Prepared in cooperation with the City of Middleton, Wisconsin

Evaluation of the Effects of City of Middleton Stormwater-Management Practices on Streamflow and Water-Quality Characteristics of Pheasant Branch, Dane County, Wisconsin, 1975–2008

Scientific Investigations Report 2012–5014

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

Cover photographs:

(Upper left) Pheasant Branch Creek at confluence pond, photograph by Warren A. Gebert

(Upper right) Pheasant Branch Creek at U.S. Geological Survey streamflow-gaging station (05427948), photograph by Herbert S. Garn

(Lower left) Repaired channel in middle reach of Pheasant Branch Creek, photograph by Warren A. Gebert

(Lower right) Pheasant Branch Creek upstream of marsh, photograph by Herbert S. Garn

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KEN SALAZAR, Secretary

U.S. Geological Survey
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Conversion Factors, Abbreviations, and Datum

Inch-pound to SI

Multiply	By	To obtain
	Length	
inch (in)	2.54	centimeter (cm)
inch (in)	25.4	millimeter (mm)
foot (ft)	.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	.4047	hectare (ha)
acre	.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	.2832	cubic meter ($m^{3)}$
	Flow rate	
cubic foot per second (ft^3/s)	.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
	Mass	
pound, avoirdupois (lb)	.4536	kilogram (kg)
pound per year (lb/yr)	.4536	kilogram per year (kg/yr)
ton, short (2,000 lb)	.9072	megagram (Mg)
ton, long (2,240 lb)	1.016	megagram (Mg)
ton per day (ton/d)	.9072	metric ton per day
ton per year (ton/yr)	.9072	metric ton per year

SI to inch-pound

Multiply	By	To obtain
	Length	
millimeter	.3937	inch (in)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

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 either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Evaluation of the Effects of City of Middleton Stormwater-Management Practices on Streamflow and Water-Quality Characteristics of Pheasant Branch, Dane County, Wisconsin, 1975–2008

By Warren A. Gebert, William J. Rose, and Herbert S. Garn

Abstract

Few long-term data sets are available for evaluating the effects of urban stormwater-management practices. Over 30 years of data are available for evaluating the effectiveness of such practices by the city of Middleton, Wis. Analysis of streamflow and water-quality data collected on Pheasant Branch, demonstrates the relation between the changes in the watershed to the structural and nonstructural best management practices put in place during 1975–2008. A comparison of the data from Pheasant Branch with streamflow and water-quality data (suspended sediment and total phosphorus) collected at other nearby streams was made to assist in the determination of the possible causes of the changes in Pheasant Branch.

Based on 34 years of streamflow data collected at the Pheasant Branch at Middleton streamflow-gaging station, flood peak discharges increased 37 percent for the 2-year flood and 83 percent for the 100-year flood. A comparison of data for the same period from an adjacent rural stream, Black Earth at Black Earth had a 43 percent increase in the 2-year flood peak discharge and a 140-percent increase in the 100-year flood peak discharge. Because the flood peak discharges on Pheasant Branch have not increased as much as Black Earth Creek it appears that the stormwater management practices have been successful in mitigating the effects of urbanization. Generally urbanization results in increased flood peak discharges. The overall increase in flood peak discharges seen in both streams probably is the result of the substantial increase in precipitation during the study period. Average annual runoff in Pheasant Branch has also been increasing due to increasing average annual precipitation and urbanization.

The stormwater-management practices in Middleton have been successful in decreasing the suspended-sediment and total phosphorus loads to Lake Mendota from the Pheasant Branch watershed. These loads decreased in spite of increased annual runoff and flood peaks, which are often expected to produce higher sediment and phosphorus loads. The biggest decreases in sediment and phosphorus loads occurred after 2001 when a large detention pond, the Confluence Pond, began operation. Since 2001, the annual suspended-sediment load has decreased from 2,650 tons per year to 1,450 tons per year for a 45-percent decrease. The annual total phosphorus load has decreased from 12,200 pounds per year to 6,300 pounds per year for a 48-percent decrease. A comparison of Pheasant Branch at Middleton with two other streams, Spring Harbor Storm Sewer and Yahara River at Windsor, that drain into Lake Mendota shows that suspended-sediment and total phosphorus load decreases were greatest at Pheasant Branch at Middleton. Prior to the construction of the Confluence Pond, annual suspended-sediment yield and total phosphorus yield from Pheasant Branch watershed was the largest of the three watersheds. After 2001, suspended-sediment yield was greatest at Spring Harbor Storm Sewer, and lowest at Yahara at Windsor; annual total phosphorus yield was greater at Yahara River at Windsor than that of Pheasant Branch. The stormwater-quality plan for Middleton shows that the city has met the present State of Wisconsin Administrative Code chap. NR216/NR151 requirements of reducing total suspended solids by 20 percent for the developed area in Middleton. In addition, the city already has met the 40-percent reduction in total suspended solids required by 2013.

Snow and ice melt runoff from road surfaces and parking lots following winter storms can effect water quality because the runoff contains varying amounts of road salt. To evaluate the effect of road deicing on stream water quality in Pheasant Branch, specific conductance and chloride were monitored during two winter seasons. The maximum estimated concentration of chloride during the monitoring period was 931 milligrams per liter, which exceeded the U.S. Environmental Protection Agency acute criterion of 860 milligrams per liter. Chloride concentrations exceeded the U.S. Environmental Protection Agency chronic criterion of 230 milligrams per liter for at least 10 days during February and March 2007 and for

45 days during the 2007–8 winter seasons. The total sodium chloride load for the monitoring period was 1,720 tons and the largest sodium chloride load occurred in March and April of each year.

Introduction

The purpose of this report is to evaluate the effectiveness of Middleton's stormwater-management practices over the period 1975–2008 on Pheasant Branch by analyzing streamflow and water-quality data collected on Pheasant Branch. The data were evaluated in relation to structural and nonstructural best management practices (BMPs) that have been put in place. Pheasant Branch data were compared with streamflow and water-quality data collected at other streams in the area to determine the possible causes of the changes in Pheasant Branch.

Pheasant Branch (fig. 1) is a tributary to Lake Mendota in Dane County in south-central Wisconsin. Much of its 24.5-square mile (mi^2) watershed is within the city of Middleton. The watershed consists of rolling hills in the uplands, some of which are cultivated; heavily cultivated fields in the glacial lowlands or outwash plains; and urban area that includes residential, commercial and light industrial development in the lower part of the watershed in Middleton. The upper part of the watershed consists of the North Fork Pheasant Branch basin (11.51 mi^2) and the South Fork Pheasant Branch basin (6.2 mi^2). The land use in the North Fork Pheasant Branch basin is mainly agricultural, with some residential and commercial development, and the South Fork Pheasant Branch basin is about 80 percent urbanized with commercial and residential development in the cities of Madison and Middleton.

The Pheasant Branch watershed is rapidly urbanizing as indicated by more than doubling of the population of Middleton since 1970, increasing from 8,266 in 1970, to 11,851 in 1980, to 16,129 in 2000 (Steuer and Hunt, 2001), and to 17,442 in 2010 (U.S. Census Bureau, 2011). In the 1970s, the city was concerned about urbanization causing increased flood peaks and increased water volumes resulting in increased channel erosion and increased pollutant loading to Lake Mendota. Studies by Grant and Goddard (1980) and Krug and Goddard (1986) documented these concerns and the adverse effects of urbanization on the stream channel. More subtly, increased urbanization could reduce recharge to the local groundwater system, resulting in decreased baseflow adversely affecting downgradient ecosystems such as the Pheasant Branch Marsh (Steuer and Hunt, 2001) and nearby streams like Black Earth Creek

In the early 1960s, the city of Middleton was concerned about the possible negative effects of urbanization and, in particular, the increased channel erosion of Pheasant Branch. Another important concern was the sediment and phosphorus load into Lake Mendota and the long term health of the lake. Lake Mendota is part of the five-lake system in Dane County that provides valuable recreational opportunities in the area. Lake Mendota has extensive algal blooms every year that have caused beach closings and other missed recreational opportunities. Local lake managers believe Pheasant Branch contributed the largest phosphorus yield of the three main streams tributary to Lake Mendota.

To address these concerns, the Middleton Water Resource Commission (MWRC) was formed in 1970 to protect and enhance the water resources of Middleton. Because Middleton was rapidly urbanizing, steps to document and minimize some of the impacts on the water resources were required; thus, several important actions were initiated in the 1970s.

One of the first actions by MWRC was the development in 1979 of a stormwater runoff-control ordinance (City of Middleton, 2008) that would prevent any development from increasing flood peaks due to the increased impervious area associated with development. The ordinance was the first in the State to address this issue, and it has been used as a model by many municipalities since then. The Middleton ordinance has been modified several times since 1979, most recently in 2009; the modifications addressed the loss of recharge to the groundwater system and the need to reduce the pollutant load entering Lake Mendota. Since the ordinance was enacted, more than 100 structural stormwater-management facilities have been constructed, and additional facilities are being planned or constructed. Key components of the Storm Water Control Ordinance are summarized in Appendix 1. In about 1979, Middleton also adopted an Erosion Control Ordinance (City of Middleton, 2008) to prevent accelerated soil erosion from construction sites, and the key components are summarized in Appendix 2.

A second important action by the MWRC was the establishment of a streamflow-gaging station on Pheasant Branch in cooperation with the U.S. Geological Survey (USGS) in 1974. The station, Pheasant Branch at Middleton (USGS number 05427948), is located immediately downstream of the confluence of the North and South Fork Pheasant Branch tributaries and near U.S. Highway 12 and Parmenter Street. The drainage area at the gaging station is 18.3 square miles of which 1.2 square miles is noncontributing. Therefore the station monitors runoff from 17.1 mi^2 of the watershed. Only streamflow data were collected initially, but an automatic pump sampler was installed in December 1977 to meet the need for additional information on sediment and water-quality characteristics of the stream. Suspended-sediment data have been collected since then, and phosphorus data have been collected since 1993. In addition, a recording rain gage was installed at the station in October 1987. The station provides one of the longest records of concurrent streamflow, sediment, and nutrient data in the State.

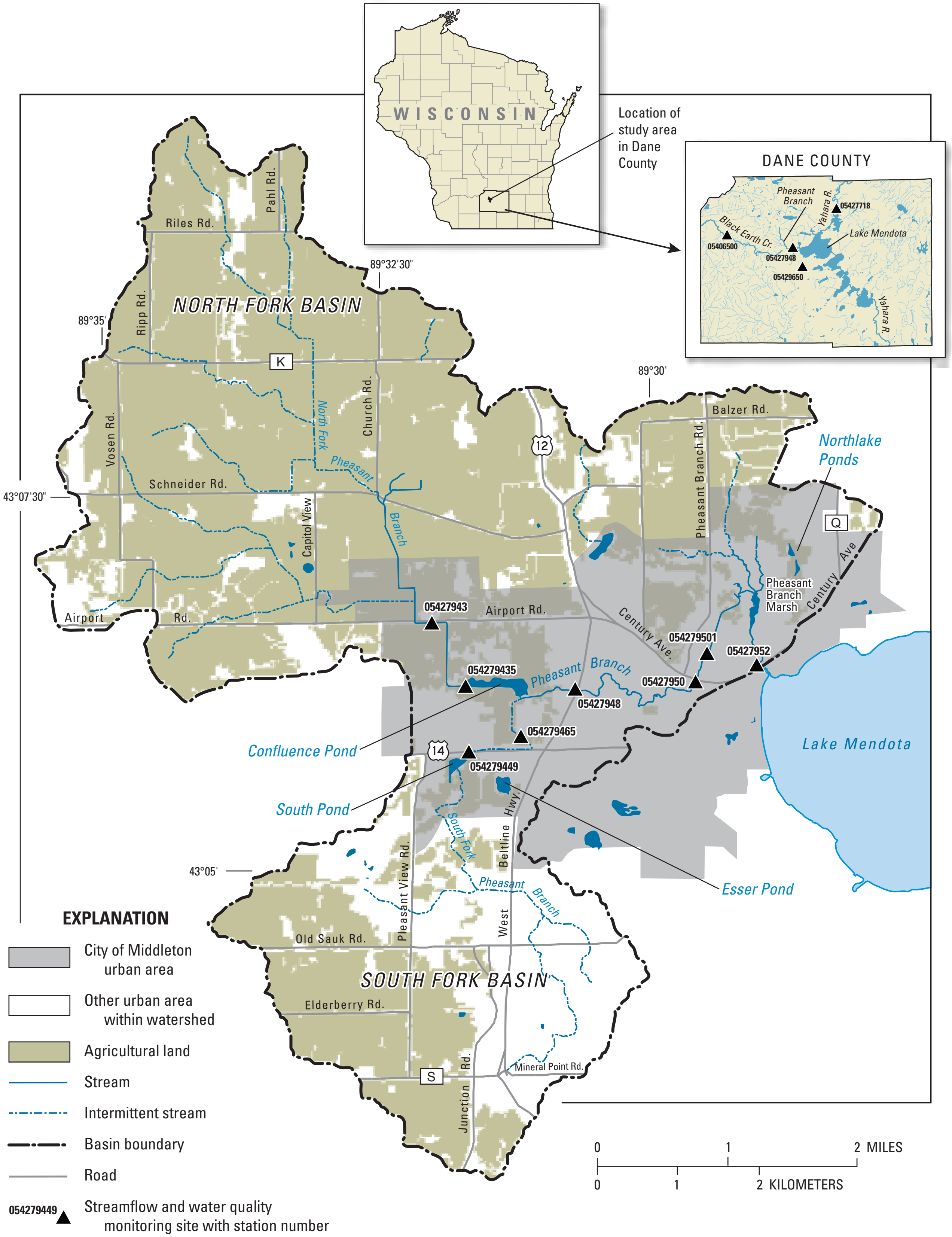

Figure 1. The Pheasant Branch watershed in Dane County, Wis.

Data collected at the gaging station have been used for a number of City projects including:

- mapping of flood plains;
- design of stormwater detention ponds (Confluence Pond and South Pond);
- design of South Pond, which includes the overflow features to Esser Pond;
- identification of sites for infiltration ponds in the North Fork Pheasant Branch basin; determination of the recharge area of Frederick Springs for protection of the Pheasant Branch Marsh; and
- design of several channel erosion-control projects on Pheasant Branch.

The data also were used during the development of the Storm Water Quality Plan (MSA Professional Services, 2007) for compliance with standards specified in State of Wisconsin rules NR216 and NR151(State of Wisconsin, Legislative Reference Bureau, 2009 a, b). Compliance with these standards is required for the city of Middleton to obtain a Wisconsin Pollution Discharge Elimination System Phase II permit to discharge stormwater runoff from the city's stormwater sewer system.

In addition, the streamflow-gaging station provides the streamflow and rainfall data required to develop and support the Middleton Storm Water Runoff Control Ordinance. In 2007 and 2008, continuous specific conductance and chloride concentration data were collected at the gaging station to evaluate salt load carried by the stream and discharged into Lake Mendota from road deicing in the watershed.

Stormwater Runoff-Management Practices

Since 1979, the city of Middleton has used two main categories of practices for controlling flood discharges and improving the water quality of runoff; stormwater-management structures and nonstructural best management practices.

Stormwater-Management Structures

The stormwater-management structures constructed since 1975 include stormwater-detention ponds, water-quality retention ponds, and, more recently, infiltration basins, rain gardens, and bioretention basins. More than 100 stormwater-management structures were constructed in Middleton during 1975–2008. Additional structures exist in Madison in the headwaters of the South Fork Pheasant Branch. Gabions, sheet piling, vane deflectors, and grade-control structures also have been installed to control channel erosion in the lower reaches of Pheasant Branch.

The two largest structures created for runoff control and water-quality retention in Middleton are locally referred to as the South Pond and the Confluence Pond. The South Pond is on the South Fork Pheasant Branch, and the Confluence Pond is on the main stem of Pheasant Branch at the confluence of the North and South Fork Pheasant Branches (fig. 1). The South Pond was constructed in 1992, and its main purpose is to reduce the flood peaks associated with nearby commercial and retail development. The South Pond outlet was redesigned in 2005 to allow higher discharges, greater than the 40-year flood, to overflow into Esser Pond to the east. The increased storage and diversion of discharges greater than the 100-year flood allowed for a narrowing of the flood plain downstream of Highway 14. In 2005, the South Pond was also deepened to provide more sediment trapping, and in 2008, it had a sediment trapping efficiency of about 30 percent (R.S. Grant Consulting Inc., oral commun., 2008). The Confluence Pond (fig. 2) was designed to reduce flood peaks and to improve water quality by trapping sediments. The pond was put into operation in November 2001 and has a trapping efficiency of about 35 percent (R.S. Grant Consulting Inc., oral commun., 2008).

The South Pond and the Confluence Pond are the major runoff-control and water-quality retention structures on the main stems of Pheasant Branch in Middleton. The other structures in the watershed are considerably smaller and generally provide control of runoff from developments to meet the Middleton Storm Water Control Ordinance. An example of a smaller water-quality detention basin is the Northlake Pond (fig. 3). This and a similar basin were built in 1997 to fulfill a requirement that a 153-acre residential development include dedicated ponds and open space. Most of the runoff from the development flows into these detention basins, which are intended to trap a large part of the sediment and attached pollutants before water is released to Pheasant Branch Marsh. The load trapped by the pond was estimated by the Source Loading and Management Model (SLAMM) to be 12 tons per year .

A commercial infiltration basin in Middleton (fig. 4) collects and infiltrates the runoff from an auto dealership parking lot and building roofs. The combined parking and roof impervious area at this location is close to 100 percent of the entire auto dealership area. Developments like this and all other retail and commercial developments, are required to meet the runoff-, infiltration-, and sediment-control requirements of Middleton's Storm Water Runoff Control Ordinance.

A bioretention facility (fig. 5) was constructed in 2007 to trap pollutants from a large retail parking lot. This facility was designed only to trap pollutants, because the soils in this area are not adequate for providing infiltration. To meet the infiltration requirement of Middleton's Storm Water Runoff Ordinance, the developer was therefore required to pay a fee in lieu of the implementation of infiltration practices. These fees contribute to funding for the construction of larger stormwater-management facilities elsewhere in the watershed. The Confluence Pond and South Pond are examples of facilities that were partly funded by fees in lieu of implementation

Figure 2. Confluence Pond on Pheasant Branch in Middleton, Wis., in 2008, with a view of the outlet structure. (Photo by W.A. Gebert)

Figure 3. Northlake Pond water-quality detention basin in Middleton, Wis., in 2008. (Photo by W.A. Gebert)

Figure 4. Infiltration basin at retail dealership on Airport Road in Middleton, Wis., in 2008. (Photo by W.A. Gebert)

Figure 5. Bioretention facility at a commercial parking lot in Middleton, Wis., in 2008. (Photo by W.A. Gebert)

of various practices. The fees have also been used to fund the construction of facilities in areas that were developed prior to the enactment of the Storm Water Control Ordinance.

Nonstructural Best Management Practices

Street sweeping and development of residential rain gardens are the main nonstructural best management practices in the Pheasant Branch watershed. Middleton adjusts its street sweeping frequency based on the amount of material on the streets. In 2008, the streets were swept once or twice per month. Records of street sweeping were not kept during the 1970s, but streets probably were swept once or twice per year at that time. In addition, weekly sweeping of private parking lots or shopping centers constructed since about 1995 is required.

In 2007, Middleton sponsored a program for developing residential rain gardens called “Plant Middleton” that solicited homeowners in Middleton who were interested in developing rain gardens to submit plans to the city for possible inclusion in the program. In 2007, 12 residences qualified for the program, and rain gardens were successfully constructed at all of the sites. Figure 6 shows one of the residential rain gardens. The program was started again in 2009, and 11 homeowners participated in it. The City program ended after 2009, because interest in it was low relative to the effort required for continuing it and because residents could also participate in a similar program sponsored by Dane County.

Figure 6. Photograph showing a residential rain garden in Middleton, Wis. (Photo by H. S. Garn)

Changes in Streamflow Characteristics

Changes or trends in Pheasant Branch streamflow characteristics were determined by analyzing discharge data from the Pheasant Branch at Middleton streamflow-gaging station and precipitation data from the National Weather Service station at the Dane County Regional Airport (U.S. Department of Commerce, 2009). Streamflow data and methods of collection are described in USGS annual data reports, Water Resources Data, Wisconsin (U.S. Geological Survey, 1976–2006;U.S. Geological Survey 2007–9). The average annual streamflow for the period is 5.19 cubic feet per second (ft^3/s). The annual average streamflow increased through the period 1975–2008 (fig. 7), and it approximately doubled from 1975 to 2008, as indicated by the least squares linear regression trend line shown in figure 7. This increase likely was caused by a combination of an increase in impervious area due to urbanization, an increase in annual precipitation (fig. 8) and expansion of the drainage area or stream network in 1999, when the city of Madison connected a 1.2-mi^2 previously noncontributing area to the upstream part of the South Fork Pheasant Branch.

The average annual baseflow of 3.71 ft^3/s for the period (fig. 7) was calculated by a baseflow separation technique (Gebert and others, 2007). Baseflow increased, as indicated by the least squares linear regression trend line shown in figure 7; however, the annual baseflow did not increase as much as annual streamflow (fig. 7). Although increased impervious area usually causes decreased infiltration, aquifer recharge, and baseflow, the increased baseflow in Pheasant Branch, is notable because a decrease in baseflow could have been expected with the increase in impervious area.

The South Fork Pheasant Branch has not had a baseflow component before development or after development because the stream does not intersect the groundwater table. The North Fork Pheasant Branch does have a baseflow component for most of its length, and there is a small increase in baseflow in the main stem as it flows through the city. At the mouth, after Pheasant Branch flows through Pheasant Branch Marsh, annual baseflow increases substantially. (table 1).

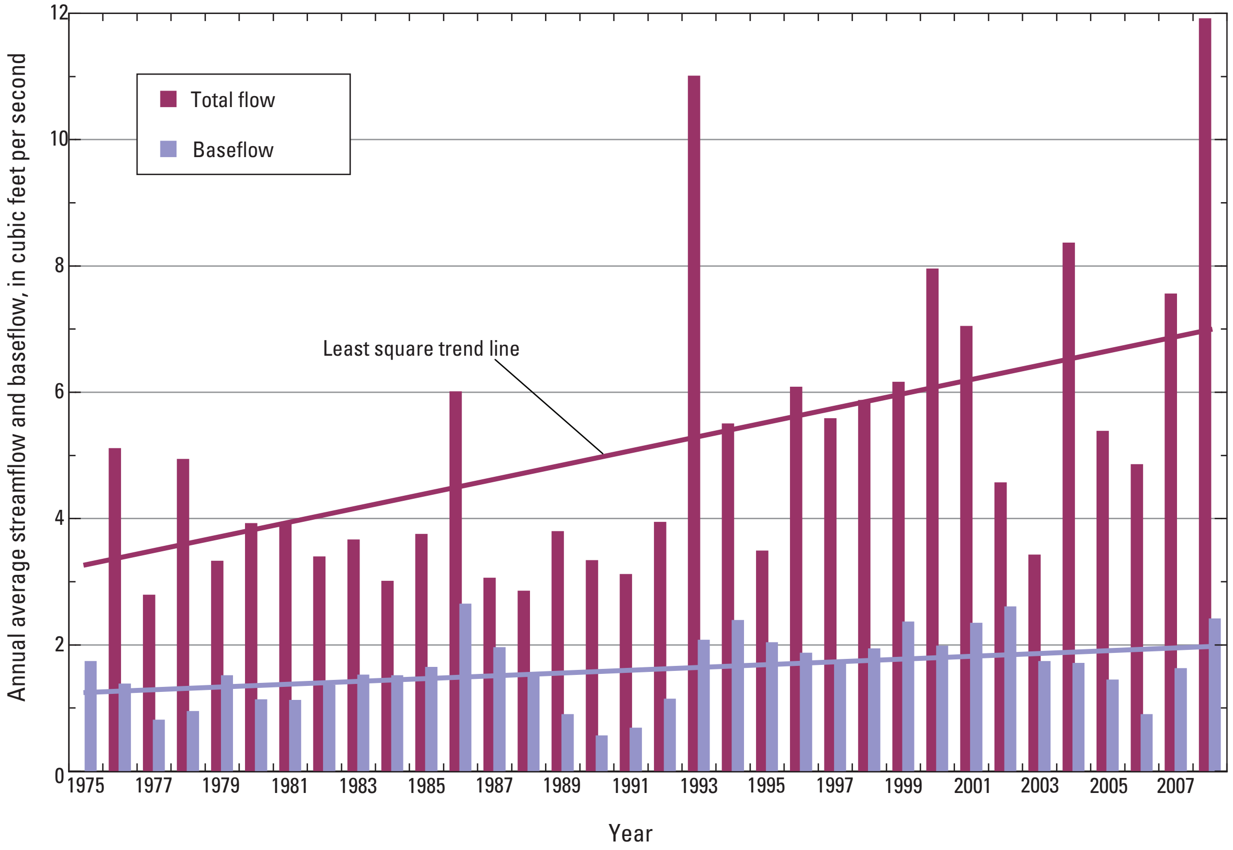

Figure 7. Annual streamflow and baseflow at Pheasant Branch at Middleton, Wis. (station 05427948), 1975–2008.

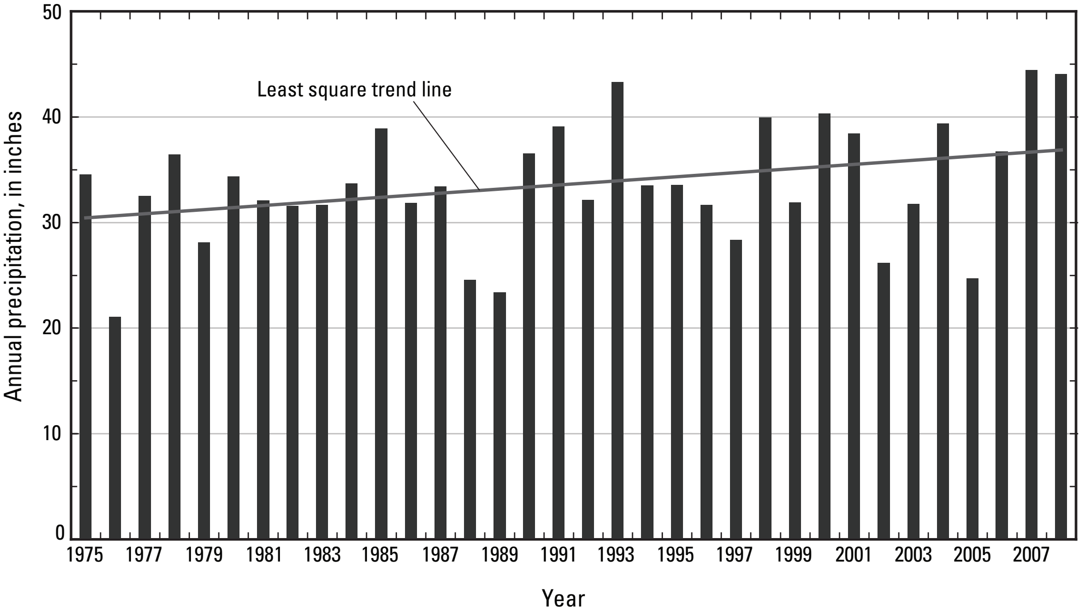

Figure 8. Annual precipitation at Madison, Wis., 1975–2008. (Data from U.S Department of commerce 2009)

Table 1. Average annual baseflow at four sites in the Pheasant Branch watershed, Dane County, Wisconsin.

[USGS, U.S. Geological Survey; mi^2, square miles; ft^3/s, cubic feet per second]

USGS station number	Station name	Drainage area (mi^2)	Average annual baseflow (ft^3/s)
05427945	South Fork Pheasant Branch at Highway 14	5.7	0
05427943	North Fork Pheasant Branch at Airport Road	9.6	2.83
05427948	Pheasant Branch at Middleton	18.3	3.71
05427952	Pheasant Branch at mouth	24.5	5.80

The annual streamflow from 1993 to 2008 showed an abrupt increase of 62 percent from the 1975–92 period (fig. 9). Some gradual increase in streamflow might be expected because of the continued increase in development in the watershed, and some of the increased annual streamflow might be attributed to increased precipitation after 1992, which was 7 percent greater than during the 1975–92 period. However, the relation of cumulative streamflow as a function of cumulative precipitation (fig. 10) indicates that unit runoff per unit of precipitation was 43 percent greater for the period after 1992. This abrupt increase in streamflow may have been due to the increase in precipitation and the rapidly increasing development in the South Fork Pheasant Branch, including the 1999 connection of an area in the watershed that had previously been internally drained. Straight line segments, rather than a more gradual curve, representing the data for the pre- and post-1993 time periods (fig. 9) illustrate the abrupt increase.

Annual flood-peak discharges at Pheasant Branch at Middleton have increased during the 1975–2008 period (fig. 11). Although a least squares linear regression trend analysis shows, the apparent trend was not statistically significant; the flood-peak discharge values for various recurrence intervals have changed considerably during the past 34 years. Flood-peak discharge values for all recurrence intervals from the 2- to the 100-year floods increased 37–83 percent from the 1975–1991 period compared with those from the 1992–2008 period (table 2). The flood-peak discharge values shown in table 2 were calculated from Log Pearson Type III analyses.

The increase in flood peak discharges could be caused by urbanization, an increase in recent precipitation, or the addition of the formerly internally drained area to the South Fork Pheasant channel.

An evaluation of the effects of urbanization on Pheasant Branch (Krug and Goddard, 1986) included a model that estimated the changes in flood peak discharges that could occur with several urbanization scenarios. The scenarios used for simulation were 1985 conditions, partial urbanization expected over the next 20 years (1985–2005), and complete urbanization of the basin. The partial urbanization scenario

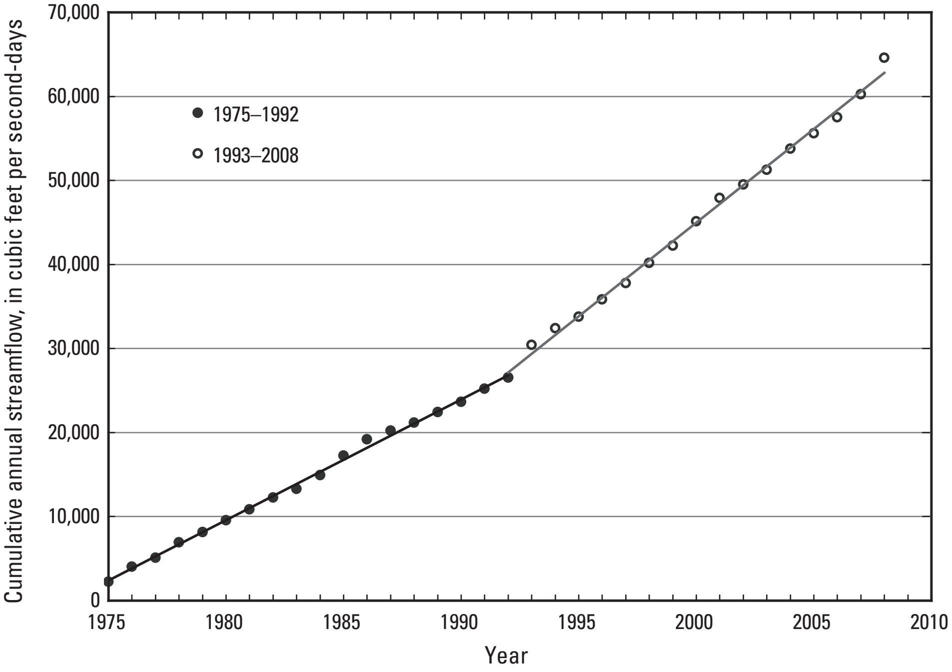

Figure 9. Cumulative annual streamflow at Pheasant Branch at Middleton, Wis. (station 05427948), 1975–2008.

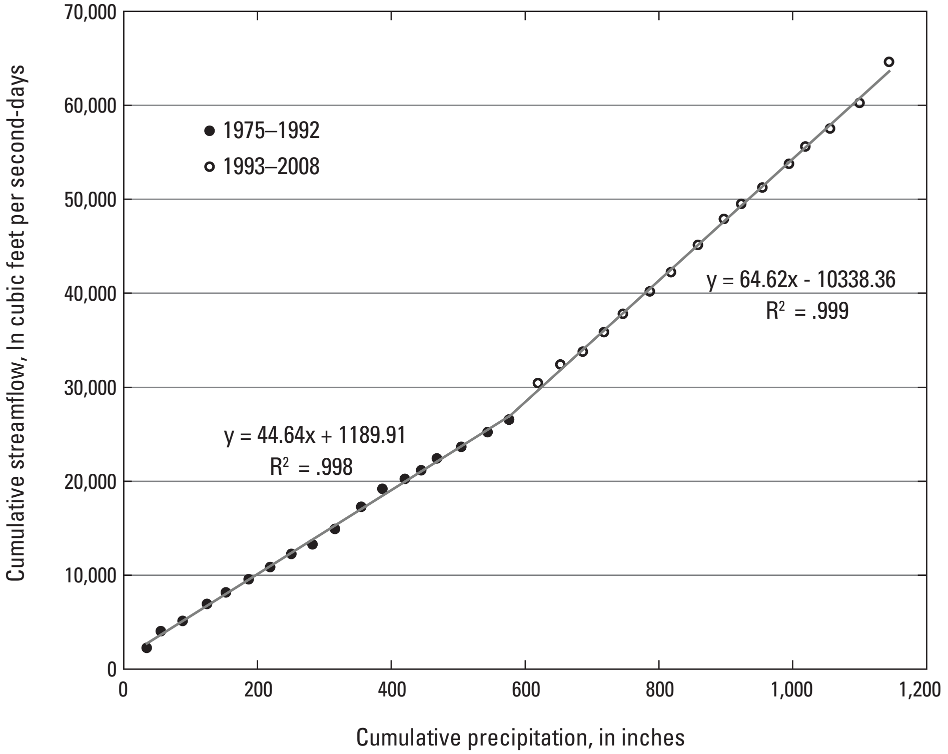

Figure 10. Comparison of annual streamflow of Pheasant Branch at Middleton, Wis. (station 05427948) and annual precipitation at Madison, Wis., 1975–2008.

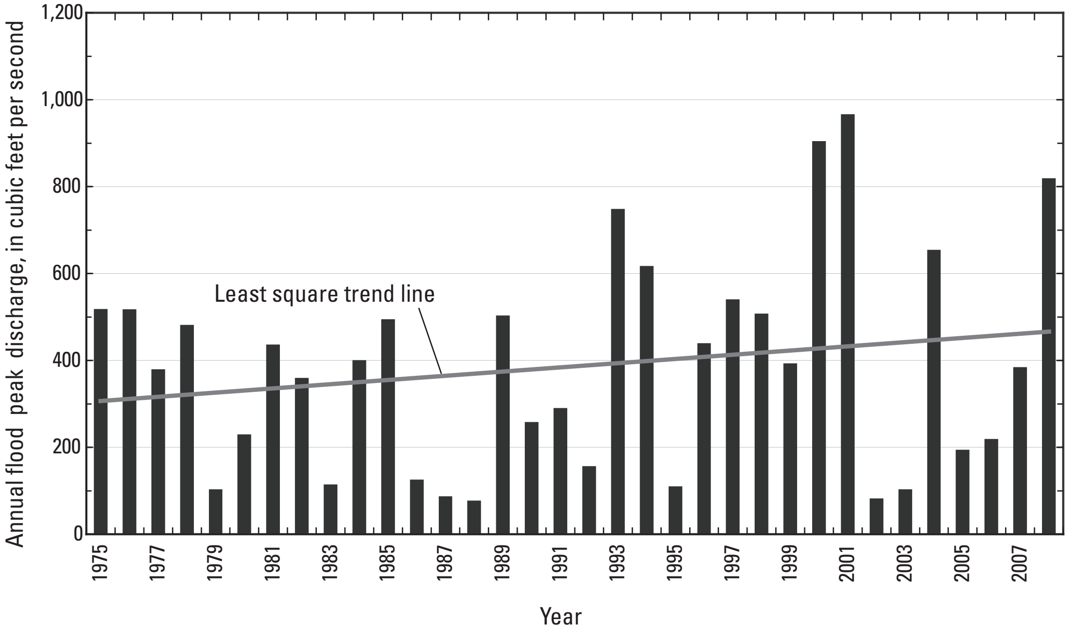

Figure 11. Annual flood-peak discharges at Pheasant Branch at Middleton, Wis. (station 05427948), 1975–2008.

Table 2. Flood-peak discharges for various recurrence intervals at Pheasant Branch at Middleton, Wis. (station 05427948), 1975–2008.

[ft^3/s, cubic feet per second]

Recurrence interval (years)	Period of record			Increase 1975–91 to 1992–2008 (percent)
	1975–91 (ft^3/s)	1992–2008 (ft^3/s)	1975–2008 (ft^3/s)	
2	276	378	320	37
5	485	736	592	52
10	635	1016	795	60
25	833	1410	1,070	69
50	985	1,740	1,290	76
100	1,140	2,090	1,510	83

best represents current (1975–2008) development in the watershed. A comparison of flood peaks based on 1975–2008 data to the flood peaks simulated for projected partial urbanization (table 3) shows that the 2-year recurrence interval flood peak for current conditions is not as large as that simulated for projected partial urbanization. For recurrence intervals of 5 years and greater, the opposite is true: flood peaks for 1975–2008 conditions are much higher than were simulated for expected partial urbanization.

The results of the model were very useful for Middleton to be aware of the increases in flood peak discharges that could occur with urbanization and the implementation of numerous storm water management practices. While the model was successfully calibrated using flow data from 1975–1980 , the model has limitations due to the complexity of handling the various water control structures. Therefore the projected flood discharges may have larger errors than those computed from recorded data and may not provide a very accurate tool for evaluating the effectiveness of stormwater management structures or the impact of urbanization.

To evaluate likely causes for the increase in flood-peak discharges at Pheasant Branch, peak discharge data from the same periods at three nearby streamflow-gaging stations were compared to data from Pheasant Branch at Middleton (05427948). One station, Spring Harbor Storm Sewer at Madison (05429650), is a completely urbanized basin, and the other two, Black Earth Creek near Black Earth (05406500) and Yahara River at Windsor (05427718), are largely agricultural basins that have small urban areas. A plot of annual flood-peak discharges shows that the same trend of increasing flood peaks observed in Pheasant Branch also occurred in these watersheds (fig. 12) probably as the result of increased precipitation. Although the flood peaks increased at all four sites, a comparison of the slope of the trend lines shows the increase was much larger for Black Earth Creek and Yahara River, where the primary land use is agricultural, than for Pheasant Branch, where the land use is a mixture of agricultural and urban, and Spring Harbor, where the land use is mostly urban.

Table 3. Comparison of flood peak discharges based on simulated annual peak discharges and actual annual flood peak discharges.

[ft^3/s, cubic feet per second; –, decrease; +, increase; simulated peak discharge from Krug and Goddard, 1986]

Recurrence interval (years)	Flood peak discharges based on simulated peak discharge for partial urbanization (ft^3/s)	Flood peak discharges based on actual annual peak discharge 1975–2008 (ft^3/s)	Difference between simulated and actual peak discharge (percent)
2	350	320	–9
5	483	592	+23
10	567	795	+40
25	670	1,070	+60
50	744	1,290	+73
100	815	1,510	+85

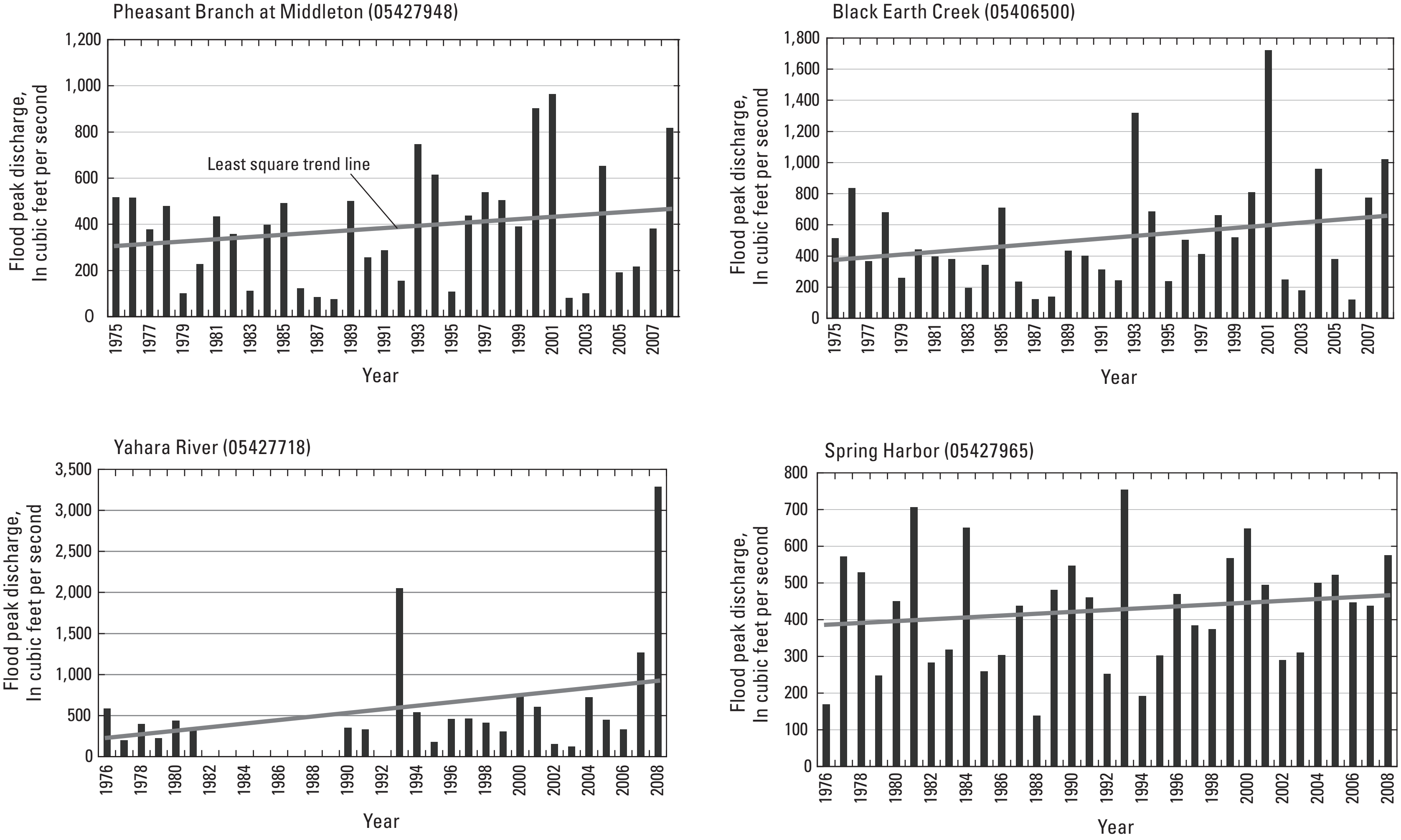

Figure 12. Comparison of annual flood peaks of Pheasant Branch at Middleton with annual flood peaks at three nearby streams at three gaging stations in Wisconsin for 1976–2008.

A more detailed comparison of the difference in flood peaks for the urban and rural watersheds is shown in table 4 for the three stations that had comparative periods of record. Changes in flood peak discharges for various recurrence intervals were compared for the three basins by calculating flood frequency values for the period 1975–91 to the values for the period 1992–2008. As mentioned previously, the flood peak discharges for Pheasant Branch increased by 37 percent for the 2-year recurrence interval and by 83 percent for the 100-year recurrence interval. The 2-year flood-peak discharges for Spring Harbor Storm Sewer increased by 11 percent but they decreased for the 10-year and greater recurrence intervals by 7-13 percent. For Black Earth Creek, the increase was 43 percent for the 2-year recurrence interval and up to 140 percent for the 100-year recurrence interval. Based on the changes in these two basins, the increase in peak discharges in Pheasant Branch was probably due to a combination of factors—increased precipitation and increased urbanization, mitigated by stormwater-management practices that help to reduce the increases. Although it is possible that the enlarged drainage area in the South Fork Pheasant Branch in 1999 contributed to the increase in flood peaks in the Pheasant Branch watershed, the enlarged drainage area is probably not significant, because the city of Madison constructed several large detention basins to control the flood peaks. In addition, the South Pond was constructed in 1992 to reduce flood peaks. These detention ponds may have mitigated the effects that increased drainage area and increasing urbanization had on increasing the flood peaks.

A comparison of flood peaks per square mile of basin (fig. 13) illustrates that flood peaks are generally much higher in urbanized areas. For Spring Harbor Storm Sewer, a completely urbanized basin, the annual flood peaks for the period average 129 ft^3/s compared to 23 ft^3/s for Pheasant Branch, a watershed that is approximately 50 percent urbanized at the Pheasant Branch at Middleton gaging station. The average annual flood peaks for the two rural watersheds are 29 ft^3/s for Black Earth Creek and 17 ft^3/s for Yahara River. Based on these comparisons it appears that Pheasant Branch flood peak discharges are similar to those of rural watersheds and the runoff control practices in the Pheasant Branch watershed have been effective in suppressing the increases in flood peaks that occur with urbanization.

Based on these analyses of flood peaks the conclusions are:

1. Flood peak discharges have been increasing since 1975.
2. The primary reason for the increase appears to be increased precipitation and increase urbanization.
3. The stormwater management techniques used by Middleton have been effective in minimizing the increase in flood peak that usually occurs with urbanization

Changes in Water-Quality Characteristics

Changes or trends in Pheasant Branch water-quality characteristics were determined by analyzing suspended-sediment and total phosphorus discharge and concentration data from the Pheasant Branch at Middleton station. In addition, specific conductance was monitored and chloride concentrations and loads were determined for two winter seasons to evaluate the effects of the application of road deicing salt on stream water quality.

Table 4. Comparison of changes in flood peak discharge values at three U.S. Geological Survey streamflow-gaging stations near Middleton, Wis.

[+, increase; –, decrease]

	Change 1975–91 to 1992–2008 (percent)		
Recurrence interval (years)	**Pheasant Branch at Middleton, Wis. (station 05427948)**	**Black Earth Creek near Black Earth, Wis. (station 05406500)**	**Spring Harbor Storm Sewer at Madison, Wis. (station 05429650)**
2	+37	+43	+11
5	+52	+72	+1
10	+60	+89	–13
25	+69	+110	–7
50	+76	+130	–9
100	+83	+140	–10

Suspended Sediment and Total Phosphorus

Suspended-sediment discharge has been determined for Pheasant Branch at Middleton (station 05427948) since December 1977. An automatic pump sampler was used to obtain sediment-concentration data during runoff events, and the concentration data were then used with the streamflow data to compute daily sediment loads according to techniques described by Porterfield (1972). The annual suspended-sediment load from 1978 to 2008 decreased, as indicated by the least squares trend line in figure 14.

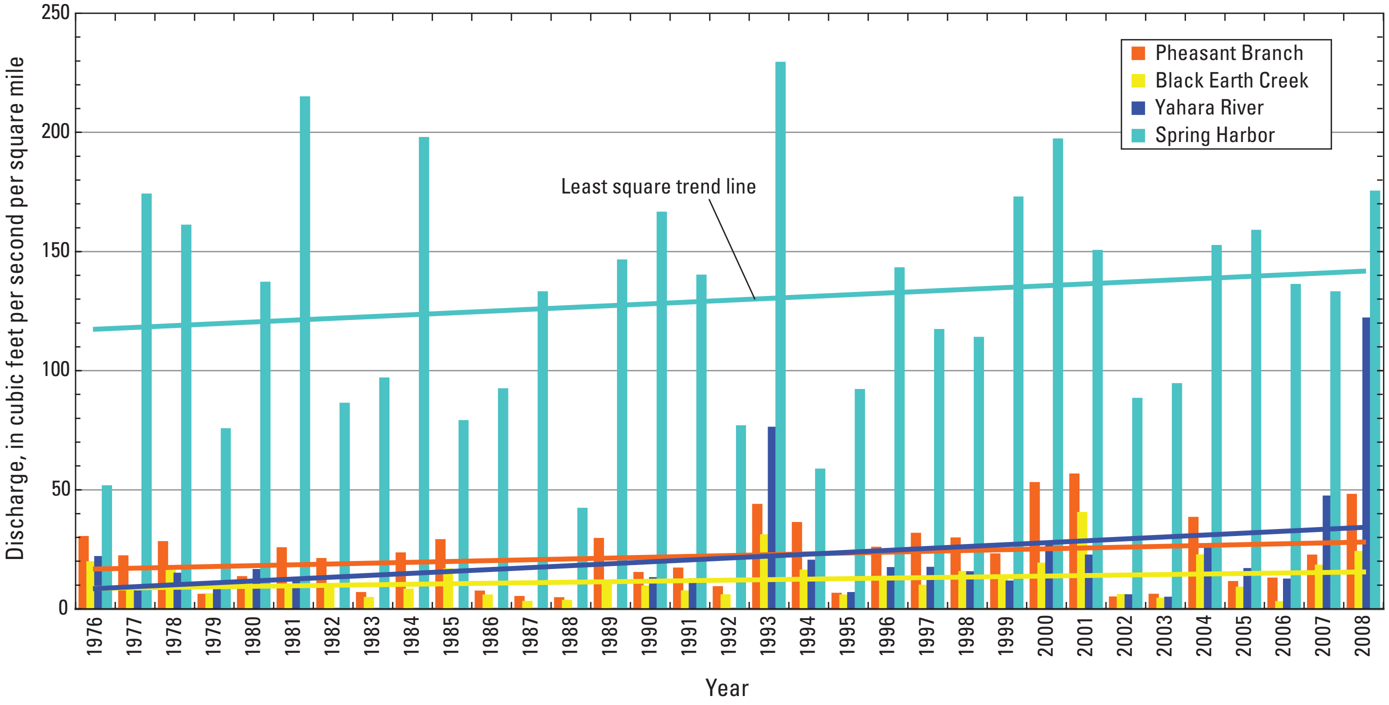

Figure 13. Comparison of annual flood peak discharges in cubic feet per second per square mile at four gaging stations in Wisconsin for 1976–2008: Pheasant Branch at Middleton (station 05427948), Black Earth Creek at Black Earth (station 05406500), Yahara River at Windsor (station 05427718), and Spring Harbor Storm Sewer at Madison (station 05429650).

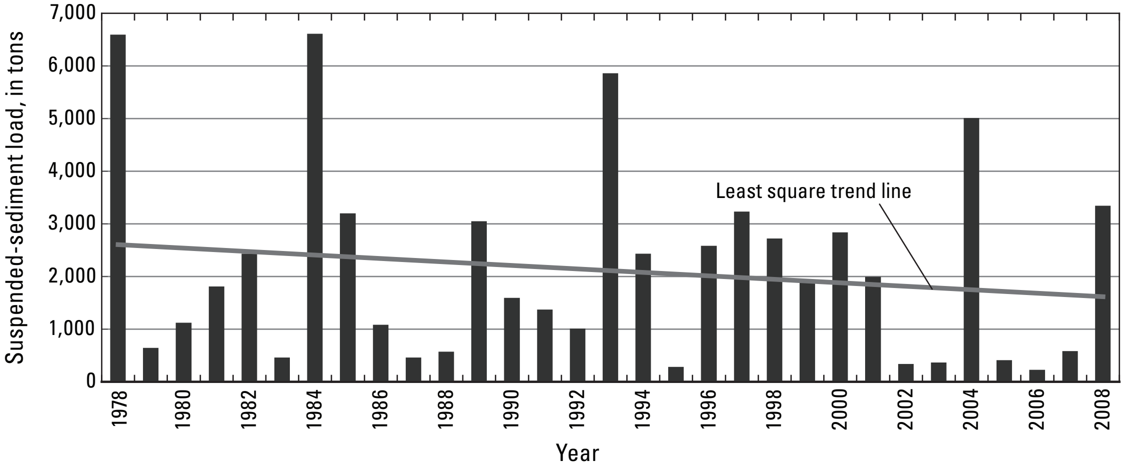

Figure 14. Annual suspended-sediment loads for Pheasant Branch at Middleton, Wis. (station 05427948), 1978–2008.

Annual average suspended-sediment concentrations were determined by dividing the annual suspended-sediment load by the annual flow volume. Suspended-sediment concentrations generally increase with increasing flows, and despite the increasing annual flow volumes in Pheasant Branch, suspended-sediment concentrations show an obvious decreasing trend (fig. 15). This unusual divergence may be a direct result of the adoption of Middleton's Storm Water Runoff Control Ordinance in 1975 and the subsequent construction of more than 100 stormwater-management facilities or structures.

Especially significant is the reduction in average annual suspended-sediment load since the construction of the Confluence Pond in 2001. The average annual sediment load for the 1978–2008 period was 2,110 ton/yr. Prior to construction of the Confluence Pond (1975–2001), the average annual suspended-sediment load was 2,650 ton/yr, but after 2002, the average annual suspended-sediment load was reduced to 1,450 ton/yr, for the period 2002–8 for a decrease of 45 percent.

Although overall suspended-sediment loads have decreased in Pheasant Branch, some years that had anomalously high loads were the result of intense rainfall or construction activities in the watershed. In 2004, during the construction of a bypass for U.S. Highway 12, several large storms struck when much of the construction area had bare soil, steep slopes, and few or no erosion-protection measures. The large sediment load in 2004 (fig. 14) was the result of those storms, and the relatively large load in 2008 was the result of many storms that produced the largest annual flow volume for the period of record. The annual suspended-sediment concentrations have been much lower than expected for the annual flow volumes since 2002, except for the unusual storm years of 2004 and 2008 (fig. 15).

Total phosphorus discharge has been determined at the Pheasant Branch at Middleton gaging station since 1993. The average annual phosphorus load for the period 1993, 1995–2008 was 9,450 pounds per year (lb/yr); fig. 16.The annual phosphorus load decreased, as shown by the least squares trend line (fig. 16), similar to the annual sediment load. This decrease was expected, because part of the total phosphorus load is attached to the sediment. Although the record for phosphorus starts in the middle of the urbanization period, the annual phosphorus load still shows a decrease, mainly because the Confluence Pond traps sediments that would have entered Pheasant Branch prior to the pond's construction in 2001.

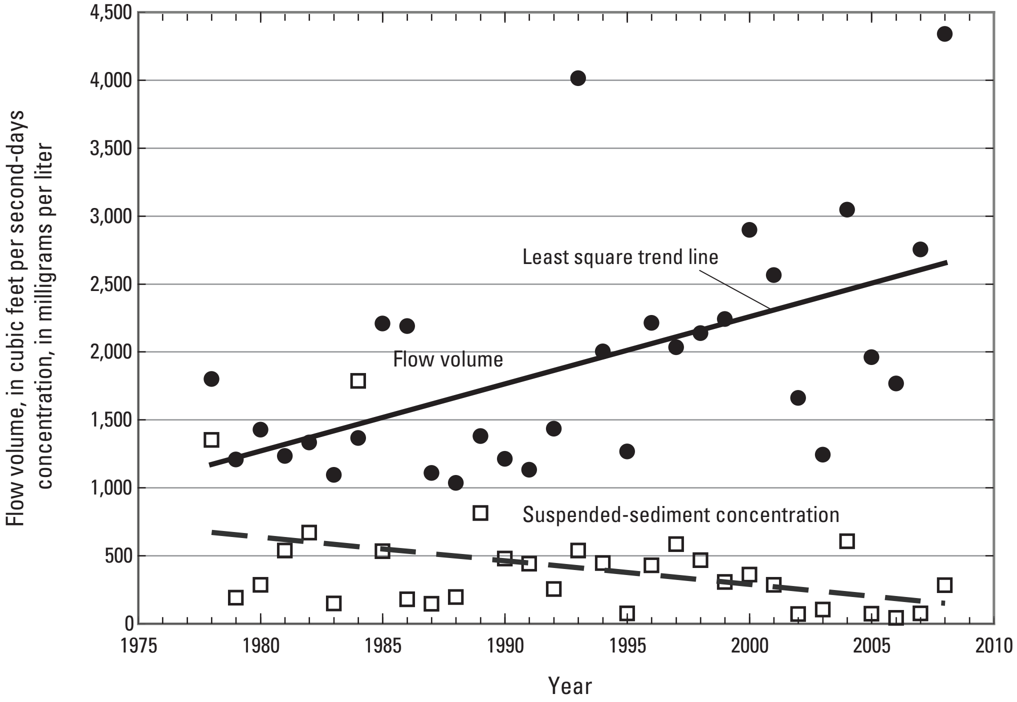

Figure 15. Annual flow volumes and annual average suspended-sediment concentrations for Pheasant Branch at Middleton, Wis. (station 05427948), 1978–2008.

During the period 1993, 1995–2001, prior to the construction of the Confluence Pond, the annual phosphorus load was 12,200 lb/yr; after 2002, the annual load decreased by 48 percent to 6,300 lb/yr. As was the case for suspended sediment, the shorter 1993–2008 record for phosphorus shows similar decreasing annual phosphorus concentrations, although flow volumes increased during the same period (fig. 17).

The other part of the total phosphorus load is dissolved ortho phosphorus, which is not attached to the sediment load and, therefore, may not show the same decreasing trend.

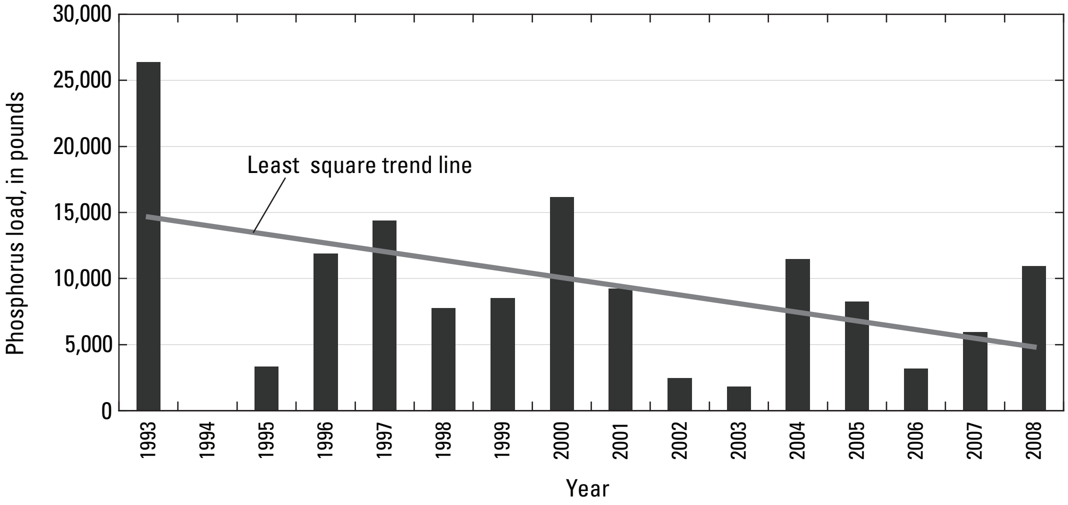

Figure 16. Annual phosphorus loads for Pheasant Branch at Middleton, Wis. (station 05427948), 1993, 1995–2008.

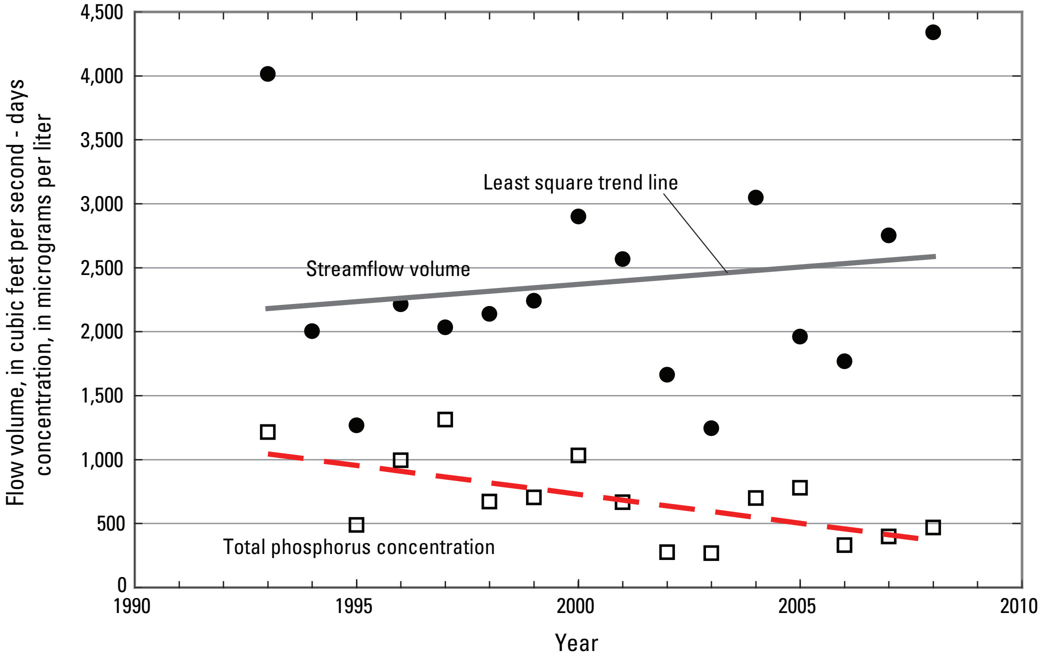

Figure 17. Annual flow volumes and annual average total phosphorus concentrations for Pheasant Branch at Middleton, Wis. (station 05427948), 1993, 1995–2008.

A good example of that divergence from the trend was in 2005 (fig. 18), when the annual phosphorus load was much larger relative to the annual sediment load. During February and March 2005, three rainfall events occurred over frozen ground, resulting in relatively modest increases in streamflow and sediment loads but very large total phosphorus loads. The total phosphorus load for those 2 months was 7,100 lb, or 87 percent of the annual load of 8,250 lb for the entire year. Normally the Confluence Pond would have reduced the total phosphorus and suspended sediment loads, but in 2005, most of the phosphorus load for February and March was dissolved ortho phosphorus that passed through the Confluence Pond because it was not attached to sediment. Agricultural runoff is usually the source of dissolved phosphorus, and in 2005 the rainfall events occurred when the ground was frozen, allowing a large amount of dissolved phosphorus to enter the stream system.

To evaluate the possible causes for the changes in annual sediment and phosphorus loads seen in Pheasant Branch, data from two other streams that discharge into Lake Mendota were compared to data from Pheasant Branch (table 5). The streams are Spring Harbor Storm Sewer at Madison, a completely urbanized basin, and Yahara River at Windsor, a basin where the predominant land use is agricultural.

For the period 1993–2001, Pheasant Branch had the highest contributing load and yields to Lake Mendota for the three major streams discharging to the lake, but annual loads changed significantly after construction of the Confluence Pond in 2001. Since that time, the annual sediment load for Pheasant Branch has decreased 45 percent and the annual phosphorus load has decreased 48 percent. In contrast, for the same period, the annual sediment load at the urban Spring Harbor Storm Sewer station decreased by 10 percent, while the annual sediment load at the agricultural Yahara River station decreased by 18 percent and the annual phosphorus load decreased by 3 percent. This difference in the change in loads for Pheasant Branch, compared with the other streams, indicates that the Confluence Pond and other stormwater-management facilities constructed since 2001 have significantly reduced the loads from Pheasant Branch. After 2001, Pheasant Branch total phosphorus yields are less than those from Yahara River at Windsor. Both Pheasant Branch and Spring Harbor Storm Sewer, the urban streams, have higher suspended-sediment yields than Yahara River (table 5).

In addition to the long-term monitoring of suspended sediment at the Pheasant Branch at Middleton, sediment was also monitored continuously at four other stations in the Pheasant Branch watershed during the period 1978–81. The four other stations were:

1. South Fork Pheasant Branch at Highway 14 (05427945),
2. North Fork Pheasant Branch at Airport Road (05427943),
3. Pheasant Branch at Century Avenue (05427950), and
4. Pheasant Branch at Mouth (05427952).

A comparison of the annual suspended-sediment loads from the five sites in the Pheasant Branch watershed indicates the variability and sources of sediment load in the watershed (table 6). The South Fork and North Fork contributed similar loads of suspended sediment, except during the wet year of

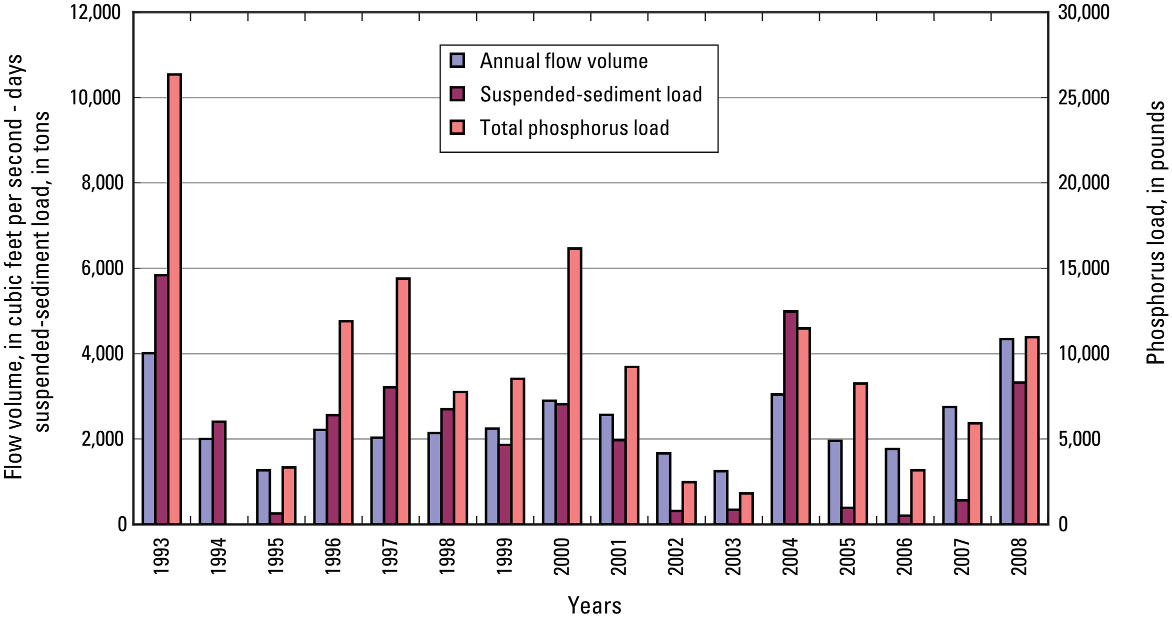

Figure 18. Annual flow volumes, suspended-sediment loads, and total phosphorus loads for Pheasant Branch at Middleton, Wis. (station 05427948), 1993–2008.

Table 5. Comparison of annual sediment and phosphorus loads for three major streams contributing to Lake Mendota, Wis., for the periods 1993, 1995–2001, and 2002–8.

[USGS, U.S. Geological Survey; mi^2, square mile; ton/mi^2; tons per square mile; lb, pound; lb/mi^2; pound per square mile:—, data not available]

USGS station number	Stream name	Contributing drainage area (mi^2)	Time period	Annual suspended sediment load (tons)	Annual suspended sediment yield (tons/mi^2)	Annual total phosphorus load (lb)	Annual total phosphorus yield (lb/mi^2)
05427948	Pheasant Branch at Middleton	17.1	1993–2001 2002–2008	2,650 1,450	155 84.7	12,200 6,300	713 368
05429650	Spring Harbor Storm Sewer	3.29	1993–2001 2002–2008	321 287	97.6 87.2	— —	— —
05427718	Yahara River at Windsor	37.0	1993–2001 2002–2008	2,460 2,010	66.3 54.3	15,700 15,300	424 413

Table 6. Comparison of annual suspended sediment load for five U.S. Geological Survey streamflow-gaging stations on Pheasant Branch near Middleton, Wis., 1978–81.

[All load data are in tons. USGS, U.S. Geological Survey; mi^2, square mile; —, data not available]

Year	South Fork Pheasant Branch at Highway 14 (station 05427945, drainage area 5.74 mi^2)	North Fork Pheasant Branch at Airport Road (station 05427943, drainage area 9.61 mi^2)	Pheasant Branch at Middleton (station 05427948, drainage area 18.3 mi^2)	Pheasant Branch at Century Avenue (station 05427950, drainage area 20.8 mi^2)	Pheasant Branch at mouth (station 05427952, drainage area 24.5 mi^2)
1978	3,478	734	6,424	6,351	5,877
1979	358	569	606	518	723
1980	555	661	1,099	1,077	1,215
1981	—	—	1,774	2,237	1,059
Total	—	—	9,903	10,183	8,874

1978, when the South Fork contributed almost five times as much suspended sediment as the North Fork. Downstream from Pheasant Branch at Middleton, the lower reach sometimes is a sediment source as shown in the increase in load for 1981 for the station at Century Avenue. The reach between these two gages has a very steep gradient and active bank erosion, and it was thought to be a large contributor of sediment, but which was apparent only in 1981. Pheasant Branch Marsh, as reflected by the data from the station at the mouth, can be a sediment trap in some years (1978, 1981) and a source in other years (1979, 1980). The trapping of sediment in Pheasant Branch Marsh, which includes the area between the Century Avenue station and the station at the mouth, averaged 13 percent of the sediment load for the monitoring period.

Spatial Variability of Suspended Sediment in Pheasant Branch in 2008

To evaluate spatial changes in sediment characteristics of South Fork Pheasant Branch, North Fork Pheasant Branch, and Pheasant Branch downstream from the Confluence Pond to the mouth at Lake Mendota, suspended sediment was sampled in 2008 at multiple sites and particle size distribution was analyzed. Representative samples were obtained by use of a depth-integrating suspended-sediment sampler and “equal-width-increment” (EWI) methods (Edwards and Glysson, 1999). These procedures generate a representative cross-sectional sample that is both flow-weighted and depth- and width-integrated. Discharge was measured to determine flow at the time of the sample. Samples were collected at five sites on Pheasant Branch:

1. North Fork Pheasant Branch immediately upstream from the Confluence Pond (culvert at foot trail crossing, station 054279435);
2. South Fork Pheasant Branch upstream from the Confluence Pond at Deming Way bridge (station 054279465);
3. Pheasant Branch at Middleton (station 05427948; high flows were collected at the trail foot bridge adjacent to new Highway 12 downstream of the Confluence Pond);
4. Pheasant Branch at trail footbridge downstream from Century Avenue and upstream from marsh (station 054279501);
5. Pheasant Branch at Mouth (trail footbridge near the mouth with Lake Mendota, upstream from Century Avenue, station 05427952).

Synoptic samples were collected at the above five sites, from upstream to downstream, over three different flow ranges (measured at the gaging station) to represent:

- lower flows (about 10–20 ft^3/s),
- medium flows (about 20–50 ft^3/s) and
- higher flows (greater than 100 ft^3/s).

Samplings were repeated for three different events during the season. This sampling schedule yielded nine samples at each site.

Water samples from all five sites were analyzed for suspended-sediment concentration and particle-size distribution, as a percentage finer than 0.0625 millimeters (mm; sand/fines particle-size break). Additional particle-size distribution analysis for percentage finer than 0.004 mm (clay/silt break) was done for samples from the downstream three sites (3–5 above) if sufficient sediment was present.

Although suspended-sediment data collected in 2008 at the five sites along Pheasant Branch are too few to calculate loads, the data indicate that concentrations and particle sizes have changed from earlier data. The greatest concentrations of suspended sediment were during high discharges, and concentrations from South Fork Pheasant Branch were greater than those from North Fork Pheasant Branch the majority of times. Concentrations at the Pheasant Branch at Middleton gaging station were lower than those of both forks, reflecting the removal of sediment by the Confluence Pond upstream from the gaging station. Suspended-sediment particle-size distribution at the Pheasant Branch at Middleton gaging station and at North and South Fork Pheasant Branch tributaries upstream from the Confluence Pond (table 7) was predominantly (generally 86–99 percent) less than sand size (0.0625 mm), similar to data collected previously during 1978–81 (U.S. Geological Survey, 1979–81). At site 4, downstream of Century Avenue and upstream from the marsh, however, suspended sediment finer than sand ranged from 10 to 99 percent. The sample collected at site 4 on April 11, 2008, after peak flow at a discharge of 324 ft^3/s and concentration of 3,040 milligrams per liter (mg/L), is noteworthy, because only 10 percent was finer than sand (90 percent was sand). Peak discharge for that event occurred at 2:00 a.m. and was about 620 ft^3/s. Results for some events are difficult to interpret, because time of sampling varied with travel time of water. Previous samples collected at site 4, downstream of Century Avenue and upstream from the marsh, during 1979–81 had sediment finer than sand ranging from 56 to 100 percent, over a range of discharges from 34 to 286 ft^3/s and concentrations from 435 to 1,450 mg/L. The lowest percentage, 56 percent, was on Sept.1, 1981, at a discharge of 286 ft^3/s and a concentration of 868 mg/L.

Almost all sources of sand in the lower reach downstream of the Pheasant Branch at Middleton station are from the sloughing of sand bluffs and erosion of channel banks in the reach. The author made the following observations from inspections of the reach from the gaging station to the marsh over the past 15 years:

1. erosion and sloughing of high sand bluffs adjacent to and undercut by the creek has accelerated with the increased frequency and magnitude of flood events since 1993, and
2. deposition of sand in the channel reach upstream of the marsh has filled and widened the channel and created a delta deposit with a braided channel where it enters the marsh (fig. 19).

Specific Conductance and Chloride Monitoring, 2007–8

"Road salt," usually sodium chloride, commonly used to deice roads in winter, is highly soluble, and moves easily through soils into water bodies or streams. A recent study of the effects of road deicing salt on water quality (Corsi and others, 2010) found that when the snow melts in urban areas where large amounts of salt are used on roads, chloride concentrations can rapidly rise to levels that may be toxic to aquatic life (Corsi and others, 2010). The authors of the study found that maximum chloride concentrations in many Milwaukee streams exceeded several thousand milligrams per liter. Samples from 7 of 13 Milwaukee area streams during two road salt runoff events exhibited toxicity to aquatic life and had chloride concentrations up to about 7,000 mg/L. The U.S. Environmental Protection Agency (EPA, U.S. Environmental Protection Agency, 1988) water-quality criteria for chloride are 230 milligrams per liter (mg/L) for chronic long-term exposure of aquatic animals (4-day average) and 860 mg/L for the acute short term. Corsi and others (2010) evaluated chloride-concentration estimates in 11 watersheds where urban land use ranged from 6 to 100 percent. Specific conductance was elevated during cold-weather months at all sites, and it remained somewhat elevated during warm-weather months at the urban land-use sites where the largest amounts of road deicing salt were applied. Estimated chloride concentrations exceeded the EPA acute (860 mg/L) and chronic (230 mg/L) water-quality criteria at 55 and 100 percent of the sites, respectively.

Table 7. Summary of suspended-sediment data collected at five U.S. Geological Survey stations on Pheasant Branch in Middleton, Wis., during 2008.

[Date is shown by year, month, and day. ft^3/s, cubic feet per second; <, less than; mm, millimeters; mg/L, milligrams per liter; streamflow conditions are represented by the colors noted below]

🟦 Lower streamflow
🟨 Medium streamflow
🟧 Higher streamflow

Station 54279435
North Fork Pheasant Branch west of Confluence Pond

Date	Time	Discharge (ft^3/s)	Percentage of suspended-sediment particle size <0.0625 mm	Suspended-sediment concentration (mg/L)
20080313	0850	🟦 5.2	70	22
20080314	1715	🟨 30	86	19
20080401	1230	🟦 10	95	10
20080409	0715	🟨 19	98	86
20080411	0645	🟧 110	99	301
20080425	0745	🟧 120	100	754
20080708	0640	🟨 15	97	39
20080711	0630	🟧 89	99	110
20080804	0835	🟦 8.3	92	4

Station 54279465
South Fork Pheasant Branch at Deming Way

Date	Time	Discharge (ft^3/s)	Percentage of suspended-sediment particle size <0.0625 mm	Suspended-sediment concentration (mg/L)
20080313	0925	🟦 1.8	93	42
20080314	1800	🟨 8.3	98	57
20080401	1305	🟦 6.3	98	44
20080409	0755	🟨 16	96	83
20080411	0615	🟧 99	98	240
20080425	0705	🟧 134	98	205
20080708	0710	🟨 25	91	116
20080711	0705	🟧 249	89	226
20080804	0900	🟦 1.3	98	24

Station 5427948
Pheasant Branch at Middleton

Date	Time	Discharge (ft^3/s)	Percentage of suspended-sediment particle size <0.0625 mm	Suspended-sediment concentration (mg/L)
20080313	1000	🟦 11	95	13
20080314	1825	🟨 41	97	40
20080401	1335	🟦 27	97	27
20080409	0825	🟨 51	98	71
20080411	0750	🟧 262	93	228
20080425	0845	🟧 272	94	149
20080708	0735	🟨 46	99	65
20080711	0745	🟧 403	86	160
20080804	0930	🟦 20	96	14

Station 54279501
Pheasant Branch upstream from marsh

Date	Time	Discharge (ft^3/s)	Percentage of suspended-sediment particle size <0.0625 mm	Suspended-sediment concentration (mg/L)
20080313	1035	🟦 11	99	50
20080314	1850	🟨 45	95	59
20080401	1410	🟦 27	96	32
20080409	0855	🟨 58	91	111
20080411	0925	🟧 324	10	3040
20080425	0935	🟧 336	67	346
20080708	0800	🟨 46	70	125
20080711	0910	🟧 393	78	373
20080804	0950	🟦 20	86	55

Station 5427952
Pheasant Branch at mouth

Date	Time	Discharge (ft^3/s)	Percentage of suspended-sediment particle size <0.0625 mm	Suspended-sediment concentration (mg/L)
20080313	1130	🟦 17	94	41
20080314	1925	🟨 77	75	38
20080401	1505	🟦 44	98	15
20080409	0930	🟨 69	97	49
20080411	1050	🟧 364	88	158
20080425	1045	🟧 276	94	110
20080708	0830	🟨 72	79	41
20080711	0955	🟧 284	48	185
20080804	1020	🟦 28	79	10

Figure 19. Pheasant Branch upstream from marsh showing sand deposition, channel widening, and overflow channels entering marsh. (Photo by H.S. Garn)

Generally, elevated chloride concentrations exceeding chronic effect levels were widespread in urban areas of the Midwest and Northeast (Mullaney and others, 2009).

To evaluate the effect of road deicing salt on stream water quality in the Pheasant Branch watershed, specific conductance and chloride were monitored during two winter seasons. Continuous specific conductance monitoring and stream water sampling to determine chloride concentrations were conducted from February 2007 through April 2008 at the Pheasant Branch at Middleton gaging station. In 2007, 16 water samples were collected for chloride analysis and 10 were collected in 2008. These data were then used to develop a regression model to estimate continuous concentrations of chloride and compute daily chloride loads (Rasmussen and others, 2008) of Pheasant Branch for the monitoring period. Analytical results from concurrent analysis of chloride and specific conductance were used to determine the relation between specific conductance and chloride concentration. Regression of sampling data resulted in an $R^2 = 0.927$ to estimate chloride concentrations (fig. 20). Time-weighted adjustments were also applied to the estimated concentrations during some periods to better-fit measured concentrations from measurement to measurement.

The measured and estimated chloride concentrations of Pheasant Branch during the two winter seasons are shown in figure 21. The maximum estimated concentration of chloride during the monitoring period was 931 mg/L on March 1, 2007, and it exceeded the EPA acute criterion of 860 mg/L. Chloride concentrations exceeded the EPA chronic criterion of 230 mg/L for at least 10 days during February and March 2007 and for 45 days from December to the first week in April during the 2007–8 winter season. The maximum concentration in 2008 reached 680 mg/L twice during February. These high concentrations of chloride occurred in spite of the attenuating effect of the Confluence Pond about 0.3 miles upstream from the gaging station. Following the winter peaks, concentrations of chloride remained elevated above background concentration through April, long after all snow had melted. Chloride concentrations during the summer generally were about 50–100 mg/L, which may still be elevated above natural background concentrations. The average chloride concentration for the

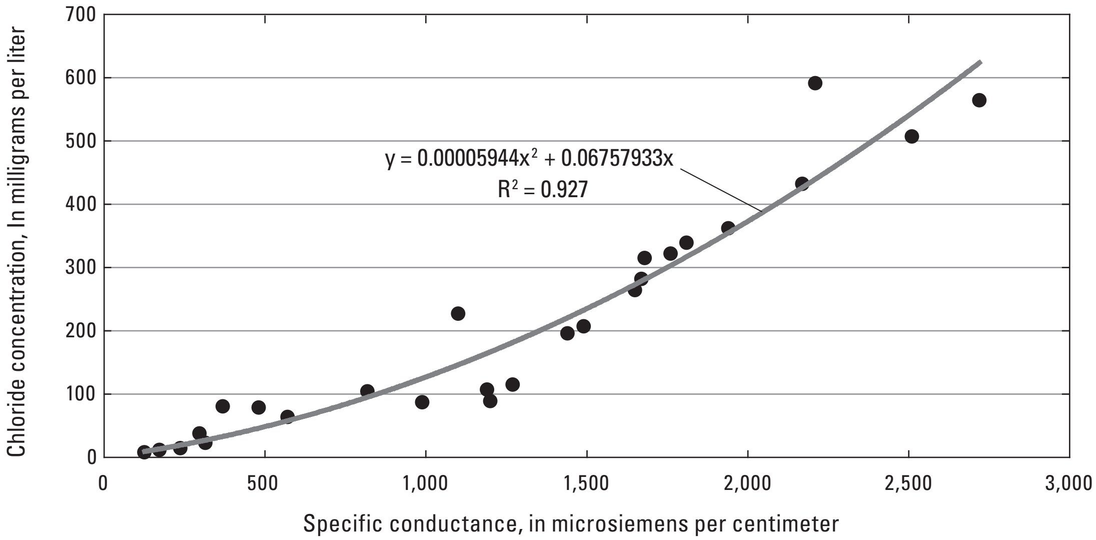

Figure 20. Regression relation of specific conductance and chloride concentration at Pheasant Branch at Middleton, Wis. (station 05427948).

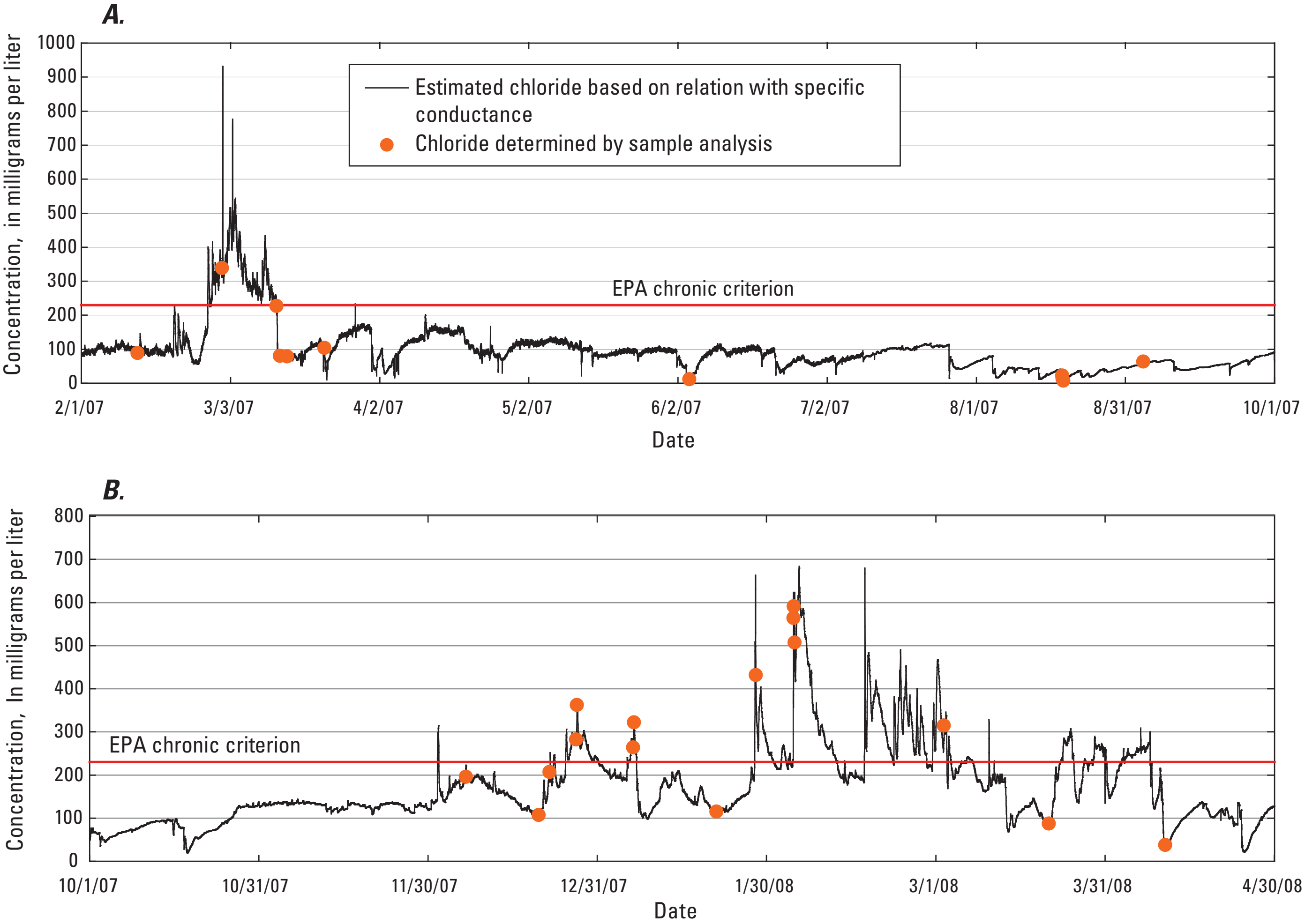

Figure 21. Measured and estimated chloride concentrations of Pheasant Branch at Middleton, Wis. (station 05427948) during February through September 2007 (A) and October 2007 through April 2008 (B). (EPA, U.S. Environmental Protection Agency)

entire monitoring period was 137 mg/L and the median was 118 mg/L. Chloride concentrations during 1977 generally ranged from about 15–25 mg/L (U.S. Geological Survey, 1978), which may be more representative of natural background concentrations.

Peak concentrations of chloride during the winter usually occurred during times of low flow, when air temperatures warmed enough to melt snow and ice on the roads, or when a light rain was sufficient to wash salt into the storm sewers; however, overall melting or rainfall did not increase runoff enough to dilute the salt. An example of this situation occurred during February 17–24, 2008 (fig. 21). Thirteen inches of snow fell on February 17, initiating road salt application. Runoff associated with a light rain at the beginning of the storm caused a peak specific conductance of 2,860 microsiemens per centimeter (µS/cm; 680 mg/L chloride). Warm afternoons on following days (February 22–24) melted snow on roadways and caused corresponding peaks in specific conductance greater than 2,000 µS/cm (370 mg/L chloride). During this time, streamflow was at baseflow, about 2.5 ft^3/s, and it never exceeded 6 ft^3/s. Diurnal peaks in chloride concentration can occur over several days during a winter when conditions include the right combination of snow on roads and midday temperatures above freezing. The small runoff events produce the highest concentration of chloride in the stream; in contrast, during large runoff events caused by extended periods of melting snow or heavy rains, the salt content in the stream is diluted and decreases with increasing flow.

Daily chloride loads were computed from the estimated continuous concentration data for the period of record (figure 22) and were summed as monthly loads expressed as chloride and salt (NaCl), assuming that all the chloride

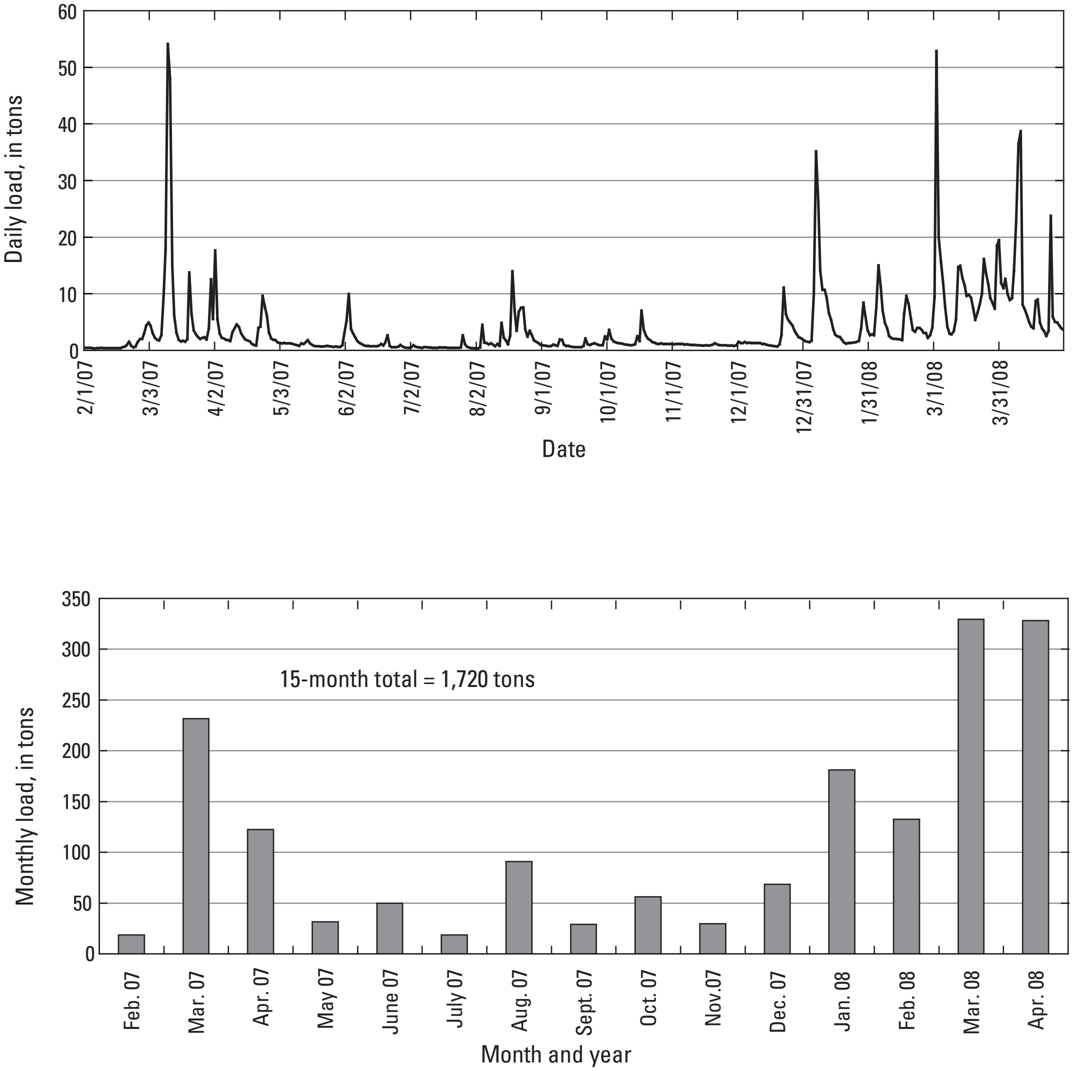

Figure 22. Daily and monthly salt loads, expressed as sodium chloride, at Pheasant Branch at Middleton, Wis. (station 05427948) for February 2007–April 2008.

originally dissociated from NaCl. The monthly loads from February 2007 through April 2008 are summarized in table 8, and the total load for that period was 1,720 tons of salt. The greatest chloride and salt loads were in March and April of each year. Daily salt loads exceeded 20 tons per day five times during the monitoring period (fig. 22).

Middleton uses a recommended road deicing salt application rate of 300 lbs. per lane mile and used 2,068 tons of salt during the record snowfall season of 2007–8 (T. Ginder, City of Middleton, Director of Public Works, written commun., 2009). In the 2008–9 season, Middleton used a more normal 1,346 tons of salt. In comparison, the Madison Streets Division utilizes a salt application rate of 150 lbs. per lane mile (City of Madison, 2006), and Madison applies a calcium chloride solution as the prewetting agent and a sand abrasive that includes 20 percent salt. Deicing salt is also applied to sidewalks, driveways, and parking lots on commercial and residential private property. Many commercial property owners hire private contractors who apply salt to the parking lots many times (up to 20–30 times) each winter. In a Madison survey, salt application rates to parking lots ranged from about 0.14 to 0.30 tons per acre for each application (City of Madison, 2006). Thus, total salt usage in Middleton is likely much greater than just the road salt applications.

Table 8. Summary of monthly chloride and sodium chloride loads at Pheasant Branch at Middleton, Wis. (station 05427948) for February 2007–April 2008.

Date	Chloride load (tons)	Sodium chloride load (tons)
Feb. 2007	11.38	18.8
Mar. 2007	140.56	231.7
Apr. 2007	74.22	122.4
May 2007	19.18	31.6
June 2007	30.19	49.8
July 2007	11.31	18.7
Aug. 2007	55.07	90.8
Sept. 2007	17.59	29.0
Oct. 2007	34.15	56.3
Nov.2007	17.91	29.5
Dec. 2007	41.48	68.4
Jan. 2008	109.93	181.2
Feb. 2008	80.42	132.6
Mar. 2008	199.80	329.4
Apr. 2008	199.18	328.4
Feb. 2007–Apr. 2008	1,042.4	1,718.5
May 2007– Apr. 2008	816.2	1,345.6

Discussion and Conclusions

Streamflow and water-quality characteristics for Pheasant Branch changed were influenced substantially by urbanization, stormwater-management practices, and increased precipitation during the 1975–2008 study period. During 1975–2008, the Pheasant Branch watershed experienced considerable urban growth and increases in impervious area, expansion of the watershed that connected previously noncontributing areas, and implementation of over 100 BMPs in Middleton and Madison. Coincidentally, 1975–2008 was a period with increasing annual precipitation and streamflow.

For the study period, the average annual streamflow was determined to be 5.19 ft^3/s and the average annual baseflow was 3.71 ft^3/s. The average annual streamflow increased by 62 percent since 1992, likely as the result of increased impervious area, enlarged surface drainage area on the South Fork Pheasant Branch, and increased precipitation. The average annual baseflow also increased, but not as the result of the enlarged drainage area on South Fork Pheasant Branch, because it lacks baseflow. A negative aspect of urbanization in many areas is decreased recharge to the groundwater system due to increased impervious area. The increase in baseflow in Pheasant Branch, however, indicates that the BMPs were beneficial for maintaining baseflow.

The annual flood peaks also increased during the study period. The 100-year flood peak discharge was determined to be 1,510 ft^3/s for the period 1975–2008. Comparing flood frequency values for the period 1975–91 to the values for the period 1992–2008, the flood peak discharges for Pheasant Branch increased by 37 percent for the 2-year recurrence interval and by 83 percent for the 100-year recurrence interval.

A comparison with an adjacent stream for the same period Black Earth Creek at Black Earth, a mainly rural stream, had increases in flood peak discharges for the 2- to 100 year recurrence intervals from 43 to 140 percent. Thus the increase in flood peak discharge for Pheasant Branch appear to be the result of increased precipitation and urbanization. The comparison with Black Earth Creek indicates that the storm water management practices have been effective in mitigating the effect of urbanization, which generally result in increased flood peaks , because Pheasant Branch had less increase in flood peak discharge for all recurrence intervals.

The stormwater-management practices have succeeded in decreasing the average annual sediment load and phosphorus load to Lake Mendota. These loads decreased in spite of increasing annual runoff and flood peaks, which would normally produce higher sediment and phosphorus loads. The biggest decreases in sediment and phosphorus loads have occurred since 2001, when the Confluence Pond began operation. Since 2002, the annual sediment load has decreased 45 percent, from 2,650 ton/yr to 1,450 ton/yr, and the annual phosphorus load has decreased 48 percent, from 12,200 lb/yr to 6,300 lb/yr. A comparison with other streams that drain into Lake Mendota and have sediment and phosphorus data show that Spring Harbor Storm Sewer had an 11-percent decrease in annual sediment load, and Yahara River at Windsor had an 18-percent decrease in annual sediment load and a 2.5-percent decrease in annual phosphorus load. Prior to the construction of the Confluence Pond, Pheasant Branch had the highest annual sediment yield and highest phosphorus yield. During 2002–8, Spring Harbor Storm Sewer had the highest sediment yield, and Yahara River, the only other stream that has phosphorus data, had a higher phosphorus yield than Pheasant Branch.

The Storm Water Quality Plan prepared for the City of Middleton by MSA Professional Services (2007) shows that Middleton has met the NR 156 requirement of reducing total suspended solids by 20 percent for the developed area in Middleton. In addition, the city has already met the 40-percent reduction in total suspended solids required by 2013 and has several alternatives for consideration for further reducing total suspended solids.

Salt usage by the City of Middleton for winter deicing of roads can result in concentrations of chloride in Pheasant Branch that are toxic to aquatic life. Chloride concentrations exceeded the EPA chronic criterion of 230 mg/L many days during the winter of 2007 and 2008. Because of the solubility of salt, the primary mitigation measure is to reduce salt usage by using substitutes and improving application techniques.

Future water-resource-management issues that Middleton may consider addressing as urbanization increases are:

1. finding ways to decrease the dissolved-phosphorus load that may be contributed by rural areas and is not trapped by the Confluence Pond;
2. determining how to mitigate the increase in the 100-year flood discharges that are the result of urbanization;
3. evaluating if the current flood plain accurately describes the 100-year flood plain commensurate with the higher 100-year flood peak; and
4. evaluating how increases in flood peaks and average annual streamflow have impacted channel erosion in various reaches of Pheasant Branch.

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Appendixes 1 and 2

Appendix 1. Storm Water Runoff Control Ordinance Summary (from City of Middleton Storm Water Control Ordinance, chap 26.0, June 2008)

Storm Water Discharge Quality.

Land-development activities subject to this ordinance shall establish on-site management practices to control the quality of storm water discharged from the site and shall meet the following minimum standards:

Sediment Control.

1. For new development, practices shall be designed to reduce by 80 percent the total suspended solids load within storm water runoff based on the average annual rainfall record, as compared to no runoff management controls.
2. For redevelopment, practices shall be designed to reduce by 40 percent the total suspended solids load within storm water runoff based on the average annual rainfall record, as compared to no runoff management controls.

Storm Water Discharge Quantity.

Land-development activities subject to this ordinance shall establish on-site management practices to control the volume and peak discharge rates of storm water runoff leaving the site. On-site management practices shall meet the following minimum performance standards:

Runoff Rate Control.

1. For new development, storm water management practices shall be designed and implemented to maintain post-development peak runoff discharge rates for the 1, 2, 5, 10, 25, and 100-year 24-hour design storms so as not to exceed those rates for each respective design storm under predevelopment conditions.
2. For redevelopment, storm water management practices shall be designed and implemented to maintain post-development peak runoff discharge rates for the 1, 2, 5, and 10- year, 24-hour design storms under predevelopment conditions, so as not to exceed those rates for each respective design storm under predevelopment conditions.

Infiltration.

New residential and nonresidential developments must implement storm water management practices designed to meet the following standards:

1. Infiltration—Residential Development. For residential development, practices shall be designed so that the post-development infiltration volume is at least 90 percent of the average annual predevelopment infiltration volume and/or the effective infiltration area comprise at least 1percent of the site, whichever is less.
2. Infiltration—Nonresidential Development. For nonresidential development, practices shall be designed so that the post-development infiltration volume is at least 60percent of the average annual predevelopment infiltration volume and/or the effective infiltration area comprise at least 2percent of the site, whichever is less.
3. Groundwater Recharge—All Development. In addition, infiltration systems and pervious surfaces for both residential and nonresidential development shall be designed to meet or exceed the estimated average annual groundwater recharge rate of at least 7.6 inches per year, regardless of the effective area of the infiltration system.

Appendix 2. Erosion Control Summary (from City of Middleton Erosion Control Ordinance, chap. 28, June 2008)

28.03 Purpose.

The purpose of this Ordinance is to conserve the soil and related resources and control erosion and sedimentation and thereby to preserve the natural resources, protect the quality of public waters, preserve wildlife, prevent impairment of dams and reservoirs, protect the tax base, and promote the health, safety, prosperity, and general welfare of the citizens of the City of Middleton.

28.05 Requirements for Erosion Control Plan.

Any person who proposes to engage in any land disturbing activities subject to this Ordinance as provided in section 28.04 shall be required to submit to the City an Erosion Control Plan. The design of all best management practices used in an erosion control plan under this ordinance shall comply with the following technical standards:

a) Natural Resources Conservation services “Field Office Technical Guide, Chapter 4” or its successor;

b) Wisconsin Department of Natural Resources “Wisconsin Construction Site Best Management Practice Handbook” or its successor;

Any other technical methodology approved by the City Engineer and the Dane County Conservationist.

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