Prepared in cooperation with the Onondaga Lake Partnership

Water-Quality Characterization of Surface Water in the Onondaga Lake Basin, Onondaga County, New York, 2005–08

Scientific Investigations Report 2009–5246

U.S. Department of the Interior
U.S. Geological Survey

Cover. Photographs showing land types that are representative of those found in the Onondaga Lake basin, New York, including a steep boulder-covered channel in a forested basin (2007), a low-gradient channel in a wetland area (2005), an agricultural area overlooking Otisco Lake (2008), and commercial and transportation land uses in an urban setting (2008). All photos were taken by William F. Coon.

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

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Conversion Factors, Datum, and Abbreviations

Inch-Pound to International System (SI) Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton per day (ton/d)	0.9072	metric ton per day
ton per year (ton/yr)	0.9072	metric ton per year

Conversion Factors, Datum, and Abbreviations—Continued

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F-32)/1.8$$

Datums

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Time Abbreviations

h	hour
min	minute
s	second

Chemical Abbreviations

N	Nitrogen
NH_3	Ammonia
NO_2	Nitrite
NO_3	Nitrate
NO_x	Nitrate-plus-nitrite
OrgN	Organic nitrogen
OrgP	Organic phosphorus
P	Phosphorus
PO_4	Orthophosphate
SC	Specific conductance
SS	Suspended-sediment
TKN	Ammonia-plus-organic nitrogen (total Kjeldahl nitrogen)
TSS	Total suspended solids

Other Abbreviations

AEM	Agricultural Environmental Management
HYSEP	USGS Hydrograph separation and analysis program
LOADEST	USGS Load estimation program
NLCD	National Land Cover Data
OCWA	Onondaga County Water Authority
RMSE	Root mean squared error
RMSEn	Root mean squared error normalized
USGS	U.S. Geological Survey
WEP	Onondaga County Department of Water Environment Protection

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By William F. Coon, Brett A. Hayhurst, William M. Kappel, David A.V. Eckhardt, and Carolyn O. Szabo

Abstract

Water-resources managers in Onondaga County, N.Y., have been faced with the challenge of improving the water-quality of Onondaga Lake. To assist in this endeavor, the U.S. Geological Survey undertook a 3-year basinwide study to assess the water quality of surface water in the Onondaga Lake Basin. The study quantified the relative contributions of nonpoint sources associated with the major land uses in the basin and also focused on known sources (streams with large sediment loads) and presumed sinks (Onondaga Reservoir and Otisco Lake) of sediment and nutrient loads, which previously had not been evaluated.

Water samples were collected and analyzed for nutrients and suspended sediment at 26 surface-water sites and 4 springs in the 285-square-mile Onondaga Lake Basin from October 2005 through December 2008. More than 1,060 base-flow, stormflow, snowmelt, spring-water, and quality-assurance samples collected during the study were analyzed for ammonia, nitrite, nitrate-plus-nitrite, ammonia-plus-organic nitrogen, orthophosphate, phosphorus, and suspended sediment. The concentration of total suspended solids was measured in selected samples. Ninety-one additional samples were collected, including 80 samples from 4 county-operated sites, which were analyzed for suspended sediment or total suspended solids, and 8 precipitation and 3 snowpack samples, which were analyzed for nutrients. Specific conductance, salinity, dissolved oxygen, and water temperature were periodically measured in the field.

The mean concentrations of selected constituents in base-flow, stormflow, and snowmelt samples were related to the land use or land cover that either dominated the basin or had a substantial effect on the water quality of the basin. Almost 40 percent of the Onondaga Lake Basin is forested, 30 percent is in agricultural uses, and almost 21 percent, including the city of Syracuse, is in developed uses. The data indicated expected relative differences among the land types for concentrations of nitrate, ammonia-plus-organic nitrogen, and orthophosphate. The data departed from the expected relations for concentrations of phosphorus and suspended sediment, and plausible explanations for these departures were posited. Snowmelt concentrations of dissolved constituents generally were greater and those of particulate constituents were less than concentrations of these constituents in storm runoff. Presumably, the snowpack acted as a short-term sink for dissolved constituents that had accumulated from atmospheric deposition, and streambed erosion and resuspension of previously deposited material, rather than land-surface erosion, were the primary sources of particulate constituents in snowmelt flows.

Longitudinal assessments documented the changes in the median concentrations of constituents in base flows and event flows (combined stormflow and snowmelt) from upstream to downstream monitoring sites along the two major tributaries to Onondaga Lake—Onondaga Creek and Ninemile Creek. Median base-flow concentrations of ammonia and phosphorus and event concentrations of ammonia increased in the downstream direction in both streams. Whereas median event concentrations of other constituents in Onondaga Creek displayed no consistent trends, concentrations of ammonia-plus-organic nitrogen, orthophosphate, phosphorus, and suspended sediment in Ninemile Creek decreased from upstream to downstream sites. Springs discharging from the Onondaga and Bertie Limestone had measureable effects on water temperatures in the receiving streams and increased salinity and values of specific conductance in base flows.

Loads of selected nutrients and suspended sediment transported in three tributaries of Otisco Lake were compared with loads from 1981–83. Loads of ammonia-plus-organic nitrogen and orthophosphate decreased from 1981–83 to 2005–08, but those of nitrate-plus-nitrite, phosphorus, and suspended sediment increased. The largest load increase was for suspended sediment; the yields were from 100- to 400-percent greater during 2005–08 than during 1981–83.

Major sediment sources in the upper Onondaga Creek Basin near Tully Valley, including Rainbow Creek, Rattlesnake Gulf, and the mudboil area—a groundwater source of fine-grained sediment—were monitored. Mudboil sediment inputs increased base-flow sediment concentrations in Onondaga Creek, but loads from Rainbow Creek and Rattlesnake Gulf were larger. Sediment loading rates from Rainbow Creek, with a drainage area less than 15 percent that

of Onondaga Creek at their confluence, were slightly greater than those for Onondaga Creek for base flow and stormflows. The loading rate of Rattlesnake Gulf was 3 times greater than that of Onondaga Creek under base-flow conditions, and 15 times greater during stormflows.

The water-quality mitigative effects of Onondaga Reservoir and Otisco Lake were assessed. Onondaga Reservoir and the low slope of Onondaga Creek upstream and downstream from the reservoir had little effect on nutrient and sediment loads carried by base flows but decreased storm loads by 40 to 60 percent. Otisco Lake has a large nutrient and sediment detention capability. Median lake outflow concentrations of ammonia-plus-organic nitrogen and nitrate-plus-nitrite were 65 and 83 percent less than the respective averages of the median concentrations in three tributaries to the lake. The median lake outflow concentrations of phosphorus and suspended sediment were only 9 and 4 percent, respectively, of the average of the three inflow median concentrations.

Concentrations of suspended sediment and total suspended solids were compared for a subset of samples and showed a negative bias in concentrations of total suspended solids; that is, concentrations of total suspended solids were significantly less than concentrations of suspended sediment. No identifiable relation existed between concentrations of suspended sediment and total suspended solids, or between either of these constituents and streamflow. Therefore, concentrations of suspended sediment and total suspended solids are not interchangeable and should not be substituted for each other.

Introduction

Onondaga Lake, which covers 4.5 mi^2, lies near the center of Onondaga County in central New York (fig. 1); the basin stretches southward and encompasses 285 mi^2 of mixed land uses. Onondaga Lake has been identified as one of the Nation's most contaminated lakes because of industrial and wastewater-treatment discharges, combined storm-and-sanitary-sewer overflows, and rural and urban nonpoint sources of pollution (Onondaga Lake Partnership, 2006; Effler and Hennigan, 1996). Consequently, Onondaga Lake has received priority cleanup status under the national Water Resources Development Act of 1990 (U.S. Congress, 1990).

Members of the Onondaga Lake Partnership, a collaboration of Federal, state, and local agencies, are committed to improving the water quality of Onondaga Lake. Onondaga County Soil and Water Conservation District (2009) has promoted best-management practices to decrease loads of nutrients and sediment from agricultural lands. Onondaga County Department of Water Environment Protection (2007) has abated or closed many of the outflows from combined sanitary-and-storm sewers in the city of Syracuse and has upgraded treatment capabilities for removal of nutrients in effluent from the Syracuse Metropolitan wastewater-treatment plant (Onondaga County Department of Water Environment Protection, 2006). Discharges from industries near the lake have been discontinued or greatly decreased over the past three decades (Effler, 1996). Despite these efforts, phosphorus (P) and nitrogen (N) loadings to Onondaga Lake have fallen short of target levels set by the Onondaga Lake Partnership because of inputs from nonpoint sources of pollution.

The major nonpoint sources of pollution are in urban and agricultural areas. Urbanization, which is characterized by an increase in impervious surfaces and an increase in the hydraulic efficiency by which water moves from land surfaces to a drainage system, reduces infiltration of precipitation and decreases traveltime of storm runoff. These changes, in turn, increase runoff and peak flows. Urbanization also increases the quantity of chemicals that can be deposited on (airborne contaminants from industries and motor vehicles) or applied to (fertilizers, pesticides, and herbicides) land surfaces, which commonly are connected directly to natural (stream channels) or man-made (ditches and culverts) drainage systems. This combination of factors results in increases in post-development chemical loads carried by storm runoff.

Agricultural areas can contribute large loads of nutrients, pesticides, and sediment to nearby streams. Best-management practices that focus on erosion control and nutrient management, such as guidance on manure spreading and fertilizer application, have been implemented on many farms in the watershed and presumably have a beneficial effect on water quality, but this effect has not been quantified in the Onondaga Lake Basin. Farmsteads that raise livestock in confined areas, primarily dairy cows, can be point sources of pollution, as well as nonpoint sources when manure spreading on nearby fields is used as a waste-disposal practice.

The various sources of pollution create a complex water-resources challenge for Federal, State, and local agencies that have been charged with improving the water quality of Onondaga Lake (Onondaga County Department of Water Environment Protection, 1998). The magnitude of the respective contributions from these sources need to be assessed, and the possible mitigative measures that could be used to decrease loads from any one source and their associated costs need to be evaluated to enable the development of a strategy by which total chemical loads to the lake can be decreased. Development of this strategy is complicated by the natural variability of hydrologic and water-quality processes, the complexity of nutrient runoff and transport relations, and the spatial and temporal variability of these relations among the subbasins within the Onondaga Lake Basin. Many mitigative steps have been implemented in the basin on a site-specific basis, that is, a particular farm or an urban neighborhood. Coordinated efforts to address this problem have seldom been undertaken basinwide, and downstream problems typically cannot be solved without the cooperation of those who live in the upstream areas of the basin.

Base from U.S. Geological Survey, Seamless Data Distribution System, accessed in 2006 at http://seamless.usgs.gov
Universal Transverse Mercator projection, Zone 18

Figure 1. Locations of water-quality monitoring sites in the Onondaga Lake Basin, Onondaga County, N.Y.

In 2005, the U.S. Geological Survey (USGS), in cooperation with the Onondaga Lake Partnership, began a 3-year program to assess the water quality of surface water in the Onondaga Lake Basin and to address the issues discussed in the preceding paragraphs. Water samples were collected at 26 surface-water sites and 4 springs from October 2005 through December 2008 and were analyzed for nutrients and suspended sediment (SS).

Previous Studies

Paschal and Sherwood (1987) provided estimates of sediment and nutrient loads from the five main tributaries of Otisco Lake during 1981–83 and related sediment and nutrient loads to land use, geology, and soil type. Disproportionately large sediment and nutrient loads were attributed to Spafford Creek compared to those generated in other subbasins. Callinan (2001) presented temperature and water-quality data for Otisco Lake during 1996–99, discussed trends in water-quality characteristics, and reported a high sediment accumulation rate—0.29 in/yr—for the lake.

Sullivan and Moonen (1994) conducted a survey of the Onondaga Lake Basin, inventoried sites of roadbank and streambank erosion, and estimated a total annual gross sediment load of 2,650 tons from these sources, of which an estimated net sediment load of 89 ton/yr (3.4 percent) was delivered to Onondaga Lake. Most of the erosion occurred in the Onondaga Creek Basin, and more than 80 percent of this load was generated by erosion of streambanks, rather than roadbanks. Blatchley (2000) repeated the inventory but only for the Onondaga Creek Basin and estimated that 2,020 tons of sediment were eroded from this basin alone, of which 69 tons (also 3.4 percent) were transported to Onondaga Lake.

Effler and others (1992) conducted a study of concentrations and loads of suspended solids in Onondaga Creek and found that most of the suspended-solids load transported during storm runoff was resuspended stream sediment and eroded bank material. On the basis of microscopy-based analyses of individual particles, they further concluded that the ultimate source of most of this material was the mudboils near the southern end of the basin.

Kappel and others (1996), Kappel and McPherson (1998), and Kappel (2009) documented the activities of mudboils—volcano-like cones of fine sand, silt, and clay created by artesian-pressured discharge of sediment-laden groundwater along Onondaga Creek near Tully Valley—and their large contributions of sediment to Onondaga Creek. Tamulonis and others (2009) documented the causes and movement of landslides at Rainbow Creek and Rattlesnake Gulf in the Tully Valley. Particle-size data and sediment concentrations and loads from the mudboils were published in USGS annual water-data reports from 1991 through 2007 (Hornlein and others, 1993 through 2002; U.S. Geological Survey, 2009).

The Upstate Freshwater Institute (2004) conducted a 1-year (2002–03) water-quality study of the Onondaga Creek Basin. Surface grab samples from eight sampling sites were analyzed for total P, total dissolved P, soluble reactive P (orthophosphate [PO_4]), nitrate-plus-nitrite (NO_x), total ammonia (NH_3), total suspended solids (TSS), and other constituents. Only one storm, which happened to fall within the biweekly sampling schedule of the study, was sampled; all other samples were collected during low-flow periods.

Prestigiacomo and others (2007) collected bi-weekly water samples from Onondaga Creek (at Dorwin Avenue) and sites near the mouths of Ley Creek and Ninemile Creek from 2001 to 2005. Concentrations of TSS were measured and used to compute TSS loads to Onondaga Lake. On the basis of these load estimates, Onondaga Creek contributed about 60 percent of the total TSS loads from among these three tributaries. In addition, an intensive 1-year study (from October 2003 through September 2004) was conducted at the Onondaga Creek site where TSS samples were collected more frequently than bi-weekly and TSS concentrations were related to continuous (15-min) measurements of turbidity. Daily TSS loads were computed on the basis of this turbidity-to-TSS relation; the annual load for water year 2004 (that period from October 1 of a given year to September 30 of the following year) was more than 32,000 tons.

A water-quality synoptic survey of the Onondaga Creek Basin was conducted by the State University of New York, College of Environmental Science and Forestry, at Syracuse during September 2007 (Limburg, 2007). Water temperature, specific conductance (SC), dissolved oxygen, and pH were measured at 40 sites. Water samples were collected and analyzed for nitrate (NO_3), total N, and P; a subset of the samples was additionally analyzed for NH_3, nitrite (NO_2), PO_4, and TSS.

Coon and Reddy (2008) developed a basin-scale precipitation-runoff model of the Onondaga Lake Basin. Streamflow, water temperature, sediment, and P and N constituents were simulated. Target loading rates for the simulated constituents that were associated with the land types simulated in the model were estimated from values found in scientific literature.

Purpose and Scope

This report presents results of water-quality data collected at 26 surface-water sites and 4 springs in the Onondaga Lake Basin. Water samples were analyzed for concentrations of NO_2, NO_x, NH_3, ammonia-plus-organic nitrogen (TKN), PO_4, P, and SS. Some selected samples were analyzed for TSS. Field measurements of water temperature, SC, salinity, and dissolved oxygen were made. The report identifies the sediment and nutrient characteristics of each site that can be associated with (1) land uses upstream from the sampling site; (2) areas of landslides and point sources of sediment, and (3) in the case of the springs, the chemical composition of groundwater discharged from carbonate bedrock to the major channels in the basin.

The data collected during this study filled the needs of other projects in the Onondaga Lake Basin by (1) identifying nonpoint-pollution sources to assist water-resources managers in the development of watershed management plans in the Onondaga Lake Basin; and (2) upgrading a precipitation-runoff model of the Onondaga Lake Basin (Coon and Reddy, 2008) with constituent loading rates directly applicable to the Onondaga Lake Basin rather than those estimated from values found in scientific literature. These data also provided the basis for many comparative and interpretive analyses, including (1) characterization of stream water quality on the basis of land use or land cover; (2) comparison of storm-runoff and snowmelt constituent concentrations; (3) documentation of the changes in the water quality from upstream to downstream sites on the two major tributaries to Onondaga Lake—Onondaga and Ninemile Creeks—and on three minor tributaries; (4) comparison of concentrations and loads with those measured during 1981–83 in three Otisco Lake tributaries that drain subbasins dominated by agricultural uses; (5) quantification of the sediment loads to Onondaga Creek from the mudboils (a groundwater source of fine-grained sediment) and from ongoing landslide activity along Rainbow Creek and Rattlesnake Gulf; (6) quantification of the mitigative water-quality effects of Onondaga Reservoir and Otisco Lake; (7) assessment of the effects of groundwater discharges on surface-water quality; (8) characterization of precipitation- and snowpack-quality data; and (9) comparison of SS and TSS concentrations.

Study Area

The Onondaga Lake Basin in Onondaga County, N.Y., covers 285 mi^2, of which almost 40 percent is forested, 30 percent is in agricultural uses, and 21 percent, including the city of Syracuse, is in residential, commercial, industrial, and transportation uses (U.S. Geological Survey, 1999). The remaining 9 percent comprises wetlands and water bodies, including Otisco and Onondaga Lakes. Onondaga Lake, at the downstream end of the basin, receives chemical and sediment loads from numerous sources, including forested, agricultural, and urban nonpoint sources, industrial waste beds, combined-sewer overflows, effluent from wastewater-treatment plants, and industrial point sources (Effler, 1996).

Site Selection

Thirty sites, including four springs, were monitored during this study (fig. 1). The selected streamflow sites represented subbasins of the Onondaga Lake Basin dominated by a particular land use or land cover (table 1). Subbasins dominated by forest, pasture-hay, row crop, residential, and commercial-transportation land uses were included in the monitoring network. A site on Meadow Brook (site 04245236), a stream that lies outside but adjacent to the Onondaga Lake Basin, was included in the study because (1) it was dominated by low-density residential land use, a use for which additional data on loading rates was desired, and (2) a USGS streamflow-monitoring site was already in operation on the stream, which provided a continuous record of streamflow. One low-gradient subbasin, North Branch Ley Creek, had a large percentage of wetland area. Another subbasin, Otisco Lake tributary at Williams Grove, because of its small size, permitted the monitoring of the end-of-basin effects of a farmstead, which in this subbasin was a dairy operation. In all cases, the water-quality data reflected the integration of the loads contributed by all land uses in the monitored subbasin. Therefore, if a dominant land use was unidentifiable for a particular subbasin, which pertained to the largest subbasins in the study, the land use of that subbasin was classified as “mixed.”

Additional sites were included in the monitoring network to provide data on particular nonpoint-source issues. Two sites—Rainbow Creek and Rattlesnake Gulf—had been identified by highway departments and the USGS as disproportionately large contributors of sediment to Onondaga Creek. Three sites—Spafford Creek, Rice Brook, and Willow Brook—were included in an earlier USGS study (Paschal and Sherwood, 1987) and provided a basis for evaluating changes in nutrient and sediment loads over time. Sites upstream and downstream from the mudboils—volcano-like cones of fine sand, silt, and clay created by the upwelling of sediment-laden groundwater along Onondaga Creek in the vicinity of Otisco Road (Kappel and others, 1996; Kappel and McPherson, 1998; Kappel, 2009)—permitted current evaluation of the effects of these features on the water quality of Onondaga Creek. Two sites—Furnace Brook and Geddes Brook—reflected the influence of large inflows from springs that drain the Onondaga and Bertie Limestone on the water quality of these two streams. Sites upstream and downstream from Onondaga Reservoir and Otisco Lake permitted assessment of the mitigative effects of these two water-detaining features on the inflow loads of sediment and nutrients.

Additional data collected at two short-term water-quality sites—Onondaga Creek at Nichols Road north of Tully Valley and Spafford Creek at Bromley Road near Spafford—addressed questions related to water-quality processes in these streams that arose during the final year of the study. Data from six long-term water-quality sites were available from the Onondaga County Department of Water Environment Protection (WEP) (Antonio Deskins, Onondaga County Department of Water Environment Protection, written commun., 2008) and were used, along with data from the other study sites, to assess changes in water quality along the main tributaries of Onondaga Lake and to identify differences between SS and TSS concentrations.

Table 1. Data-collection sites in the Onondaga Lake Basin, Onondaga County, N.Y.

[Site locations are shown in figure 1. mi^2, square miles; na, not applicable; –, no data]

Site-identification number	Site name	Drainage area (mi^2)	Land use and land cover, in percent of total subbasin area[1]					Number of farmsteads	Hydrologic soil group runoff potential[2]	
			Forest	Pasture-hay	Row crops	Wetland	Developed[3]		Low	High
			Surface-water sites							
04237917	Onondaga Creek northwest of Tully	6.4	62	27	6.0	2.4	1.0	2	67	22
04237950	Onondaga Creek at Tully Valley	16.4	65	25	6.6	2.3	0.8	5	63	26
04237952	Rainbow Creek at Route 11A at Tully Valley	2.37	66	20	6.2	3.8	3.0	0	77	6
04237953	Rattlesnake Gulf at Otisco	2.77	29	46	17	6.0	0.8	2	57	18
04237955	Rattlesnake Gulf at Tully Farms Road near Cardiff	9.06	47	38	9.0	4.5	0.4	4	66	20
04237956	Onondaga Creek north of Tully Valley	28.9	59	28	7.6	3.8	0.8	9	65	22
04237962	Onondaga Creek near Cardiff	33.9	59	28	7.9	4.5	0.7	9	63	23
04237995	West Branch Onondaga Creek near South Onondaga	12.6	42	39	8.7	8.0	1.5	4	68	13
04238000	West Branch Onondaga Creek at South Onondaga	22.1	41	38	11	7.0	1.5	7	67	13
04238550	Onondaga Creek at Indian Village	69.9	54	30	8.3	6.1	1.0	18	65	19
04239800	Furnace Brook at Syracuse	3.71	51	15	3.8	3.5	24	0	36	30
04240108	North Branch Ley Creek at Collamer	4.15	37	20	5.7	27	8.0	0	10	46
0424011445	South Branch Ley Creek at Exeter Street at East Syracuse	3.73	10	1.5	3.9	5.8	75	0	4	8
04240145	Spafford Creek at Bromley Road near Spafford	3.14	67	24	7.7	1.7	0.1	0	23	67
04240150	Spafford Creek at Sawmill Road at Otisco Valley	8.06	68	21	7.1	3.7	0.0	1	52	34
04240152	Otisco Lake tributary at Williams Grove	0.56	30	55	14	0.4	0.1	1	77	8
0424015305	Rice Brook at Rice Grove	2.44	33	45	14	7.3	0.9	3	58	20
04240158	Willow Brook near Borodino[4]	1.95	20	62	17	0.6	0.1	1	57	25
04240170	Otisco Lake at Marietta	42.3	50	36	8.2	4.5	0.8	17	56	30
04240180	Ninemile Creek near Marietta[5]	45.1	44	40	12	2.6	0.5	–	56	29
04240182	Doust Creek near Marcellus	1.01	22	61	8.0	8.2	0.0	0	72	12
04240200	Ninemile Creek at Camillus[5]	84.3	40	39	8.6	7.0	3.4	–	60	20
04240253	Geddes Brook at Fairmount	8.29	33	20	4.6	5.5	29	–	37	16
04245236	Meadow Brook at Hurlburt Road, Syracuse	3.06	10	2.7	1.9	0.0	76	0	–	–
430317076054201	Erie Boulevard outfall to South Branch Ley Creek, Syracuse	0.10	25	–	–	4.3	67	0	–	–
430415076055901	Lamson Street outfall to South Branch Ley Creek tributary, Syracuse	0.09	–	–	–	–	99	0	–	–

Table 1. Data-collection sites in the Onondaga Lake Basin, Onondaga County, N.Y.—Continued

[Site locations are shown in figure 1. mi^2, square miles; na, not applicable; –, no data]

Site-identification number	Site name	Drainage area (mi^2)	Land use and land cover, in percent of total subbasin area[1]					Number of farmsteads	Hydrologic soil group runoff potential[2]	
			Forest	Pasture-hay	Row crops	Wetland	Developed[3]		Low	High
		Springs								
425822076081601	Cold Spring along Smith Avenue in Nedrow	na	–	–	–	–	–	–	–	–
425903076093101	Dorwin Spring along State Highway 80 near Nedrow	na	–	–	–	–	–	–	–	–
430022076200901	Railroad Spring along State Highway 174 near Marcellus Falls	na	–	–	–	–	–	–	–	–
430036076202001	Mossbank Spring along Lawless Road near Marcellus Falls	na	–	–	–	–	–	–	–	–
	Additional water-quality monitoring sites (operated by Onondaga County Department of Water Environment Protection)									
04239000	Onondaga Creek at Dorwin Avenue, Syracuse[6]	88.5	–	–	–	–	–	–	–	–
04240011	Onondaga Creek at Kirkpatrick Street, Syracuse[6]	110	–	–	–	–	–	–	–	–
04240100	Harbor Brook (at Velasko Road) at Syracuse[6]	10.0	–	–	–	–	–	–	–	–
0424013502	Bloody Brook above mouth at Liverpool	3.86	–	–	–	–	–	–	–	–
04240300	Ninemile Creek at Lakeland[6]	115	–	–	–	–	–	–	–	–
04240470	Sawmill Creek at Liverpool	2.34	–	–	–	–	–	–	–	–

[1] Percentages do not include areas covered by urban and recreational grass or lakes.

[2] Based on sum of forest and pasture-hay areas only.

[3] Developed land uses include residential, commercial, and transportational uses.

[4] Percentages are based on acreages for the entire Willow Brook Basin (3.72 mi^2).

[5] Percentages pertain to the drainage area between Otisco Lake outlet and the monitoring site only; 2.8 mi^2 for Marietta; 42.0 mi^2 for Camillus.

[6] Periodic suspended-sediment samples were collected at these sites as part of this study.

Climate

Precipitation in Onondaga County is derived mainly from storms that pass across the interior of the country northeastward toward the St. Lawrence valley. Lake Ontario influences the distribution and quantity of rain and snowfall, because prevailing winds generally move southeastward across the lake, which seldom freezes during the winter, and pick up and transport moisture landward. Thunderstorms, common during the summer months, occur an average of 30 days per year and can generate short-lived, but intense, downpours (National Weather Service, 2007). Average annual precipitation (1971–2000) in the Syracuse, N.Y., area is about 40 in., including that from an average snowfall of about 121 in., as recorded by the National Weather Service station at the Syracuse Hancock International Airport (National Climatic Data Center, 2009). During the study period (2005–08), annual precipitation totals ranged from 40.5 to 48.7 in. and were, therefore, above-average quantities. Precipitation quantities show a seasonal pattern; precipitation is greater during the summer than during the winter; the average monthly precipitation for June through September is 3.86 in., whereas that for January through March is 2.58 in. (National Climatic Data Center, 2009). Spatial variation in precipitation quantities across the study area can be substantial; annual totals differ by an average of 3 to 7 in. and by as much as 13 in. among three precipitation-recording stations in the study area (Coon and Reddy, 2008).

The annual mean temperature is 47.4°F. Monthly mean temperatures range from 22.4°F in January to 70.4°F in July; the lowest and highest percentages of possible sunshine are recorded during the same months—33 and 63 percent, respectively (Northeast Regional Climate Center, 2005).

Geology

The Onondaga Lake Basin is underlain by layers of glaciated sedimentary bedrock of Devonian and Silurian age that strike east-west and dip gently to the south at 40 to 50 ft/mi (Kappel and Miller, 2005). The bedrock is commonly overlain by glaciated drift including till, kame, lacustrine, and outwash deposits. The thickness of unconsolidated deposits can range from an average of 420 ft in valley bottoms (Kappel and Miller, 2003) to an average of less than 10 ft on hill tops where bedrock is at or near the surface (W.M. Kappel, U.S. Geological Survey, oral commun., 2005).

Till is the dominant glacial material and overlies 56 percent of the bedrock in the basin, especially in the upland areas in the central and southern parts of the basin. Proglacial lacustrine silt and clay deposits, which cover 19 percent of the basin, are found across the northern part of the basin and in the valley bottoms of the southern part of the Onondaga Creek Basin and of the Ninemile Creek and Spafford Creek subbasins, north and south, respectively, of Otisco Lake. These deposits, when eroded by high-gradient streams, such as Rainbow Creek and Rattlesnake Gulf, or disturbed by agricultural activities, such as in the Spafford Creek subbasin, can be large sources of sediment for fluvial transport.

Carbonate bedrock can transmit large volumes of groundwater through fractures, bedding planes, and solution openings. In the Onondaga Lake Basin where carbonate bedrock crops out, mainly along the topographically prominent Onondaga-Bertie Escarpment, spring discharges dominate the base flows in the receiving surface channels—Onondaga Creek, Harbor Brook, and Ninemile Creek.

Soils

Soils in Onondaga County are generally derived from glacial deposits—mainly till, but also outwash and lacustrine silt and clay—or underlying sedimentary rocks—shale, limestone, and dolostone. For the most part, the resulting soils are more than 40 in. deep, gently sloping to moderately sloping, and medium textured, that is dominated by particles that range in size from very fine sand to silt. Soils are mainly well-drained or moderately well-drained, which means when infrequently saturated, they do not remain so for long periods (Hutton and Rice, 1977). Till and lacustrine silt and clay are the parent materials of 75 percent of the soils in the Onondaga Lake Basin and generally produce soils with low permeability and high runoff potential. Most of Onondaga Lake Basin soils are expected to have moderate to slow infiltration rates when thoroughly wetted and moderate to slow rates of water transmission within the soil profile.

Land Use and Land Cover

On the basis of National Land Cover Data (NLCD) derived from satellite imagery during 1991 to 1993 (U.S. Geological Survey, 1999), almost 40 percent of the Onondaga Lake Basin is forested and 24 percent is covered in pasture or hay (fig. 2). About 6 percent of the basin is used for row crops or livestock operations. Almost 18 percent of the basin is classified as developed, including low- and high-intensity residential uses (13.5 percent) and commercial, industrial, and transportation uses (4.5 percent). An additional 3 percent is urban or recreational grass; wetlands, ponds, and small lakes cover 6.4 percent. Wetlands in the basin are mainly riparian, but they also cover large expanses in the headwaters of Ley Creek and are common in the low-gradient areas along the drainage divides of many subbasins, especially between the Otisco Lake–Ninemile Creek Basin and the West Branch Onondaga Creek Basin.

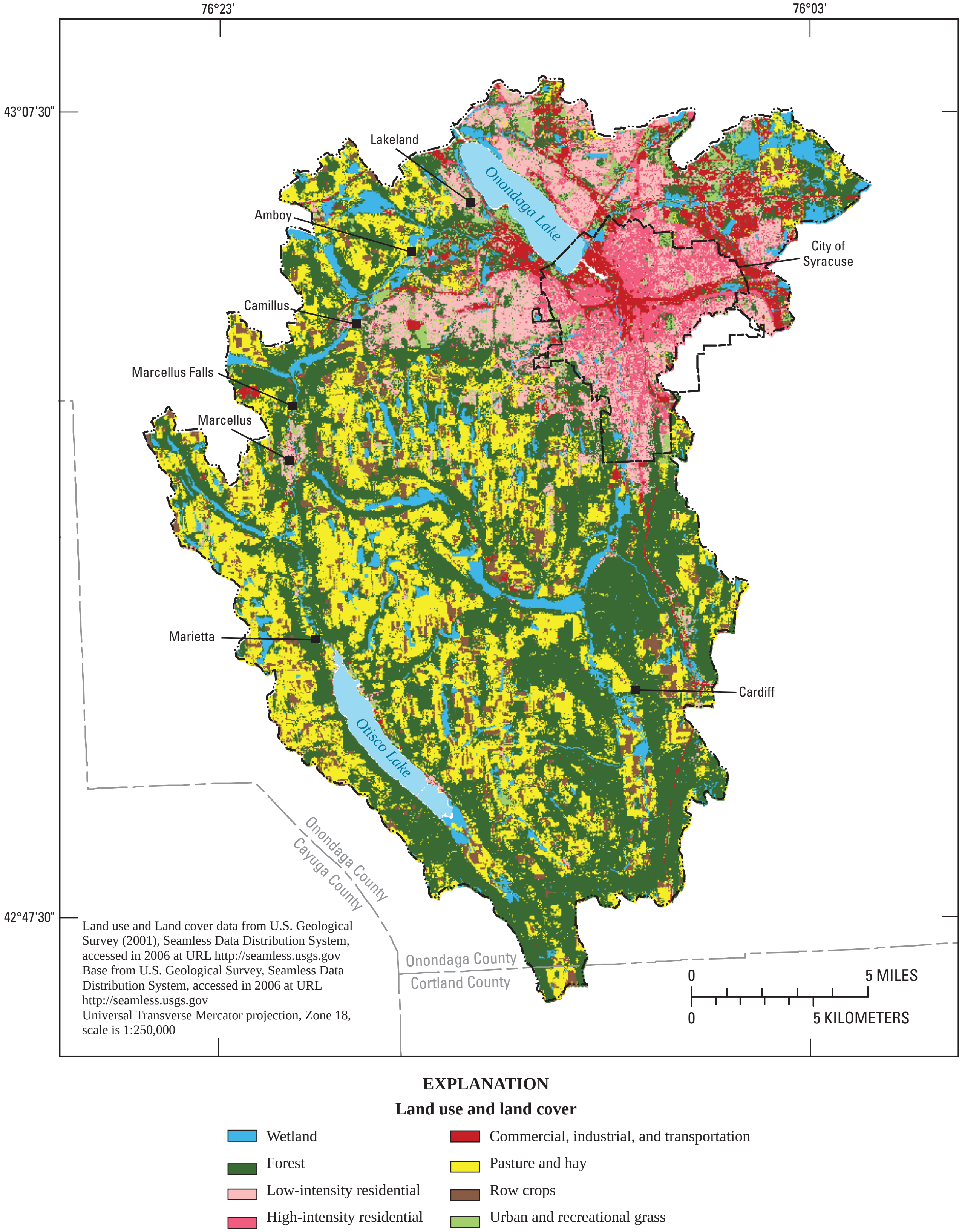


Figure 2. Land use and land cover in the Onondaga Lake Basin, Onondaga County, N.Y.

The southern half of the basin retains a rural nature with a mix of forest, pasture, and agricultural uses. Forests cover nearly 60 percent of the headwater areas of the Onondaga Creek Basin, and agricultural operations use more than 40 percent of the land in the West Branch Onondaga Creek, Otisco Lake, and middle Ninemile Creek subbasins. These percentages decrease as urban development increases to the north around Onondaga Lake, especially from the city of Syracuse at the southeastern end of the lake. Developed land uses cover more than 40 percent of the Harbor Brook Basin and more than 50 percent of the lower Onondaga Creek subbasin and Ley Creek Basin.

Groundwater

Groundwater discharge to surface channels accounts for most of the streamflow in the Onondaga Lake Basin—ranging from 56 percent of streamflow in Ley Creek to 80 percent in Ninemile Creek on the basis of a hydrograph-separation analysis performed by using HYSEP (Sloto and Crouse, 1996). Springs are common at outcrops of carbonate bedrock along Onondaga Creek north of the southern boundary of the city of Syracuse, along Ninemile Creek between Marcellus and Camillus, and in the headwaters of Furnace Brook and Harbor Brook. As a result of spring discharges, base flows in these reaches are sustained, and water temperatures are lower during the summer and higher during the winter than in streams in other subbasins.

Groundwater in the southern part of the Onondaga Creek valley is under confined conditions with hydraulic heads (water levels) tens of feet above land surface (Kappel and Miller, 2005). A layer of lacustrine silt and clay extends down to a basal valley-fill sand-and-gravel aquifer in the bedrock trough, resulting in confined conditions and limiting the flow of groundwater northward into the northern part of the aquifer (Kappel and Miller, 2005). This fine-grained confining layer is the source of sediment discharged by the mudboils into Onondaga Creek near Otisco Road.

Methods

Twenty-six surface-water sites and four springs were monitored (table 1; fig. 1). Three of the streamflow sites—Ninemile Creek near Marietta, Rice Brook, and Willow Brook—were instrumented with automatic stage recorders and water-quality samplers. Ninemile Creek near Marietta is a long-term continuous-record streamflow monitoring site that measures outflow from Otisco Lake. Rice Brook and Willow Brook are tributaries to Otisco Lake and are referred to in this report as agricultural environmental management (AEM) sites because of the widespread implementation of agricultural management plans by the Onondaga County Soil and Water Conservation District within each of these basins. Data were collected more frequently from these two sites than from other sites to enable comparison of constituent concentrations and loads with those measured during a 1981–83 study (Paschal and Sherwood, 1987) and to identify any changes in loading rates that might have occurred during the intervening years. A third AEM site, Spafford Creek, was added to the monitoring network during the second year of the study.

Sample Collection

During the first year of the study (2005–06), base flows at all sites were sampled seasonally, at least four times a year; the AEM sites were sampled six times a year. Stormflows were sampled at least three times a year; stormflows at the AEM sites were sampled six times. During the subsequent years of the study (2007–08), the frequency of sampling at all sites was increased to match that of the AEM sites; that is, six base flows and six storms were sampled at each site. Nearly every major stormflow was monitored to some degree as manpower limitations permitted. The objective of each storm-sampling effort was to sample flows once each during three hydrologic conditions—the rising stage, near the peak, and the falling stage. This target of three samples per storm was difficult to achieve, usually because of the unpredictability of weather patterns and the short duration of many stormflows. Each of these hydrologic conditions was well represented in the collected samples; 40, 22, and 38 percent of the storm samples were collected during the rising stage, near the peak, and during the falling stage, respectively. Four springs discharging from the Onondaga and Bertie Limestone—two each in the Onondaga and Ninemile Creek valleys—were sampled quarterly during water years 2007 and 2008.

Nutrient and SS samples were collected isokinetically by the depth-integrated equal-width-increment method (Wilde and others, 1999a; Edwards and Glysson, 1999) by using either a hand-held sampler on a rod (DH-48) or a rope-suspended sampler (DH-59) (fig. 3). Isokinetic methods maintain the ambient flow velocity and direction as the sample enters the intake nozzle of the sampler, thus ensuring that the concentrations of constituents in the water both inside and outside the sampler are comparable. The isokinetic depth-integrated equal-width-increment method increased the likelihood that the concentration of a given constituent in the sample was representative of the mean concentration of that constituent across the entire sampled cross section. This sampling method minimized the uncertainty in load calculations that might otherwise arise from using concentration data collected by surface grab-sampling methods. Sampled water from equal-spaced verticals (or points at which the sampler was lowered and raised through the water column) in the stream cross section was composited in a churn splitter. SC, salinity, dissolved oxygen, and water temperature were periodically measured in the field with a digital water-quality meter.

Figure 3. Hand-held water-quality samplers: (*A*) rod-suspended DH-48 sampler for wading (left) and rope-suspended DH-59 sampler for use from a bridge (right), (*B*) rope-suspended weighted bottle, (*C*) and telescoping rod with weighted bottle for use from streambank. (Photographs by W.F. Coon, U.S. Geological Survey.)

Isokinetic sampling methods could not be used at some sites or under certain flow conditions at other sites. When depths were too shallow to use a DH-48 sampler, usually during low-flow summer periods, samples were collected by dipping with a hand-held narrow-mouth bottle. When the mean velocity in the vertical did not exceed the minimum-velocity requirement of an isokinetic sampler (1.5 ft/s; Wilde and others, 1999a), such as in the outlet from Otisco Lake (site 04240170), samples were collected by a rope-suspended weighted bottle (fig. 3). At Onondaga Creek at Tully Valley (site 04237950), where no bridge spans the channel, high flows were sampled from the bank at several points across the stream with a rope-suspended weighted bottle on the end of a telescoping rod (fig. 3). In these cases, the depth-integrated equal-width-increment protocol was still followed. The only departure from this sampling protocol occurred when very low flows were confined to a small area of the channel and samples were collected directly by a single vertical dip or by a sweep across the entire flow area.

When extremely high flow velocities (estimated to be greater than 10 ft/s) prevented a rope-suspended isokinetic sampler from being lowered into the water column, such as at the two storm-sewer sites—Erie Boulevard and Lamson Street—or subjected the glass sample bottle to mobile bed material and the possibility of breakage, such as at Doust Creek near Marcellus (site 04240182), alternate sampling methods were used. A rope-suspended bucket was used to collect samples at the storm-sewer sites and a weighted plastic bottle was used at Doust Creek. Although depth-integrated methods could not be used at these high-velocity sites, the turbulent conditions supported the assumption that flows were well mixed and that the sampled water was representative of the water in the entire flow area.

In addition to these manually collected samples, samples at three sites—Rice Brook (site 0424015305), Willow Brook (site 04240158), and Ninemile Creek near Marietta (site 04240180)—were collected by automatic samplers. These samplers were programmed to collect samples at a specified time increment when a stage threshold in the stream was exceeded. Discrete (non-composited) samples were stored in a refrigerated compartment. Samples were processed as soon after collection as possible, typically within 48 hours. Automatic samples were collected from a single point in a stream cross section; therefore, constituent concentrations in the samples could not be assumed to reflect mean concentrations across the entire cross section. Concurrent equal-width-increment samples were periodically collected to identify any bias in the constituent concentrations of the automatically collected samples that could be attributed to the single-point automatic sampling method. (See the section, “Quality Assurance,” for discussion of concentration bias in the automatically collected samples.)

Sample Processing and Analyses

Samples were processed in the field according to methods described by Wilde and others (1999b). Subsamples of the water that had been collected and composited in a churn splitter were withdrawn while the water was churned at a constant rate. The first subsample was withdrawn into a 500-mL glass bottle for SS analyses. When appropriate, the second subsample was withdrawn into a 250-mL plastic bottle for TSS analyses (only about 15 percent of the collected samples were analyzed for TSS concentrations). The third subsample was withdrawn into a 125-mL bottle filled to its shoulder and fixed by addition of 1 mL of 4.5-normal sulfuric acid. This subsample was analyzed for whole-water (unfiltered) nutrient concentrations (total P and TKN). Subsamples analyzed for dissolved constituents were withdrawn last (churning was not required for this subsample), filtered through a 0.45-micron filter, and placed in a 125-mL bottle; the analyses were performed on the filtrate. All nutrient samples were stored on ice after field processing and during transit to the USGS National Water Quality Laboratory in Denver, Colo., where the samples were analyzed for NH_3, NO_2, NO_x, TKN (unfiltered and filtered), PO_4, and P (unfiltered and filtered). Selected samples also were analyzed for TSS. All analyses were performed according to methods described by Fishman and Friedman (1989).

Concentrations of SS were measured in all sediment samples, and particle-size-distribution analyses were performed on selected samples collected during high flows. Both types of sediment analyses were performed by the USGS Sediment Laboratory in Rolla, Mo., according to methods described by Guy (1969). SC usually was measured in the field; measurements of SC from the sediment laboratory were used when field measurements were not made.

Samples were periodically collected at four long-term monitoring sites by WEP personnel. The sites are near the downstream ends of Onondaga Creek (2 sites), Harbor Brook, and Ninemile Creek. These samples were analyzed for concentrations of SS or TSS by the USGS laboratories. Concurrent samples and other samples collected at these and other WEP monitoring sites were analyzed in the WEP laboratory for concentrations of soluble reactive phosphorus (SRP or PO_4), total P, NH_3, TKN, NO_2, NO_3, and TSS. These data were added to the database to improve the longitudinal assessments of water quality in Onondaga and Ninemile Creeks from their respective headwaters to their mouths.

Measured concentrations were reported as “less than” when interference in baseline concentrations of an analyte prevented verifiable measurement of a “true” lower concentration. Concentrations were flagged as “estimated” when a measurement indicated a concentration below the statistically determined detection limit of the analytical method or the reported value was less than the lowest concentration standard used to calibrate the instrument (K. Pearsall, U.S. Geological Survey, oral commun., 2007). Concentrations of NO_3, organic nitrogen (OrgN), total N, and organic phosphorus (OrgP) were computed from analyzed concentrations of other constituents. The concentration of NO_3 was computed as the concentration of NO_x minus the concentration of NO_2. Similarly, OrgN equaled TKN minus NH_3, and OrgP equaled total P minus PO_4. Total N equaled the sum of TKN and NO_x. In all calculated concentrations, the censored values (those concentrations less than the analytical detection limit) were assumed to be zero, and concentrations flagged by the laboratory as "estimated" were used as "actual" values. The particulate forms of NH_3, NO_x, and PO_4 were assumed to be negligible in the calculation of OrgN, total N, and OrgP concentrations, respectively, because these nutrient forms, if present, would have very low concentrations.

Stage and Streamflow Measurements

Surface-water stage measurements were read from vertical staff gages or measured from reference points on or near the bridge or culvert at each site. Streamflow measurements were made at all the study sites, except the two storm-sewer sites—Erie Boulevard and Lamson Street—by using a current meter or acoustic Doppler current profiler according to the methods described by Rantz and others (1982) or Oberg and others (2005), respectively. Extremely high velocities of storm runoff at the sewered sites prevented the safe and reliable measurement of streamflow by either current-meter or volumetric methods. Indirect measurements of streamflow by the flow-through-culvert method (Bodhaine, 1968) were computed at Doust Creek (site 04240182), Geddes Brook (site 04240253), and Rattlesnake Gulf at Otisco (site 04237953), sites at which high flows were difficult to measure. Stage-to-discharge relations were developed for each study site according to the methods described by Rantz and others (1982). The streamflow associated with each water-quality sample was either measured directly or determined from the stage-to-discharge relation. Pressure transducers, which included a temperature sensor and a data logger, were deployed at 17 sites during the non-winter periods of the study; they were removed from the channel during the winter to avoid damage from ice. Time series of stage were used to compute continuous records of flow at some sites.

Estimation of Flows and Loads at Selected Sites

Daily flows from three tributaries of Otisco Lake—Spafford Creek (site 04240150), Rice Brook (site 0424015305), and Willow Brook (site 04240158)—were required to compute loads for comparison with those computed with data from an earlier study. Missing flows were computed with a previously developed basin-scale precipitation-runoff model of the Onondaga Lake Basin (Coon and Reddy, 2008) after the model had been recalibrated to flows measured during the present study. Loads of selected constituents at these sites were computed with a USGS load-estimation program, LOADEST (Runkel and others, 2004; Cohn and others, 1992). LOADEST was also used to compute (1) loads of selected constituents in Meadow Brook, the urban site outside, but adjacent to, the Onondaga Lake Basin, and (2) sediment loads discharged from the mudboils to Onondaga Creek, which were computed from weekly sediment concentrations and daily flows leaving the mudboil area; these data were collected as part of another USGS study (Kappel, 2009).

Quality Assurance

Several measures were taken to ensure the quality of the concentration data presented herein or to quantify any bias or systematic error that might be present in the data due to collection, field-processing, or analytical procedures according to guidance provided by Mueller and others (1997). Deionized or blank-water samples were processed and three types of replicate samples were collected. A total of 89 quality-assurance samples, or 1 for every 11 environmental samples, was collected and processed for this study.

Blank Samples

Blank samples were processed and analyzed to ensure that environmental samples were not contaminated during the overall data-collection process. In particular, the adequacy of field-cleaning procedures and field-processing techniques were checked by processing 4 L of reagent-grade deionized water, which had been purified by activated carbon organic absorption, reverse osmosis, mixed bed double-deionization, ultraviolet light irradiation, and 0.2-micron membrane filtration. Field equipment was rinsed with about 2 L of the blank water, then a sample was processed with the remaining water following identical procedures as those used for environmental samples. On the basis of the results from 20 blank samples, no problems in field techniques were identified. Most concentrations were below the detection limits of the respective constituents. In a few instances, concentrations were measured that actually were lower than the censored concentrations of other samples for a given constituent. For four analyses of NO_2 and one each of total and dissolved P, concentrations greater than the censored values of other samples for a given constituent were measured, but these measured values were only 0.001 mg/L above their respective maximum censored values.

Split-Replicate Samples

As a check on the precision of laboratory analytical procedures, replicate samples were processed from water composited in a churn splitter and subsequently subsampled. Replicates of essentially the same water were sent to the USGS National Water Quality Laboratory for nutrient analyses and the USGS Sediment Laboratory for SS analyses. These samples, which are contemporaneous in time and space, are referred to as “split-replicate” samples.

Fifty-one split-replicate samples were collected and analyzed. Paired-sample tests of significance (Helsel and Hirsch, 1992) were performed for each constituent. The mean of the differences between the paired concentrations for any given constituent was not significantly different from zero. Therefore, laboratory results were deemed to be acceptable.

Concurrent-Replicate Samples

To identify and quantify the natural variability in constituent concentrations in streamflow, replicate sampling was conducted by concurrent collection of two independent samples by methods described in Wilde and others (1999a). Each vertical across a channel was sampled twice and the sampled water was poured into one, then the other, of two churn splitters. The order of the churn splitters that received the first sampled water at each subsequent vertical was alternated, so that by the time the stream cross section had been traversed, two independent composited samples of the same water had been collected. The water in each churn splitter was processed separately, and replicate samples were sent to the USGS National Water Quality Laboratory for nutrient analyses and the USGS Sediment Laboratory for SS analyses. These samples are referred to as “concurrent-replicate” samples. Any variability that might be introduced to a sample from collection, processing, shipping, and laboratory handling was assumed to be negligible.

Ten concurrent-replicate samples were collected and analyzed. Small differences between the paired concentrations of a given constituent were expected. Therefore, the root mean squared error (RMSE) was computed to quantitatively assess these differences. The RMSE for the nutrient constituents generally ranged from 0.027 mg/L for P (unfiltered) to 0.001 mg/L for NO_2 and P (filtered). The RMSE for TKN (unfiltered) concentrations (0.347 mg/L) was high because of one anomalous pair of concentrations. The largest RMSE (10.214 mg/L) was associated with the SS concentrations. As a means of comparing the precision of the data among the reported constituents, the RMSE of each constituent was normalized (RMSEn) by dividing it by the mean concentration of the constituent. The RMSEn is typically large for constituents that are usually measured at low concentrations—a small error in concentration produces a large RMSEn—whereas constituents that typically are reported at high concentrations, have RMSEn values that are small in comparison to other constituents. Excluding TKN concentrations with the anomalous data pair, the greatest RMSEn values were for concentrations of NH_3 (0.278 mg/L) and PO_4 (0.183 mg/L); the smallest values were for concentrations of NO_x (0.008 mg/L) and SS (0.041 mg/L). These results indicated that natural variability in flow patterns and constituent loading to a stream can produce differences in constituent concentrations at a given point in time in a given stream that are to be expected, but these differences are small relative to the measured concentrations.

Paired-Replicate Samples

Automatic water-quality samplers were installed at three sites—Rice Brook (site 0424015305), Willow Brook (site 04240158), and Ninemile Creek near Marietta (site 04240180)—to permit sampling of more stormflows than would have been logistically possible otherwise. To assess any bias in the concentrations measured in the water samples collected by the automatic samplers, manually collected depth-integrated cross-sectional samples and automatic grab samples were collected near in time. These samples, which are referred to as “paired-replicate” samples, were processed and sent to the USGS National Water Quality Laboratory for nutrient analyses and the USGS Sediment Laboratory for SS analyses.

Thirty-five of the 55 event (stormflow and snowmelt) samples collected in Willow Brook, 15 of the 35 event samples collected in Rice Brook, and 9 of the 27 event samples collected in Ninemile Creek near Marietta were automatically collected. Eight paired-replicate event samples were collected. Six paired-replicate samples at Willow Brook covered a flow range from 16 to 196 ft^3/s (mean, 55 ft^3/s); the 35 automatically collected samples spanned flows from 23 to 217 ft^3/s (mean, 61 ft^3/s). Two paired-replicate samples at Ninemile Creek near Marietta were collected when flows were 179 and 352 ft^3/s (mean, 266 ft^3/s); the nine automatically collected samples spanned flows from 118 to 219 ft^3/s (mean, 158 ft^3/s). No paired-replicate samples were collected at Rice Brook.

Coefficients to adjust the measured concentrations of constituents in event samples collected automatically were computed by dividing the concentration of the manually collected sample by the concentration of the automatically collected sample. A mean coefficient (table 2) was applied to the concentrations of the automatically collected storm and snowmelt samples when the bias of coefficients for a particular constituent was consistent (always less than 1.00 or always greater than 1.00) and the mean coefficient was less than 0.90 or greater than 1.10. On the basis of these criteria, adjustments were required to concentrations of PO_4 and SS measured in the 35 automatically collected event samples at Willow Brook and to all constituent concentrations, except PO_4, in the nine samples from Ninemile Creek near Marietta.

Table 2. Adjustment coefficients applied to constituent concentrations measured in storm and snowmelt samples automatically collected at Willow Brook near Borodino and Ninemile Creek near Marietta, N.Y., 2005–08.

[Site locations are shown in figure 1. –, coefficient not required for this constituent]

Constituent	Adjustment coefficient	
	Willow Brook near Borodino (04240158)	Ninemile Creek near Marietta (04240180)
Ammonia, filtered	–	0.88
Ammonia-plus-organic nitrogen, unfiltered	–	.85
Nitrate, filtered	–	1.18
Nitrate-plus-nitrite, filtered	–	1.19
Orthophosphate, filtered	1.12	–
Phosphorus, unfiltered	–	.72
Suspended sediment	.87	.41

These adjusted concentrations were used in all subsequent data analyses. No adjustments to the concentrations in samples collected automatically at the Rice Brook site were possible; however, few, if any, constituents were expected to require adjustments owing to the highly turbulent, well-mixed conditions that existed at this sampling site.

Characterization of Water Quality

Nine hundred and seventy-two environmental samples, including 357 base-flow samples, 585 storm and snowmelt samples, and 30 spring samples, were collected and analyzed for nutrients and SS from 26 surface-water sites and 4 springs from October 2005 through December 2008. The concentration of TSS was measured in selected samples. The water-quality data were published in the USGS annual water-data reports for 2006 through 2008 (U.S. Geological Survey, 2009). Ninety-one additional samples were collected, including 80 samples from 4 WEP monitoring sites, which were analyzed for SS or TSS, and 8 precipitation and 3 snowpack samples, which were analyzed for nutrients. These data provided the basis for many comparative and interpretive analyses, including (1) characterization of stream water quality on the basis of land use or land cover; (2) comparison of storm-runoff and snowmelt constituent concentrations; (3) documentation of the changes in the water quality from upstream to downstream sites on the two major tributaries to Onondaga Lake—Onondaga and Ninemile Creeks—and on three minor tributaries; (4) comparison of concentrations and loads with those measured during 1981–83 in three Otisco Lake tributaries, which drain subbasins dominated by agricultural uses; (5) quantification of the sediment loads to Onondaga Creek from the mudboils (a groundwater source of fine-grained sediment) and from ongoing landslide activity along Rainbow Creek and Rattlesnake Gulf; (6) quantification of the mitigative water-quality effects of Onondaga Reservoir and Otisco Lake; (7) assessment of the effects of groundwater discharges on surface-water quality; (8) characterization of precipitation- and snowpack-quality data; and (9) comparison of concentrations of SS and TSS.

Water Quality Related to Land Use and Land Cover

The mean concentrations for constituents in base-flow, stormflow, and snowmelt samples at the 26 surface-water sites, as well as SS data from 4 WEP water-quality monitoring sites, are listed in appendix 1. Presentation of mean concentrations of non-normally distributed data, rather than median concentrations, was deemed acceptable given the grouping of the data by these three flow conditions. Results from 20 study sites are presented for comparison in figure 4 (in back of report). Sites with sparse water-quality data—Onondaga Creek north of Tully Valley (site 04237956) and near Cardiff (site 04237962) and Spafford Creek at Bromley Road (site 04240145)—and those with large drainage areas for which a dominant land use could not be identified—Onondaga Creek at Indian Village (site 04238550), Otisco Lake at Marietta (site 04240170), and Ninemile Creek at Camillus (site 04240200)—were excluded from the figure. Data from two small developed basins monitored by WEP—Bloody Brook (site 0424013502) and Sawmill Creek (site 04240470)—were included in the figure (data provided by A. Deskins, Onondaga County Department of Water Environment Protection, written commun., 2009). The sites presented in figure 4 have been grouped by the land use or land cover that either dominates the basin or is presumed to have a substantial effect on the water quality of the basin. A basin identified as “Forest” had over 60 percent of the basin covered by forests. An “Agriculture” basin was one with 47 to 79 percent of the basin in use for pasture-hay and row crops. One basin was identified as “Farmstead” because the quality of water in the stream that drained this 0.56-mi^2 basin was affected by a dairy operation. Another basin was identified as “Wetland” because 27 percent of the basin was covered by this land type. A “Developed” basin had 24 to 99 percent of the basin in use for residential, commercial, or transportation purposes. Within each land-type category, the sites were ordered from lowest to highest percentage of the basin in the specified land type; agricultural basins were ordered by the percentage of area in row-crop use.

Specific Water-Quality Constituents

Mean NH_3 concentrations (fig. 4A) were highest in basins with high percentages of high-intensity residential, commercial-transportation, and agricultural land uses; NH_3 concentrations were lowest in forested basins. Base-flow concentrations were less than event concentrations (the combined results of stormflow and snowmelt data), except in the wetland and a high-intensity residential and commercial-use basin. In forested and half the agricultural basins, the mean NH_3 concentrations in base flows generally were below the analytical detection limit.

Mean concentrations of TKN (fig. 4B) were highest in basins dominated by farmstead and agricultural uses. Developed basins generally had the lowest mean TKN concentrations; forested basins had intermediate concentrations. TKN concentrations in stormflow samples were greater than those in snowmelt samples.

Mean NO_x concentrations (fig. 4C) were highest in the farmstead basin and other agricultural basins. The lowest NO_x concentrations were measured in the wetland basin. Mean base-flow concentrations were comparable to mean event concentrations and, in many agricultural and developed basins, exceeded mean storm and (or) snowmelt concentrations. Mean NO_x concentrations in snowmelt samples generally were greater than those in stormflow samples.

Mean PO_4 concentrations (fig. 4D) were highest in the agricultural basins and some developed basins; concentrations were lowest in forested basins. Concentrations in base-flow samples were less than those in event samples, except in a few developed basins.

Mean P concentrations (fig. 4E) were highest in the agricultural basins and lowest in the developed basins, except for one high-intensity residential basin, which had the highest mean stormflow concentration. Forested basins had intermediate concentrations. Base-flow concentrations were much lower than event concentrations, except in the wetland basin and three developed basins, where base-flow and event concentrations of P were comparable.

Mean concentrations of SS (fig. 4F) were highest in Rattlesnake Gulf (site 04237955) and Rainbow Creek (site 04237952), both basins that are known to be large sediment contributors to Onondaga Creek from erosion of glacial deposits and landslide materials (Tamulonis and others, 2009). Excluding these two unique basins, forested and agricultural basins had similar ranges of SS concentrations. This unexpected result might be explained by comparing the sediment-generating processes of these two land types in the Onondaga Lake Basin. Agricultural lands, which are found on low-gradient hilltops and valley bottoms, have disturbed soils that, when exposed to the impact of raindrops, can be loosened and transported to nearby streams. Although forest soils are generally protected from raindrop impact by the forest canopy and the accumulation of organic matter, forested areas of the Onondaga Lake Basin are more likely to be found on steep valley sides, which are prone to landslides and gully or roadbank erosion. (Roadbank erosion was documented by Sullivan and Moonen (1994) as a localized source of sediment in the basin.) These different sources of sediment might produce similar concentrations of SS in streams and account for the similar ranges of SS concentrations depicted in figure 4F. The wetland-dominated basin had the lowest SS concentrations owing to the natural sedimentation function of wetlands. SS concentrations in developed basins were low probably because impervious areas created less erodible surfaces than in other land types. In all cases, mean SS concentrations in stormflow samples were greater than those in snowmelt samples.

SC values (fig. 4G) were highest in the developed basins and the wetland basin. The agricultural basins, as a group, had the lowest mean SC. Values of SC in event flows generally were less than in base flows because of dilution by a greater volume of water in stormflows and snowmelt. SC in stormflow and snowmelt samples was comparable, except in the wetland basin and the developed basins where snowmelt values were greater. The high SC in the snowmelt from developed basins was probably a result of winter road-salt usage.

Factors that Affect Relation Between Water Quality and Land Type

Loading rates published in the scientific literature commonly are associated with a dominant land cover or land use within the area contributing flows and loads to a particular point. Among many basins, these land uses can be classified identically, with no consideration of other characteristics of the basin that might have a great influence on runoff and loads. Additionally, the monitoring point where nutrient and sediment concentrations are measured commonly is at the downstream end of the basin, rather than at the edge of the field, and reflects the integration of contributions from several land types. The current study was designed with end-of-basin monitoring sites because the objective of the study was to characterize the water quality of the entire Onondaga Lake Basin and not that of isolated single-land-use plots.

On the basis of loading-rate data summarized by Coon and Reddy (2008) and although loads were not computed from the data collected for this study, certain relative differences in constituent concentrations among the given land types were expected. The concentration data presented in figure 4 showed expected relative differences among the land types for concentrations of NO_3, TKN, and PO_4; however, the data departed from the expected relations for P and SS. Concentrations of P in developed basins were expected to be greater than those in agricultural and forested basins, and those in forested basins were expected to be lower relative to agricultural concentrations. Similarly, SS concentrations were expected to increase from relatively low values in forested basins to intermediate values in developed basins and to be largest in agricultural basins. These relations were not borne out by the study data, even with the sites grouped by dominant land type and ordered within each group by the percentage of the basin in the specified land type.

Many factors besides land type can influence the concentrations of P and SS. One such characteristic is land-surface slope. The concentrations of P and SS from low-sloped areas can be much different from those derived from high-sloped areas of the same land type. In addition, a monitoring site immediately downstream from a high-gradient reach might not yield results representative of the low-gradient areas further upstream. In a similar manner, a site just downstream from an expansive wetland area would unlikely reflect the contributions of the high-gradient areas that drain into the wetland. Additionally, localized roadbank erosion, especially in high-sloped basins, can obscure the data results that might otherwise have been obtained. These factors were potentially present in all the monitored basins and could have obscured the relation between the dominant land type in a given basin and the measured concentrations of P and SS.

Comparison of Storm Runoff and Snowmelt

SS and associated nutrients can be found in streamflow from three sources: (1) washoff from or erosion of the land surface, (2) stream-channel erosion and resuspension of material deposited in a channel during the recession of an earlier storm event, and (3) direct deposition from the atmosphere, which is considered a negligible source relative to the other two pathways. Within-channel sources of sediment (channel erosion and resuspension) are assumed to be relatively constant for a given flow in a given channel, but, in the northern United States, land-surface sources (washoff and scour) can vary seasonally and constituent concentrations in storm runoff can be substantially different from those in snowmelt runoff.

The processes of load generation from storm runoff differ substantially from those related to snowmelt runoff. Storm-runoff loads result from rainfall that disrupts and loosens the soil matrix at the land surface and provides a ready source of sediment to the erosive forces of storm runoff. When the infiltration capacity of the soil is exceeded, storm runoff is fast and potentially can transport large quantities of sediment and associated constituents. Snowmelt, on the other hand, typically is a slower process than storm runoff and commonly flows across frozen ground, which does not yield loads as large as storm runoff. Therefore, loads in streamflow generated by snowmelt are likely to reflect smaller contributions from land-surface sources and larger contributions from within-channel sources relative to storm runoff.

The data collected during snowmelt were compared with those collected during storm runoff from the same site and at similar flow rates; 73 data pairs from 24 sites were tabulated (appendix 2). These comparisons pertain to within-bank low- and medium-stage flows and not to overbank flows. Paired-sample tests of significance (Helsel and Hirsch, 1992) were performed. No significant difference between storm and snowmelt flow rates was expected nor found, because similar flow rates were intentionally selected for this analysis. Snowmelt SC and concentrations of NH_3 and NO_x were significantly higher than storm-runoff values, whereas snowmelt concentrations of TKN, PO_4, P, and SS were significantly lower than storm-runoff concentrations. Generally, snowmelt concentrations of dissolved constituents, except for PO_4, were higher and those of particulate constituents were lower than storm-runoff concentrations. Anecdotally, hydrographers noted this conclusion in the field by observing that snowmelt runoff generally was less turbid than storm runoff in a given stream. Presumably, the snowpack acted as a short-term sink for dissolved constituents that had accumulated from atmospheric deposition, and streambed erosion and resuspension of previously deposited material, rather than land-surface erosion, were the primary sources of particulate constituents in snowmelt flows. High SC values in snowmelt were likely a result of road-salt washoff.

Longitudinal Comparison of Water Quality

Water-resources managers in the Onondaga Lake Basin have questioned the fate of constituents that are generated in the headwater subbasins and transported along major tributaries to their presumed deposition in Onondaga Lake. Constituent loads, rather than concentrations, would be the preferred data form to address this question, owing to complicating factors that could obscure the interpretation of concentration data, such as dilution and the losses of particulate constituents by sedimentation and nutrients by plant and microbial uptake. These factors would be exhibited in the data by a decrease in concentration as one proceeded downstream and would prevent the drawing of any definitive conclusions about the loads of these constituents. Longitudinal comparisons of concentration data (from upstream to downstream monitoring sites) can still be illustrative, however, and conclusions about water quality can be stated in those cases where concentrations, and therefore loads, increase in the downstream direction.

Major Tributaries

Median concentrations from base-flow samples and from stormflow and snowmelt samples (event samples) were evaluated from upstream to downstream monitoring sites along Onondaga Creek and Ninemile Creek. These two creeks represent flows and constituent contributions from almost 80 percent of the Onondaga Lake Basin.

Onondaga Creek

Median NH_3 concentrations in base-flow and event samples (fig. 5) generally increased in Onondaga Creek from Tully Farms Road northwest of Tully (site 04237917) to Kirkpatrick Street in Syracuse (site 04240011). Base-flow concentrations of TKN and P increased slightly from upstream to downstream; those of SS remained fairly constant (74 mg/L ±13 mg/L) from Otisco Road (site 04237950) to Kirkpatrick Street. High-flow concentrations of TKN, P, and SS spiked at State Highway 20 (site 04237962), likely owing to the contributions from Rattlesnake Gulf (site 04237955) and Rainbow Creek (site 04237952).

Ninemile Creek

Concentrations in the outflow from Otisco Lake (site 04240170) were grouped together and treated as base-flow concentrations for the purpose of this analysis because Otisco Lake greatly mitigated water quality in its outflow regardless of stormflow inputs from elsewhere in the basin. Concentrations of constituents in Otisco Lake generally were lower than or comparable to those of base-flow samples from any other monitoring site along Ninemile Creek (fig. 6). Concentrations in event samples collected at Schuyler Road (site 04240180), 1.8 mi downstream from Otisco Lake, were noticeably greater than those in concurrent Otisco Lake outflow samples. From Schuyler Road to the mouth of the creek near Lakeland (site 04240300), median base-flow concentrations of NH_3, P, and SS increased; those of other constituents did not show clear trends. Event concentrations of TKN, PO_4, and P decreased from upstream to downstream sites.

Minor Tributaries

Two pairs of monitoring sites on minor tributaries to Onondaga Creek and one pair on a tributary to Otisco Lake provided additional data to identify changes in constituent concentrations along each respective reach. These comparisons illustrated differences in water quality associated with changes in land uses or unique extenuating conditions between a given pair of sites.

Rattlesnake Gulf

Rattlesnake Gulf at Cook Road at Otisco (site 04237953) is dominated by agricultural activities; 63 percent of its drainage area is used for row crops, pasture, and farmstead purposes. The water-quality effect of these uses is suggested by the high median concentrations of NH_3, NO_x, and PO_4 (fig. 7) relative to those measured at the downstream site at Tully Farms Road (site 04237955). The total acres in agricultural uses increase as one goes downstream, but the percentage of agricultural uses decreases and that of forested land increases as the drainage area encompasses the steep west valley wall of the Onondaga Creek Basin. Rattlesnake Gulf erodes and transports large quantities of sediment to the Onondaga Creek valley floor. Loads of fine-grained sediment are derived mainly from unstable glacial deposits of lacustrine silt and clay that have slumped into the narrow stream channel (Tamulonis and others, 2009); these loads are mostly carried directly into Onondaga Creek. Loads of coarse-grained sediment are generated from erosion of outwash deposits of sand and gravel; these loads are deposited, usually within the channel, from the valley wall to the stream mouth. Turbidity is evident near the mouth of the stream year-round, and aggradation of the channel at the Tully Farms Road bridge decreases flow conveyance under the bridge and periodically causes flooding problems. Although aggradation is episodic, occurring during the recession of major storm runoff, an average aggradation rate of 1 ft/yr has been documented. (See “Additional Notes” on this site in appendix 3.)

West Branch Onondaga Creek

West Branch Onondaga Creek drains 12.6 mi^2 of mixed land uses at the upstream site at Tanner Road (site 04237995). Forty-two percent of the basin is forested and 48 percent is in agricultural uses upstream from this point. The land-use percentages are relatively unchanged by the additional 9.5 mi^2 between Tanner Road and the downstream site at State Highway 80 (site 04238000). Although the headwater subbasins are in areas of high relief, they drain to low-gradient wetlands that, in some areas, occupy the entire West Branch Onondaga Creek valley bottom. These low-gradient areas affect the hydrology of the basin by delaying storm-runoff peaks, which occur later than those in other basins of similar size, and by prolonging the high-flow recession. Between the upstream monitoring site at Tanner Road (site 04237995) and the site 1.9 mi downstream at State Highway 80 (site 04238000), several factors have a combined effect on the water quality of the stream. These factors include (1) a golf course immediately downstream from Tanner Road; (2) a large wetland that covers the entire valley bottom for at least half the length of the reach; and (3) two high-gradient tributaries that discharge to West Branch Onondaga Creek, at least one of which is a large source of sediment and joins the stream downstream from the wetland area and about 0.5 mi upstream from the State Highway 80 site. These factors cause an increase in the base-flow and event median concentrations of all constituents, except those for base-flow NO_x concentrations, which decrease, and those for base-flow concentrations of PO_4 and SS, which are similar at both sites (fig. 8).

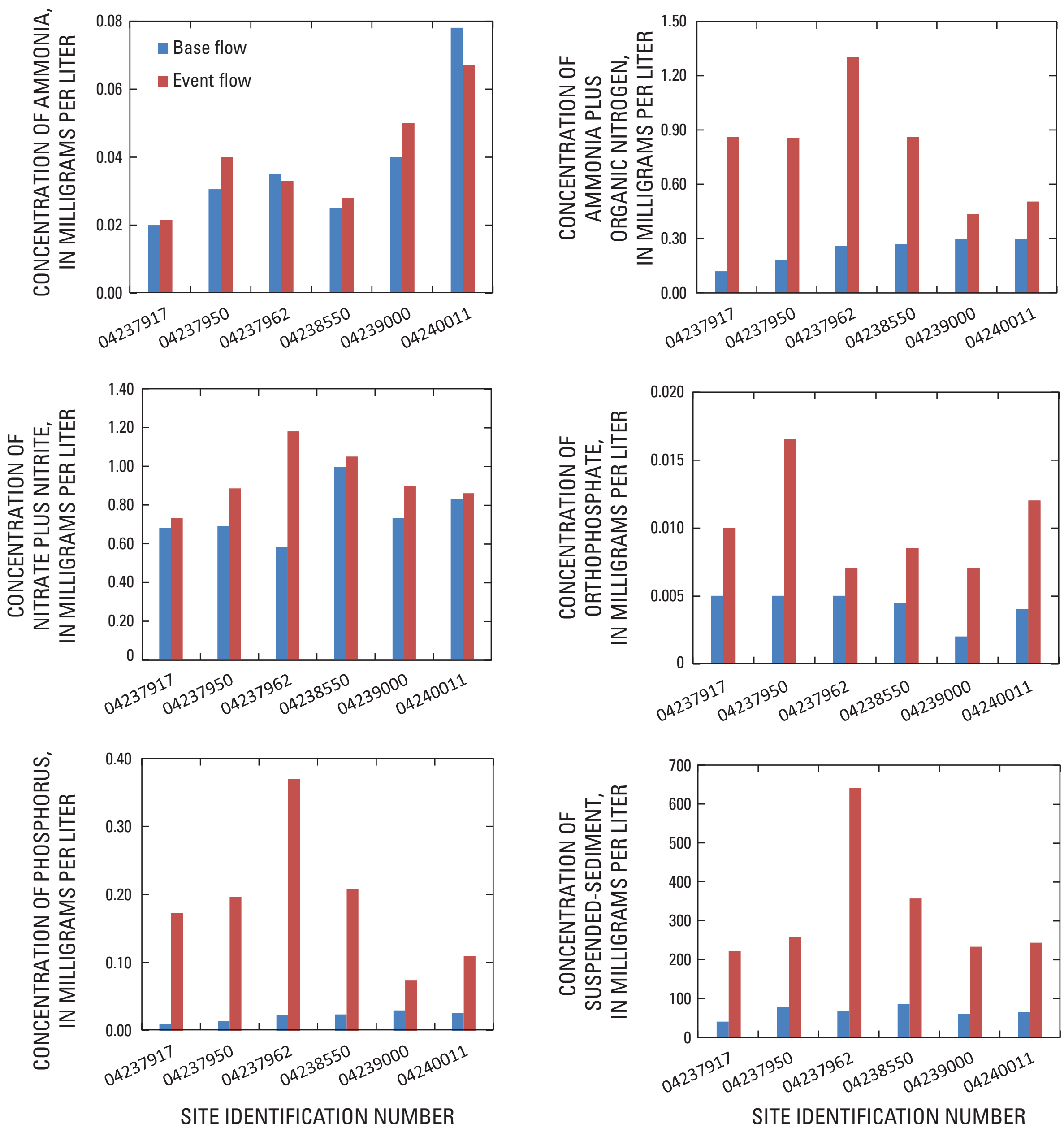


Figure 5. Changes in the median concentrations of selected constituents in samples collected from upstream to downstream monitoring sites on Onondaga Creek, Onondaga County, N.Y., 2005–08.

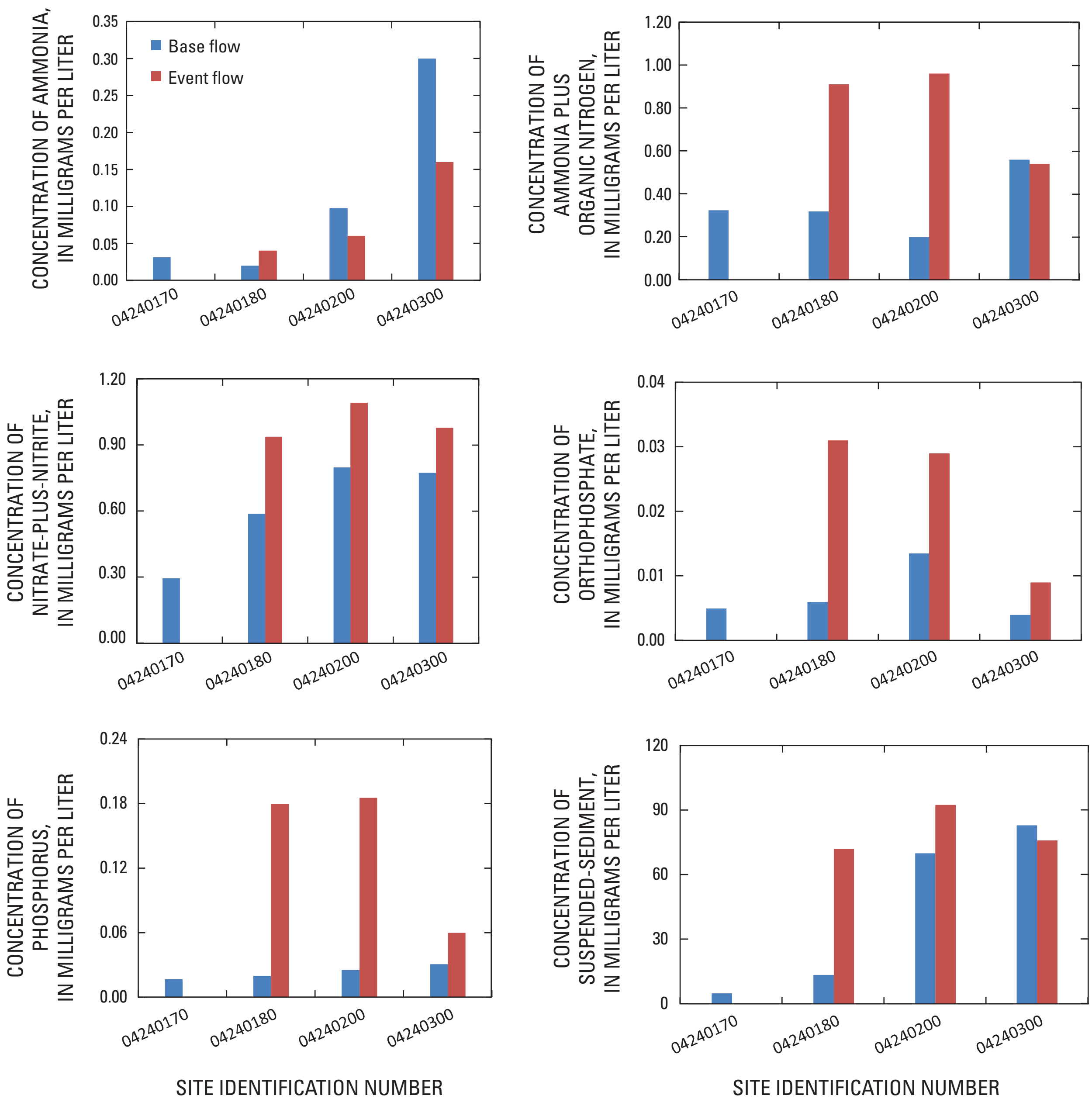


Figure 6. Changes in the median concentrations of selected constituents in samples collected from upstream to downstream monitoring sites on Ninemile Creek, Onondaga County, N.Y., 2005–08.

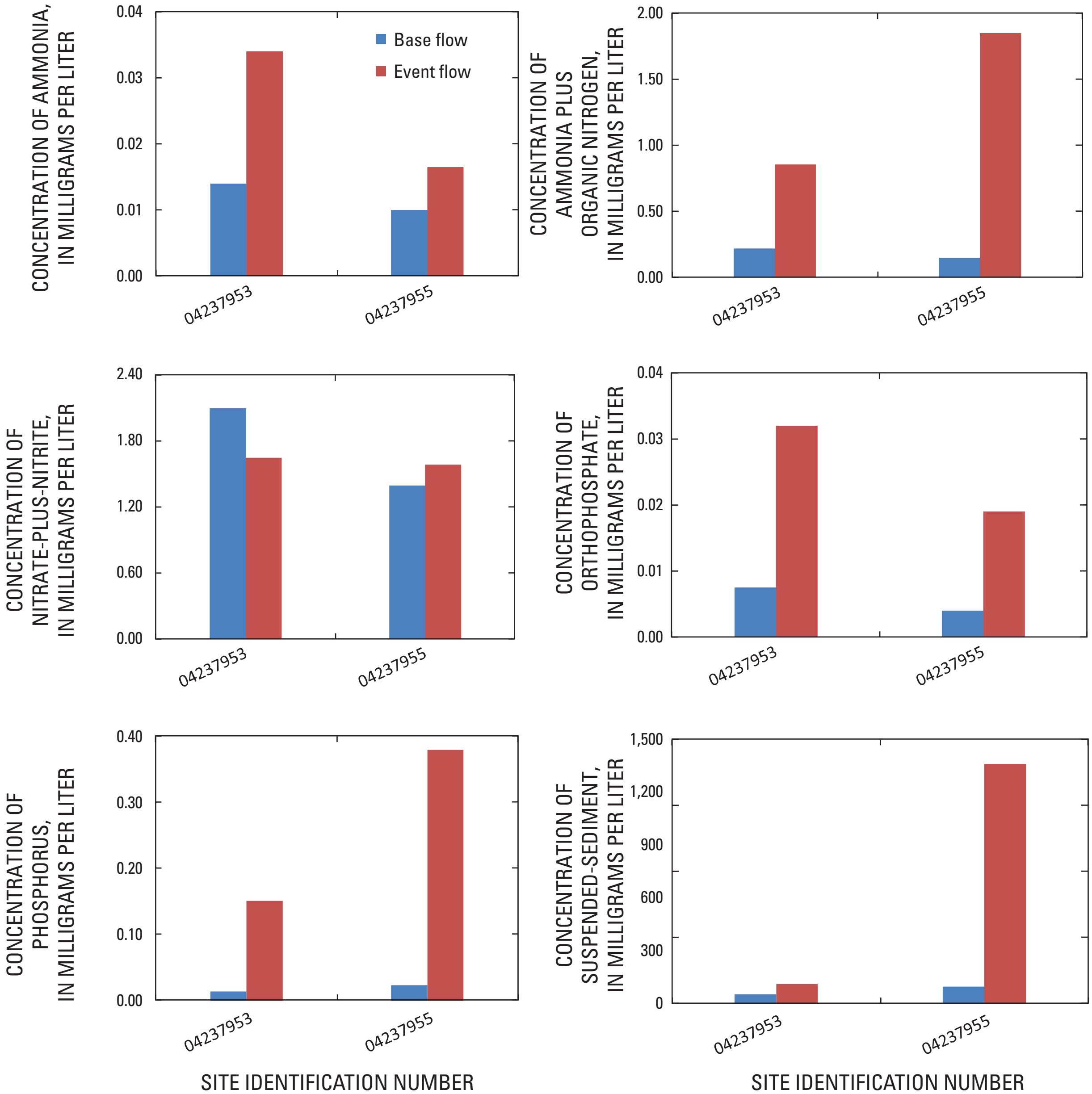


Figure 7. Changes in the median concentrations of selected constituents in samples collected from upstream to downstream monitoring sites on Rattlesnake Gulf, Onondaga County, N.Y., 2005–08.

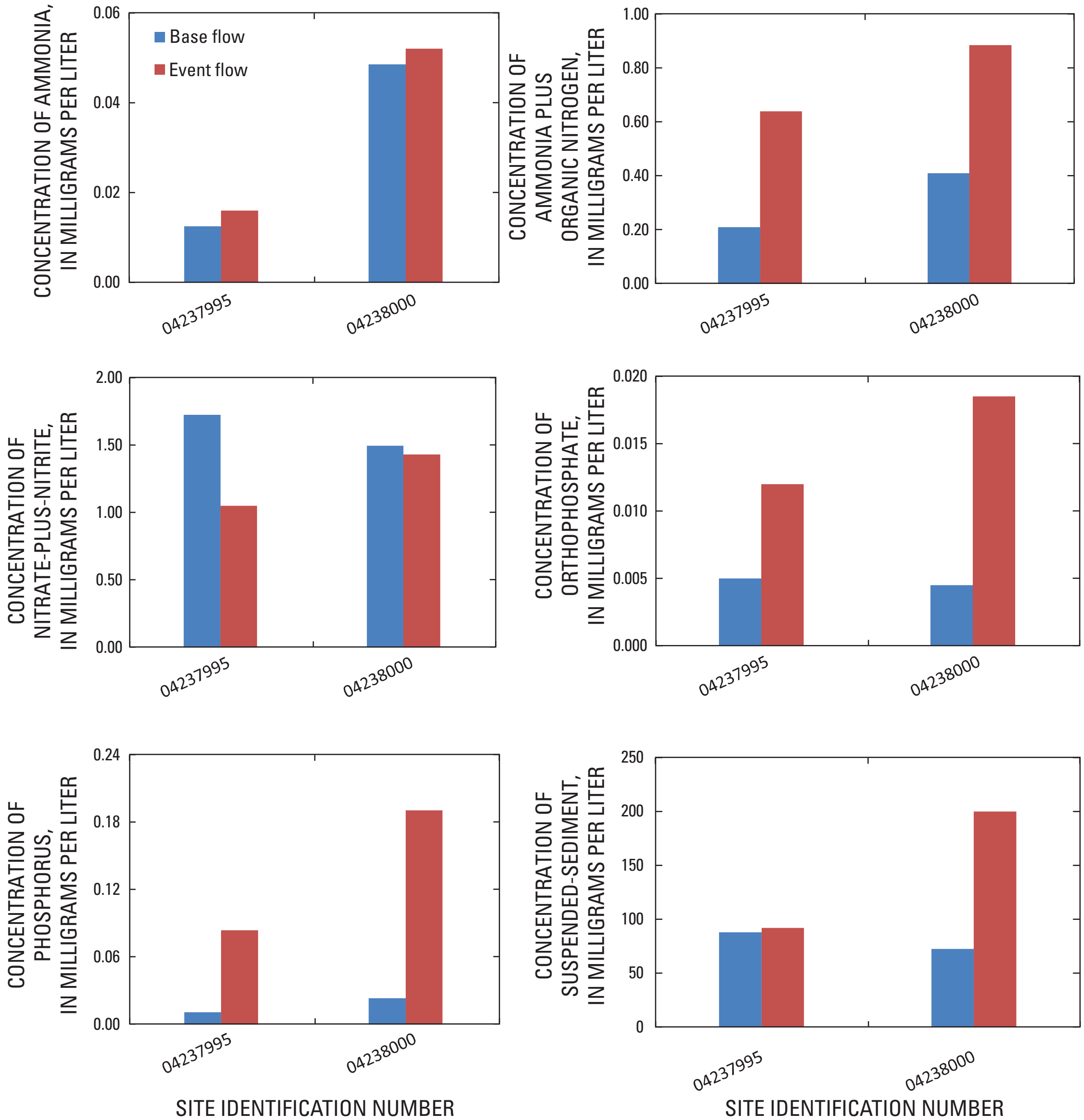


Figure 8. Changes in the median concentrations of selected constituents in samples collected from upstream to downstream monitoring sites on West Branch Onondaga Creek, Onondaga County, N.Y., 2005–08.

Spafford Creek

Spafford Creek at Bromley Road near Spafford (site 04240145) was added to the monitoring network during the last year of the study in an effort to clarify water-quality differences that exist between Bromley Road and the monitoring site 3.5 mi downstream at Sawmill Road (site 04240150). Only three base-flow and three event samples were available for a comparison between upstream and downstream sites on Spafford Creek; these samples were collected concurrently from July to December 2008. The land-use percentages are similar for both sites, but the upstream site at Bromley Road has twice as much area (67 percent) with soils that are classified (U.S. Department of Agriculture, 2005) as high runoff potential than does the downstream site at Sawmill Road (34 percent). Soils with high-runoff potential have slow infiltration rates when thoroughly wetted and slow subsurface transmission rates (U.S. Department of Agriculture, 2001). In the case of the upper Spafford Creek Basin, these soil characteristics are a result of thin soils over bedrock or soils derived from kame-moraine deposits. The high median concentrations of TKN, P, and SS at Bromley Road relative to those at Sawmill Road likely reflect the erodibility of these high-runoff soils (fig. 9). Another extenuating condition of the Spafford Creek Basin is that much of the valley bottom between Bromley and Sawmill Roads has soils that are derived from lacustrine silt and clay deposits, and row crops dominate the agricultural use of these easily erodible soils. These conditions could be responsible for the high median concentrations of NH_3 and PO_4 at Sawmill Road relative to those at Bromley Road (fig. 9).

Agricultural Environmental Management (AEM) Subbasins

Otisco Lake is the public-water source for several towns and villages mostly located in southwestern Onondaga County. Onondaga County Water Authority (OCWA) withdraws about 17 Mgal/d from Otisco Lake (1998–2008 data provided by M. Murphy, Onondaga County Water Authority, written commun., 2009) to meet these water needs. Nonpoint sources of nutrients and sediment from the tributary subbasins of the lake are a concern because these loads affect the water quality of the lake. Great effort has been expended by farm owners and the Onondaga County Soil and Water Conservation District to implement AEM plans to mitigate nutrient and sediment loads from agricultural activities (Onondaga County Soil and Water Conservation District, 2009). The intensity of these efforts in the Otisco Lake Basin has led to the reference of these tributary watersheds as AEM subbasins.

The five major tributaries to the lake were monitored during 1981–83 (Paschal and Sherwood, 1987). Three of those subbasins—Willow Brook (site 04240158), Rice Brook (site 0424015305), and Spafford Creek (site 04240150)—were also monitored during 2005–08, which provided a basis for assessing changes in nutrient and sediment loads that might be attributable to AEM measures. Streamflows were monitored on a continuous basis at all three sites from November 1981 to September 1983. For the current analysis, 2 complete water years of data were needed. Therefore, streamflows during October 1981 were estimated by comparison with the flows from a USGS streamflow-monitoring site on Butternut Creek (station number 04245200), a site with topography, soils, and hydrology similar to the Otisco Lake tributaries and about 10 mi east of Otisco Lake. During 2005–08, streamflows were monitored on a continuous basis from November 2005 to December 2007 and April to September 2008 on Willow Creek, from November 2005 to November 2007 and April to September 2008 on Rice Brook, and from April to November 2007 and April to September 2008 on Spafford Creek. Missing daily flows were computed using a precipitation-runoff model of the Onondaga Lake Basin (Coon and Reddy, 2008) after the model had been recalibrated to flows measured during the present study. All three sites during 1981–83 and Willow Brook and Rice Brook during 2005–08 were instrumented with automatic water-quality samplers to increase the frequency of stormflow sampling.

Several differences between the 1981–83 and 2005–08 studies exist. First, the 1981–83 study period was drier than the 2005-08 period. The average annual precipitation during the 1981–83 study was 35.1 in., whereas the average annual precipitation during the 2005–08 study was 43.4 in. The mean daily flows at the three sites reflected these precipitation differences. The 2005–08 flows were 30 to 45 percent greater than the 1981–83 flows in Spafford Creek and Rice Brook, respectively (table 3). Second, the monitoring site on Willow Creek during 1981–83 was located near the mouth of the stream, whereas in 2005–08, the site was about 1.1 mi upstream from the original monitoring site, at a location that was not subject to backwater from the lake and that provided convenient and safe access to the stream for high-flow sampling and streamflow measurements. In regards to the differences in mean flows mentioned above, although the 2005–08 Willow Creek site monitored flows from only 52 percent of the basin, the mean flow at this location was equal to the mean flow measured for the entire basin during 1981–83. Third, the study sites were sampled more frequently during the 1981–83 study, which was conducted over 2 water years during which a yearly average of 31 nutrient and 71 suspended-sediment samples were collected per site. The 2005–08 study spanned 3 water years and a yearly average of 18 nutrient and sediment samples were collected per site.

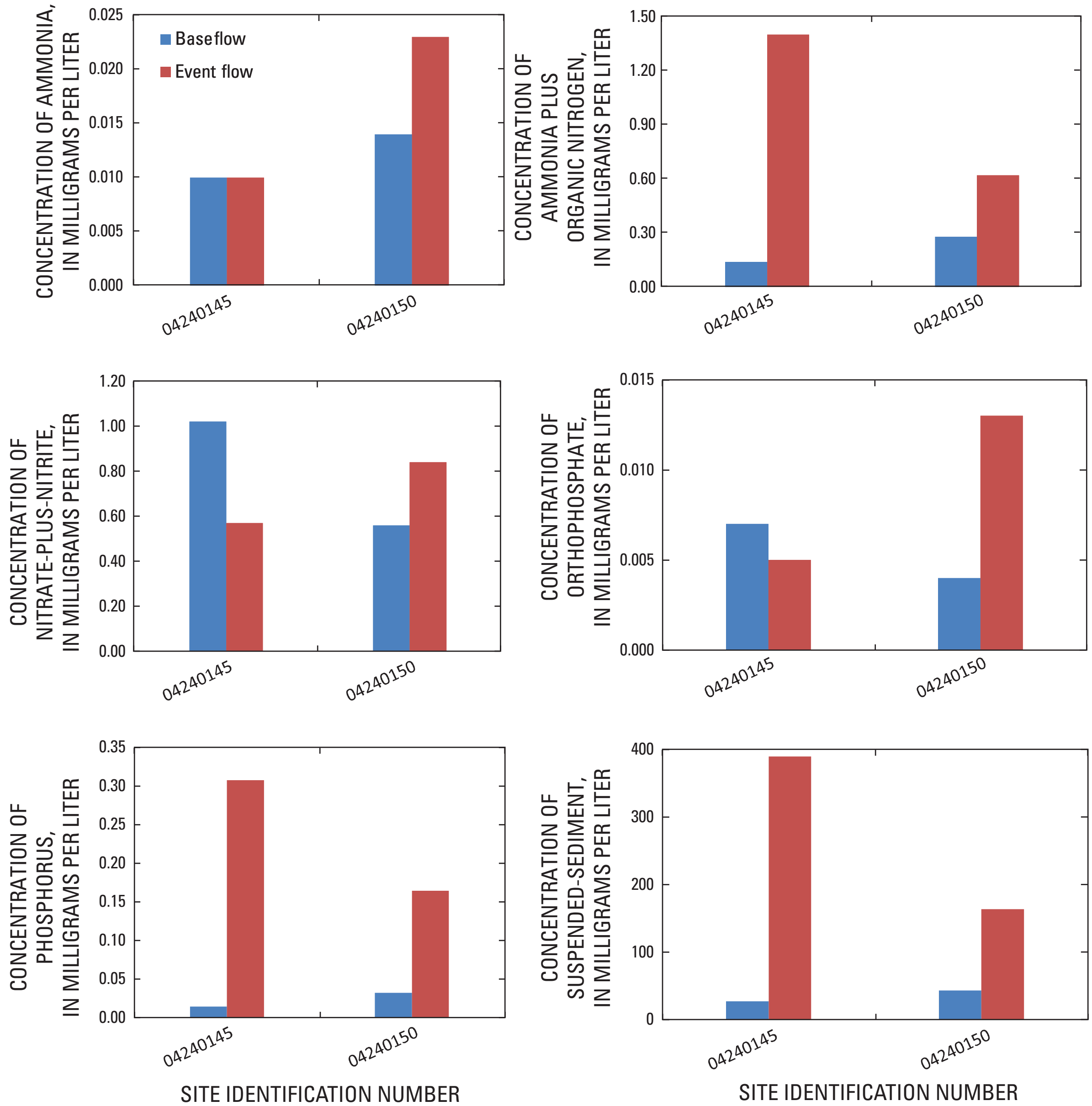


Figure 9. Changes in the median concentrations of selected constituents in samples collected from upstream to downstream monitoring sites on Spafford Creek, Onondaga County, N.Y., July to December 2008.

Table 3. Concentrations and yields of nutrient and suspended sediment in Otisco Lake tributaries, Onondaga County, N.Y., water years 1982–83 and 2006–08.

[Site locations are shown in figure 1. Concentrations are in milligrams per liter. ft^3/s, cubic feet per second; (lb/acre)/in., pounds per acre per inch of precipitation; (ton/acre)/in., tons per acre per inch of precipitation; –, no data]

Water years	1982 to 1983			2006 to 2008		
Mean annual precipitation[1] (inches)	35.1			43.4		
	Spafford Creek (04240150)	Rice Brook (0424015305)	Willow Brook[2] (04240158)	Spafford Creek (04240150)	Rice Brook (0424015305)	Willow Brook[2] (04240158)
Drainage area (square miles)	8.06	2.44	3.73	8.06	2.44	1.95
Number of nutrient samples	84	55	48	36	53	74
Number of sediment samples	171	140	117	36	53	74
Mean daily flow (ft^3/s)	12.3	3.3	4.5	16.0	4.8	4.5
Ammonia-plus-organic nitrogen, unfiltered						
Maximium concentration	10.0	7.0	6.8	3.3	14.0	12.0
Water-weighted mean concentration[3]	.98	1.24	1.71	.73	.71	.95
Minimum concentration	.14	.10	.10	.14	.15	.19
Yield[4] (pounds per acre per year)	4.61	5.14	6.35	4.48	4.31	6.73
Yield percent difference[5]	–	–	–	-2.82	-16.1	5.98
Precipitation-weighted yield[6] [(lb/acre)/in.]	.13	.15	.18	.10	.10	.16
Nitrate-plus-nitrite, filtered						
Maximium concentration	2.35	4.04	5.94	2.03	4.60	7.88
Water-weighted mean concentration[3]	1.00	1.89	3.34	1.20	3.07	2.66
Minimum concentration	.22	.22	.20	.39	.84	.35
Yield[4] (pounds per acre per year)	4.71	7.87	12.4	7.30	18.6	18.9
Yield percent difference[5]	–	–	–	55.0	136	52.4
Precipitation-weighted yield[6] [(lb/acre)/in.]	.13	.22	.35	.17	.43	.44
Orthophosphate, filtered						
Maximium concentration	.478	.925	.505	.049	.464	.217
Water-weighted mean concentration[3]	.026	.032	.080	.014	.030	.039
Minimum concentration	.001	.001	.001	.003	.003	.003
Yield[4] (pounds per acre per year)	.12	.13	.30	.08	.18	.28
Yield percent difference[5]	–	–	–	-33.3	38.5	-6.7
Precipitation-weighted yield[6] [(lb/acre)/in.]	.003	.004	.008	.002	.004	.006
Phosphorus, unfiltered						
Maximium concentration	1.40	1.28	.88	.80	3.31	1.81
Water-weighted mean concentration[3]	.18	.12	.19	.18	.13	.18
Minimum concentration	.015	.015	.015	.010	.008	.010
Yield[4] (pounds per acre per year)	.86	.49	.71	1.08	.76	1.26
Yield percent difference[5]	–	–	–	25.6	55.1	77.5
Precipitation-weighted yield[6] [(lb/acre)/in.]	.024	.014	.020	.025	.018	.029
Suspended sediment						
Maximium concentration	5,910	2,060	1,150	1,870	5,600	1,960
Water-weighted mean concentration[3]	206	55	110	347	202	175
Minimum concentration	4	0	0	19	1	16
Yield[4] (tons per acre per year)	.48	.11	.20	1.06	.61	.62
Yield percent difference[5]	–	–	–	121	454	210
Precipitation-weighted yield[6] [(ton/acre)/in.]	.014	.003	.006	.024	.014	.014

[1] Precipitation at the Onondaga County Water Authority monitoring site at Otisco Lake (M. Murphy, Onondaga County Water Authority, written commun., 2009).

[2] Data for Willow Brook during water years 1982–83 were collected at a site near the mouth of the stream (USGS station number 0424016205); whereas those for water years 2006–08 were from a site about 1.1 miles upstream (number 04240158).

[3] Average daily load divided by average daily flow volume.

[4] Loads were computed by identical regression models using the data from each respective time period. As a result, the 1982–83 yields differ from those that could be computed from the data presented by Paschal and Sherwood (1987).

[5] A positive (negative) percent difference indicates a larger (smaller) average yield during water years 2006–08 than during water years 1982–83.

[6] Yield normalized (divided) by mean annual precipitation.

Loads of nutrients and SS for the 2005-08 period were computed using LOADEST (Runkel and others, 2004; Cohn and others, 1992) and were compared with those for the 1981-83 period, which were computed by regression equations based on streamflow and SS concentration (table 3). The comparison was problematic because (1) load-estimation methods differed for each study, (2) at least for Willow Creek, the location of the monitoring site differed, and (3) climatic conditions differed between the study periods. To address these differences, which could affect the interpretation of the load data, (1) the 1981–83 loads were recomputed using LOADEST regression models identical to those used to compute the 2005–08 loads, (2) total annual loads were converted to yields (mass per unit area) to permit comparisons among the three sites and between the two sampling locations on Willow Brook, and (3) the yields were normalized by the mean annual precipitation for each time period to permit comparisons between the two sampling periods (table 3).

The 2005–08 precipitation-weighted yields of TKN, PO_4, and P were comparable to the 1981–83 yields. The yields of NO_x in Rice Brook and Willow Brook and those of SS in all three subbasins increased (table 3). The largest yield increase was shown for SS; the yields during 2005–08 were 100- to 400-percent greater than during 1981–83. Although Spafford Creek, the largest of the Otisco Lake tributaries, had the highest precipitation-weighted yield of SS among the three sites, the 2005–08 yields in Rice Brook and Willow Brook increased greatly compared to their respective 1981–83 yields, as well as relative to the Spafford Creek yield.

Effect of the Mudboils on Onondaga Creek

The mudboils are a unique hydrologic and sedimentological phenomenon along Onondaga Creek upstream from Otisco Road near Tully Valley. Mudboils are volcano-like cones of fine sand and silt that range from several inches to several feet in height and from several inches to more than 30 ft in diameter (Kappel and McPherson, 1998). Groundwater under artesian pressure moves upward through a dense layer of silt and clay and deposits the coarse portion of its sediment load on the land surface near a mudboil vent and carries the fine-grained particles to Onondaga Creek. The composition of the sediment entering Onondaga Creek averages 2 percent sand, 31 percent silt, and 67 percent clay, on the basis of particle-size analyses performed from 1993 to 2005 (Hornlein and others, 1994 through 2001; U.S. Geological Survey, 2009). Historically, the mudboils have been a large source of sediment to the creek and can contribute to turbid conditions that, at times, can persist all the way to Onondaga Lake, over 16 mi downstream. During 1992, the average daily sediment load from the mudboils was 30 tons. Remediation efforts, including the diversion of surface water from the mudboil area, installation of depressurizing wells, construction of an impoundment dam, and removal of accumulated sediment upstream from the dam, decreased loads to an average daily load of less than 2 tons during 1994–95 (Kappel and McPherson, 1998; Kappel, 2009). Sediment loads from the mudboils during the 2005–08 study period were computed with LOADEST on the basis of daily flows and sediment concentrations from weekly samples. Annual (water year) loads ranged from 192 to 231 tons; the average daily load was 0.58 ton. These results indicate that maintenance of the mitigation measures continue to have the desired effect of decreasing sediment loads from the mudboils to Onondaga Creek.

Sediment concentrations in the outflow from the mudboils (site 04237946), which in 1992 were greater than 5,000 mg/L (Kappel and others, 1996), ranged from 10 to 4,140 mg/L, but typically were between 50 and 200 mg/L during the 3-year study period. To assess the effect of the mudboils on Onondaga Creek, concurrent samples were collected during 19 base-flow periods and 21 stormflow and snowmelt events on Onondaga Creek at Tully Farms Road (site 04237917; about 2.6 mi upstream from the mudboils) and at Otisco Road (site 04237950; immediately downstream from the mudboils).

The addition of the mudboil sediment load to Onondaga Creek base flows contributed to an increase in sediment concentrations in base flows from an average concentration of 43 mg/L in samples collected at Tully Farms Road to 83 mg/L in samples collected at Otisco Road (table 4). Although the sediment loading rate from the mudboils is high (0.81 lb/mi^2) compared to that from the Tully Farms Road site (0.09 lb/mi^2), the sum of the instantaneous sediment loads indicated that the sediment load from the mudboils (0.26 lb/s) accounted for only about 10 percent of the base-flow load passing Otisco Road. Seventy percent of the load was generated from the intervening drainage area between Tully Farms Road and Otisco Road.

Mean concentrations of SS from stormflow and snowmelt events decreased from 648 mg/L at Tully Farms Road to 405 mg/L at Otisco Road; however, the sum of the instantaneous loads for the sampled flows increased from 127 lb/s at Tully Farms Road to 170 lb/s at Otisco Road. Of this increase, the mudboils contributed only 0.44 lb/s or less than 1 percent of the total load passing Otisco Road. Of the total load measured at Otisco Road, 75 percent was measured at Tully Farms Road; the remaining 25 percent was generated from the intervening drainage area.

Because the mudboils sediment loading rate to Onondaga Creek is fairly constant, at least on a seasonal basis, the magnitude of the mudboils contribution is not proportional to other sediment sources in the basin. The effect of the mudboils on sediment concentrations and loads in the creek is inversely related to the flow regime of the creek and can be obscured by other larger sediment inputs during storm events.

Table 4. Sediment concentrations and loads at selected sites in the upper Onondaga Creek Basin, Onondaga, County, N.Y., 2005–08.

[Site locations are shown in figure 1. Concentrations are in milligrams per liter. Loads are in pounds per second. E, estimated; lb/mi^2, pounds per square mile]

Site name		Mean sediment concen-tration	Sum of instan-taneous sediment loads	Loading rate (lb/mi^2)	Mean sediment concen-tration	Sum of instan-taneous sediment loads	Loading rate (lb/mi^2)
Effect of the mudboils on sediment concentrations and loads in Onondaga Creek, 2005-08							
		Base flow (19 samples)			Stormflow and snowmelt (21 samples)		
04237917	Onondaga Creek (at Tully Farms Road) northwest of Tully	43	0.57	0.09	648	127	19.84
04237946	Onondaga Creek tributary 6 below mudboil area at Tully	320	.26	.81	126	.44	1.38
04237950	Onondaga Creek (at Otisco Road) at Tully Valley	83	2.80	.17	405	170	10.36
Effect of sediment loads from Rainbow Creek and Rattlesnake Gulf on sediment concentrations and loads in Onondaga Creek, 2008							
		Base flow (7 samples)			Stormflow and snowmelt (3 samples)		
04237917	Onondaga Creek (at Tully Farms Road) northwest of Tully	28	0.23	0.04	E128	0.63	0.10
04237950	Onondaga Creek (at Otisco Road) at Tully Valley	58	.70	.04	207	2.75	.17
04237952	Rainbow Creek at State Highway 11A at Tully Valley	90	.13	.05	254	.57	.24
04237955	Rattlesnake Gulf at Tully Farms Road near Cardiff	133	1.18	.13	2,220	24.24	2.68
04237956	Onondaga Creek (at Nichols Road) north of Tully Valley	96	2.23	.08	442	13.33	.46

Sediment Loads to the Upper Onondaga Creek

Rattlesnake Gulf and Rainbow Creek, directly opposite each other to the west and east of Onondaga Creek, respectively, contribute large loads of sediment to the upper reach of Onondaga Creek near Tully Valley. In Rattlesnake Gulf, these loads are derived from outwash deposits of sand and gravel and from unstable lacustrine silt and clay deposits that slump into the stream channel; turbidity is evident near the mouth of this stream year-round. In Rainbow Creek, the source of sediment is highly erodible glacial deposits of outwash sand and gravel overlying lacustrine silt and clay that have been incised by the stream. Rainbow Creek can be relatively clear during low-flow periods but very turbid during high flows. Coarse sediments are carried to and deposited on the Onondaga Creek valley floor; fine sediments are carried to Onondaga Creek and might remain in suspension all the way to Onondaga Lake, over 16 mi downstream.

During 2008, a new monitoring site on Onondaga Creek north of Tully Valley (at Nichols Road) was added to the network in an effort to better characterize the combined water-quality effects of Rainbow Creek, Rattlesnake Gulf, and the Tully Valley mudboils on Onondaga Creek. (The effects of the mudboils were discussed in the previous section.) A series of concurrent samples were collected during seven base-flow periods, two storm-runoff events, and one snowmelt event on Rainbow Creek (site 04237952), Rattlesnake Gulf (site 04237955), and three sites on Onondaga Creek—Tully Farms Road (site 04237917; upstream from all the major sediment sources), Otisco Road (site 04237950; immediately downstream from the mudboils, but upstream from the confluences with Rainbow Creek and Rattlesnake Gulf), and Nichols Road (site 04237956; downstream from all the major sediment sources) (fig. 1). The sediment loading rates from Rainbow Creek were slightly higher than those for Onondaga Creek at Tully Farms Road and Otisco Road for both base flow and stormflows (table 4), despite the fact that the drainage area of Rainbow Creek is less than 15 percent that of Onondaga Creek at Otisco Road. Rattlesnake Gulf was by far the largest sediment contributor of the three potential sources; the loading rate was 3 times greater than that of Onondaga Creek at Otisco Road under base-flow conditions (0.13 lb/mi^2), but 15 times greater during stormflows (2.68 lb/mi^2).

The loading rates at Nichols Road increased noticeably over those computed at Otisco Road (table 4); the rates were twice as high during base flows (0.08 lb/mi^2) and almost three times as high during stormflows (0.46 lb/mi^2). During base flows, Onondaga Creek at Otisco Road, Rainbow Creek, and Rattlesnake Gulf accounted for about 30, 6, and 50 percent, respectively, of the base-flow sediment load passing Nichols Road. The fine-grained sediment carried into Onondaga Creek in base flows remained suspended and was transported past Nichols Road; the combined contributions from the three inflow sites were 2.0 lb/s, whereas the outflow load past Nichols Road was 2.2 lb/s. Conversely, the combined loads during storm events, almost 28 lb/s, were greatly decreased before reaching Nichols Road, where the outflow load was only 13 lb/s. Presumably the coarse-grained sediment carried by Rainbow Creek and Rattlesnake Gulf was deposited on the low-gradient floodplain before reaching Onondaga Creek. Although these summary statements are based on limited data, they nevertheless suggest sediment processes and relations among the different sediment sources that are deemed valid.

Mitigative Effects of Onondaga Reservoir

The Onondaga Reservoir on Onondaga Creek downstream from the confluence with West Branch Onondaga Creek was constructed by the U.S. Army Corps of Engineers in 1949 to control flooding in Syracuse, N.Y. This dam, which has a capacity of 18,200 acre-ft and can create an 860-acre pool at the spillway crest elevation of 504.5 ft (U.S. Army Corps of Engineers, 1945), controls flows from a 67.7-mi^2 drainage area. Although this dam is a flow-through structure without gates or any other mechanism to retain storm runoff, by design it does attenuate stormflows and cause temporary detention and, depending on water levels, dispersal of stormwater across the floodplain. The presumed water-quality benefits of this structure by the removal of sediment and particulate loads of nutrients have not been previously documented.

The two major inflows to the reservoir—Onondaga Creek at State Highway 20 near Cardiff (site 04237962) and West Branch Onondaga Creek at State Highway 80 at South Onondaga (site 04238000)—and the outflow from the reservoir—Onondaga Creek (at Gibson Road) at Indian Village (site 04238550)—were monitored (fig. 1). Given the long reach of low-gradient channel between State Highway 20 and the dam (2.2 mi) and from the dam downstream to Gibson Road (0.8 mi), any water-quality changes identified by this study could not definitively be attributed to the reservoir alone. Although the reservoir is expected to have a greater effect on any changes in the water quality of stormflows than the low-gradient channel slope would have, the effects of these two factors could not be separated on the basis of the data collected during this study.

Seven nutrient and 14 SS samples were collected concurrently during the study. The sediment samples were collected during all 3 years of the study, whereas the nutrient samples were only collected during 2008. Instantaneous loads computed from these data indicate that the reservoir has little effect on loads during base flows but has a substantial effect on stormflow loads of dissolved and particulate constituents (table 5). Storm loads of NO_x and SS at the outflow monitoring site were almost 40 percent less than the combined loads at the inflow monitoring sites. Loads of NH_3 and PO_4 were decreased by over 50 percent, whereas those of TKN and P were decreased by over 60 percent. Although the data on which these percentages of load removal by the reservoir are sparse, they nevertheless suggest that, in addition to flood control, the reservoir does provide water-quality benefits. In addition, the water-quality benefits might actually be greater than indicated, because loads from the area between the inflow monitoring sites and the reservoir were not taken into account.

Mitigative Effects of Otisco Lake

Otisco Lake is a complex hydrologic system, but a simple comparison of inflow and outflow concentrations can be made to illustrate the natural mitigative effects that the lake, functioning as a large detention basin, has on the outflow water quality. The lake has a surface area of 2.93 mi^2 and an average depth of 33.5 ft (Bloomfield, 1978); its drainage area is 42.3 mi^2. Three of the major tributaries to the lake—Spafford Creek (site 04240150), Rice Brook (site 0424015305), and Willow Brook (site 04240158)—which represent flows and loads from 43 percent of the Otisco Lake Basin were monitored. Lake outflow quality was monitored at the Otisco Valley Road bridge (site 04240170), immediately downstream from the Otisco Lake dam. Flows and water quality also were monitored at the USGS continuous-record streamflow-monitoring site 1.8 mi downstream from the dam on Ninemile Creek at Schuyler Road (site 04240180). Large constituent loads that entered Ninemile Creek between the dam and Schuyler Road produced discrepancies in constituent concentrations in samples collected near in time at these two sites, indicating that water-quality results at the Schuyler Road site were not representative of lake outflow quality. Therefore, only the concentration data from the Otisco Valley Road site, and not those from the Schuyler Road site, were used in this analysis.

The Otisco Lake outflows are regulated by the dam at the north end of the lake. Water flows over the sill of the dam when lake levels are high, usually during late winter and early spring; outflows during other periods are controlled by the openings of three gates near the base of the dam. Storm runoff entering the lake will not readily be transmitted to Ninemile Creek at the dam outlet. If lake levels are above the sill of the dam, lake outflows might increase over the following days,

Table 5. Effects of Onondaga Reservoir on inflow loads of nutrients and suspended sediment from Onondaga Creek and West Branch Onondaga Creek, Onondaga County, N.Y., 2006–08.

[Site locations are shown in figure 1. Results are based on concurrent samples collected at the two inflow sites—Onondaga Creek near Cardiff and West Branch Onondaga Creek at South Onondaga—and the outflow site—Onondaga Creek at Indian Village. Sediment samples were collected during 2006–08. All nutrient samples were collected during 2008. The loads for base flows were based on data from four nutrient samples and five sediment samples. Those for stormflows were based on data from three nutrient samples and nine sediment samples. A negative change-in-load percentage indicates a decrease in the combined inflow loads that is attributed to the constituent-detention effects of the reservoir.]

	Sum of instantaneous loads (pounds)				Change in loads (percent)
	Onondaga Creek near Cardiff (04237962)	West Branch Onondaga Creek at South Onondaga (04238000)	Sum of inflow loads to Onondaga Reservoir	Onondaga Creek at Indian Village (04238550)	
			Ammonia, filtered		
Base flow	0.0002	0.0004	0.0006	0.0004	-33
Stormflow	0.0028	0.0038	0.0066	0.0032	-52
All flows	0.003	0.0042	0.0072	0.0036	-50
			Ammonia-plus-organic nitrogen, unfiltered		
Base flow	0.0022	0.0024	0.0046	0.0052	13
Stormflow	0.1158	0.0306	0.1464	0.0518	-65
All flows	0.1181	0.033	0.1511	0.057	-62
			Nitrate-plus-nitrite, filtered		
Base flow	0.0121	0.0084	0.0205	0.0235	15
Stormflow	0.0793	0.0646	0.1439	0.0885	-38
All flows	0.0914	0.073	0.1644	0.1121	-32
			Orthophosphate, filtered		
Base flow	4.50E-5	3.57E-5	8.07E-5	8.29E-5	3
Stormflow	8.00E-4	8.55E-4	1.66E-3	7.57E-4	-54
All flows	8.45E-4	8.91E-4	1.74E-3	8.39E-4	-52
			Phosphorus, unfiltered		
Base flow	0.0002	0.0002	0.0004	0.0005	25
Stormflow	0.0295	0.0082	0.0377	0.0135	-64
All flows	0.0298	0.0084	0.0382	0.0140	-63
			Suspended sediment		
Base flow	1.86	0.66	2.52	2.54	1
Stormflow	134.32	29.06	163.38	98.95	-39
All flows	136.19	29.73	165.92	101.50	-39

but if lake levels are below the dam, storm runoff will be detained in the lake and will not be reflected in an increase in outflow. Therefore, outflows do not necessarily reflect hydrologic processes occurring in the basin. For this reason, median concentrations, rather than loads, of nutrients and SS were compared.

The concentrations in the lake outflow were much lower than in the inflow for all constituents, except NH_3, which had concentrations similar in magnitude (fig. 10). Median lake outflow concentrations of TKN, NO_x, and PO_4 were 65, 83, and 85 percent lower than the respective averages of the median concentrations in the three tributaries to the lake. The most striking differences were for P and SS. The median lake outflow concentrations were only 9 and 4 percent, respectively, of the average of the three inflow median concentrations. For all analyzed constituents, except NH_3, the data indicate that Otisco Lake has a positive mitigative effect on retention of nutrients and sediment.

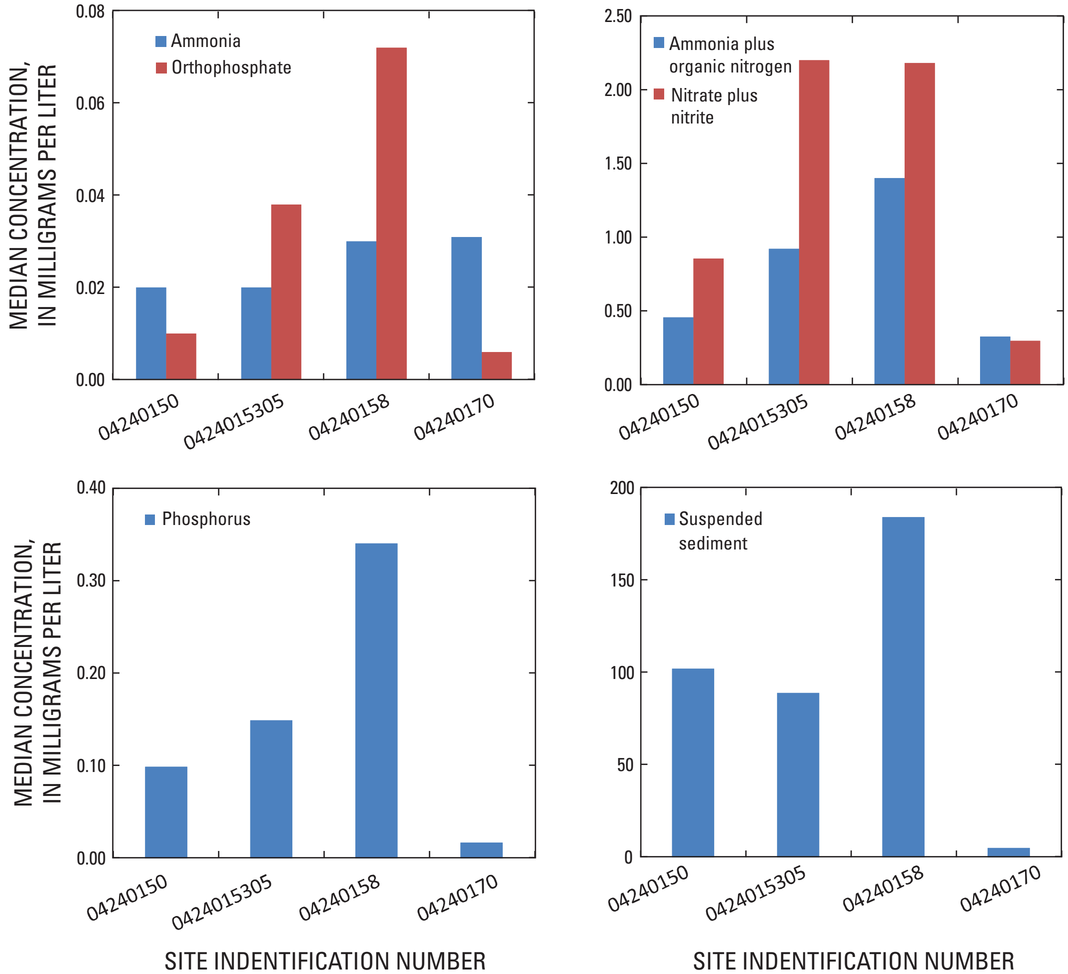


Figure 10. Median concentrations of nutrients and suspended sediment in three tributaries to and the outflow from Otisco Lake, Onondaga County, N.Y., 2005–08.

Effects of Groundwater Discharge

The carbonate-rock aquifers of the Onondaga and Bertie Limestone are important for the transmission of groundwater in the central part of the Onondaga Lake Basin. Water that enters the groundwater flow system through fractures and joints in the bedrock follows these flow paths to where the bedrock crops out, and springs discharge to surface-water channels. Four such springs–Dorwin and Cold Springs in the Onondaga Creek Basin and Mossbank and Railroad-bed Springs in the Ninemile Creek Basin—were sampled quarterly (table 6) to assess the effects of groundwater on surface-water quality. Concentrations of NO_x and PO_4 in spring water fell within the range of concentrations measured in surface-water base-flow samples. Concentrations of TKN, NH_3, and P were slightly higher than or below their respective analytical detection limits and below concentrations measured in surface-water base-flow samples. Values of SC in spring water were consistently greater than base-flow values for surface-water sites in forested and agricultural subbasins (except for the Onondaga Creek site downstream from the mudboils (site 04237950), where water quality was influenced by brackish discharges from that groundwater source), but were lower than those measured in surface water draining the wetland and developed subbasins. Spring water temperatures generally varied less than 2°C year round.

Three sites in the monitoring network—Furnace Brook (site 04239800), Ninemile Creek at Camillus (site 04240200), and Geddes Brook (site 04240253)—were located downstream from the Onondaga-Bertie Escarpment, which contributes large volumes of groundwater to streams that incise the escarpment. The two smallest subbasins—Furnace Brook and Geddes Brook—exhibited unique base-flow water-quality characteristics among the monitoring sites that were attributed to the relatively large spring inputs to these sites (table 6). Water temperatures at these locations generally were warmer during the winter and cooler during the summer than at other sites. Salinity and SC values generally were greater than those measured at other sites. Furnace Brook and Geddes Brook typically had base-flow SC values that exceeded 1,000 µS/cm. Concentrations of other constituents in Furnace Brook and Geddes Brook samples were similar to those measured in samples from other sites and, therefore, any additional effects of spring inflows could not be identified. The influence of spring inputs on the water quality of Ninemile Creek at Camillus (with a drainage area of 84.3 mi^2) was partly masked by the disproportionate dilution of spring discharges by base flows that originated upstream from where the creek cuts through the Onondaga-Bertie Escarpment.

Precipitation and Snowpack Quality

Eight precipitation samples were collected at the monitoring site near Cardiff (site 04237962) during 2006–07 and three snowpack samples were collected on March 13, 2007, at three locations, including Tully Valley (site 04237962), Syracuse (site 04239800), and the Otisco Lake valley (site 04240150; table 7). The constituent concentrations in the precipitation samples were comparable to those measured in precipitation samples from the Irondequoit Creek Basin in Monroe County, N.Y. (Hornlein and others, 1993 through 2002; U.S. Geological Survey, 2009), which is about 70 mi west of Onondaga County and is similar in size and mix of land uses. The median concentrations of NH_3 and PO_4 were an order of magnitude larger than median concentrations of these constituents in stormflows, whereas concentrations of NO_3 and P in precipitation were generally lower than stormflow concentrations. Constituent concentrations in snowpack were similar to those in precipitation, except for concentrations of TKN, PO_4, and P, which were generally lower.

Comparison of Suspended Sediment and Total Suspended Solids

The terms suspended sediment (SS) and total suspended solids (TSS) are often used interchangeably in the literature to describe the solid-phase material suspended in a water-sediment mixture. Water samples for SS and TSS analyses are commonly collected and field-processed the same way; however, the analytical methods used to measure their respective concentrations differ, and different results should be expected (Gray and others, 2000). The concentration of SS is produced by measuring the dry weight of all the sediment from a known volume of a water-sediment mixture, whereas that for TSS is produced by several methods, most of which entail measuring the dry weight of sediment from a known volume of a subsample of the original. A potential negative bias in TSS concentrations can become pronounced when sand-sized material composes a substantial percentage of the sediment in the sample. To document the differences, if any, in SS and TSS concentrations in the waters of Onondaga Lake Basin, paired samples of SS and TSS were collected as part of the monitoring program (appendix 4).

TSS concentrations were measured in the USGS National Water Quality Laboratory and the WEP laboratory. A comparison of 10 paired TSS samples indicated no significant difference between the TSS results obtained from the two laboratories; therefore, all TSS and SS data were used in the following analysis. Seventy-six samples of paired SS and TSS concentrations were measured at USGS laboratories.

Table 6. Quality of water discharging from the Onondaga and Bertie Limestone and its effects on surface-water quality: mean concentrations of selected constituents in water samples from four springs and three surface-water sites in the Onondaga Lake Basin, Onondaga County, N.Y.

[Site locations are shown in figure 1. Concentrations are in milligrams per liter. µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; E, estimated; <, less than; –, no data; mi^2, square miles]

	Number of samples	Discharge (cubic feet per second)	Salinity (parts per thousand)	Specific conductance (µS/cm at 25°C)	Water temperature (°C)	Ammonia-plus-organic nitrogen, filtered	Ammonia-plus-organic nitrogen, unfiltered	Ammonia, filtered	Nitrate-plus-nitrite, filtered	Nitrite, filtered	Nitrate, filtered	Total nitrogen	Orthophosphate, filtered	Phosphorus, filtered	Phosphorus, unfiltered
Mean concentrations in samples from four springs, by site, 2006–08 (all seasons included)															
Cold Spring	6	1.18	0.6	1,220	8.1	0.10	0.11	<0.020	0.40	0.002	0.40	0.51	E0.005	<0.006	E0.010
Dorwin Spring	8	1.10	.6	1,250	8.7	E.11	E.10	<.020	1.09	<.002	1.08	E1.2	E.005	E.004	E.006
Railroad-bed Spring	8	.19	.8	1,580	9.1	<.10	E.09	<.020	.74	E.002	.74	E.83	E.004	<.006	<.008
Mossbank Spring	8	.82	.6	1,110	9.3	<.10	E.08	<.020	.39	E.002	.38	E.47	E.004	<.006	<.008
Mean concentrations in samples from four springs, by season, 2006–08 (all sites included)															
Fall	8	.43	.7	1,380	8.8	E.10	<.14	<.020	.58	<.002	.58	–	E.004	<.006	<.020
Winter	8	1.98	.6	1,240	8.2	E.10	.11	<.020	.79	E.002	.78	.90	E.005	<.006	<.008
Spring	8	.79	.6	1,190	8.6	<.14	E.09	<.020	.66	0.003	.66	E.75	E.006	<.006	<.008
Summer	6	.10	.7	1,400	10.0	<.14	<.14	<.020	.66	E.002	.66	–	E.005	<.006	<.008
Mean concentrations in base-flow samples from three surface-water sites[1], 2005–08															
04239800	17	8.8	.7	1,310	9.9	.12	.14	<.020	1.14	.002	1.14	1.27	.005	.006	.024
04240253	16	12	1.0	1,910	11.8	.11	.13	<.020	1.42	.003	1.42	1.54	.005	.005	.023
04240200	16	113	.5	939	10.3	.17	.22	E.024	.86	.006	.85	1.07	.013	.015	.027

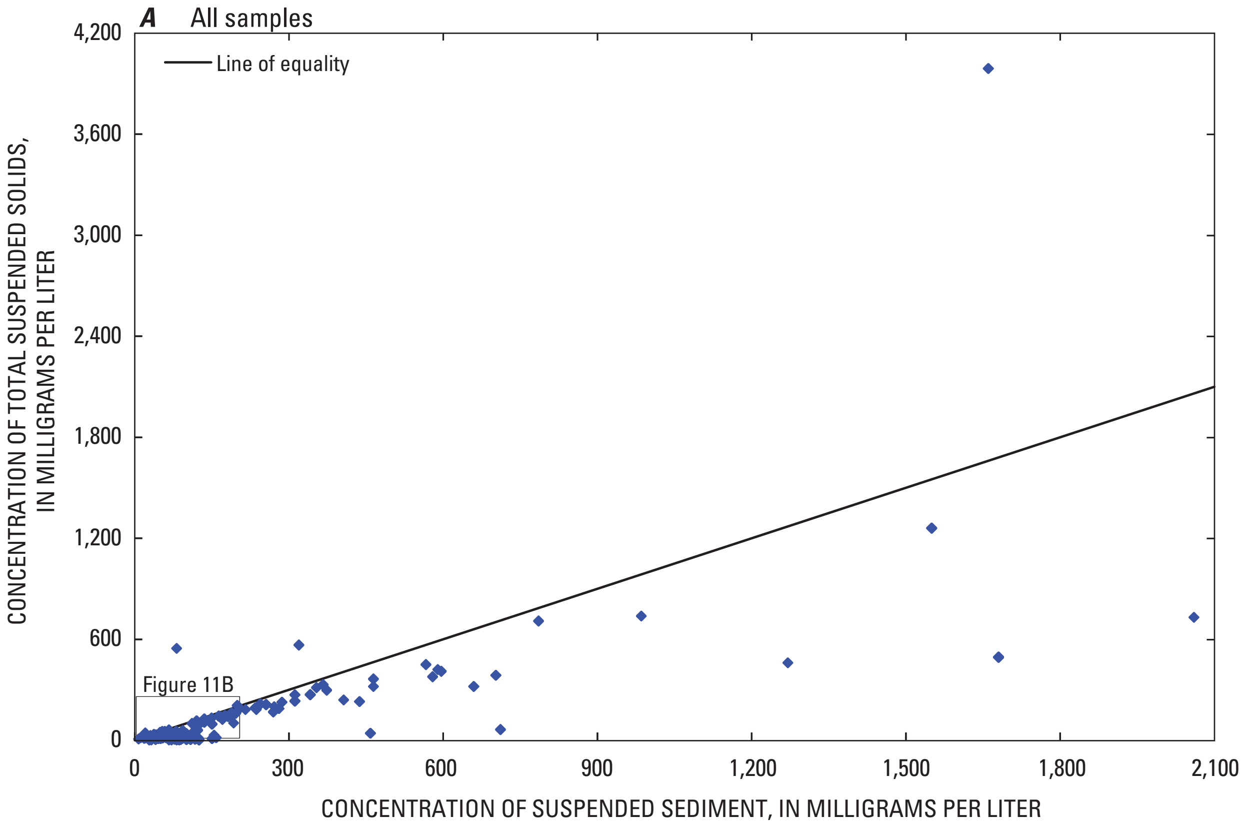
[1] 04239800, Furnace Brook at Syracuse (drainage area (DA) = 3.71 mi^2); 04240253, Geddes Brook at Fairmount (DA = 8.29 mi^2); 04240200, Ninemile Creek at Camillus (DA = 84.3 mi^2).

Table 7. Precipitation quality for selected dates and snowpack quality for selected locations in the Onondaga Lake Basin, Onondaga County, N.Y., 2006–07.

[Site locations are shown in figure 1. Site names are given in table 1. Concentrations are in milligrams per liter. Values in parentheses below constituent names are USGS National Water Quality Laboratory parameter codes. E, estimated; <, less than]

Date or location	Time	Ammonia-plus-organic nitrogen, filtered (00623)	Ammonia-plus-organic nitrogen, unfiltered (00625)	Ammonia, filtered (00608)	Nitrate-plus-nitrite, filtered (00631)	Nitrite, filtered (00613)	Nitrate, filtered (00618)	Total nitrogen (00600)	Ortho-phosphate, filtered (00671)	Phos-phorus, filtered (00666)	Phos-phorus, unfiltered (00665)
Precipitation quality near Cardiff, N.Y.											
07/12/2006	0640	2.90	3.40	0.355	0.10	0.004	0.09	3.50	0.201	0.270	0.430
09/02/2006	0730	.48	.94	.187	.31	.004	.31	1.30	.113	.129	.200
09/28/2006	1330	.88	1.00	.535	.97	.007	.96	2.00	.073	.093	.114
10/19/2006	1530	1.90	2.10	1.040	.28	.011	.26	2.40	.137	.177	.191
12/01/2006	0940	.12	.38	.039	.21	.008	.20	.58	.025	.034	.059
08/07/2007	1545	1.30	1.30	.473	.51	.005	.50	1.80	.144	.188	.197
09/27/2007	1645	1.50	1.40	.289	.22	.002	.22	1.70	.325	.340	.340
10/23/2007	0750	<.14	E.10	.021	.07	E.002	.07	.17	.010	.011	.020
Median		1.30	1.30	.322	.25	.005	.24	1.75	.125	.153	.194
Snowpack quality at three locations in the Onondaga Lake Basin. Samples collected on March 13, 2007											
04237950	0920	E0.07	0.26	0.038	0.16	0.005	0.15	0.42	E0.004	E0.004	0.023
04239800	1040	.61	.78	.271	.23	.006	.22	1.00	.009	.012	.034
04240150	0900	.32	.55	.269	.45	.003	.45	1.00	.007	.007	.035
Median		.32	.55	.269	.23	.005	.22	1.00	.007	.007	.034

Seventy-three samples—17 to 20 samples from each of 4 WEP monitoring sites—paired SS concentrations measured at the USGS Sediment Laboratory with TSS concentrations measured at the WEP laboratory. On the basis of a comparison of the 149 paired analyses of SS and TSS (figs. 11A and 11B), a negative bias in TSS concentrations was evident. TSS concentrations were significantly lower than SS concentrations no matter how the data set was subdivided—whether by the laboratory measuring the TSS concentrations or by site. Also, no identifiable relation existed between SS and TSS concentrations or between either of these constituents and streamflow. The lack of relation held true whether the data were (1) log-transformed, (2) combined from all sites (fig. 12), (3) analyzed on a site-by-site basis, or (4) grouped by increasing or decreasing stage at the time of sample collection. These results confirm that SS and TSS concentrations are not the same and should not be substituted one for the other, as was also concluded by Gray and others (2000).



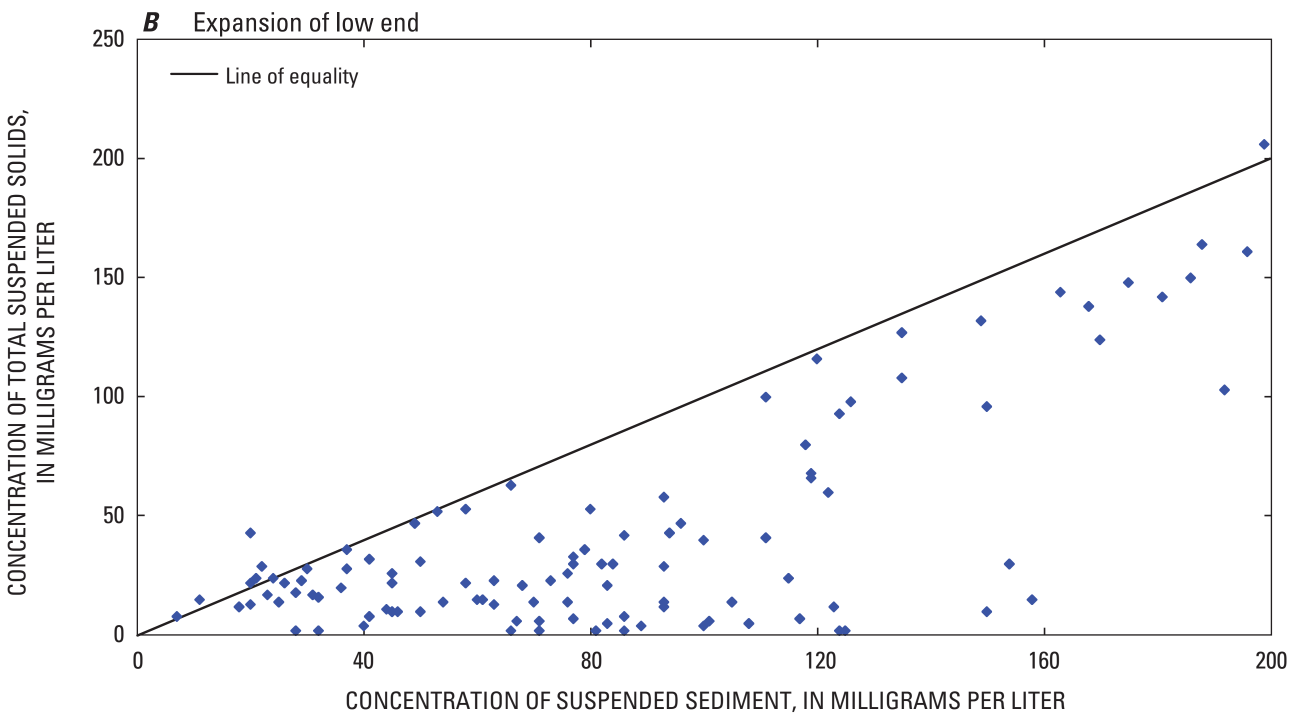


Figure 11. Paired measurements of concentrations of suspended sediment and total suspended solids: (*A*) all samples, and (*B*) an expanded view of the low-end of the graph.

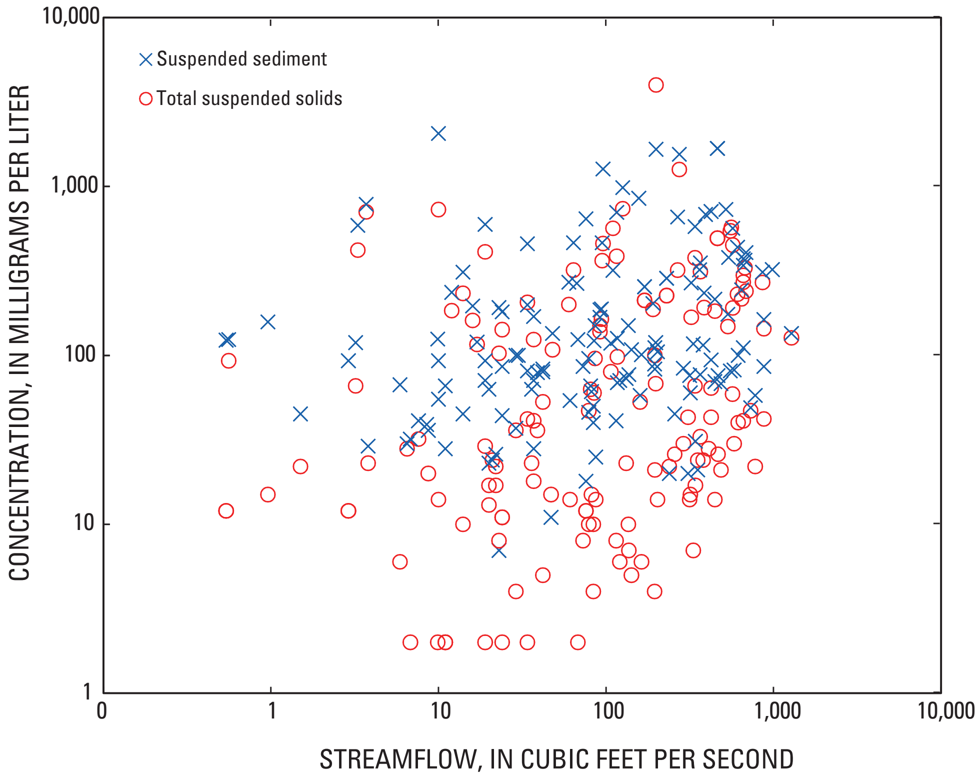


Figure 12. Relation between streamflow and concentrations of suspended sediment and total suspended solids.

Suspended-Sediment Particle-Size Characteristics

A subset of samples sent to the USGS Sediment Laboratory for measurement of SS concentrations was also subjected to particle-size analyses to approximately quantify the fractions of sediment being transported in the streams of the Onondaga Lake Basin. Samples from 18 sites that evenly represented the major land types in the basin were analyzed (table 8). The sediment in the samples was analyzed using only two break points. Any particles with sizes ranging between 2 and 0.063 mm in diameter were classified as sand. Particle sizes finer than 0.063 mm were lumped into a single silt-plus-clay class.

Although the silt-plus-clay fraction dominated the sediment particles in suspension at the sampled study sites, the data indicated a wide range in the percentages of the two particle-size classes (table 8); the sediment load comprised 57 to 92 percent silt-plus-clay and 8 to 43 percent sand. No relations between the particle-size percentages and the dominant land type in a basin or between particle size and channel slope were evident. Presumably the composition of the source material in a given basin, the existence of a local "point" source of sediment, and the presence of a detention area (such as a wetland or reservoir) immediately upstream from a monitoring site were all factors that influenced, to varying degrees, the composition of the sediment in suspension in a given channel.

Table 8. Percentages of silt-plus-clay and sand in streamflow samples from selected sites in Onondaga Lake Basin, Onondaga County, N.Y., 2007–08.

[Site locations are shown in figure 1. Site names are given in table 1. mg/L, milligrams per liter. Percent silt-plus-clay, percentage of suspended-sediment particles smaller than 0.063 millimeters. Percent sand equals 100 minus percent silt-plus-clay.]

Site	Date	Time	Suspended-sediment concentration (mg/L)	Percent silt-plus-clay	Percent sand
04237917	02/06/2008	0820	702	65	35
04237950	02/06/2008	1115	659	79	21
04237952	01/07/2008	0855	311	90	10
04237953	10/23/2007	1710	1,140	68	32
04237955	01/07/2008	1215	464	87	13
04237995	10/23/2007	1415	79	57	43
04238000	10/23/2007	1320	192	73	27
04238550	02/06/2008	1140	175	88	12
04239000	11/27/2007	1010	81	77	23
04239800	09/27/2007	2105	162	58	42
0424011445	09/27/2007	2055	170	88	12
04240150	10/23/2007	0815	181	89	11
04240152	10/23/2007	0910	124	74	26
0424015305	10/23/2007	0940	119	66	34
04240158	10/23/2007	1050	196	92	8
04240158	12/23/2007	1110	151	87	13
04240253	02/06/2008	0755	118	74	26
04245236	09/27/2007	2005	155	84	16
430317076054201	09/27/2007	1930	280	81	19

Summary

Water samples were collected and analyzed for nutrients and suspended sediment at 26 surface-water sites and 4 springs in the 285-mi^2 Onondaga Lake Basin from October 2005 through December 2008 (actual data-collection periods varied from site to site). Many of the streamflow sites were selected because each represented a basin dominated by a particular land use or land cover. Other sites were included in the monitoring network to (1) document changes in water quality from the headwaters to the mouths of selected streams; (2) compare current nutrient and sediment loads in tributaries to Otisco Lake with those that had been computed during an earlier (1981–83) U.S. Geological Survey study; (3) document unusually large loads of sediment contributed to Onondaga Creek from Rainbow Creek, Rattlesnake Gulf, and the mudboils—a groundwater source of fine-grained sediment; (4) assess the water-quality mitigative effects of Onondaga Reservoir and Otisco Lake; and (5) assess the effects of groundwater discharges on surface-water quality.

Base flows were sampled bi-monthly and nearly every major stormflow was monitored to some degree as manpower limitations permitted. The objective of each storm-sampling effort was to sample flows once each during the rising stage, near the peak, and during the falling stage; this sampling target was difficult to achieve, however, because of the unpredictability of weather patterns and the short duration of many stormflows. Springs discharging from the Onondaga and Bertie Limestone were sampled quarterly.

A total of 1,061 samples, including 357 base-flow samples, 585 storm and snowmelt samples, 30 spring samples, and 89 quality-assurance samples, were collected from the 30 study sites and analyzed for ammonia, nitrite, nitrate-plus-nitrite, ammonia-plus-organic nitrogen, orthophosphate, phosphorus, and suspended sediment. The concentration of total suspended solids was measured in selected samples. Ninety-one additional samples were collected, including 80 samples from 4 county-operated sites, which were analyzed for suspended sediment or total suspended solids, and 8 precipitation and 3 snowpack samples, which were analyzed for nutrients. Field measurements of specific conductance, salinity, dissolved oxygen, and water temperature were periodically measured with a digital water-quality meter.

The mean concentrations of selected constituents in base-flow, stormflow, and snowmelt samples were grouped by the land use or land cover that either dominated the basin or was presumed to have a substantial effect on the water quality of the basin. Almost 40 percent of the Onondaga Lake Basin is forested, 24 percent is covered in pasture or hay, and about 6 percent is used for row crops or livestock operations. Developed areas, including the city of Syracuse, cover almost 21 percent of the basin. The southern half of the basin is rural with a mix of forest, pasture, and agricultural uses. These rural land types decrease as urban development increases to the north around Onondaga Lake. The data confirmed expected relative differences among the land types for concentrations of nitrate, ammonia-plus-organic nitrogen, and orthophosphate. The data departed from the expected relations for phosphorus and suspended sediment, and plausible explanations were posited. Snowmelt concentrations of specific conductance, ammonia, and nitrate-plus-nitrite were significantly higher than storm-runoff concentrations, whereas snowmelt concentrations of ammonia-plus-organic nitrogen, orthophosphate, phosphorus, and suspended sediment were significantly lower than storm-runoff concentrations. Except for orthophosphate, snowmelt concentrations of dissolved constituents were higher and those of particulate constituents were lower than storm-runoff concentrations. Presumably, the snowpack acted as a short-term sink for dissolved constituents that had accumulated from atmospheric deposition, and streambed erosion and resuspension of previously deposited material, rather than land-surface erosion, were the primary sources of particulate constituents in snowmelt flows.

Longitudinal assessments of constituent concentrations showed that median base-flow concentrations of ammonia, ammonia-plus-organic nitrogen, and phosphorus increased in the downstream direction in Onondaga Creek, whereas those of ammonia, phosphorus, and suspended sediment increased in Ninemile Creek. Median event (stormflows and snowmelt combined) concentrations of ammonia increased in both channels. Whereas median event concentrations of other constituents in Onondaga Creek displayed no consistent trends, those of ammonia-plus-organic nitrogen, orthophosphate, and phosphorus in Ninemile Creek decreased from upstream to downstream sites. Analysis of the concentration data did not permit conclusions to be drawn regarding changes in loads of these constituents, except for constituents with increasing concentrations, which along with increasing flows would result in increasing loads in the downstream direction.

Loads of selected nutrients and suspended sediment were computed and compared with those computed from data collected during 1981–83 on three tributaries of Otisco Lake, which drain subbasins dominated by agricultural uses. Loads were normalized to remove the effects of the different precipitation quantities that were measured during the two study periods. Loads of ammonia-plus-organic nitrogen and orthophosphate decreased from 1981–83 to 2005–08, but those of nitrate-plus-nitrite, phosphorus, and suspended sediment increased. The largest load increase was for suspended sediment; the yields were from 100- to 400-percent greater during 2005–08 than during 1981–83.

Major sediment sources in the upper Onondaga Creek Basin near Tully Valley, including Rainbow Creek, Rattlesnake Gulf, and the mudboils, were monitored. Sediment loads from the mudboils were computed on the basis of daily flows and sediment concentrations from weekly samples. Annual loads ranged from 192 to 231 tons. The average daily load was 0.58 ton, far below the 30-ton daily load that existed prior to implementation of sediment-mitigation measures in 1993. Mudboil sediment inputs increased base-flow sediment concentrations in Onondaga Creek, but sediment loads from Rainbow Creek and Rattlesnake Gulf were larger than those from the mudboils. Large sediment loads from Rainbow Creek and Rattlesnake Gulf are derived from the erosion of outwash deposits of sand and gravel and from unstable lacustrine silt and clay deposits that slump into the stream channel. Sediment loading rates from Rainbow Creek, with a drainage area less than 15 percent that of Onondaga Creek at their confluence, were slightly greater than those for Onondaga Creek for both base flow and stormflows. The loading rate for Rattlesnake Gulf was 3 times greater than that of Onondaga Creek under base-flow conditions, but 15 times greater during stormflows.

The water-quality mitigative effects of Onondaga Reservoir and Otisco Lake were assessed. Onondaga Reservoir, which controls flows from a 67.7-mi^2 drainage area, and the low slope of Onondaga Creek upstream and downstream from the reservoir have little effect on nutrient and sediment loads carried by base flows but decrease storm loads by 40 to 60 percent. Otisco Lake has a great nutrient and sediment detention capability. Median lake outflow concentrations of ammonia-plus-organic nitrogen and nitrate-plus-nitrite were 65 and 83 percent less than the respective averages of the median concentrations in three tributaries to the lake, which represent flows and loads from 43 percent of the Otisco Lake Basin. The median lake outflow concentrations of phosphorus and suspended sediment were only 9 and 4 percent, respectively, of the average of the three inflow median concentrations.

Springs discharging from the carbonate-rock aquifers of the Onondaga and Bertie Limestone to streams that cut through this formation had identifiable effects on surface-water quality at two monitoring sites. Compared to other water-quality monitoring sites, base-flow water temperatures at sites under the influence of spring inputs generally were warmer during the winter and cooler during the summer. Salinity and values of specific conductance generally were greater at spring-influenced sites than at other sites.

The water quality of precipitation samples was compared to constituent concentrations in stormflows. The median concentrations of ammonia and orthophosphate in precipitation were an order of magnitude larger than median concentrations of these constituents in stormflows, whereas concentrations of nitrate and phosphorus in precipitation were generally lower than stormflow concentrations. Constituent concentrations in snowpack were similar to those in precipitation, except for concentrations of ammonia-plus-organic nitrogen, orthophosphate, and phosphorus, which were generally lower.

Concentrations of suspended sediment and total suspended solids were compared for a subset of samples and showed a negative bias in concentrations of total suspended solids; that is, concentrations of total suspended solids were significantly less than concentrations of suspended sediment. No identifiable relation existed between concentrations of suspended sediment or total suspended solids nor did either of these constituents show a linear relation with streamflow. Therefore, concentrations of suspended sediment and total suspended solids are not the same and should not be substituted for each other. Particle-size analyses on a subset of sediment samples were performed to quantify the sand and silt-plus-clay fractions of suspended sediment. The results indicated a wide range in the percentages of each particle class. The silt-plus-clay fraction dominated the sediment particles in suspension and made up 57 to 92 percent of the sediment load. No relations between the particle-size percentages and the dominant land type in a basin or between particle size and channel slope were evident. Factors that presumably influenced, to varying degrees, the composition of the sediment in suspension in a given channel included the composition of the source material in a given basin, the existence of a local “point” source of sediment, and the presence of a detention area (such as a wetland or reservoir) immediately upstream from a monitoring site.

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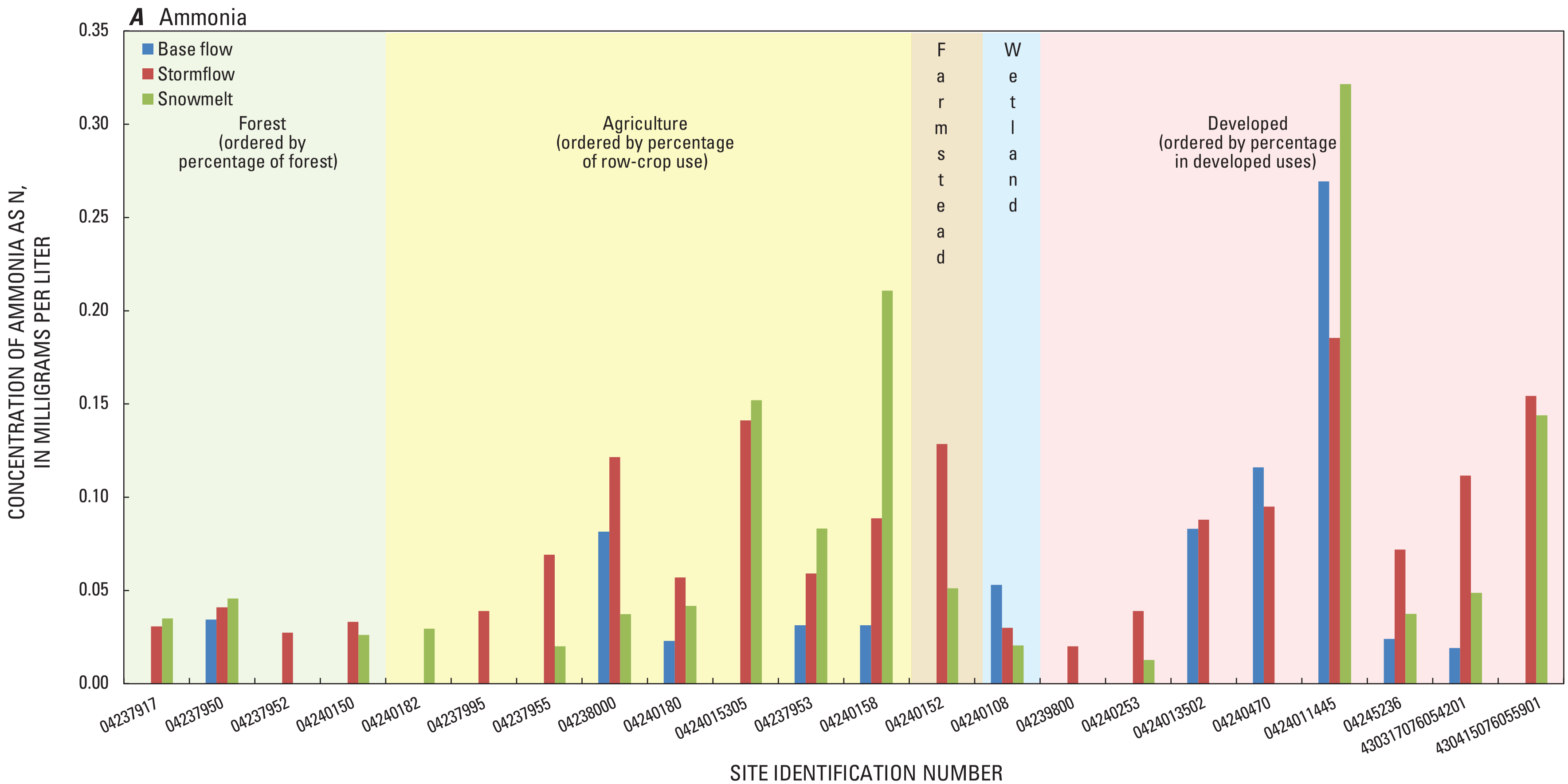
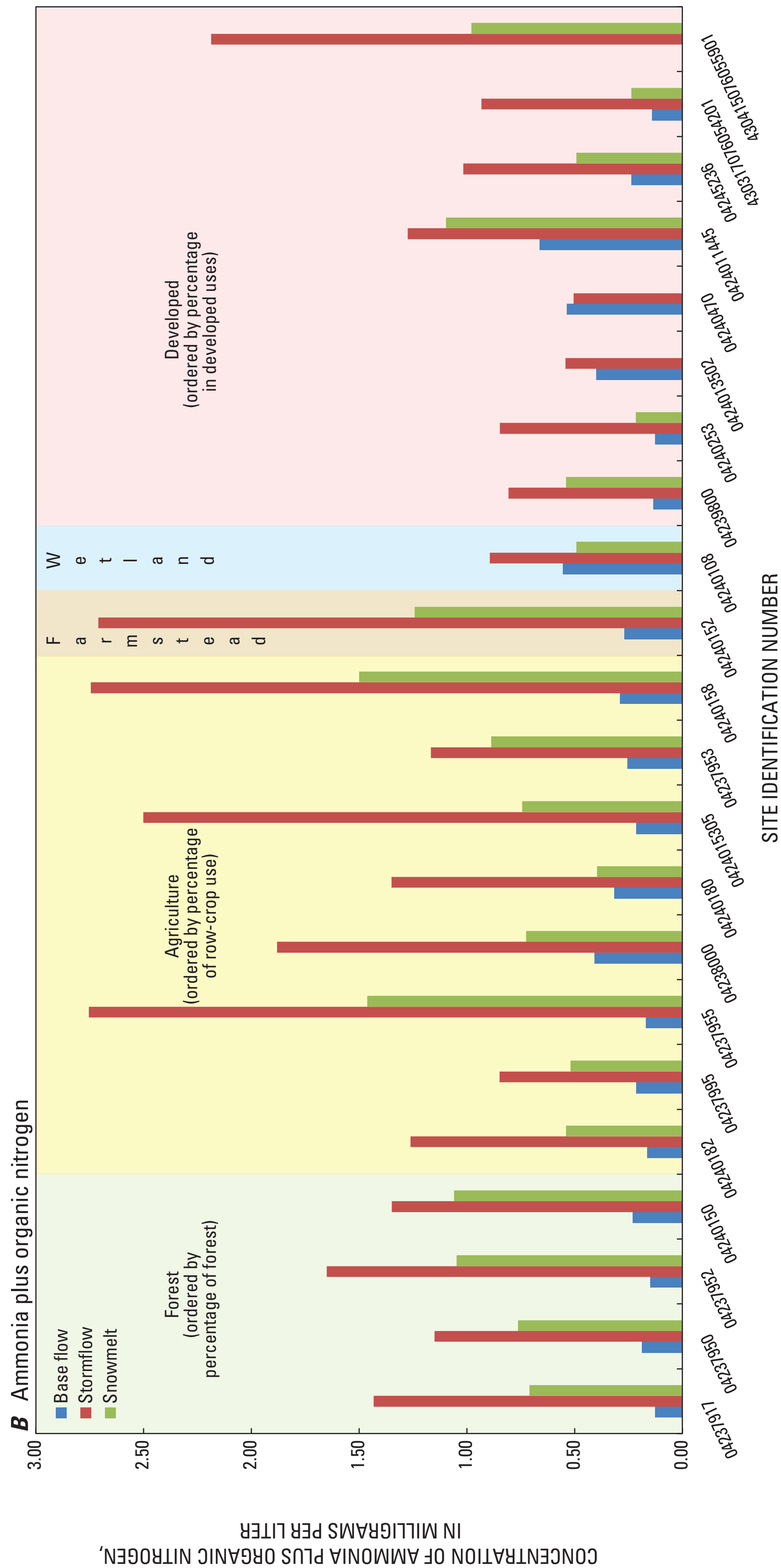


Figure 4. Mean concentrations of selected constituents in base-flow, stormflow, and snowmelt water samples from streamflow monitoring sites in the Onondaga Lake Basin, Onondaga County, N.Y., 2005–08, grouped by dominant land use or land cover: (*A*) ammonia, (*B*) ammonia-plus-organic nitrogen, (*C*) nitrate-plus-nitrite, (*D*) orthophosphate, (*E*) phosphorus, (*F*) suspended sediment, and (*G*) specific conductance.



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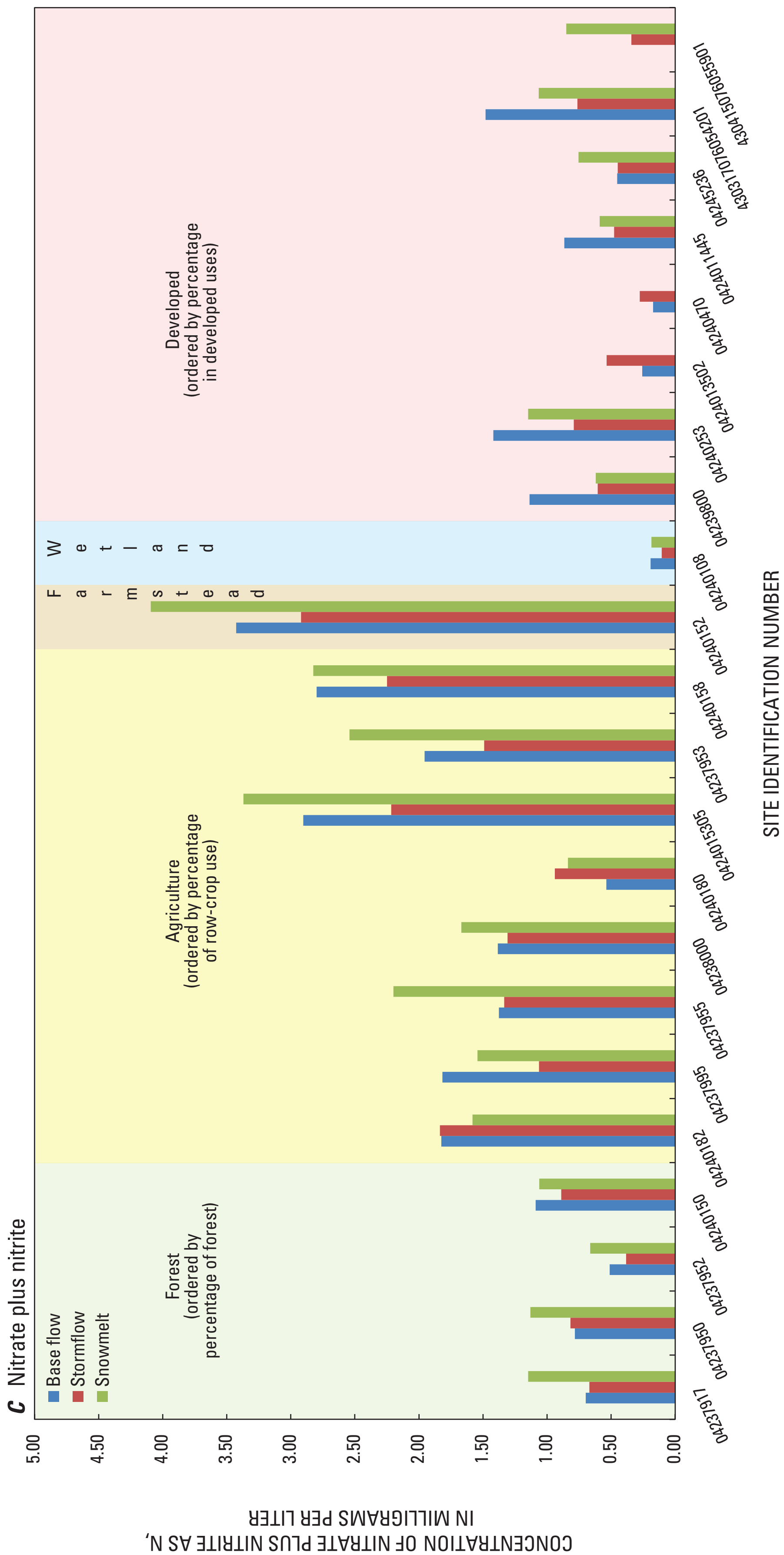

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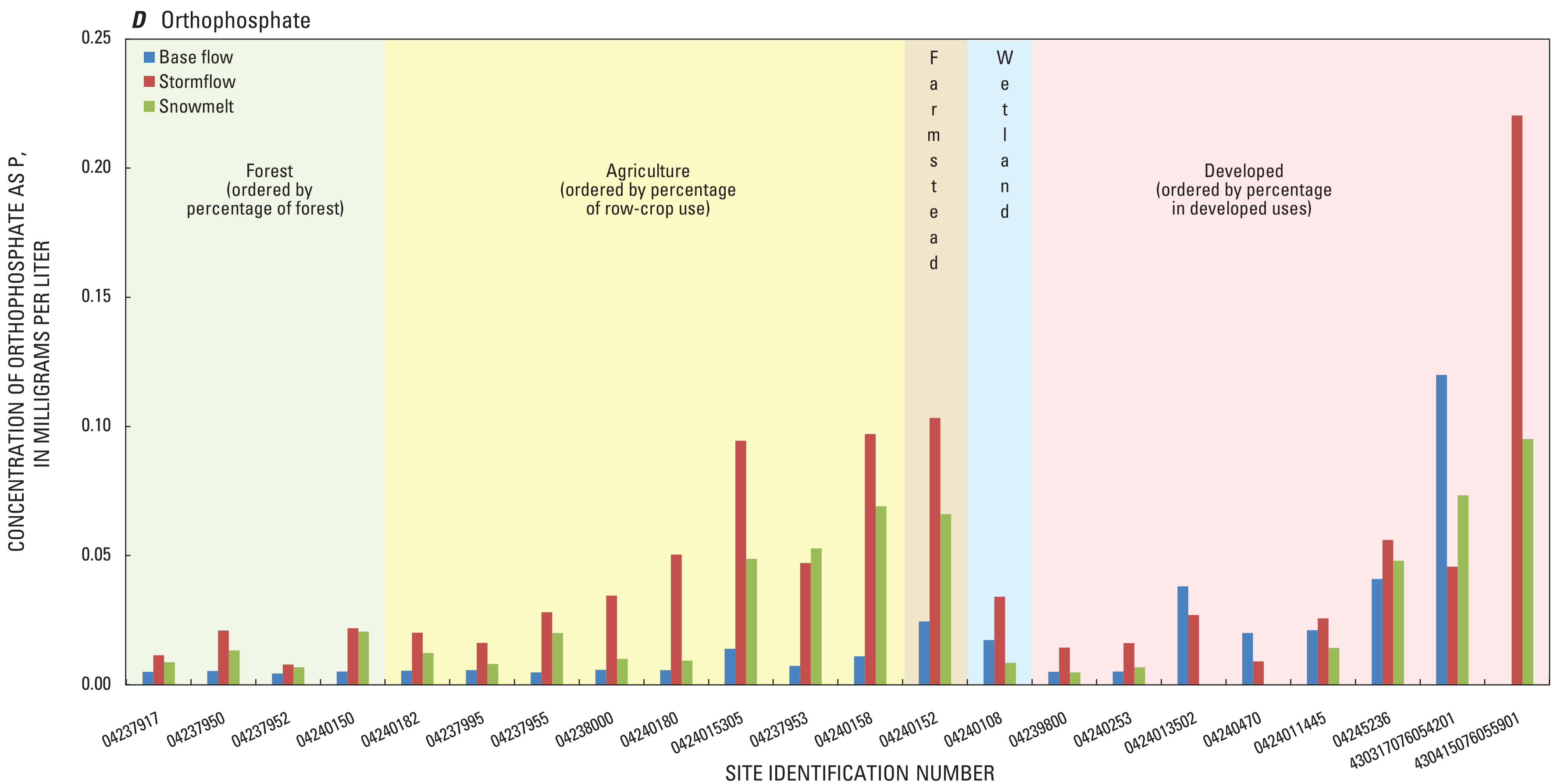

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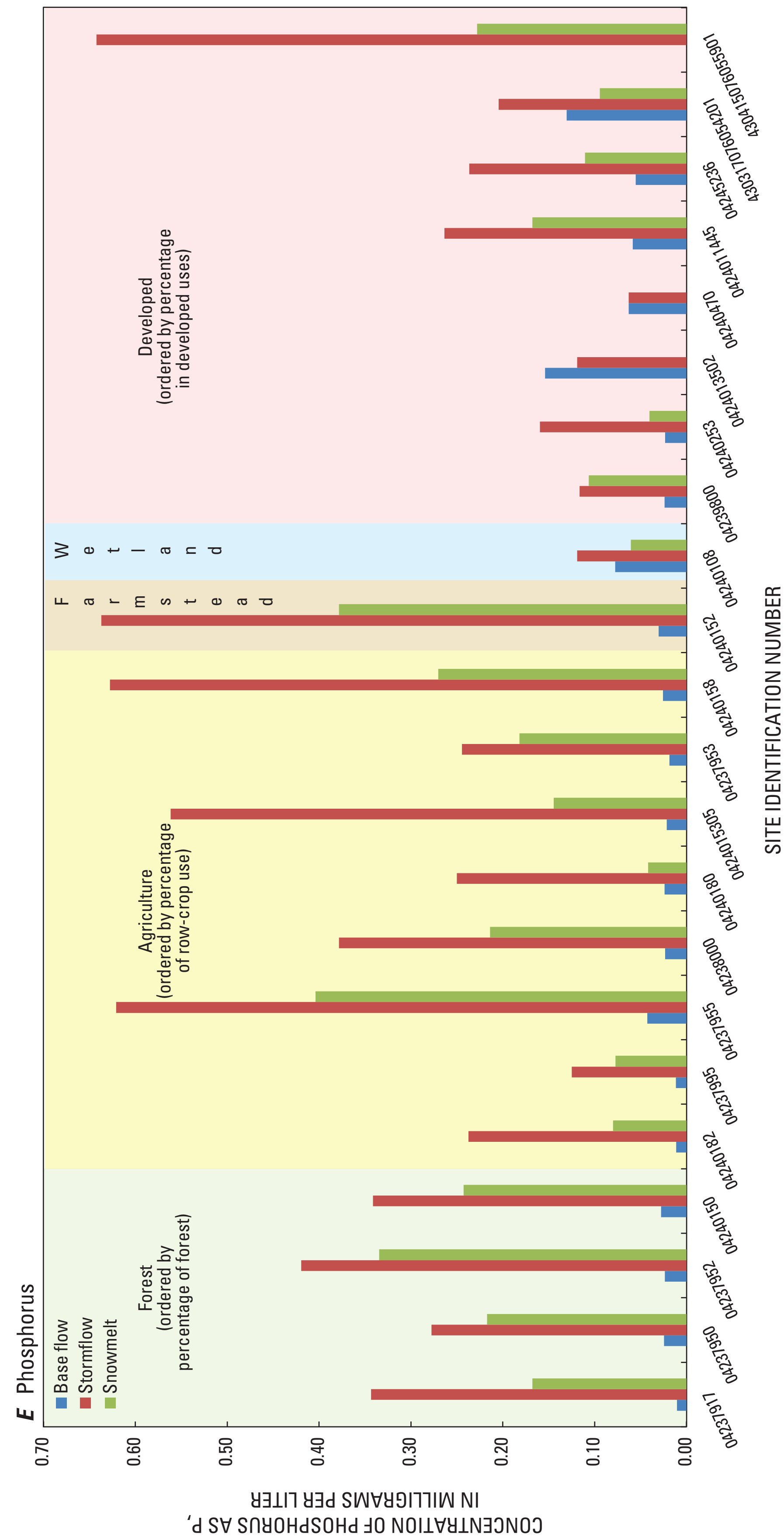

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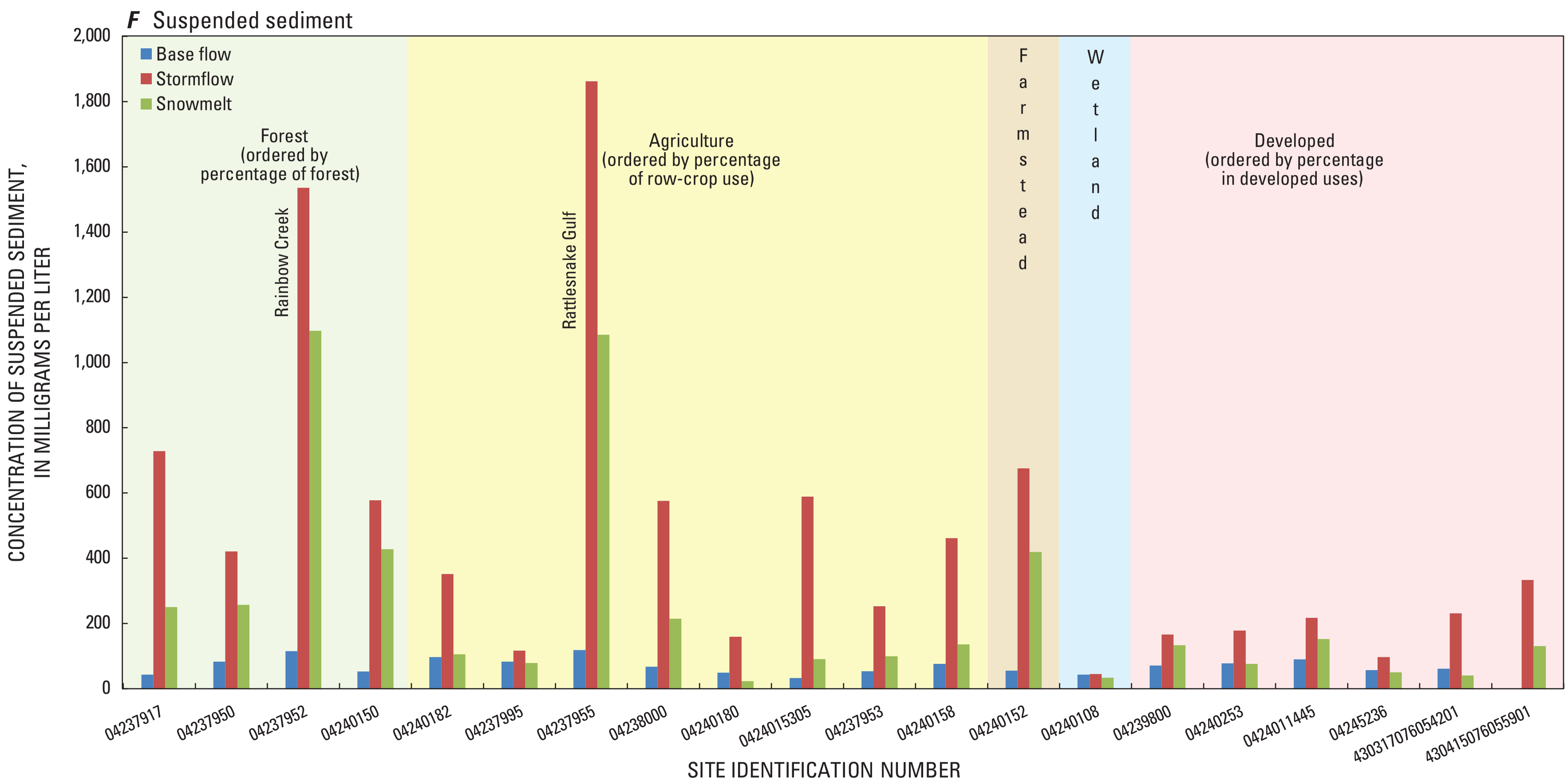

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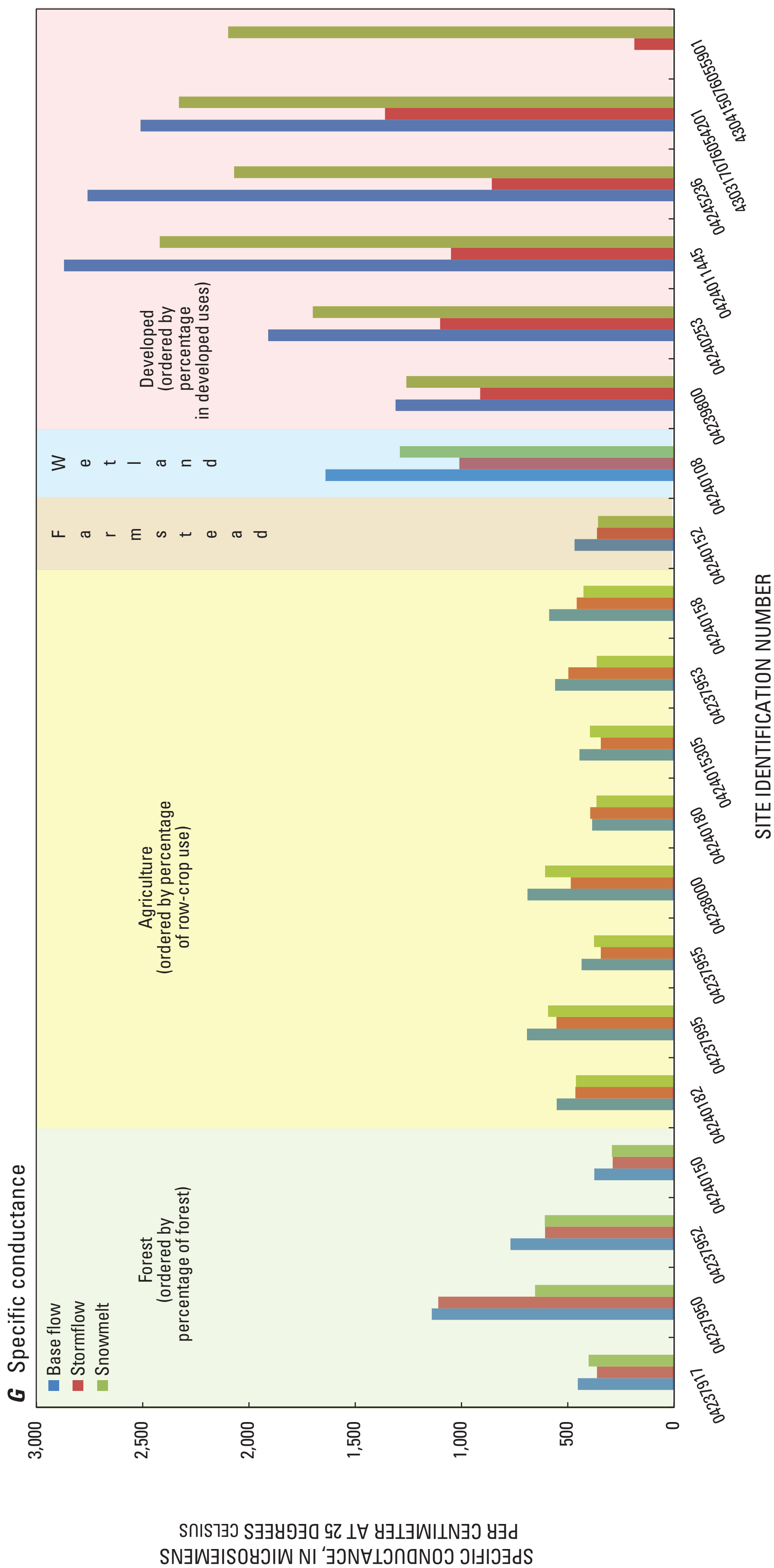

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Appendix 1. Constituent Concentrations in Surface Water of Onondaga Lake Basin

Table 1-1. Mean concentrations of selected constituents in base flow, stormflow, and snowmelt water samples from 30 monitoring sites in Onondaga Lake Basin, Onondaga County, N.Y., 2005–08.

[Site locations are shown in figure 1. Concentrations are in milligrams per liter. µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; E, estimated; <, less than; –, no data]

Sample type	Number of samples	Discharge (cubic feet per second)	Salinity (parts per thousand)	Specific conductance (µS/cm at 25°C)	Water temperature (°C)	Ammonia-plus-organic nitrogen, filtered	Ammonia-plus-organic nitrogen, unfiltered	Ammonia, filtered	Organic nitrogen, unfiltered	Nitrate-plus-nitrite, filtered	Nitrite, filtered	Nitrate, filtered	Total nitrogen	Orthophosphate, filtered	Phosphorus, filtered	Phosphorus, unfiltered	Organic phosphorus, unfiltered	Suspended sediment
04237917 Onondaga Creek northwest of Tully, N.Y.																		
Baseflow	19	11	0.2	453	9.5	0.10	0.13	<0.020	0.13	0.70	0.002	0.70	0.81	0.005	0.004	0.010	0.006	43
Stormflow	17	70	.2	363	10.8	.22	1.43	.031	1.42	.67	.007	.67	2.09	.011	.017	.343	.332	729
Snowmelt	6	75	.2	402	3.6	.19	.71	.035	.69	1.15	.004	1.14	1.85	.009	.012	.168	.159	251
04237950 Onondaga Creek at Tully Valley, N.Y.																		
Baseflow	19	28	.6	1,140	10.5	.15	.19	.034	.16	.78	.005	.78	.97	.005	.005	.024	.020	83
Stormflow	19	170	.5	1,110	10.3	.29	1.15	.041	1.12	.82	.007	.81	1.97	.021	.031	.278	.258	421
Snowmelt	4	127	.3	654	3.5	.25	.76	.046	.72	1.13	.006	1.13	1.90	.013	.019	.217	.204	257
04237952 Rainbow Creek at State Highway 11A at Tully Valley, N.Y.																		
Baseflow	20	3	.4	769	9.5	.13	.15	<.020	.15	.51	.003	.51	.63	.004	<.006	.023	.020	115
Stormflow	24	23	.3	607	12.1	.25	1.65	.027	1.63	.38	.005	.38	2.04	.008	.016	.419	.414	1,536
Snowmelt	6	28	.3	609	2.9	.20	1.05	<.020	1.04	.66	.004	.66	1.72	.007	.009	.335	.330	1,098
04237953 Ratltlesnake Gulf at Otisco, N.Y.																		
Baseflow	16	2.6	.3	561	10.2	.21	.26	.031	.24	1.96	.008	1.95	2.22	.007	.008	.018	.013	54
Stormflow	22	48	.3	497	12.2	.46	1.17	.059	1.12	1.49	.012	1.48	2.66	.047	.068	.245	.200	253
Snowmelt	4	41	.2	365	2.8	.45	.89	.083	.80	2.54	.007	2.54	3.45	.053	.074	.182	.129	100
04237955 Ratllesnake Gulf at Tully Farms Road near Cardiff, N.Y.																		
Baseflow	20	18	.2	435	10.5	.12	.17	<.020	.17	1.37	.003	1.37	1.54	.005	<.006	.043	.039	119
Stormflow	23	105	.2	345	11.2	.42	2.75	.069	2.71	1.34	.012	1.32	4.09	.028	.050	.621	.596	1,863
Snowmelt	5	118	.2	376	3.3	.33	1.46	E.020	1.45	2.20	.011	2.19	3.66	.020	.035	.404	.384	1,086
04237956 Onondaga Creek north of Tully Valley, N.Y.																		
Baseflow	7	39	.5	971	14.0	.14	.21	.021	.20	.83	.006	.83	1.05	.005	.005	.030	.026	96
Stormflow	2	113	.5	913	8.9	.19	.63	<.020	.63	.92	.009	.91	1.56	.006	.007	.217	.212	429
Snowmelt	1	200	.3	570	3.1	.35	1.40	.049	1.30	1.51	.011	1.49	2.90	.014	.022	.497	.483	467
04237962 Onondaga Creek near Cardiff, N.Y.																		
Baseflow	4	46	.9	1,740	11.8	.19	.26	.033	.23	.75	.006	.74	1.01	.005	<.006	.024	.021	106
Stormflow	1	427	.5	664	12.7	.36	2.70	.068	2.70	1.14	.008	1.13	3.90	.020	.029	.650	.630	758
Snowmelt	2	264	.3	632	3.3	.23	.93	E.020	.91	1.41	.011	1.40	2.35	.007	.019	.264	.257	408
04237995 West Branch Onondaga Creek near South Onondaga, N.Y.																		
Baseflow	16	14	.4	692	10.6	.19	.22	<.020	.21	1.82	.005	1.81	2.04	.006	.006	.012	.007	83
Stormflow	15	155	.3	553	10.2	.33	.85	.039	.82	1.06	.007	1.05	1.91	.016	.022	.125	.110	117
Snowmelt	4	130	.3	593	4.8	.26	.52	<.020	.51	1.54	.006	1.54	2.05	.008	.014	.077	.069	79

Table 1-1. Mean concentrations of selected constituents in base flow, stormflow, and snowmelt water samples from 30 monitoring sites in Onondaga Lake Basin, Onondaga County, N.Y., 2005–08.—Continued

[Site locations are shown in figure 1. Concentrations are in milligrams per liter. µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; E, estimated; <, less than; –, no data]

Sample type	Number of samples	Discharge (cubic feet per second)	Salinity (parts per thousand)	Specific conductance (µS/cm at 25°C)	Water temperature (°C)	Ammonia-plus-organic nitrogen, filtered	Ammonia-plus-organic nitrogen, unfiltered	Ammonia, filtered	Organic nitrogen, unfiltered	Nitrate-plus-nitrite, filtered	Nitrite, filtered	Nitrate, filtered	Total nitrogen	Orthophosphate, filtered	Phosphorus, filtered	Phosphorus, unfiltered	Organic phosphorus, unfiltered	Suspended sediment
04238000 West Branch Onondaga Creek at South Onondaga, N.Y.																		
Baseflow	12	29	.3	690	11.7	.33	.41	.082	.33	1.38	.015	1.37	1.80	.006	.009	.023	.018	68
Stormflow	10	367	.3	487	9.1	.47	1.88	.122	1.77	1.31	.017	1.29	3.18	.035	.051	.378	.344	576
Snowmelt	4	193	.3	607	3.8	.26	.73	.037	.70	1.67	.008	1.66	2.38	.010	.017	.214	.204	215
04238550 Onondaga Creek at Indian Village, N.Y.																		
Baseflow	12	90	.6	1,060	10.9	.21	.26	.030	.24	1.07	.007	1.06	1.32	.005	.006	.025	.021	82
Storm flow	9	530	.6	752	8.8	.29	.94	.033	.91	.87	.011	.86	1.82	.015	.025	.248	.233	365
Snowmelt	3	360	.3	630	2.8	.24	.78	.037	.76	1.33	.008	1.32	2.10	.006	.015	.202	.196	339
04239000 Onondaga Creek at Dorwin Avenue, Syracuse, N.Y.																		
Baseflow	9	162	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	68
Stormflow	10	496	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	234
Snowmelt	1	660	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	341
04239800 Furnace Brook at Syracuse, N.Y.																		
Baseflow	17	8.8	.7	1,310	9.9	.12	.14	<.020	.13	1.14	.002	1.14	1.27	.005	.006	.024	.025	71
Stormflow	20	32	.4	912	11.4	.24	.81	E.020	.80	.61	.005	.60	1.42	.014	.020	.116	.104	167
Snowmelt	4	55	.6	1,260	3.1	.17	.54	<.020	.54	.62	.005	.62	1.15	.005	.009	.106	.102	134
04240011 Onondaga Creek at Kirkpatrick Street, Syracuse, N.Y.																		
Baseflow	8	196	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	69
Stormflow	11	574	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	273
Snowmelt	1	860	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	311
04240100 Harbor Brook at Syracuse, N.Y.																		
Baseflow	8	18.2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	68
Stormflow	9	36	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	106
Snowmelt	1	126	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	985
04240108 North Branch Ley Creek at Collamer, N.Y.																		
Baseflow	16	2.8	.8	1,640	10.6	.51	.56	.053	.52	.19	.006	.19	.70	.017	.027	.078	.064	44
Stormflow	24	28	.5	1,010	11.7	.62	.89	E.030	.87	.10	.004	.10	.97	.034	.052	.119	.086	45
Snowmelt	4	44	.7	1,290	0.9	.35	.49	.021	.48	.19	.005	.18	.68	.009	.019	.061	.052	34
0424011445 South Branch Ley Creek at Exeter Street at East Syracuse, N.Y.																		
Baseflow	12	4.2	1.5	2,870	10.8	.61	.66	.269	.39	.87	.025	.84	1.52	.021	.029	.058	.037	90
Stormflow	24	40	.5	1,050	14.8	.57	1.27	.185	1.11	.48	.021	.45	1.75	.026	.050	.264	.238	218
Snowmelt	4	27	1.2	2,420	4.2	.62	1.10	.322	.77	.59	.016	.57	1.68	.014	.024	.168	.154	153

Table 1-1. Mean concentrations of selected constituents in base flow, stormflow, and snowmelt water samples from 30 monitoring sites in Onondaga Lake Basin, Onondaga County, N.Y., 2005–08.—Continued

[Site locations are shown in figure 1. Concentrations are in milligrams per liter. µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; E, estimated; <, less than; –, no data]

Sample type	Number of samples	Discharge (cubic feet per second)	Salinity (parts per thousand)	Specific conductance (µS/cm at 25°C)	Water temperature (°C)	Ammonia-plus-organic nitrogen, filtered	Ammonia-plus-organic nitrogen, unfiltered	Ammonia, filtered	Organic nitrogen, unfiltered	Nitrate-plus-nitrite, filtered	Nitrite, filtered	Nitrate, filtered	Total nitrogen	Orthophosphate, filtered	Phosphorus, filtered	Phosphorus, unfiltered	Organic phosphorus, unfiltered	Suspended sediment
04240145 Spafford Creek at Bromley Road near Spafford, N.Y.																		
Baseflow	3	3.3	.2	524	14.7	.13	.15	<.020	.15	1.03	.002	1.03	1.17	.006	.005	.014	.008	27
Stormflow	1	9.6	.2	427	12.1	.25	1.40	<.020	1.40	.50	.004	.50	1.90	.005	.010	.307	.302	390
Snowmelt	2	14	.1	282	2.6	.19	.89	<.020	.89	.62	.003	.62	1.47	E.005	.008	.206	.203	230
04240150 Spafford Creek at Sawmill Road at Otisco Valley, N.Y.																		
Baseflow	14	7.9	.2	375	11.9	.16	.23	<.020	.23	1.09	.005	1.08	1.31	.005	.007	.028	.022	53
Stormflow	16	101	.1	289	8.4	.27	1.35	.033	1.32	.89	.007	.88	2.24	.022	.032	.341	.320	578
Snowmelt	6	79	.2	293	3.2	.25	1.06	.026	1.04	1.06	.006	1.06	2.13	.021	.029	.243	.222	428
04240152 Otisco Lake Tributary at Williams Grove, N.Y.																		
Baseflow	16	2.8	.3	468	9.3	.26	.27	[1]<.020	.26	3.43	.005	3.42	3.69	.025	.025	.030	.009	56
Stormflow	21	11	.2	363	11.8	.67	2.71	.129	2.60	2.92	.015	2.90	5.65	.103	.128	.637	.534	675
Snowmelt	4	7.4	.2	358	3.7	.39	1.24	.051	1.17	4.09	.008	4.09	5.33	.066	.079	.378	.312	420
0424015305 Rice Brook at Rice Grove, N.Y.																		
Baseflow	18	7.7	.2	446	9.2	.21	.22	<.020	.21	2.90	.004	2.90	3.11	.014	.015	.021	.010	33
Stormflow	32	43	.2	346	8.6	.66	2.50	.141	2.43	2.22	.014	2.20	4.74	.094	.124	.562	.467	589
Snowmelt	3	25	.3	396	2.8	.54	.74	E.152	.64	3.37	.008	3.36	4.13	.049	.081	.145	.096	91
04240158 Willow Brook near Borodino, N.Y.																		
Baseflow	19	1.8	.4	587	9.5	.26	.29	.031	.27	2.80	.008	2.79	3.08	.011	.015	.026	.017	76
Stormflow	50	58	.3	458	8.7	.61	2.75	.089	2.67	2.25	.020	2.23	5.02	.097	.111	.628	.549	462
Snowmelt	5	37	.2	427	3.7	.69	1.50	.211	1.27	2.82	.013	2.81	4.32	.069	.101	.270	.204	136
04240170 Otisco Lake at Marietta, N.Y.																		
Regulated outflow from Otisco Lake	18	42	.2	316	12.3	.28	.35	.039	.31	.35	.006	.34	.67	.005	.008	.021	.018	12
04240180 Ninemile Creek near Marietta, N.Y.																		
Baseflow	18	59	.2	386	11.5	.25	.32	.023	.30	.54	.007	.53	.85	.006	.009	.024	.020	50
Stormflow	24	123	.2	394	13.6	.49	1.35	.057	1.29	.94	.014	.92	2.32	.050	.072	.250	.199	159
Snowmelt	3	120	.2	365	3.7	.27	.40	.042	.35	.84	.007	.83	1.23	.009	.018	.042	.032	23
04240182 Doust Creek near Marcellus, N.Y.																		
Baseflow	16	1.3	.3	553	9.1	.14	.16	<.020	.16	1.83	.002	1.83	1.98	.005	.004	.011	.008	97
Stormflow	18	23	.2	465	10.6	.45	1.26	<.020	1.26	1.84	.006	1.83	3.09	.020	.033	.237	.218	352
Snowmelt	4	24	.2	462	4.6	.26	.54	.030	.53	1.58	.005	1.58	2.15	.012	.012	.080	.071	106

Table 1-1. Mean concentrations of selected constituents in base flow, stormflow, and snowmelt water samples from 30 monitoring sites in Onondaga Lake Basin, Onondaga County, N.Y., 2005–08.—Continued

[Site locations are shown in figure 1. Concentrations are in milligrams per liter. µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; E, estimated; <, less than; –, no data]

Sample type	Number of samples	Discharge (cubic feet per second)	Salinity (parts per thousand)	Specific conductance (µS/cm at 25°C)	Water temperature (°C)	Ammonia-plus-organic nitrogen, filtered	Ammonia-plus-organic nitrogen, unfiltered	Ammonia, filtered	Organic nitrogen, unfiltered	Nitrate-plus-nitrite, filtered	Nitrite, filtered	Nitrate, filtered	Total nitrogen	Orthophosphate, filtered	Phosphorus, filtered	Phosphorus, unfiltered	Organic phosphorus, unfiltered	Suspended sediment
04240200 Ninemile Creek at Camillus, N.Y.																		
Baseflow	16	113	.5	939	10.3	.17	.22	E.024	.21	.86	.006	.85	1.07	.013	.015	.027	.016	97
Stormflow	15	480	.4	698	10.7	.38	1.06	.063	1.02	.97	.010	.97	2.03	.043	.063	.220	.177	155
Snowmelt	3	477	.3	607	3.5	.64	1.04	.241	.79	1.30	.013	1.30	2.37	.030	.056	.143	.113	71
04240253 Geddes Brook at Fairmount, N.Y.																		
Baseflow	16	12	1.0	1,910	11.8	.11	.13	<.020	.13	1.42	.003	1.42	1.54	.005	.005	.023	.019	78
Stormflow	27	60	.6	1,100	14.6	.27	.85	.039	.82	.79	.008	.78	1.64	.016	.026	.160	.144	178
Snowmelt	3	39	.9	1,700	7.4	.13	.22	.013	.22	1.15	.005	1.14	1.33	.007	.010	.040	.034	77
04240300 Ninemile Creek at Lakeland, N.Y.																		
Baseflow	9	157	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	73
Stormflow	11	558	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	87
Snowmelt	1	876	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	163
04245236 Meadow Brook at Hurlburt Road, Syracuse, N.Y.																		
Baseflow	12	2.1	1.4	2,760	12.4	.19	.24	E.024	.23	.45	.006	.44	.57	.041	.048	.055	.015	57
Stormflow	20	25	.4	858	14.7	.42	1.02	.072	.95	.45	.014	.43	1.46	.056	.084	.237	.181	97
Snowmelt	4	24	1.1	2,070	4.3	.26	.49	.038	.46	.76	.011	.74	1.28	.048	.057	.111	.063	51
430317076054201 Erie Boulevard Outfall to South Branch Ley Creek, N.Y.																		
Baseflow	12	–	1.3	2,510	12.4	.12	.14	.019	.13	1.48	.002	1.48	1.62	.120	.124	.130	.012	62
Stormflow	28	–	.7	1,360	14.8	.47	.93	.112	.83	.76	.017	.75	1.69	.046	.065	.205	.164	231
Snowmelt	4	–	1.2	2,330	6.8	.18	.24	.049	.19	1.07	.006	1.06	1.30	.073	.077	.094	.021	41
430415076055901 Lamson Street Outfall to South Branch Ley Creek tributary, Syracuse, N.Y.																		
Baseflow	[2]1	–	2.5	4,730	5.6	22.00	23.00	9.78	13.00	3.24	.443	2.80	26.00	1.490	1.540	1.540	.050	10
Stormflow	27	–	.1	187	15.5	.80	2.19	.154	2.06	.34	.017	.33	2.49	.220	.301	.642	.422	333
Snowmelt	4	–	1.2	2,440	7.4	.53	1.04	.153	.89	.84	.038	.80	1.90	.098	.123	.245	.147	163

[1] 04240152: Average of three uncensored ammonia concentrations is 0.052 mg/L.

[2] 430415076055901: All nutrient concentrations are anomalously high for this "base-flow" sample.

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Appendix 2. Constituent Concentrations in Storm Water and Snowmelt

Table 2-1. Concentrations of selected constituents in storm and snowmelt water samples collected in flows of similar magnitude, Onondaga Lake Basin, Onondaga County, N.Y., 2005-08.

[Site locations are shown in figure 1. Site names are given in table 1. Concentrations are in milligrams per liter. µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; <, less than; –, no data; d, measured value deleted. A T-test statistic, which absolute value exceeds 1.96, indicates a significant difference between stormflow and snowmelt concentrations.]

Site	Discharge (cubic feet per second)		Specific conductance (µS/cm at 25°C)		Ammonia, filtered		Ammonia-plus-organic nitrogen, unfiltered		Nitrate-plus-nitrite, filtered		Orthophosphate, filtered		Phosphorus, unfiltered		Suspended sediment	
	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt
04237917	39	42	262	467	0.02	0.01	0.68	0.21	0.70	1.27	0.01	0.01	0.13	0.06	98	80
	81	69	–	d	<.010	.05	1.8	.62	.32	1.04	.01	.01	.39	.14	1,150	213
	116	116	–	d	<.04	.06	4.6	1.8	.62	1.35	.01	.01	1.1	.47	2,050	796
04237950	74	74	–	d	<.04	.08	1.5	1.5	.93	1.04	.03	.02	.46	.48	336	486
	94	85	–	d	.03	.03	.60	.24	.75	1.2	.02	.01	.11	.07	138	122
	181	183	396	650	<.020	.06	.85	.52	.74	1.19	.03	.02	.22	.10	326	105
04237952	12	12	–	d	.09	<.020	2	.42	.54	.77	<.006	<.006	.44	.14	1,260	131
	14	14	–	d	.01	.02	.67	.34	.22	.54	.01	.01	.17	.17	242	311
	18	20	541	678	–	–	–	–	–	–	–	–	–	–	630	231
	33	36	447	630	<.020	.03	1.3	.87	.33	.77	<.006	.01	.70	.32	1,670	644
	59	46	–	d	<.010	.02	4.1	2.8	.18	.98	0.00	<.006	.54	.58	3,890	3,850
04237953	21	21	–	d	.02	.05	.93	.42	2.91	2.89	.04	.03	.12	.07	48	24
	34	37	–	d	.04	.22	.68	1.2	1.66	2.12	.03	.11	.07	.26	17	71
	81	86	327	262	<.020	.04	.99	1.5	1.82	1.88	.10	.05	.26	.34	80	281
04237955	58	64	–	d	.02	.04	.67	.64	1.73	2.6	.02	.01	.19	.34	291	464
	74	66	418	427	.06	.01	4.2	.77	1.09	2.97	.02	.02	.91	.29	1,730	493
	88	93	381	421	<.020	<.020	.94	2.7	1.63	2.24	.03	.01	.28	.29	475	2,260
	127	148	–	d	<.04	.04	3.4	1.3	1.24	1.74	.06	.04	.81	.45	1,760	761
	231	221	–	d	<.04	<.020	8.2	1.9	1.14	1.45	<.02	.02	3.11	.65	5,460	1,450
04237956	190	200	586	570	.01	.05	.67	1.4	1.52	1.51	.01	.01	.26	.50	579	467
04237962	157	170	1,060	698	–	–	–	–	–	–	–	–	–	–	851	255
	362	393	–	–	–	–	–	–	–	–	–	–	–	–	321	683
04237995	66	69	–	d	.03	<.020	1.1	.25	1.01	1.76	.01	.01	.16	.02	160	93
	88	98	402	666	.02	<.020	.64	.33	.89	1.67	.01	.01	.08	.02	104	17
	176	164	–	d	<.020	.06	.61	.70	.82	1.51	.02	.02	.07	.13	30	92
	198	188	535	486	.10	<.020	.92	.80	1.55	1.23	.02	0.00	.16	.13	119	112
04238000	124	195	394	660	.14	.04	4.8	.35	1	1.94	.11	.01	1.2	.03	1,070	42
	323	246	462	607	.14	.05	.98	.62	1.36	1.65	.03	.01	.26	.18	269	200
04239000	660	660	–	–	–	–	–	–	–	–	–	–	–	–	373	341

Table 2-1. Concentrations of selected constituents in storm and snowmelt water samples collected in flows of similar magnitude, Onondaga Lake Basin, Onondaga County, N.Y., 2005-08.—Continued

[Site locations are shown in figure 1. Site names are given in table 1. Concentrations are in milligrams per liter. µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; <, less than; –, no data; d, measured value deleted. A T-test statistic, which absolute value exceeds 1.96, indicates a significant difference between stormflow and snowmelt concentrations.]

Site	Discharge (cubic feet per second)		Specific conductance (µS/cm at 25°C)		Ammonia, filtered		Ammonia-plus-organic nitrogen, unfiltered		Nitrate-plus-nitrite, filtered		Orthophosphate, filtered		Phosphorus, unfiltered		Suspended sediment	
	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt
04239800	32	32	1,240	1,470	<.020	<.020	.27	.28	.85	.47	0.00	0.00	.04	.03	74	42
	59	55	408	1,440	.01	<.020	1.6	.58	.28	.59	.03	.01	.34	.11	367	127
	94	100	710	1,050	<.020	.04	.89	1.1	.47	.66	.01	.01	.18	.27	188	318
04240011	877	860	922	1,030	–	–	–	–	–	–	–	–	–	–	86	311
04240100	110	126	649	778	–	–	–	–	–	–	–	–	–	–	319	985
04240108	18	18	1,070	1,110	<.020	.01	.54	.38	.09	.21	.02	.01	.05	.03	8	8
	30	33	528	1,190	.03	.01	1.1	.45	.06	.10	.02	.01	.22	.03	141	13
	64	58	746	1,460	<.04	.05	.80	.67	<.06	.18	.02	.01	.12	.12	33	85
	70	66	–	d	<.010	.01	.88	.47	.06	.25	.04	.01	.14	.06	52	28
0424011445	7.4	7.7	2,040	2,870	<.020	.49	.92	.84	.67	.76	.02	.01	.13	.05	46	86
	17	19	1,370	2,070	.30	.23	.87	1.8	.39	.68	.02	.02	.10	.41	42	402
	29	29	622	2,620	.09	.19	.80	.65	.24	.43	.03	.01	.18	.07	105	28
	29	29	1,180	2,620	.30	.19	2.9	.65	.69	.43	.02	.01	.70	.07	451	28
	56	54	764	2,120	.12	.38	.83	1.1	.32	.49	.02	.01	.14	.14	104	95
04240150	28	36	202	203	.04	.02	.74	.29	1.2	.92	.04	.01	.19	.09	112	90
	89	92	304	285	.02	.02	1.6	1.7	.70	.91	.03	.03	.36	.17	549	168
	110	95	145	308	.05	.04	2	1.8	1.34	1.13	.03	.03	.62	.45	1,130	698
	183	166	216	265	.03	.04	3.3	1.2	.73	1.52	.01	.03	.80	.35	1,870	1,240
04240152	1.9	1.5	155	521	.01	.05	.99	.53	3.61	6.03	.04	.04	.21	.08	62	45
	3.7	3.7	–	d	.01	.06	3	.44	3.34	5.02	.04	.03	.39	.08	388	63
	5.6	4.6	557	310	.03	.05	1.1	1.5	3.94	2.92	.06	.06	.16	.44	58	597
0424015305	8.7	8.7	475	460	.02	<.020	1.9	.46	3.15	3.5	.08	.01	.43	.05	348	36
	18	18	466	281	.02	.02	.97	.27	1.81	3.81	.02	.01	.11	.05	89	50
	48	48	–	d	.01	.28	2.5	1.5	1.79	2.8	.05	.13	.55	.33	779	187
04240158	16	15	1,510	315	.02	.34	1.7	1.2	3.1	3.04	.10	.07	.37	.17	196	27
	34	34	375	463	.02	.24	2.3	2	1.55	2.81	.10	.08	.71	.45	330	283
	36	37	–	d	.01	.09	1.4	1.4	1.79	3.27	.15	.08	.32	.14	97	28
	45	45	519	440	.06	.24	1.6	1.7	2.8	2.89	.08	.06	.36	.34	151	214
	57	56	–	d	.03	.15	8.5	1.2	1.33	2.11	.13	.06	1.76	.26	992	127
04240180	48	47	–	d	.05	.07	.60	.51	.32	.94	.01	.01	.07	.05	53	11
	158	152	–	d	.03	.03	.59	.28	1.02	.79	.04	.01	.09	.02	13	11
	163	161	–	d	<.020	.03	1.28	.40	1.3	.78	.06	.01	.33	.06	148	47

Table 2-1. Concentrations of selected constituents in storm and snowmelt water samples collected in flows of similar magnitude, Onondaga Lake Basin, Onondaga County, N.Y., 2005-08.—Continued

[Site locations are shown in figure 1. Site names are given in table 1. Concentrations are in milligrams per liter. µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; <, less than; –, no data; d, measured value deleted. A T-test statistic, which absolute value exceeds 1.96, indicates a significant difference between stormflow and snowmelt concentrations.]

Site	Discharge (cubic feet per second)		Specific conductance (µS/cm at 25°C)		Ammonia, filtered		Ammonia-plus-organic nitrogen, unfiltered		Nitrate-plus-nitrite, filtered		Orthophosphate, filtered		Phosphorus, unfiltered		Suspended sediment	
	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt	Storm	Snowmelt
04240182	13	14	–	d	<.020	.02	.72	.28	1.89	2.1	.03	.03	.09	.02	18	45
	18	18	575	545	<.040	.04	.86	.48	2.02	1.31	.04	.01	.15	.07	67	48
	23	23	575	484	<.020	.04	.67	1.2	1.39	1.12	.04	0.00	.13	.21	59	287
	50	42	–	d	<.04	.02	3	.20	.81	1.8	.02	.01	.58	.03	1,190	42
04240200	393	370	–	d	.03	.51	.69	1.2	.80	1.29	.04	.03	.14	.10	67	40
	549	532	582	715	<.020	.07	1.1	.96	1.22	1.53	.09	.02	.27	.15	91	78
04240253	23	23	1,320	1,680	<.020	.01	.33	.11	.69	1.42	.01	0.00	.05	.01	56	79
	26	25	859	2,230	.03	.01	.37	.23	1.11	1.1	.01	0.00	.06	.02	101	85
	64	67	593	1,550	.06	.01	1.6	.31	.36	.92	.03	.01	.30	.10	273	66
04245236	3.6	3.6	1,060	2,830	.04	.02	1.7	.30	.51	.78	.13	.05	.35	.07	24	26
	22	22	948	2,320	.02	.03	.59	.39	.30	.67	.05	.03	.12	.08	26	23
	44	47	725	1,360	.05	.07	1.1	.78	.29	.90	.02	.07	.26	.18	118	109
Mean	103	103	666	1,013	.04	.08	1.63	.87	1.17	1.56	.04	.02	.37	.18	507	308
Median	57	54	566	663	.02	.04	.99	.65	.91	1.27	.03	.01	.22	.13	151	105
T-test	0.94		-3.95		-2.80		4.15		-5.64		3.82		3.80		2.63	

Appendix 3. Additional Notes on Selected Sites

Onondaga Creek northwest of Tully (at Tully Farms Road; 04237917) underwent streambed modifications to stabilize the banks upstream and downstream from the culvert under Tully Farms Road during August 2006. The channel downstream from the culvert was dredged, and a V-shaped weir of limestone blocks was placed across the channel. The installation of this weir, plus the planting of willow saplings, was completed by the Onondaga County Soil and Water Conservation District. Prior to August 2006, the physical feature of the channel that controlled the low-water level at the stage-monitoring point on the downstream side of the culvert was a gravel-cobble riffle about 60 ft downstream. The installation of the weir lowered the pool on the downstream side of the culvert by 0.5 ft. The weir acted as the stage control from Aug. 21, 2006, until March 14, 2007, when the first major storm event subsequent to weir installation completely negated any effect the weir had as a stage-controlling feature. After that date, additional high flows caused aggradation of the channel (at least 0.4 ft) and the newly established riffle control progressively moved from 60 ft downstream from the culvert to within 15 to 20 ft of the culvert. Following the peak flow of December 23, 2008, the effectiveness of the weir as an erosion-controlling feature was essentially removed. A continuous riffle was present in the channel from about 15 ft downstream from the culvert to a short distance downstream from the weir; the weir was completely buried by sediment. During 2008, high flows began to rearrange and gradually remove some of the newly deposited sediment.

Rattlesnake Gulf at Otisco (site 04237953) had been part of the nonpoint-source monitoring network for about 1.5 years when a dam was constructed by the landowner to recreate an abandoned mill pond that had existed at this site decades ago. The pond was constructed immediately upstream of the culvert on Cook Road and created a potential settling basin for particulate constituents. This change in the subbasin was unforeseen but provided an opportunity to assess the effects that an instream detention basin might have on water quality of the stream.

The dam was completed during September 2007. The concentration data were divided into pre-dam and post-dam data sets, and T-tests were performed to identify statistically significant differences between the respective constituent means of the two data sets. The t-statistics ranged between 0.13 for ammonia-plus-organic nitrogen and 0.46 for orthophosphate, which indicated that the dam and pond had no significant effect on constituent concentrations. This finding probably resulted because the dam, due to design limitations, acted more as an obstruction with water flowing through or around it rather than as a detention mechanism. Design modifications in the future might produce measurable decreases in constituent concentrations, especially those of particulate constituents.

Rattlesnake Gulf at Tully Farms Road near Cardiff (site 04237955) is a large source of sediment to Onondaga Creek, both of fine-grained material from the slumping of lacustrine silt and clay deposits into the stream, as well as coarse-grained material from erosion of glacial deposits along the west valley wall of Onondaga Creek. During the study period, the channel filled in to less than 2.5 ft of clearance under the Tully Farms Road bridge.

Between September 30 and October 10, 2008, the Onondaga County Highway Department dredged the channel from 100 ft upstream to 500 ft downstream from the bridge. Given that the channel was last dredged during the summer of 2004, this excavation provided an opportunity to measure previous depths of sediment at the downstream side of the bridge and permitted an estimate of aggradation rates.

The downstream northern bridge footer and a staff gage installed on the downstream wingwall by the USGS on August 17, 2005, were used as reference points to estimate the rate of aggradation in the channel. Measurements made on October 20, 2008, indicated at least 2.9 ft of sediment (from the top of the footer to the base of the staff gage) had been deposited in the channel in a year. The total depth of accumulated sediment was likely greater than 2.9 ft because dredging of the channel during 2004 would have extended below the top of the footer. This deposition reflected the effects of storm runoff during the fall of 2004 and spring of 2005 and the mobilization of a large volume of material that had been previously deposited in the channel from Tully Farms Road upstream to the western valley wall or had been bulldozed to the streambanks in 2004.

By October 2, 2008, when dredging of the channel was underway, an additional 2.9 ft of sediment had accumulated (fig. 3-1) at an average aggradation rate of almost 1 ft per year and clearance under the bridge had been decreased from a dredged condition of about 10 ft to an aggraded condition of about 2.5 ft. Aggradation was not a gradual or constant process, rather it was episodic with large volumes of sediment deposited during major stormflows as was observed following the peak flow on December 23–24, 2007. Subsequent to the October 2008 dredging, aggradation was periodically measured from several points on the downstream side of the bridge. By March 10, 2009, the channel had already aggraded 3 to 4.5 ft (fig. 3-2).

Figure 3-1. Dredging of accumulated sediment on downstream side of bridge over Rattlesnake Gulf at Tully Farms Road. Person is standing on bridge footer. Note: The mud line on the bridge abutment at the level of the person's head was the level of sediment prior to dredging (Photograph by W.M. Kappel, U.S. Geological Survey)

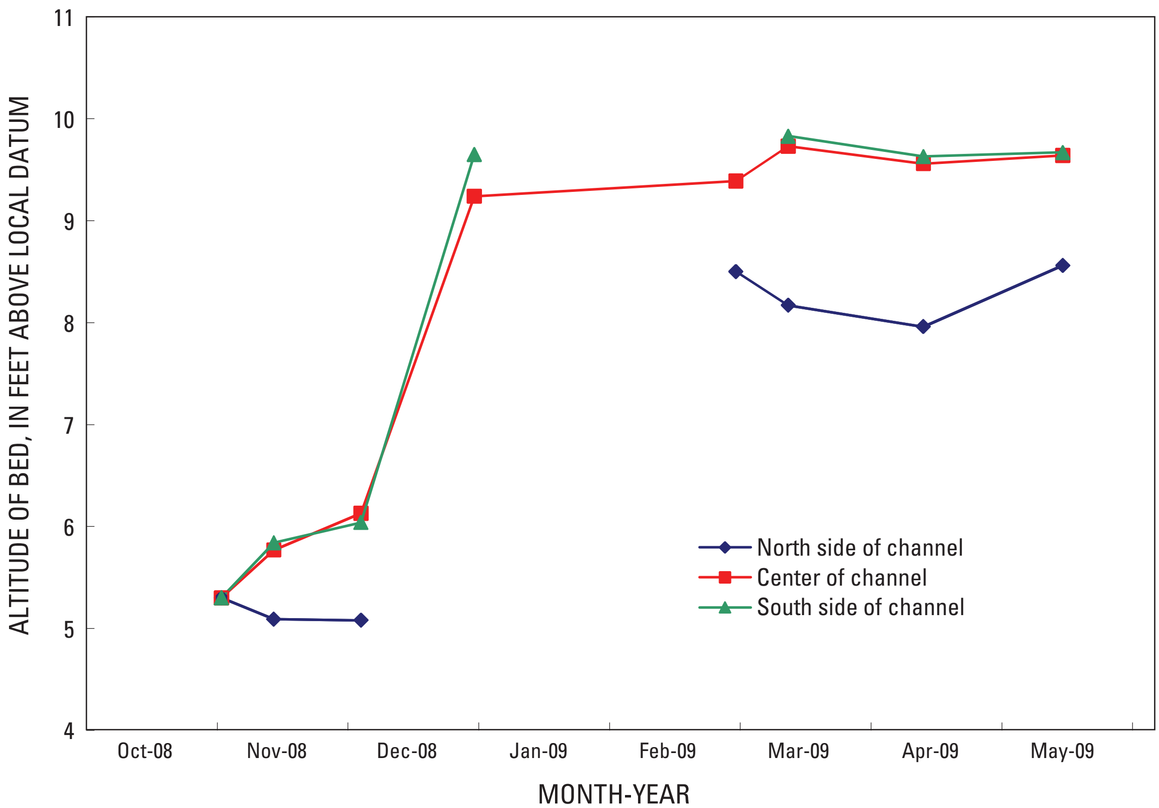

Figure 3-2. Bed aggradation of Rattlesnake Gulf across channel on downstream side of bridge at Tully Farms Road, October 2008 to May 2009.

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Appendix 4. Suspended Solids and Sediment Data from Selected Sites

Table 4-1. Concentrations of total suspended solids and suspended sediment in water samples collected at five continuous-record streamflow and water-quality monitoring sites in the Onondaga Lake Basin, Onondaga County, N.Y., 2006-08.

[Site locations are shown in figure 1. Concentrations are in milligrams per liter. ft^3/s, cubic feet per second; –, no data; USGS, U.S. Geological Survey; OC-WEP, Onondaga County Department of Water Environment Protection. All samples except those from station 04237962 were collected by OC-WEP.]

Date	Time	Hydrologic condition[1]	Hydrologic event[2]	Discharge (ft^3/s)	Total-suspended-solids concentration		Suspended-sediment concen-tration
					USGS	OC-WEP	
04237962 Onondaga Creek (at State Highway 20) near Cardiff, N.Y.							
10/20/2006	0805	5	J	362	–	–	321
10/20/2006	1640	8	J	520	–	–	731
11/27/2006	1110	9	9	67	–	–	267
03/15/2007	1200	7	J	984	–	–	322
07/19/2007	1015	5	J	157	–	–	851
07/19/2007	1435	5	J	76	–	–	643
12/12/2007	1515	5	4	230	226	–	286
01/07/2008	1420	6	4	170	212	–	255
02/06/2008	1045	8	J	463	494	–	1,680
03/05/2008	1200	7	4	393	–	–	683
03/13/2008	1350	9	9	117	–	–	69
05/14/2008	1200	9	9	30	–	–	100
07/10/2008	1230	9	9	10	–	–	55
09/11/2008	1450	9	9	8.5	–	–	39
04239000 Onondaga Creek at Dorwin Avenue, Syracuse, N.Y.							
06/29/2006	0840	8	J	366	–	313	353
07/11/2006	0830	9	9	117	–	98	126
07/13/2006	0935	8	J	660	–	298	373
08/08/2006	0815	9	9	132	–	23	73
08/22/2006	0845	9	9	79	–	10	46
09/06/2006	0800	9	9	82	–	15	61
10/03/2006	0835	9	9	84	–	10	50
10/31/2006	0835	9	9	257	–	26	45
11/14/2006	0935	9	9	239	–	22	20
12/12/2006	0930	9	9	137	–	7	77
01/09/2007	0915	8	J	365	–	33	77
02/07/2007	0915	9	9	332	–	7	117
03/14/2007	0800	8	4	660	–	271	341
03/20/2007	0830	5	J	582	–	30	82
03/28/2007	0810	6	J	731	–	47	49
04/03/2007	0840	6	J	290	–	30	84
11/27/2007	1010	7	J	552	640	546	81
01/09/2008	0930	5	J	340	46	66	–
02/05/2008	0935	8	J	571	–	450	566
03/04/2008	0915	6	J	385	–	192	234
04/01/2008	0915	8	J	610	–	230	437
04240011 Onondaga Creek at Kirkpatrick Street, Syracuse, N.Y.							
07/11/2006	0950	9	9	160	–	53	58
07/12/2006	1105	8	J	540	–	–	380
07/13/2006	1105	8	J	676	–	330	366
08/08/2006	0950	9	9	203	–	14	105
08/22/2006	1000	9	9	121	–	6	71
10/03/2006	1025	9	9	115	–	8	41
10/31/2006	1020	9	9	319	–	15	60
11/14/2006	1002	9	9	309	–	43	20
12/12/2006	1115	9	9	195	–	4	89
01/09/2007	1115	8	J	424	–	43	94
02/07/2007	1030	9	9	142	–	5	108
03/14/2007	0940	8	4	860	–	270	311

Table 4-1. Concentrations of total suspended solids and suspended sediment in water samples collected at five continuous-record streamflow and water-quality monitoring sites in the Onondaga Lake Basin, Onondaga County, N.Y., 2006-08—Continued.

[Site locations are shown in figure 1. Concentrations are in milligrams per liter. ft^3/s, cubic feet per second; –, no data; USGS, U.S. Geological Survey; OC-WEP, Onondaga County Department of Water Environment Protection. All samples except those from station 04237962 were collected by OC-WEP.]

Date	Time	Hydrologic condition[1]	Hydrologic event[2]	Discharge (ft^3/s)	Total-suspended-solids concentration		Suspended-sediment concentration
					USGS	OC-WEP	
04240011 Onondaga Creek at Kirkpatrick Street, Syracuse, N.Y.—Continued							
03/20/2007	0950	5	J	660	–	41	111
03/28/2007	1000	6	J	877	–	42	86
04/03/2007	1035	6	J	380	–	24	115
11/27/2007	1235	7	J	560	430	572	–
01/09/2008	1100	5	J	424	61	64	711
02/05/2008	1115	8	J	686	–	240	406
03/04/2008	1115	6	J	447	–	183	215
04/01/2008	1115	8	J	645	–	216	244
04240100 Harbor Brook (at Velasko Road) at Syracuse, N.Y.							
08/08/2006	1305	9	9	10	–	14	93
08/22/2006	1315	9	9	68	–	<4	124
09/06/2006	0900	9	9	5.9	–	6	67
10/03/2006	0840	9	9	6.8	–	<4	32
10/31/2006	0850	9	9	11	–	<4	28
11/14/2006	0930	9	9	23	–	8	7
12/12/2006	1215	9	9	11	–	<4	66
01/09/2007	1215	8	J	19	–	<4	71
02/07/2007	1000	9	9	9.9	–	<4	125
03/14/2007	1150	8	4	126	–	738	985
03/20/2007	1300	6	J	29	–	4	100
03/28/2007	0820	8	J	42	–	5	83
04/03/2007	0935	5	J	24	–	<4	86
11/27/2007	1115	5	J	22	15	17	–
01/09/2008	1035	5	J	20	–	13	63
02/05/2008	1125	7	J	110	–	566	319
03/04/2008	1005	5	J	24	–	11	44
04/01/2008	1015	5	J	34	–	<4	81
04240300 Ninemile Creek (at State Highway 48) at Lakeland, N.Y.							
06/29/2006	1110	8	J	196	–	100	111
07/11/2006	1030	9	9	61	–	14	54
07/13/2006	1140	8	J	1,280	–	127	135
08/08/2006	1030	9	9	196	–	21	83
08/22/2006	1035	9	9	84	–	4	40
09/06/2006	1045	9	9	2.9	–	12	93
10/03/2006	1050	9	9	73	–	8	86
10/31/2006	1145	9	9	342	–	17	31
11/14/2006	1105	9	9	353	–	24	21
12/12/2006	1150	9	9	163	–	6	101
01/09/2007	1155	8	J	316	–	14	76
02/07/2007	1115	9	9	136	–	10	150
03/14/2007	1030	8	4	876	–	144	163
03/20/2007	1015	5	J	467	–	26	76
03/28/2007	1320	6	J	778	–	22	58
04/03/2007	1200	6	J	447	–	14	70
11/27/2007	1450	7	J	572	180	191	–
01/09/2008	1150	5	J	410	19	28	–
02/05/2008	1225	8	J	616	114	40	100
03/04/2008	1205	6	J	486	55	21	68
04/01/2008	1155	5	J	570	61	59	–

[1] Hydrologic condition: 5 = Falling stage; 6 = Stable, high stage; 7 = Peak stage; 8 = Rising stage, 9 = Stable, normal stage

[2] Hydrologic event: 4 = Snowmelt; 9 = Routine; J = Storm

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Appendix 5. Steps to Retrieve Water-Quality Data

Water-quality data collected during the Onondaga Lake Basin study from field measurements and laboratory analyses can be retrieved from the USGS National Water Information System (NWIS) website at http://waterdata.usgs.gov/nwis/qw.

1. Click **Field/lab Samples** to enter site-selection criteria.
2. Select site identifier **Site Number** (to retrieve data for one site) or **Multiple Site Numbers** (to retrieve data for many sites) and **Submit**.
3. Enter site numbers from table 1 for the desired sites of interest.
4. Under **Choose Output Format** and **Retrieve Water Quality Samples for Selected Sites**:
    - Input desired range of dates (for example, **2005-10-01** to **2008-12-10** will retrieve all the data collected during the study).
    - To view data on screen, activate the button **Table of data**, accept the **Default attributes** from the pull-down menu, and **Submit**.
    - To save to a tab-separated file, activate the button **Tab-separated data**, revise the output formatting options as desired, and **Submit**.

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