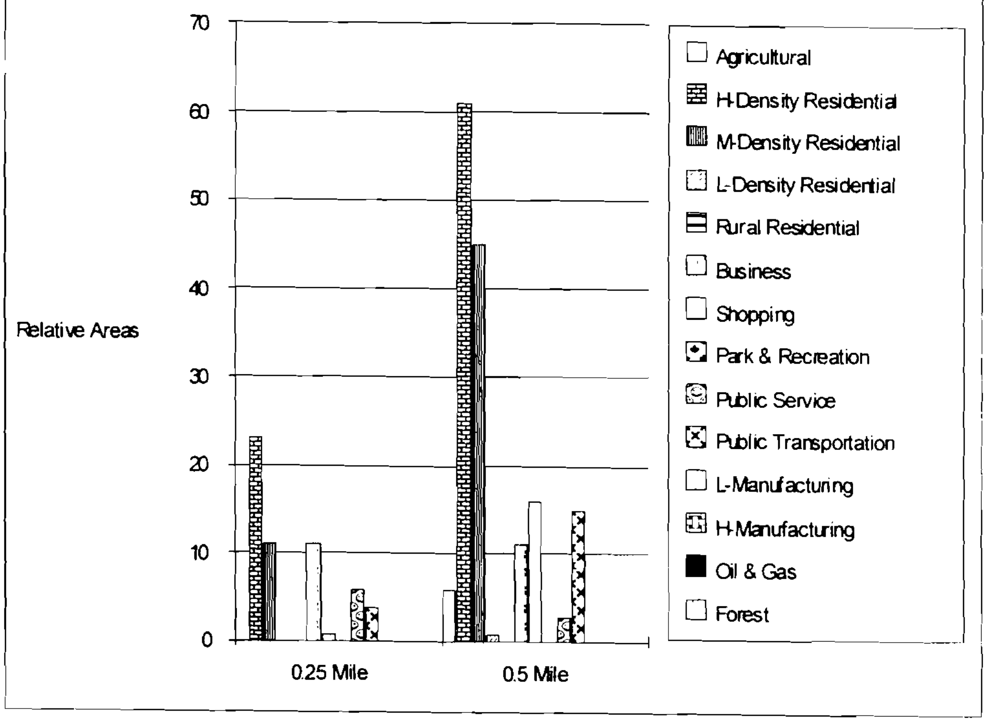
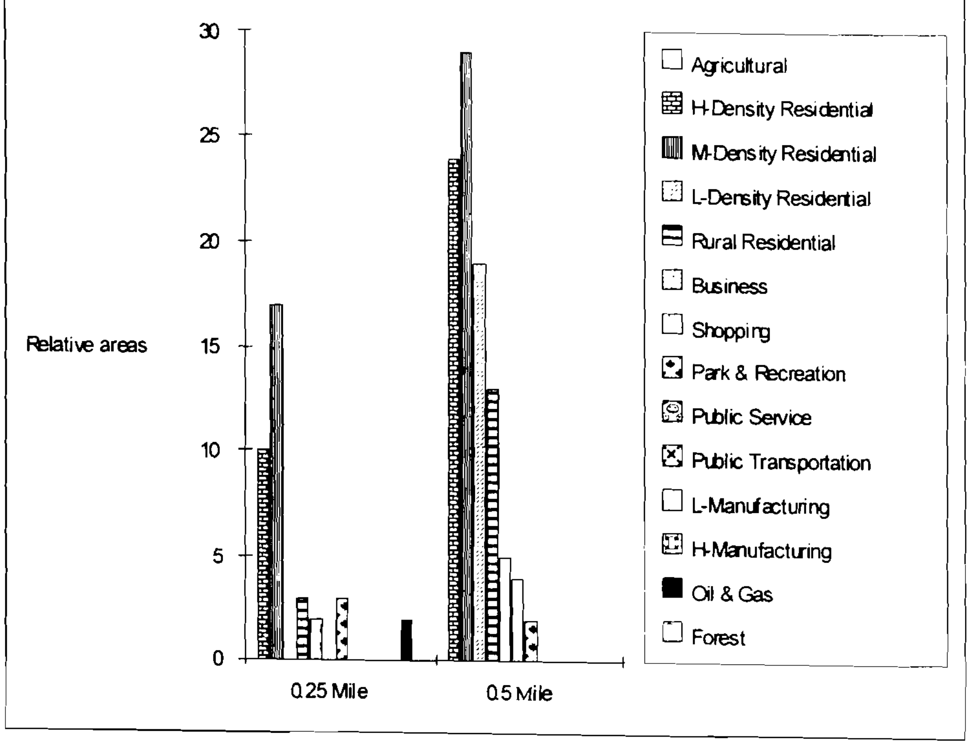


Figure 4. Land Use within 0.25 and 0.5 Mile of Low WQI Sites of 99 Event#1



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