Urbanization and Recharge in the Vicinity of East Meadow Brook, Nassau County, New York

Part 4—Water Quality in the Headwaters Area, 1988-93

By Craig J. Brown, Michael P. Scorca, Glenda G. Stockar,
Frederick Stumm, and Henry F. H. Ku

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CONVERSION FACTORS, ABBREVIATIONS AND VERTICAL DATUM

Multiply	By	To Obtain
	Length	
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
	Area	
hectare (ha)	2.471	acre
	Flow	
liters per second (L/s)	0.03531	cubic feet per second

Chemical concentration

milligrams per liter (mg/L)
milliequivalents per liter (meq/L)

Specific conductance

microsiemens per centimeter at 25 degrees Celsius (µS/cm)

Other abbreviations used

minute (min)
less than (<)

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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Abstract

Surface-water and ground-water quality in the East Meadow Brook headwaters area was monitored during 1988-93 to determine the effects of urban stormwater on water quality before, and for 1 year after, the construction of a stormwater-detention basin in 1992. Stormwater samples were collected from the stream during storms. Between storms, water samples were collected from the stream and from a network of monitoring wells in the headwaters area. The detention basin was constructed as part of a pilot project to increase aquifer recharge while decreasing the discharge of contaminated stormwater to coastal waters.

Bacteria and road salt were the major contaminants detected in stormwater samples, and the concentrations of organic compounds and nutrients in the samples rarely exceeded New York State drinking-water standards. Lead and chromium were detected in only a few of the stormwater samples, and cadmium was not detected in any of the samples.

Loads of most inorganic constituents in stormwater reflected the season and the magnitude of the storm and were proportional to the total stormwater volume measured at the headwaters area. Stormwater during the non-winter (non-road-salting) season had a diluting effect on shallow ground water adjacent to the stream.

Large amounts of sodium and chloride that entered the stream and ground water after road-salt applications to the Westbury drainage area affected the ground-water quality beneath and adjacent to the stream for several months. Concentrations of sodium and chloride in streamwater on March 6, 1989, reached 1,700 mg/L (milligrams per liter) and 2,700 mg/L, respectively, as a result of road salt washed in by stormwater. Median concentrations of sodium and chloride in wells in an area affected by road salt were generally several times higher than concentrations in shallow wells in unaffected suburban areas. Bromide-to-chloride ratios were used to distinguish road salt from atmospherically derived sea salt within the shallow aquifer and indicated that ground water was affected by road salt to a depth of 14 meters.

INTRODUCTION

The widespread urbanization of Nassau County since the 1950's has resulted in a decrease in ground-water levels (Franke, 1968) and in the base flow of streams (Pluhowski and Spinello, 1978). These decreases have resulted from the loss of recharge through (1) sanitary sewers, which do not return pumped water to the aquifer system, but discharge it to sewage-treatment plants and from there to coastal waters, and (2) storm sewers, which intercept stormwater from impervious (paved) surfaces and divert it to streams that discharge to coastal waters (Simmons and Reynolds, 1982; Ku and others, 1992).

Shallow ground water in urbanized parts of Nassau County has much higher concentrations of chemical constituents and bacteria than ground water in unsewered and rural areas of Long Island (Eckhardt and others, 1989; Stackelberg, 1995); the major contaminants are road-deicing salt (NaCl), nitrate, and coliform bacteria. Stormwater from urbanized areas of Nassau County contains many of these contaminants, especially coliform bacteria which are derived largely from dog and waterfowl waste; these bacteria (and other constituents) can enter the water-table aquifer and the south-shore bays from stormwater that enters recharge basins or streams. Several closures of coastal areas to shellfishing along Long Island's southern shore have resulted from contamination by streamborne bacteria (Koppelman, 1978).

East Meadow Brook (fig. 1), the longest stream in Nassau County, flows 12 km southward through south-central Nassau County. Stormwater that originates in the Westbury drainage area (fig. 1) discharges into the stream channel through culverts at the headwaters, about 550 m north of Charles Lindbergh Blvd. (fig. 2). Stormwater that enters the stream channel either infiltrates to the water table or discharges as streamflow to south-shore bays, depending on whether the reach is under gaining or losing conditions, as explained further on.

Many of Long Island's south-shore stream channels, including East Meadow Brook, are used for disposal of stormwater, which has become a major source of bacterial loading in Great South Bay. Federal grants issued by the U.S. Environmental Protection Agency (USEPA) to construct sanitary sewers and sewage-treatment plants in Nassau County contained a condition that the County would study the effect of the sewers on the ground-water system. In response, the Nassau County Department of Public Works (NCDPW) in the 1980's studied the environmental effects of decreased streamflow and developed methods to augment streamflow at selected south-shore streams and to protect the freshwater environment. The study included construction of a 2.8-ha stormwater-detention basin in 1992 in the headwaters area of East Meadow Brook and a series of check dams downstream to increase ground-water recharge and thereby attenuate the discharge of contaminants to south-shore bays. During 1988-93, the U.S. Geological Survey (USGS), in cooperation with the NCDPW, studied the effects of stormwater on water quality at the headwaters of East Meadow Brook, as a part of the Nassau County Streams and Wetlands Area Management Program (SWAMP).

The study was divided into four parts and includes (1) long-term changes in regional hydrologic conditions near the stream (Scorca, 1997), (2) the response of streamflow to urban runoff and the percentage of streamflow that recharges the local ground-water system during storms at the headwaters site (Stumm and Ku, in press), (3) ground-water levels and flow conditions in the headwaters area before basin construction and during the first year thereafter (Scorca and Ku, 1997), and (4) surface-water and ground-water quality at the headwaters site (this report).

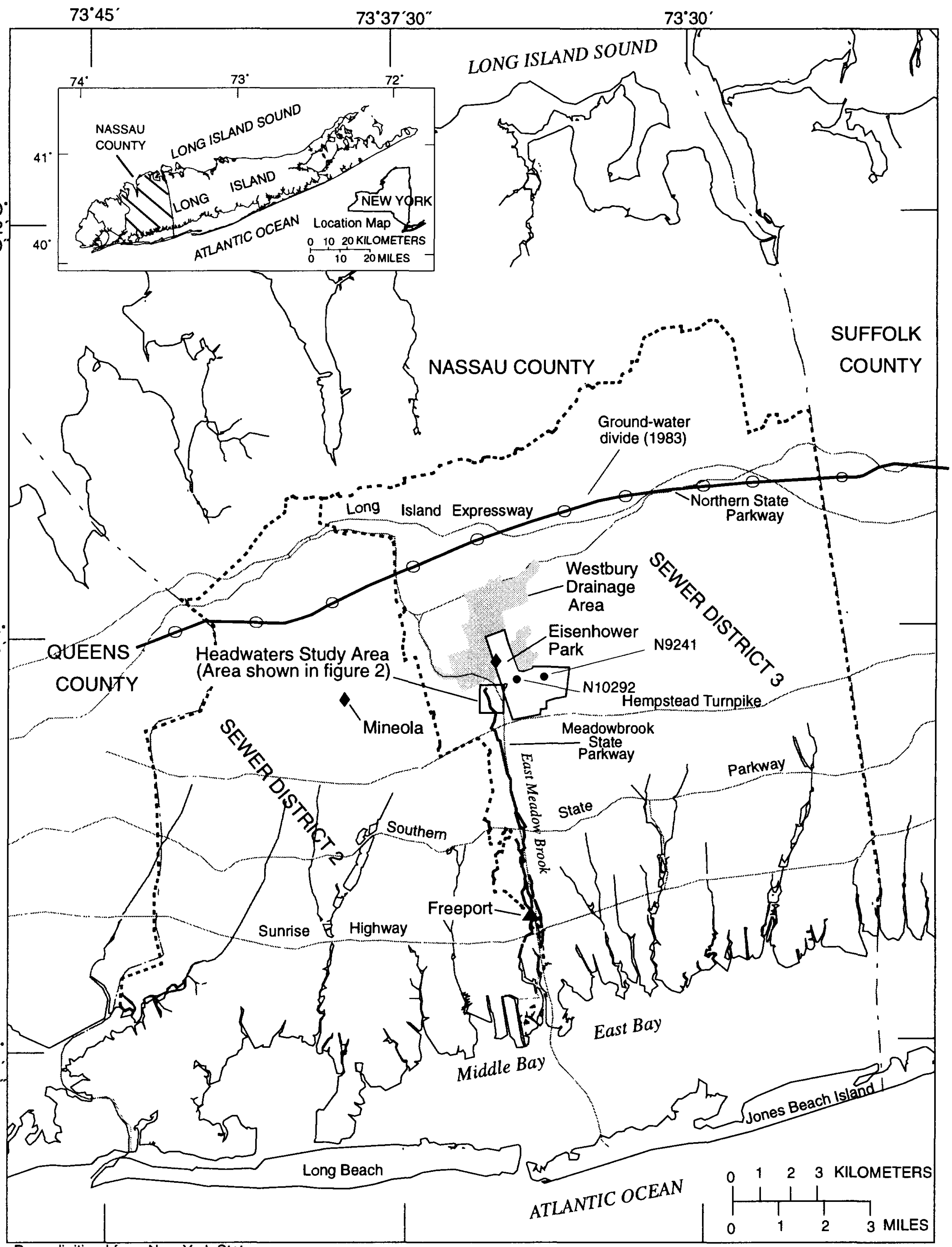
The water-quality phase of the program investigated surface-water and ground-water quality in the East Meadow Brook headwaters area before construction of the basin and for 1 year thereafter, and data on the chemical interactions between stormwater and ground water were used to assess the effects of these stream-channel modifications on local ground-water quality.

Purpose and Scope

This report (1) discusses the concentrations of constituents in precipitation and stormwater in the headwaters area of East Meadow Brook, and (2) describes the extent, and depth to which ground water beneath the stream is affected by stormwater. It also relates the concentrations and loads of selected constituents, including sodium and chloride, to storm discharge and season. This is the final report from the four-part study that examined stormwater and ground water at East Meadow Brook during 1988-93.

Location of Study Area

East Meadow Brook lies near the western edge of Sewer District 3, which was sewered from 1974 to 1988, and just east of Sewer District 2, which has been sewered since 1964 (fig. 1). The study area consists of a 3.6-ha strip of County-owned land just north of Charles Lindbergh Boulevard (fig. 2); it lies between Nassau County Community College to the west and the Meadowbrook Parkway to the east. A network of interconnected stormwater sewers drains stormwater from roads in part of the Village of Westbury (fig. 1), just north of the study area, and discharges into the head of the stream through culverts at the northern end of the site. The channel length in the study area was about 460 m. The stormwater-detention basin (fig. 2), constructed in 1992, is about 412 m long by 88 m wide.



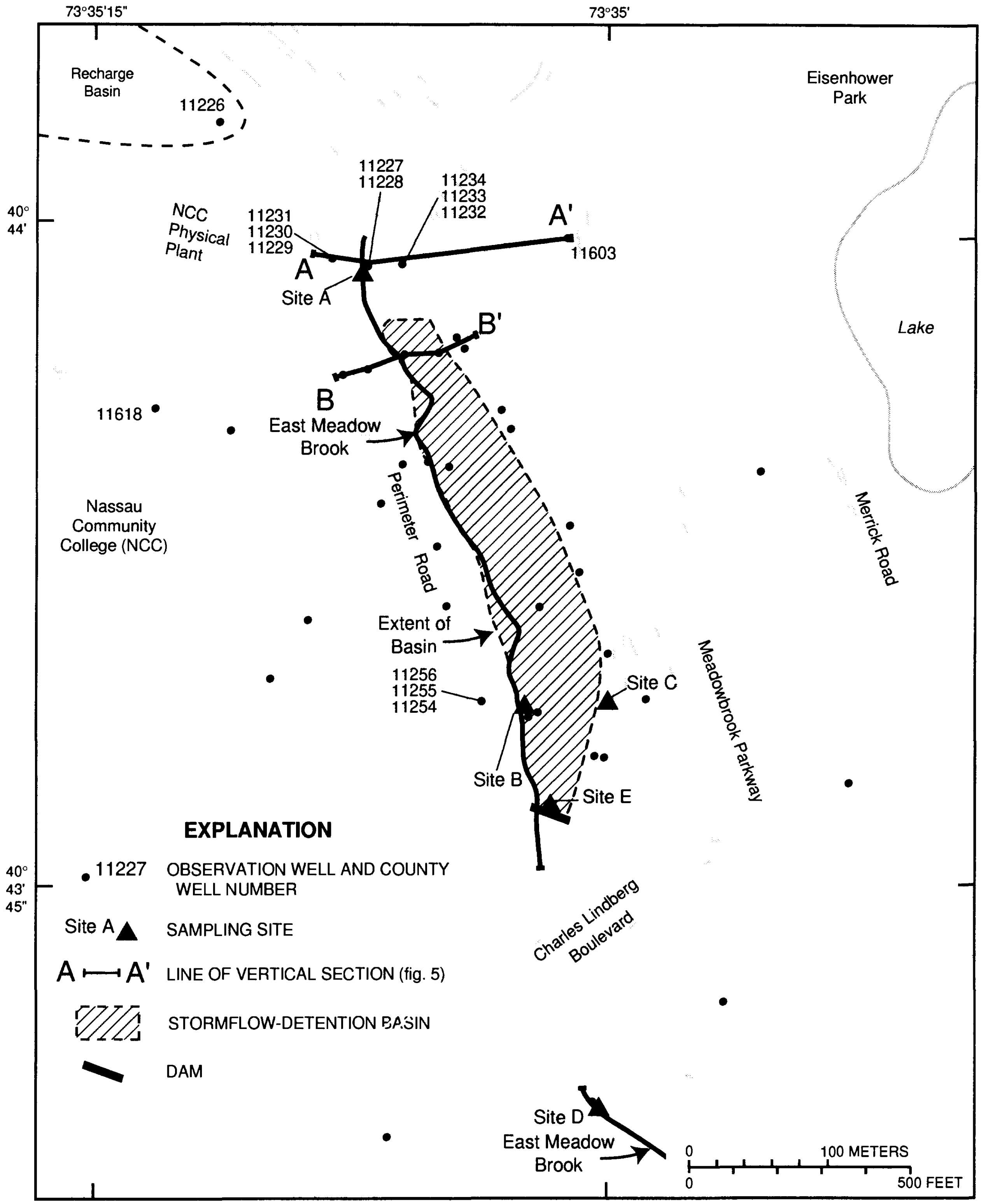
Base digitized from New York State Department of Transportation, 1981, 1:24,000

EXPLANATION

◆ Streamflow-gaging station ▲ Precipitation station • Well location

------- Sewer-district boundary — · — · — County border

Figure 1. Location of East Meadow Brook and selected data-collection sites in Nassau County, N.Y.



Base from aerial photo, 1:24,000 scale

Figure 2. Location of sampling sites in the East Meadow Brook headwaters area, Nassau County, N.Y., before construction of stormwater-detention basin.

Previous Studies

A comprehensive study of the hydrologic effects of urbanization on East Meadow Brook is described by Seaburn (1969). Other reports that describe Long Island's south-shore streams include an analysis of Foster's Brook (8 km to the west in western Nassau County) by Prince (1984) and of Connetquot Brook (33 km to the east in Suffolk County) by Prince and others (1989).

Koppelman (1978) and Koppelman and Tanenbaum (1982) found that nitrogen was among the major contaminants in runoff from highways, medium- and high-density residential areas, and commercial/industrial areas, and observed, during the Nationwide Urban Runoff Program (NURP) study, that the stormwater loading of nitrogen species was affected more by rainfall characteristics of individual storms than by seasonal conditions, whereas chloride loads varied seasonally and increased significantly after road-salt applications during the winter. Ku and Simmons (1986) examined the chemical quality of urban runoff that discharged to streams and recharge basins on Long Island. Schoonen and others (1995) used chloride-to-bromide ratios to distinguish the chloride derived from halite (road salt) from chloride derived from precipitation.

Several investigations, as part of this study, have examined related aspects of East Meadow Brook. Scorca (1997) studied long-term changes in hydrologic conditions along the entire stream. Stumm and Ku (in press) examined the response of streamflow to urban runoff and calculated the percentage of stormflow that infiltrates to the aquifer through the streambed during storms in the headwaters area. Scorca and Ku (1997) described fluctuations of ground-water levels in the headwaters area. Stockar (1994) studied the sources and fate of nitrogen and chloride in urban runoff in the headwaters area. Brown and Scorca (1995) studied the effects of road salt on stormwater and ground-water quality in the headwaters area.

Acknowledgments

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DESCRIPTION OF STUDY AREA

Hydrogeologic Setting

Long Island is underlain by unconsolidated sediments of Late Cretaceous to Quaternary age that overlie a southeastward-dipping bedrock surface (fig. 3). The hydrogeologic setting of Nassau County has been described in detail by Suter and others (1949), Perlmutter and Geraghty (1963), Ku and others (1975), and Smolensky and others (1989).

Upper Pleistocene deposits in the study area range from 15 to 30 m in thickness. The saturated part of these deposits forms the upper glacial (water table) aquifer throughout the study area. These deposits are highly permeable; horizontal hydraulic conductivity

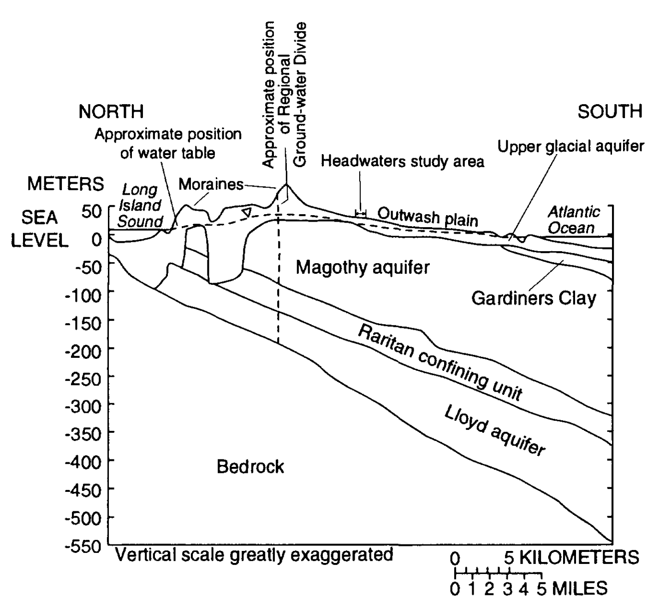

Figure 3. Generalized hydrogeologic section through Nassau County, N.Y., showing hydrogeologic units. (Modified from Smolensky and others, 1989, sheet 1.)

averages 82 m/d, and the anisotropy (ratio of vertical to horizontal conductivity) is about 10:1 (Smolensky and others, 1989). Silt and clay lenses of low hydraulic conductivity are present locally. The local subsurface lithology in the headwaters area is described by Scorca and Ku (1997) and soils in the region surrounding the headwaters are described by Stumm and Ku (in press). The topographic drainage basin of East Meadow Brook is underlain by alluvial and glacial-outwash deposits that consist largely of Holocene alluvium and upper Pleistocene outwash sand with some silt and clay lenses.

Precipitation Volume

Mean annual precipitation on Long Island ranges from slightly more than 104 cm on the southern shore of Nassau County to slightly more than 127 cm in the central part of the island; the islandwide long-term mean annual is 112 cm (Ku and Simmons, 1986). The mean annual precipitation at Mineola (fig. 1) for 1939-90 is 114 cm/yr (National Oceanic and Atmospheric Administration, 1992). Monthly precipitation measured at Mineola during the study is plotted along with the water-table altitude at well N9241 in Eisenhower Park in figure 4.

Hydrologic Conditions and Streamflow Characteristics

East Meadow Brook

East Meadow Brook flows southward at a gradient of about 2.3 m/km (Seaburn, 1969). The stream channel generally is less than 1.5 m deep and is 3 to 6 m wide. The water-table altitude and ground-water flow at the site fluctuate in response to climatic conditions. The start-of-flow of East Meadow Brook shifts with the altitude of the water table and has been recorded as far north as the headwaters area on several occasions. Regional ground-water flow is generally southwestward, and the vertical hydraulic gradient beneath the site fluctuates with the water table. Base flow in the headwaters area generally was negligible during the study and constituted less than 1 percent of the total flow during monitored storms.

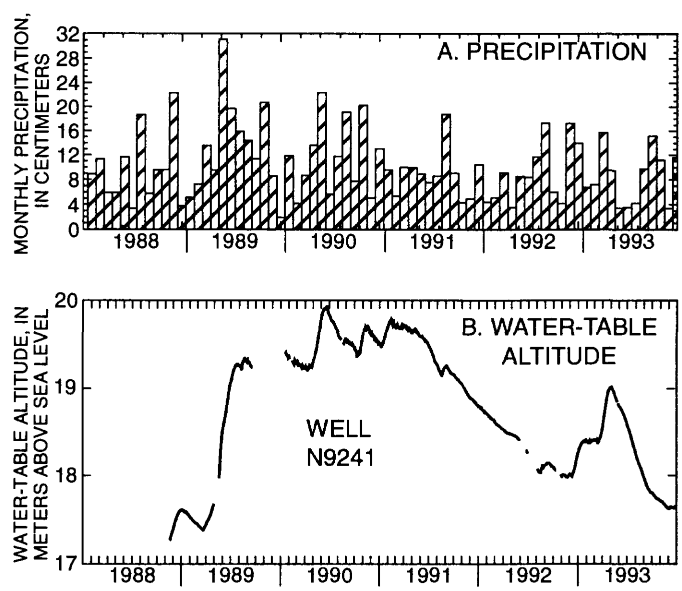

Figure 4. Hydrologic data from study area, Nassau County, N.Y, 1988-93: A. Monthly precipitation measured at Mineola. B. Water-table altitude at monitoring well N9241, screened in the upper glacial aquifer in Eisenhower Park. (Locations are shown in fig. 1.)

During predevelopment conditions, about 95 percent of the total streamflow at East Meadow Brook consisted of ground water discharged from the upper glacial aquifer (base flow) (Franke and McClymonds, 1972), and 5 percent consisted of stormwater. The large population increase in Nassau County during the 20th century, and the attendant increase in ground-water pumpage, and in the construction of roads and other impervious surfaces, together with sanitary sewering, resulted in a loss of recharge to the ground-water system, a lowering of the water table, and a reduction in stream base flow. By the late 1980's, the base-flow contribution to East Meadow Brook was only about 55 percent of total flow, and the stormwater contribution had increased proportionately (Scorca, 1997).

The headwaters of the stream are at the convergence of three main culverts, about 550 m north of Charles Lindbergh Blvd. (fig. 2). The former channel north of this point was modified by the construction of the Meadowbrook Parkway in the 1950's; only the 12-km-long stream channel south of this point still can receive base flow.

Headwaters Area

Hydrologic conditions at the headwaters site fluctuated substantially during the study period; these fluctuations are discussed in detail in Scorca and Ku (1997) and Stumm and Ku (in press). Water levels recorded in well N9241 (figs. 1 and 4B) show the magnitude of these fluctuations.

At the start of the project (October 1988), the headwaters area was under losing-stream conditions[1] (fig. 5A) and flowed only during storms; precipitation was less than normal from then through March 1989, and the water table declined to 0.6 to 1.2 m below the streambed. Water-table maps of the site (Scorca and Ku, 1997) indicate that a ground-water mound had formed beneath the stream as a result of localized clay lenses that retard downward flow, and water levels at well pairs indicate a downward head gradient, with horizontal gradients away from the stream. The mound that forms on underlying clay layers after storms dissipates over several days.

Greater-than-normal precipitation in 1989 caused gaining-stream conditions as the water table rose into the streambed, and vertical gradients at well clusters reversed to upward during this time (fig. 5B). This allowed base flow at the headwaters to resume in 1990, and it continued throughout the year, although flow was typically less than 0.3 m^3/s (Stumm, 1992).

Below-average precipitation in late 1990 and early 1991 resulted in a water-table decline at the headwaters site; other changes in hydrologic conditions at the headwaters site also occurred during this period (Scorca and Ku, 1997). For example, a nearby water-main break in early 1991 caused a small amount of water to enter the stream through storm sewers and resulted in a rise in stage that maintained base flow from June through September. A small amount of water continued to flow from the culverts after the water-main break was repaired; this apparently was water pumped for ground-water remediation at one or more service stations in the Westbury drainage area.

A decrease in flow volume along the headwaters area between Sites A and B (fig. 2) during several storms is attributed to infiltration through the streambed; the amount of infiltration ranged from 1 to 30 percent of the total storm volume, with an average of 22.9 percent (Stumm and Ku, in press).

[1]Lohman and others (1972) define a losing stream as "a stream or reach of stream that is losing water to the ground" and, conversely, a gaining stream as "a stream or reach of stream whose flow is being increased by inflow of ground water."

Sources of Water Constituents

The principal source of dissolved constituents in pristine surface waters on Long Island is precipitation (Schoonen and Brown, 1994). The main sources of contaminants in runoff entering the headwaters of East Meadow Brook include (1) road salt, (2) animal wastes, and (3) fertilizers and pH adjusters used on lawns, parks, and golf courses. Contaminants from point sources, such as fuel spills and industrial discharges, also can enter stormwater. Contaminants also can enter shallow ground water from leaking sewers and in areas where precipitation recharges the water table, such as in parks, cemeteries, lawns, recharge basins, and losing stream beds. Constituents most commonly detected in highway runoff include sodium, calcium, magnesium, chloride, aluminum, beryllium, bromide, cadmium, chromium, copper, cyanide, iron, lead, manganese, nickel, sulfate, and zinc, as well as other organic chemicals and particulates (Howard and Beck, 1993; Granato and others, 1994). Another source of dissolved ions in ground water is the weathering of soils and aquifer materials and other geochemical reactions within the aquifer.

Precipitation

The constituent load in atmospheric deposition is derived from both wetfall and dryfall. Wetfall consists of rain and snow, which carry ions in solution; dryfall (which was not measured in this study) occurs between wetfall events and consists of aerosols and particulates that fall to the ground. The predominant ions in precipitation are chloride, sulfate, sodium, calcium, magnesium, ammonium, and nitrate. Dryfall can account for up to 50 percent of the total precipitation input (Huntington and others; 1994; Art and others, 1974), yet it is often ignored in precipitation-load estimates because it is difficult to measure.

Precipitation quality is related to the origin and path of the storm (Miller and Frederick, 1969; Proios and Schoonen, 1994); thus, concentrations of chloride, sodium, magnesium, and other sea salts carried in precipitation decrease rapidly with distance inland from the coast (Junge and Gustafson, 1957) and also vary locally on Long Island, depending on the distance

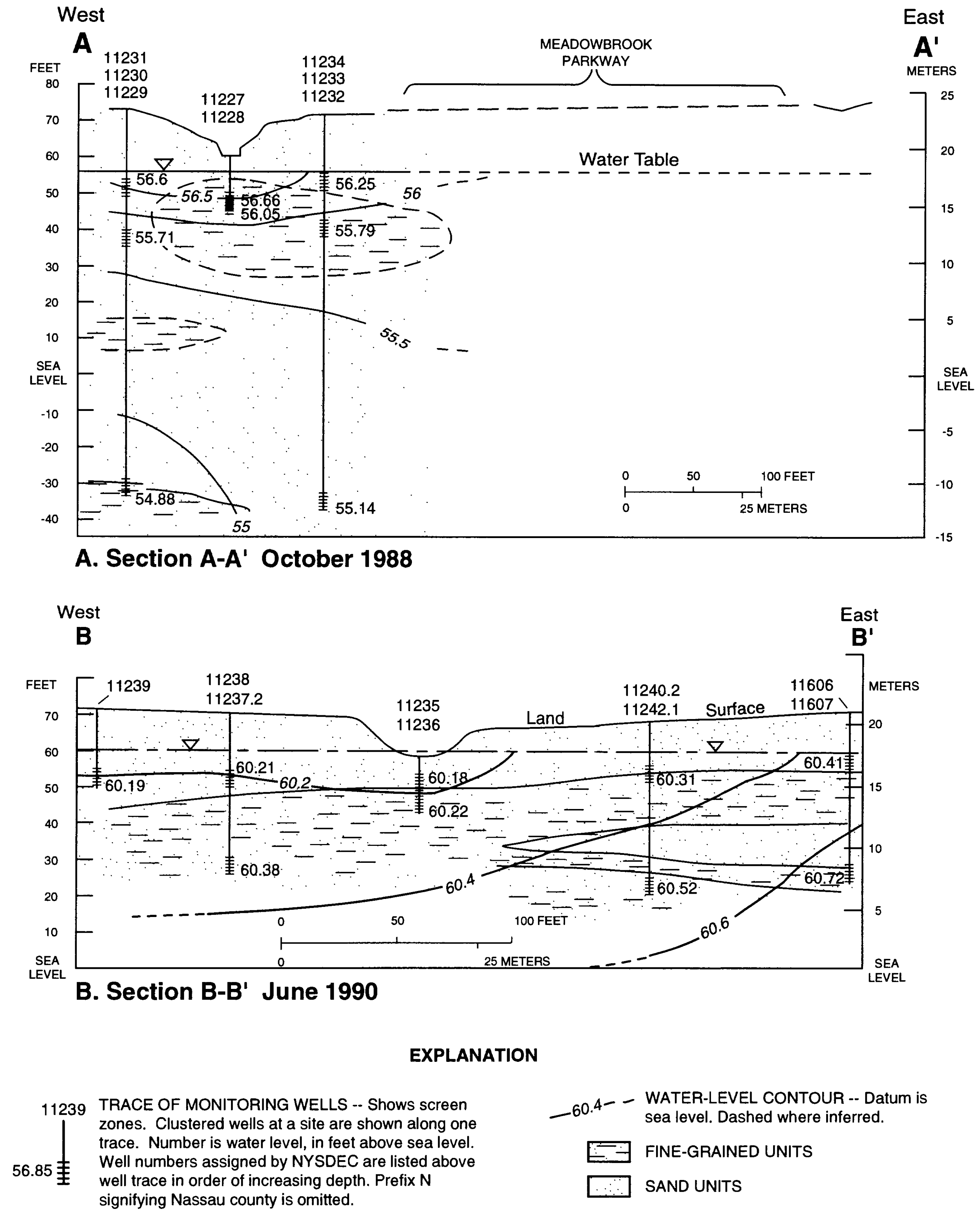

Figure 5. Hydrogeologic section through study area, Nassau County, N.Y., showing: A. Losing-stream conditions, October 1988. B. Gaining-stream conditions, June 1990. (Location shown in fig. 2.)

from sea water (Art and others, 1974; Schoonen and Brown, 1994).

Precipitation on Long Island also is affected by airborne emissions from combustion and contains sulfuric, nitric, and hydrochloric acid (Peters and others, 1982), as well as heavy metals (Pinkerton and others, 1975). Other constituents, including calcium, potassium, sulfate, nitrate, and ammonia, are derived mostly from terrestrial sources such as soil dust and agricultural activities (Berner and Berner, 1987).

Wetfall deposition of nitrate is greatest in the summer, lowest in the spring, and intermediate in the fall and winter; wetfall deposition of ammonium is also lowest in the spring (Sperber and Hameed, 1986; Sperber, 1987). These patterns could cause a detectable seasonal variation in the wetfall nitrate and ammonium loading to stormwater that enters the headwaters of East Meadow Brook.

Concentrations of nitrogen species and chloride have been found to be extremely low in precipitation, but become elevated in stormwater as it flows overland and enters recharge basins; Ku and Simmons (1986) reported that about half of the nitrogen and 80 to 90 percent of the chloride detected in the urban runoff was derived from roads and other impervious surfaces. Peak concentrations of chloride and total nitrogen coincide with the initial stormflow but generally not with later discharge peaks; this may be due to the early washoff of these constituents from surfaces (Zarriello and others, 1984; Ku and Simmons, 1986), or to the "rainout effect" (the decrease of atmospheric chloride and nitrogen at the beginning of the storm).

Weathering of Soils and Aquifer Materials

Ground-water constituents derived from soils and the weathering of aquifer materials are apparent in water samples from rural parts of Long Island (Pearsall and Aufderheide, 1995; Brown and Schoonen, 1994), but can be masked in samples from urbanized areas by constituents derived from human-derived sources. The surficial soils on Long Island contain minor amounts of organic matter, some reactive minerals, and coliform bacteria. The upper glacial aquifer, which consists mostly of unreactive quartz, also contains relatively unstable minerals including iron oxides and hydroxides, feldspar, biotite, chlorite, garnet, hornblende, and rock fragments. Weathering of aluminosilicate minerals produces cations in native ground water, among which are sodium, calcium, magnesium, and potassium. Weathering of iron- and manganese-bearing minerals contribute to dissolved iron in ground water, particularly under reducing conditions (Brown, 1996). Ground water that has had a long residence time and (or) flowpath in an aquifer often will have a higher ionic strength than water that has entered the aquifer recently; thus, the shallow ground water examined in this study, which has a short residence time, has a lower ionic strength than deep ground waters.

Road Salt

Road salting is a common practice in north-temperate regions of the United States, where millions of tons of deicing agents are applied to roads and highways each year (Howard and others, 1993). Road salt, which in Nassau County mostly consists of NaCl (halite), is a major source of ground-water contamination along roads and other paved surfaces in the study area. Residues from road salting during a snow or ice storm increase the concentrations of sodium and chloride in runoff and in shallow ground water. The calcium and potassium found in stormwater after road salting are derived from impurities in the road salt or, possibly, from other deicing chemicals, such as calcium chloride or calcium-magnesium acetate. Metals and other ionic constituents sorbed to sediment surfaces can be mobilized through ion exchange with sodium and chloride ions leached from road salt (Howard and Beck, 1993).

The amount of road salt applied in a given winter depends on several factors, including the number, magnitude, and duration of storms; the air temperature; and the ratio of sand to salt in the mixture. The general formula used in Nassau County is about 560 kg per center-lane kilometer of major roads for each application during a snow or ice storm (Sal Iannucci, Nassau County Department of Public Works, oral commun., 1995). The total length of roads in the Westbury drainage area that have storm sewers that discharge into the headwaters area is estimated to be 69 km (Stumm and Ku, in press). Given that most roads in the drainage basin are in residential areas and have only one or two lanes, the road-salt application for a typical snowstorm could be from 38,800 to 77,700 kg. If all salt were carried to the stream, the total loads in stormwater at the East Meadow Brook headwaters area would be from 15,200 to 30,300 kg sodium and 23,700 to 47,400 kg chloride. Estimation of road-salt loading for an individual storm is difficult, however, because the applications depend on several variables and because road salt from preceding snow or ice storms may still remain on the land surface and in the soil.

Fertilizers and Waste Materials

Nitrogen.—Nutrients in ground water originate from fertilizers, animal wastes, human wastes, and precipitation. Stockar (1994) estimated nitrogen loading to stormwater from dog waste using (1) published values of nitrogen loading per dog per day (Koppelman, 1978; Ragone and others, 1981), and (2) the number of dogs in the drainage basin, as calculated by Ragone and others (1981) from the estimated human-to-dog ratio. The daily loading of nitrogen to the stream from dog waste was decreased by factors ranging from 0.3 to 0.5 to account for nitrogen loss through ammonia volatilization and resulted in a loading of 15.2 to 25.2 kg/d from the impervious part (30 percent) of the drainage basin. Nitrogen loading from fertilizers was calculated from published estimates of annual fertilizer applications in the county and apportioned over the permeable part (70 percent) of the Westbury drainage basin; an estimated annual load of about 15,000 kg of nitrogen was applied to roadside vegetation, residential lawns, and a cemetery within the drainage basin (Stockar, 1994).

Bacteria.—Enteric bacteria, including fecal coliform and fecal streptococcus, are derived from warm-blooded animals (Geldreich and Kenner, 1969). Major sources of enteric bacteria in runoff from urbanized areas are humans (sewage), pets, birds, and small mammals. Bacteria from wastes deposited on impervious surfaces are transported by stormwater to East Meadow Brook. Stormwater typically contains a variety of bacteria, including "indicator" organisms (fecal coliforms and fecal streptococci), that are indicative of sewage; total coliforms in stormwater consist of both fecal coliform and native soil organisms. The major source of coliform bacteria in an urban environment such as the East Meadow Brook vicinity is fecal material from dogs, cats, birds, and other small animals. The area surrounding the East Meadow Brook recharge basin, for example, contains waterfowl feces, which probably increase the bacteria levels in the basin.

The microbial character of stormwater reflects the intensity and duration of the storm and is likely to vary seasonally as a result; Ku and Simmons (1986) found that fecal coliforms and fecal streptococci in Nassau County stormwater increased by 1 to 2 orders of magnitude during the warm season. The quantity of fecal coliform in stormwater apparently is not affected by the length of time between storms, however, because fecal organisms begin to die out upon leaving their host (Wolf, 1972). Stormwater and ponded water are not favorable habitats for the growth of enteric bacteria, and salts and organic constituents, in addition to nonideal temperatures and low nutrient levels, contribute to their rapid decline (Mallard, 1981).

Ground water typically does not contain coliform bacteria because they are relatively large and tend to be filtered by, or sorbed to, sediment. For example, coliform bacteria associated with tertiary-treated sewage traveled less than 6.1 m downward through the aquifer sand during a deep-well recharge study in southern Nassau County (Vecchioli and others, 1972).

Stormwater

Previous studies have shown that recharge basins on Long Island, which are used to dispose of stormwater and to recharge ground water, do not appear to have significant adverse effects on ground-water quality (Schneider and others, 1987; Ku and Simmons, 1986). Stormwater-borne contaminants, including coliform bacteria, poorly soluble metals, organic compounds, and nutrients, are generally attenuated by surficial sediments. More-soluble contaminants, such as road salt (sodium and chloride), are relatively nontoxic, and concentrations in stormwater rarely exceed drinking-water standards. Nearly 90 percent of the public-supply wells in Nassau County are screened below the water-table aquifer (Nassau County Department of Health, 1988) and are therefore less susceptible to contamination from stormwater than those screened near land surface.

DATA-COLLECTION NETWORK AND SAMPLING PROCEDURES

The USGS established a data-collection network of streamflow-gaging stations, base-flow-sampling sites, monitoring wells, and a precipitation-gaging station to examine the chemical interaction between surface water and ground water at the headwaters of East Meadow Brook. The sampling sites were closely spaced (fig. 2) for detailed study of the effects of urban runoff, stream-channel modification, and increased recharge on water quality.

Precipitation

The NCDPW has monitored daily precipitation amounts at Mineola, about 5.6 km west of the study site, since 1938 (figs. 1 and 4A). The USGS installed a tipping-bucket rain gage at Eisenhower Park, about 0.8 km east of the study site (fig. 1), in 1989 to collect precipitation data from individual storms. Precipitation amounts at Eisenhower Park were recorded at 5-min intervals from 1989 through 1993.

As part of the New York State Atmospheric Deposition Monitoring program, the NYSDEC collected precipitation when the samples exceeded 250 ml with a wetfall/dryfall collector and performed all the precipitation chemical analyses (New York State Department of Environmental Conservation, 1991). Sample pH was measured at the NYSDEC laboratory after sample collection. Dryfall samples were not collected in this study.

Surface Water

Surface-water quality was monitored during storms and between storms from July 1988 through November 1993. Surface water includes stormwater, which was collected during and immediately after storms, and stream water collected between storms, depending upon stream conditions; stream water may consist all or partly of (1) base flow, (2) stormwater pooled from previous storms, and (3) water resulting from the nearby water-main break in 1991 or from local ground-water-remediation activities in 1992. Dates and locations of sampling are listed in table 1. In general, base flow constituted only a small contribution to total flow during storms, usually less than 1 percent.

Two streamflow-gaging stations were installed in 1988 in the headwaters area. Site A was constructed about 15 m south of the main culverts where stormwater enters the study area, and Site B was constructed about 370 m downstream (fig. 2). A third station was installed at a culvert originating from Eisenhower Park (Site C), and a fourth station was installed at a downstream site south of Charles Lindbergh Blvd. where streamflow leaves the study area (Site D, fig. 2). Each station was instrumented with a datalogger to monitor stage and discharge. Sites B and C were destroyed during construction of the detention basin in 1992, and an additional site (Site E, fig. 2) was established at the

Table 1. Dates and locations of surface-water sampling for chemical and bacteria analyses for East Meadow Brook headwaters study, Nassau County N.Y., 1988-93

[Site locations are shown in fig. 2]

Sampling date		Sampling site		
During storm	Between storms	Major ions	Volatile organic compounds	Bacteria
7/27/88		A,B	A	
	9/7/88	A		A
11/1/88		A		A
	12/5/88	A	A	A
2/3/89		A		
	3/2/89	A		A
	3/6/89	A,B	A,B	A,B
3/18/89		A,B		
4/15/89		A,B		A,B
5/10/89		A,B		A,B
6/6/89		A,B		
	6/19/89	A,B	A,B	
	10/3-5/89	A,B	A,B	A,B
	1/23-31/90	A,B	A,B	A,B
	5/1-3/90	A,B,C,D	A,B,C,D	A,B,C,D
	7/23/90			
	7/31-8/2/90	A,B,C,D	A,B,C,D	A,B,C,D
9/19/90		A,B		A,B
9/22/90		A,B		
10/18/90		A,B		A,B
	12/12/90	A,B,D	A,B,D	A,B,D
	3/13/91	A		
	3/29/91	A,B,D	A,B,D	A,B,D
4/15/91		A,C,D		
5/30/91		A,D		A,D
7/23/91		A,C,D		A,C,D
9/19/91		A,C,D		A,C,D
10/15/91		A,C,D		A,C,D
11/22/91		A,C,D		
	7/22/93	A	A	
8/17/93	8/16-8/25/93			A,E
	11/9-10/93	A,D,E	A,D,E	A,D,E

detention-basin dam after construction of the detention basin in 1993.

Stormwater samples were collected during and after storms at the four sites with an automated sampler interfaced with a datalogger. The automated sampler was initiated whenever the stream stage rose above about 0.1 m. Streamflow samples were collected with the samplers at regular intervals (usually about 15 min) during storms, or until stage dropped to its initial level. Samples were stored in coolers with ice and delivered to the NCDPW laboratory for analysis. Samples analyzed for metals were acidified with nitric acid and nutrient samples were preserved with sulfuric acid when the samples were retrieved from the field (within 12-24 hrs from the end of the storm). Bacteria analyses were performed by the NCDH. Samples collected during this study generally were unfiltered and analyzed for "total" (suspended and dissolved) concentrations of constituents; field personnel filtered the samples through a 0.45-micron filter on a few occasions during storms to allow a separate measurement of the dissolved component. Volatile organic compound analyses were done periodically. Stream-water samples, which generally were assumed to represent base flow, were collected occasionally from the stream channel between storms.

Ground Water

Water samples were collected from several wells adjacent to the stream in the headwaters area. Some of these wells had been installed by the USGS and NCDPW; several older wells also were incorporated into the data-collection network. Other wells (including replacement wells) were added as the project progressed. Data on monitoring wells used in the study are given in table 2. Water-table fluctuations during the study were measured continuously at well N9241 (figs. 1 and 4B), which is screened in the upper glacial aquifer at Eisenhower Park.

Well clusters (fig. 2) within the headwaters area were sampled periodically and analyzed to determine the vertical extent of ground water affected by stormwater constituents. At least three casing volumes were pumped from the wells, and stable readings of temperature and specific conductance of the pumped water were obtained, before sampling.

WATER QUALITY

The study of water quality at the headwaters site entailed chemical analysis of precipitation, stormwater, and ground water to estimate what amount of each constituent is derived from precipitation and to delineate the extent of contaminant migration to the underlying aquifer. The effects of the detention basin on water quality and contaminant migration were examined to a lesser extent.

Precipitation

Wetfall was collected at Eisenhower Park during selected storms from April 1989 through December 1991. The storm and sampling dates, and concentrations of selected constituents in the samples, are given in table 3. A wetfall sample was not collected after the April 15, 1989 storm; pH and concentrations of selected constituents used for this storm are the precipitation-weighted means for the April-June 1989 period.

Surface Water

Surface water analyzed at East Meadow Brook includes base flow, stormwater, and water collected from the detention basin after its construction. Results of analyses of surface-water samples collected during dry periods are presented in table 4. Concentrations of surface-water constituents analyzed in East Meadow Brook reflect (1) the source of the constituents, (2) the relative contributions of stormwater and base flow, (3) the mechanism of source input into the hydrologic system, and (4) precipitation amount, intensity, and quality. Concentrations of nitrate, for example, are relatively low in stormwater but elevated in base flow because base flow consists of ground water that contains nitrate from nonpoint-source contamination, such as fertilizers and leaky sanitary sewers. Chloride, sodium, and calcium concentrations were also generally higher in base flow than in stormflow, except during periods of road salting, when all three were higher in stormflow than in base flow. Calcium and nitrate also are derived from agricultural sources (fertilizers and pH adjusters). Concentrations of potassium, phosphate, magnesium, and sulfate were higher in stormwater than in base flow because they are sorbed to sediment and, thus, were retained within the aquifer matrix. Potassium and phosphate, in particular, tend to be sorbed to

Table 2. Physical description of wells near the East Meadow Brook headwaters area, Nassau County, N.Y.

[Locations are shown in figs. 1 and 2. Dash indicates no data available]

Well number	Latitude	Longitude	Aquifer	Measuring point (meters above sea level)	Land-surface altitude (meters above sea level)	Depth to screen (meters)	
						Top	Bottom
N 9406. 3	404446	733530	Upper glacial	31.68	31.70	--	--
N10292. 1	404412	733438	Upper glacial	23.91	23.77	13.7	15.2
N11226. 1	404402	733512	Upper glacial	19.98	18.90	--	3.0
N11227. 1	404359	733507	Upper glacial	20.16	18.29	3.4	4.3
N11228. 1	404359	733507	Upper glacial	19.55	18.29	3.7	4.6
N11229. 1	404359	733508	Magothy	22.15	21.33	32.0	32.9
N11230. 1	404359	733508	Upper glacial	21.91	21.33	32.0	32.9
N11231. 1	404359	733508	Upper glacial	21.86	21.33	6.1	7.0
N11232. 1	404359	733506	Magothy	21.51	21.33	9.2	10.1
N11233. 1	404359	733506	Upper glacial	22.33	21.33	8.2	9.1
N11234. 1	404359	733506	Upper glacial	21.22	21.33	5.2	6.1
N11235. 1	404356	733505	Upper glacial	19.57	18.29	2.4	3.4
N11236. 1	404356	733505	Upper glacial	19.52	18.29	3.4	4.3
N11237. 1	404356	733506	Upper glacial	21.84	22.86	7.6	8.5
N11237. 2	404356	733506	Upper glacial	21.69	21.79	12.2	13.4
N11238. 1	404356	733506	Upper glacial	21.79	21.33	6.1	7
N11239. 1	404356	733508	Upper glacial	22.32	21.33	6.1	7
N11240. 1	404356	733504	Upper glacial	21.57	21.33	8.8	9.8
N11240. 2	404356	733504	Upper glacial	20.73	20.88	13.7	16.2
N11241. 1	404356	733504	Upper glacial	21.83	21.33	4.3	5.2
N11241. 2	404356	733504	Upper glacial	20.71	18.29	2.7	5.2
N11242. 1	404355	733505	Upper glacial	19.37	18.29	1.8	2.7
N11243. 1	404355	733505	Upper glacial	19.38	18.29	2.7	3.7
N11244. 1	404354	733506	Upper glacial	22.15	21.33	9.4	10.4
N11244. 2	404354	733506	Upper glacial	21.85	21.94	12.2	13.7
N11245. 1	404354	733506	Upper glacial	22.10	21.33	6.4	7.3
N11245. 2	404354	733506	Upper glacial	21.87	21.94	3.0	5.8
N11246. 1	404355	733504	Upper glacial	20.80	19.81	8.5	9.5
N11247. 1	404355	733504	Upper glacial	20.83	19.81	5.5	6.4
N11248. 1	404352	733504	Upper glacial	22.63	22.86	9.1	10.1
N11248. 2	404352	733504	Upper glacial	22.68	22.86	12.2	13.8
N11249. 1	404352	733504	Upper glacial	22.90	22.86	6.1	7.0
N11249. 2	404352	733504	Upper glacial	22.63	22.86	4.9	6.7
N11250. 1	404352	733502	Upper glacial	20.50	19.81	8.8	9.8
N11251. 1	404352	733502	Upper glacial	20.47	19.81	5.5	6.4
N11252. 1	404349	733502	Upper glacial	19.14	18.29	3.0	4.0
N11253. 1	404349	733502	Upper glacial	19.09	18.29	4.6	5.5
N11254. 1	404349	733503	Magothy	22.13	21.33	30.2	31.1
N11255. 1	404349	733503	Upper glacial	22.12	22.25	8.8	9.8
N11256. 1	404349	733503	Upper glacial	22.26	22.25	5.8	6.7
N11257.1	404349	733501	Upper glacial	20.36	19.81	8.8	9.8
N11258.1	404349	733501	Upper glacial	20.32	19.81	5.8	6.7
N11504. 1	404349	733459	Upper glacial	20.13	20.27	6.4	7.9
N11505. 1	404339	733448	Upper glacial	22.63	22.86	9.8	11.3
N11506. 1	404356	733456	Upper glacial	20.38	20.42	9.8	11.3
N11602. 1	404410	733523	Upper glacial	26.33	26.52	12.2	13.7
N11603. 1	404400	733501	Upper glacial	21.60	21.79	12.2	13.7
N11604. 1	404351	733523	Upper glacial	26.70	26.82	12.2	13.7
N11605. 1	404356	733529	Upper glacial	26.97	27.13	12.2	13.7

Table 2. Physical description of wells near the East Meadow Brook headwaters area, Nassau County, N.Y.—continued

Well number	Latitude	Longitude	Aquifer	Measuring point (meters above sea level)	Land-surface altitude (meters above sea level)	Depth to screen (meters)	
						Top	Bottom
N11606. 1	404356	733503	Upper glacial	20.94	21.03	11.9	13.7
N11607. 1	404356	733503	Upper glacial	20.76	21.03	3.0	5.2
N11608. 1	404353	733501	Upper glacial	20.66	20.73	10.7	11.9
N11609. 1	404253	733501	Upper glacial	20.66	20.73	3.0	5.5
N11610. 1	404350	733501	Upper glacial	20.25	20.88	13.7	14.9
N11611. 1	404350	733501	Upper glacial	20.36	20.88	3.0	5.5
N11612. 1	404347	733500	Upper glacial	19.57	19.81	10.7	11.9
N11613. 1	404347	733500	Upper glacial	19.61	19.81	3.0	5.5
N11618. 1	404356	733513	Upper glacial	27.56	27.74	11.6	13.1
N11829. 1	404356	733511	Upper glacial	27.17	27.43	12.5	14.0
N11830. 1	404354	733507	Upper glacial	22.88	23.01	3.4	9.4
N11831. 1	404352	733509	Upper glacial	26.18	26.33	12.2	13.7
N11832. 1	404359	733511	Upper glacial	26.04	26.21	11.0	12.5
N12282. 1	404359	733506	Upper glacial	21.62	21.64	12.5	14.0
N12283. 1	404359	733506	Upper glacial	21.54	21.64	4.6	6.1
N12284. 1	404357	733504	Upper glacial	21.57	21.64	4.3	5.8
N12292. 1	404348	733459	Upper glacial	20.81	21.03	13.4	14.9
N12293. 1	404348	733459	Upper glacial	20.81	21.03	4.3	5.8

Table 3. Concentrations of constituents in wetfall samples collected in Eisenhower Park, Nassau County, N.Y., April 1989 through November 1991

[All concentrations in milligrams per liter. Samples collected and analyzed by the New York State Department of Environmental Conservation (New York State Department of Environmental Conservation, 1991; P.J. O'Connell, New York State Department of Environmental Conservation, written commun., 1992). Location shown in fig. 1]

Constituent	Storm date, wetfall-sampling period, and wetfall quantity (in centimeters)					
	4-15-89 April-May 1989[1] (3.18)	5-10-89 May 9-16, 1989 (4.88)	6-6-89 June 6-13, 1989 (0.76)	7-23-91 July 16-30, 1991 (2.26)	9-19-91 September 17-24, 1991 (1.27)	11-22-91 November 12-26, 1991 (0.84)
pH, laboratory	4.2	4.4	4.2	3.9	4.1	4.4
Calcium, total	.43	.41	.06	.80	.25	.08
Magnesium, total	.31	.26	.37	.08	.07	.10
Sodium, total	.26	.08	.08	.18	.35	.66
Potassium, total	.03	0	.01	.04	.03	.25
Sulfate, total	2.8	1.6	2.2	5.6	3.3	1.5
Chloride, dissolved	1.1	.54	.78	.37	.69	1.5
Nitrate as N, total	.33	.20	.30	.83	.42	.27
Ammonia as N, total	.24	.11	.21	.53	.23	.14

[1] No sample was collected on 4-15-89; the precipitation-weighted means were used for the second quarter (April-June 1989).

Table 4. Physical-property values and concentrations of constituents in surface water sampled between storms at Site A in East Meadow Brook headwaters area, Nassau County, N.Y.,1988-93

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; all concentrations are in milligrams per liter. Site A location shown in figs. 2 and 3]

Property or constituent	Storm date											
	12-5-88	3-2-89	3-6-89	6-19-89	10-3-89	1-23-90	5-1-90	7-31-90	12-12-90	3-13-91	7-22-93	11-9-93
Specific conductance (µS/cm)	214	182	7,300	211	173	571	526	414	535	331	365	335
pH (standard units)	6.8	7.1	7.1	7.1	7.0	7.0	7.0	7.0	7.2	7.8	6.7	7.2
Calcium, total	13	7.6	24	16	12	20	23	17	19	17	15	12
Magnesium, total	3.2	1.7	1.8	3.6	2.7	3.6	4.6	4.0	4.2	3.8	4.2	3.5
Sodium, total	19	24	1,700	19	14	82	73	44	75	47	43	43
Potassium, total	2.7	1.1	3.0	1.4	1.7	4.5	3.5	2.7	3.8	1.7	1.9	2.1
Alkalinity, as HCO_3^-	11	13	21	16	16	26	17	13	24	78	13	14
Sulfate, total	14	10	26	10	10	38	34	24	34	5.1	16	14
Chloride, dissolved	25	25	2,700	25	20	116	110	78	110	57	65	66
Nitrate as N, total	7.0	6.3	.88	7.4	5.2	7.0	7.2	8.5	7.3	3.0	7.7	5.8
Ammonia as N, total	<0.1	< 0.1	0.6	< 0.1	< 0.1	1.1	0.36	< 0.1	0.56	0.58	< 0.1	< 0.1
Organic N, total	0.4	0.3	0.8	< 0.1	0.6	0.3	0.2	0.3	0.3	0.1	0.2	0.2
Iron, total	<.05	.07	.94	.06	.05	.41	.31	1.2	3.2	.55	.04	.06
Manganese, total	<.02	<.02	<.02	<.01	<.01	1.3	.68	.38	.82	.22	.03	.13

suspended sediment or occur as colloids and are transported during peaks in precipitation and discharge.

Stormwater

Stormwater flowing overland within the study area entrains constituents from dryfall, animal waste, road salt, fertilizers, and other sources, and carries them to storm sewers that discharge into the headwaters of East Meadow Brook. Concentrations of most major constituents, except bacteria, are lower in stormwater than in base flow or ground water at all times except during periods of road salting.

Constituent Concentrations

Streamflow at the headwaters area consisted mostly of stormwater, particularly during losing-stream conditions (when the water table was lower than the streambed). Chloride concentrations (in mg/L) in stormwater generally were higher than sodium concentrations, probably because the ratio of sodium to chloride in road salt and in precipitation is lower than in ground water and because sodium has a greater tendency than chloride to be sorbed to sediments and transported with stormwater. A typical response of sodium and chloride concentrations in streamflow to the inflow of stormwater during losing-stream conditions is shown in the graph of sodium and chloride concentrations in relation to discharge during a storm monitored on May 30, 1991 (fig. 6A). Concentrations of sodium and chloride, the major constituents in precipitation, peaked during the initial runoff on this date, then decreased through a rapid flushing of salts from impervious surfaces as the storm progressed. Calcium, bicarbonate, and nitrate, which were detected in much higher concentrations in ground water than in stormwater (table 9 and fig. 6A), were probably derived from fertilizers and lime used on residential lawns and farms, and from leaking sewers and animal waste. Some constituents, including potassium, organic nitrogen, and bacteria, which tend to be sorbed to suspended sediment or to form colloids, are transported during peaks in precipitation and discharge and were detected at higher concentrations in stormwater than in ground water. Concentrations of total and dissolved solids during the storm of April 15, 1989 (fig. 6B) illustrate the difference in magnitude between total and dissolved fractions of constituents in urban runoff.

Concentrations of certain stormwater constituents, including chloride, sodium, and nitrogen species, seem related to seasonal factors and, therefore, can be higher or lower than in base flow or shallow ground water. Streamflow samples collected during a storm and during the period of gaining-stream conditions (water table higher than streambed) show the effects of dilution by stormwater; for example, concentrations of constituents in surface water, including bicarbonate, nitrate, and calcium (table 4), decreased during the September 19, 1990 storm (fig. 7) as the base flow component of the stream was diluted by stormwater. Constituent concentrations related to specific processes or contaminant sources are discussed below.

Road salt.—Concentrations of most major ions were lower in stormwater than in base flow or ground water at all times except during periods of road salting. Sodium and chloride concentrations in streamflow were more than 2 orders of magnitude greater during a storm on March 18, 1989, as a result of road salting (fig. 8A) than during storms following no road salting. Concentrations of chloride and sodium each exceeded 250 mg/L during two such storms, but were generally below 10 mg/L during summer and fall storms (for example, fig. 6A). Calculated concentrations of sodium and chloride in streamflow milliequivalents (meq/L) (fig. 8B) generally reflect the 1:1 stoichiometric ratio of the source, which is usually halite (NaCl) during periods of road salting.

Concentrations of other constituents during the March 18, 1989 storm, including calcium and magnesium (fig. 8C), sulfate, bicarbonate, iron, and lead, were higher than in other sampled storms, probably because (1) the March 18 storm was relatively large, (2) the road-salt mixture contained trace elements other than NaCl, and (or) (3) ion-exchange processes occurred on surfaces that were exposed to waters of extremely high ionic strength after road-salt applications, and (4) saltwater is very corrosive. Road-salt constituents showed an elevated concentration early in the storm, then a gradual decline throughout the course of the storm as they were diluted and washed from impervious surfaces. Subsequent storms continued to wash road salt from streets within the basin. Samples from the next monitored storm (April 15, 1989) contained maximum concentrations of only 15 and 10 mg/L, respectively; therefore, road salt was

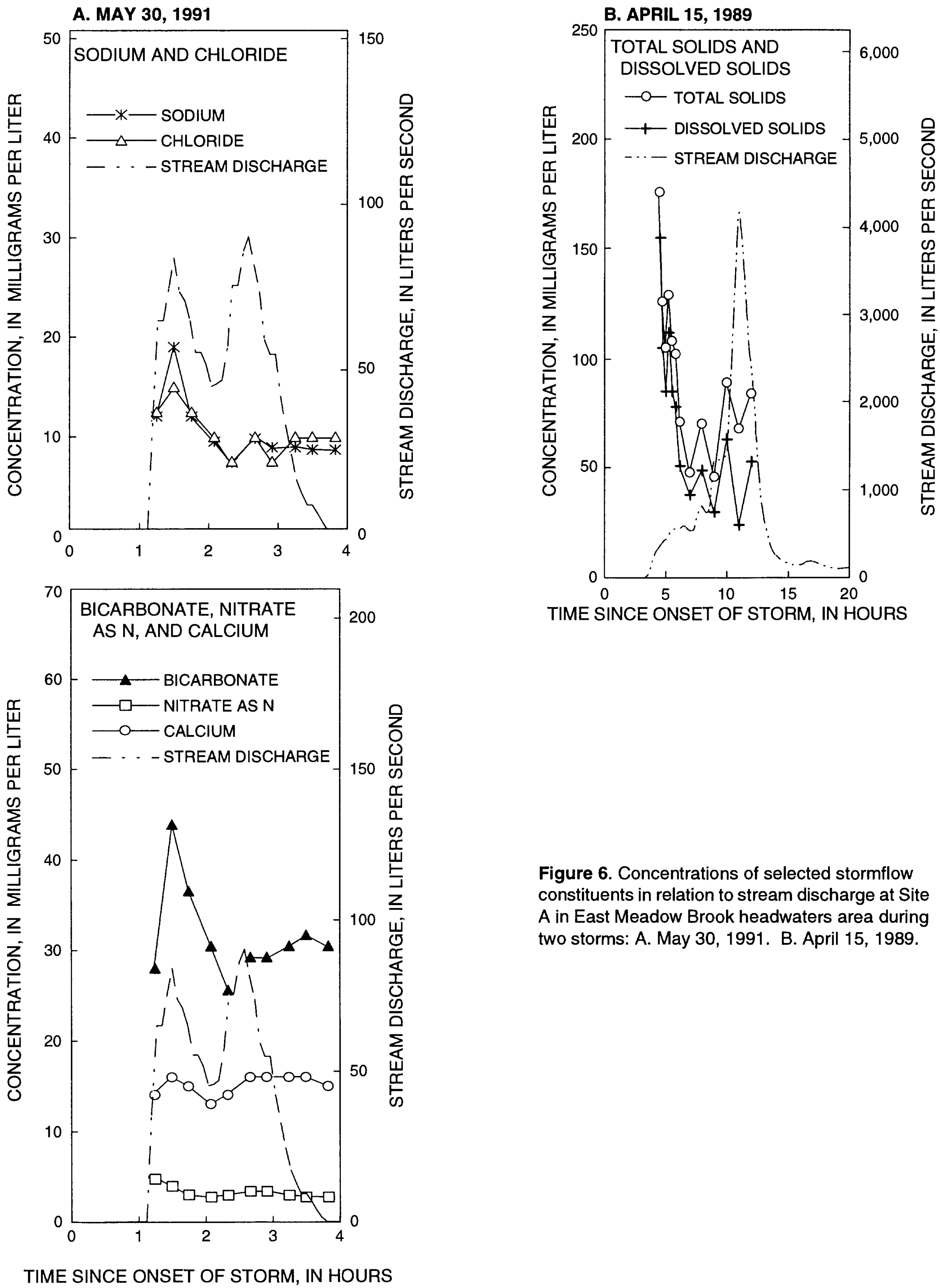

Figure 6. Concentrations of selected stormflow constituents in relation to stream discharge at Site A in East Meadow Brook headwaters area during two storms: A. May 30, 1991. B. April 15, 1989.

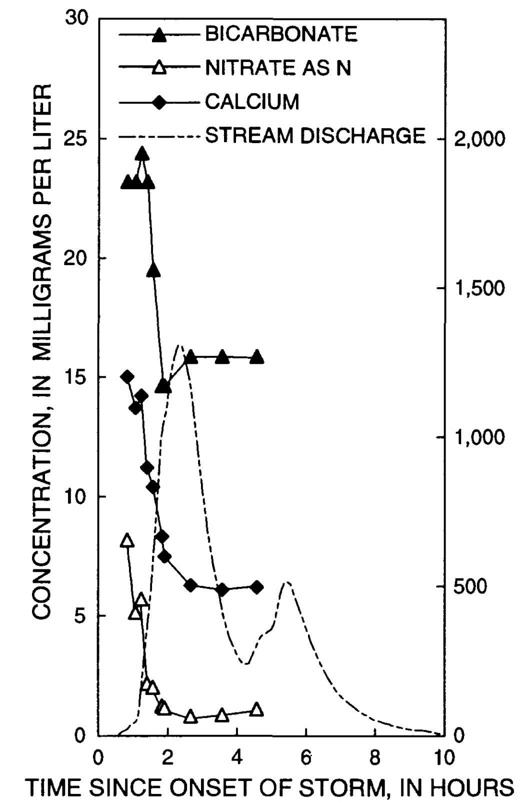

Figure 7. Concentrations of bicarbonate, nitrate, and calcium in relation to stream discharge at Site A in East Meadow Brook headwaters area during storm of September 19, 1990.

not present in significant amounts in the stream 1 month after the March 18, 1989 storm.

Nutrients.—Nitrogen and phosphorus concentrations in stormwater differed from those in ground water. Nitrate is the most soluble form of nitrogen; it generally enters the ground-water system in dissolved form through infiltration from the land surface and usually occurs in greater concentrations in ground water and base flow than in surface runoff (Halberg and others, 1984). Organic nitrogen and ammonia tend to be transported in surface runoff as a sorbed or particulate phase. Concentrations of nitrite as N in stormwater were generally less than 0.1 mg/L. Nitrogen species concentrations in streamwater at East Meadow Brook apparently are affected by (1) season, (2) flow conditions, and (3) the transport mechanisms by which they enter the stream. Concentrations of phosphorus as total phosphate, like organic nitrogen and ammonia, were much higher in stormwater than in ground water because phosphate tends to be sorbed by the soil.

Concentrations of organic-N often were elevated during spring and fall storms, possibly as a result of fertilizer applications. Organic-N concentration exceeded 4 mg/L during the storms of March 18, 1989, and April 15, 1989, and exceeded 1 mg/L during storms on October 18, 1990, September 19, 1991, October 15, 1991, and November 22, 1991. Concentrations of ammonia exceeded 1 mg/L as N only on March 18, 1989; this may partially be a result of ion-exchange processes on surficial sediments after the large input of sodium and other road-salt constituents into stormwater. Concentrations of nitrate in base flow generally ranged from 5 to 10 mg/L as N.

The dominant nitrogen species in a given storm depended upon whether the stream was losing or gaining, and the amount of base flow entering the stream. Organic nitrogen in stormflow had the highest concentrations of the nitrogen species during losing-stream conditions and before June 1989, as shown in figure 9A for the storm of April 15, 1989. The water table rose thereafter and, from June 1989 through September 1991, was higher than average and caused gaining-stream conditions (base flow) at the headwaters site (see fig. 5B), and nitrate became the dominant form of nitrogen, as illustrated in figure 9B for the storm of September 19, 1990. Stormwater lowered the nitrate concentrations in the stream during this period by dilution, however. The November 1991 storm reflected declining ground-water levels and a smaller contribution of nitrate-rich ground waters, as evidenced by the predominance of organic N over nitrate.

Metals.—Iron (total) was measured at high concentrations during several storms, particularly during spring and fall (fig. 9C). Total iron concentrations exceeded 8 mg/L on November 22, 1991. Manganese concentrations generally were below 0.1 mg/L during all storms. Iron and manganese concentrations peaked during the early part of the storm and rapidly decreased. Total and dissolved iron were measured during the early part of the storm of September 19, 1990 (fig. 9C); the large difference between total and dissolved iron concentration indicates that most iron, and probably other metals, including manganese, chromium, cadmium, and lead, are associated with sediment and (or) colloidal transport.

Lead and chromium (total) were detected in a few of the stormwater samples analyzed during the study period, but cadmium was not detected in any samples. Chromium was detected at very low concentrations (at

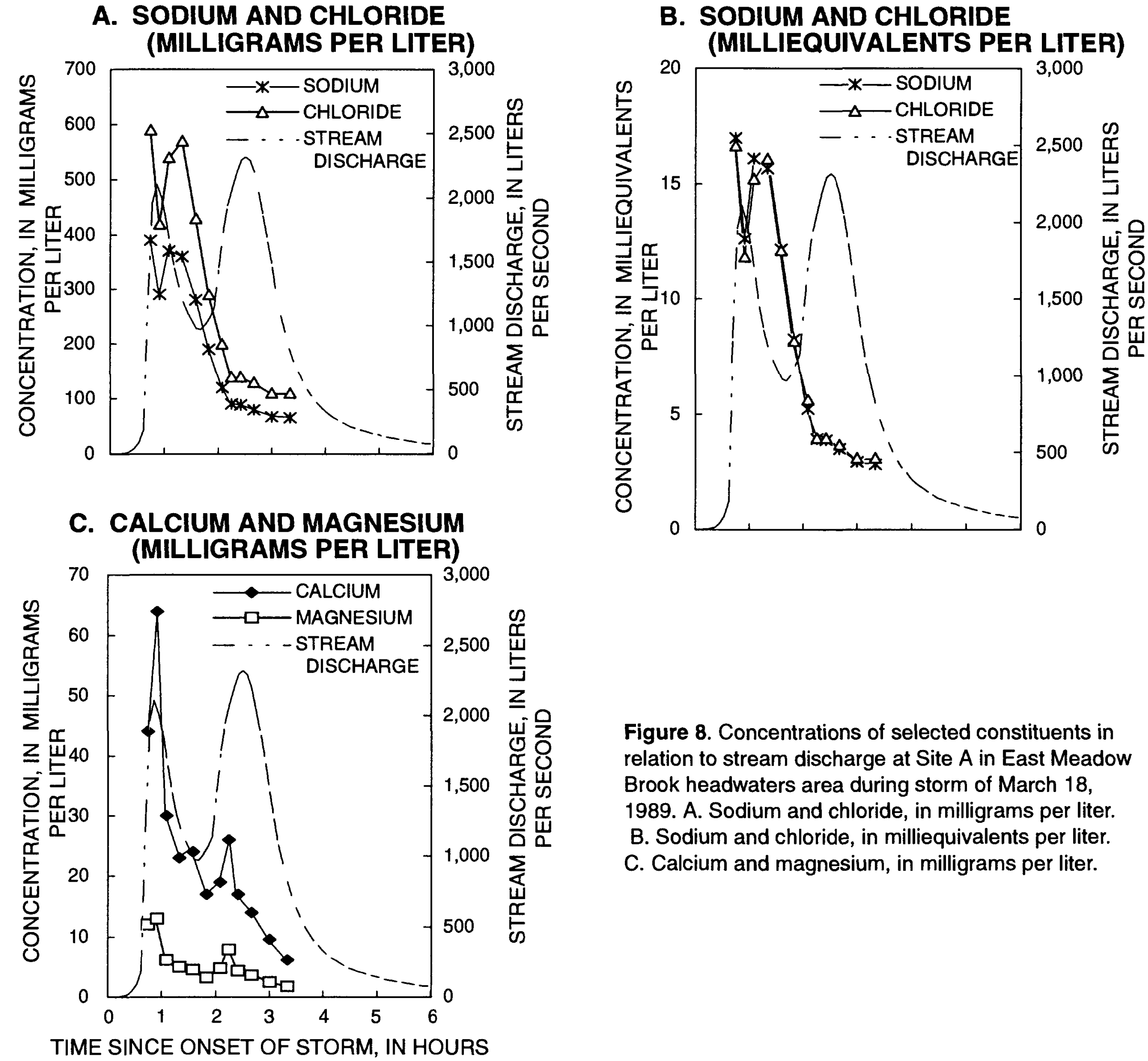

Figure 8. Concentrations of selected constituents in relation to stream discharge at Site A in East Meadow Brook headwaters area during storm of March 18, 1989. A. Sodium and chloride, in milligrams per liter. B. Sodium and chloride, in milliequivalents per liter. C. Calcium and magnesium, in milligrams per liter.

or near the detection limit) in two of the storms analyzed. Lead concentrations exceeded the NCDH drinking-water standards of 0.05 mg/L (Nassau County Department of Health, 1992) during two storms; a concentration of 0.52 mg/L was measured in one sample collected just after the peak discharge on November 22, 1991 (fig. 9E), and a concentration of 0.38 mg/L was measured on March 18, 1989 (fig. 9E). Measurable lead concentrations also were detected in samples from storms of September 19, 1990, October 18, 1990, and September 19, 1991. Many of these detections were probably related to metals sorbed onto suspended sediment.

The concentrations of total lead and manganese were correlated positively with discharge, much like other cations, such as calcium, magnesium, and potassium. Lead and manganese concentrations peaked with the initial peak discharge during the storm of March 18, 1989, and followed a similar declining trend over time (fig. 9E).

Bacteria.—Coliform bacteria counts in stormwater at Site A correlated positively with discharge during most storms. A graph of the data for the storm of May 30, 1991, for example, illustrates the direct correlation between fecal coliform and discharge over

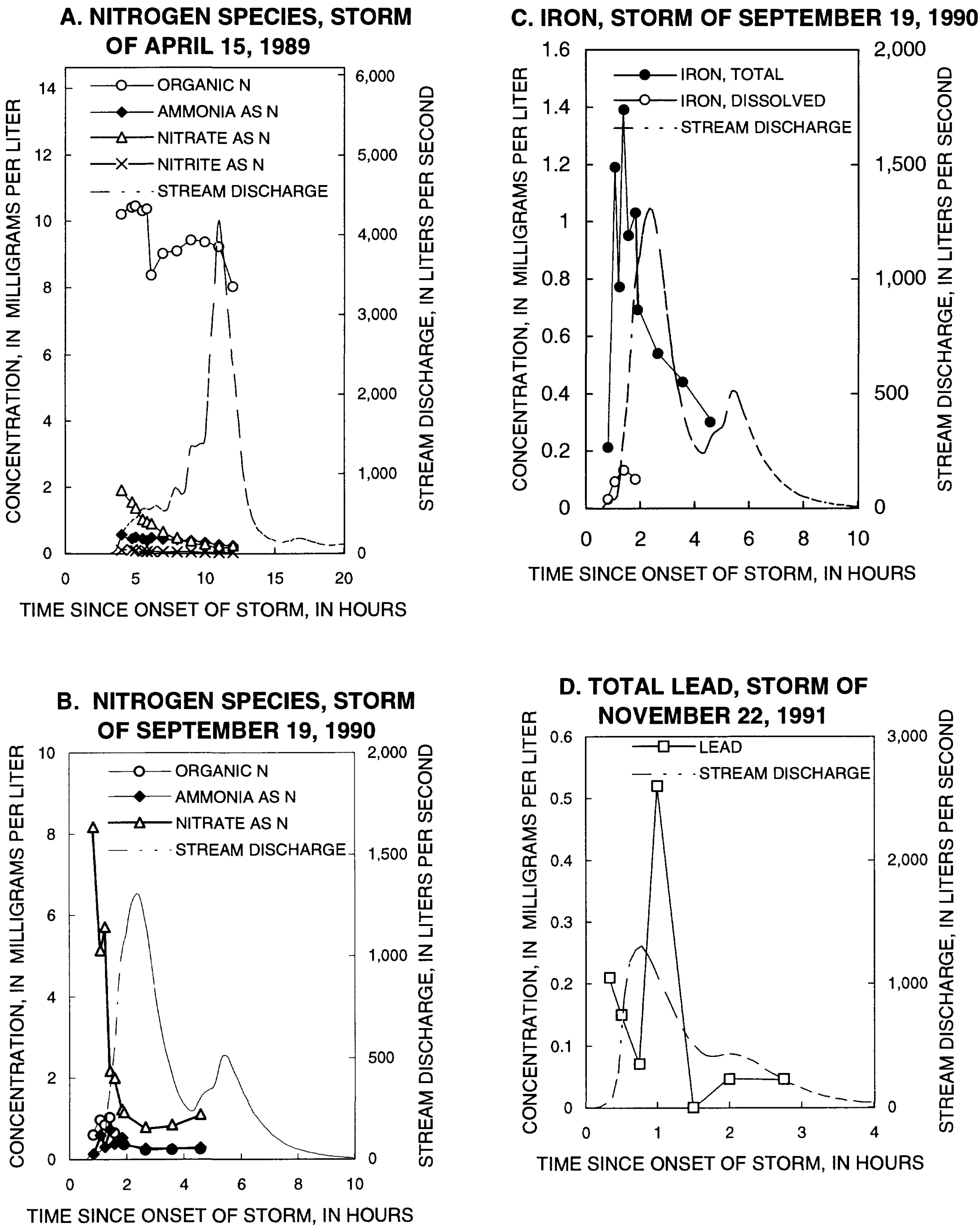

Figure 9. Concentrations of selected constituents in relation to stream discharge at Site A in East Meadow Brook headwaters area during selected storms, 1989-91. A. Nitrogen species (total), storm of April 15, 1989. B. Nitrogen species, storm of September 19, 1990. C. Iron, storm of September 19, 1990. D. Lead, storm of November 22, 1991.

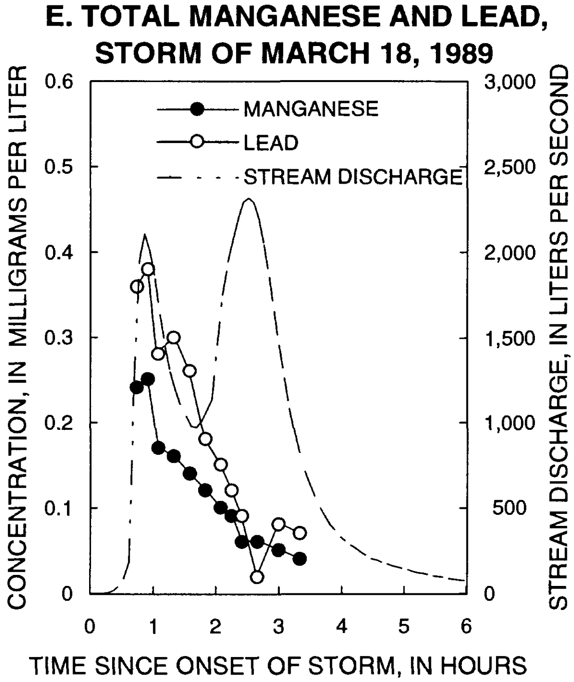

Figure 9 (continued). Concentrations of selected constituents in relation to stream discharge at Site A in East Meadow Brook headwaters area during selected storms, 1989-91. E. Manganese and lead, storm of March 18, 1989.

time (fig. 10). Similarly, total coliform, fecal coliform, and fecal streptococcus counts peaked during the early part of the storm of October 15, 1991, then decreased with time (fig. 10). The peaks occur as bacteria are washed from paved areas, soils, and other surfaces within the drainage area, and the subsequent decrease results from (1) the decrease in suspended sediment (onto which bacteria sorb), (2) die-off of bacteria, (3) dilution by base flow (during gaining-stream conditions), and (4) dilution with rain water. A decline in bacteria was documented in greater detail after construction of the stormwater-detention basin and is discussed in the final section of this report (Effects of Stormwater-Detention Basin).

The coliform bacteria count in stormwater was slightly higher during fall storms than in storms in other seasons. Storm data indicate that only a very light rainfall will cause an increase in the bacteria count in the stream by more than an order of magnitude, as shown in the graph of the data for the storm of May 30, 1991 (fig. 10A), which brought only 0.28 cm of rain. A much larger storm, such as the 1.0-cm storm

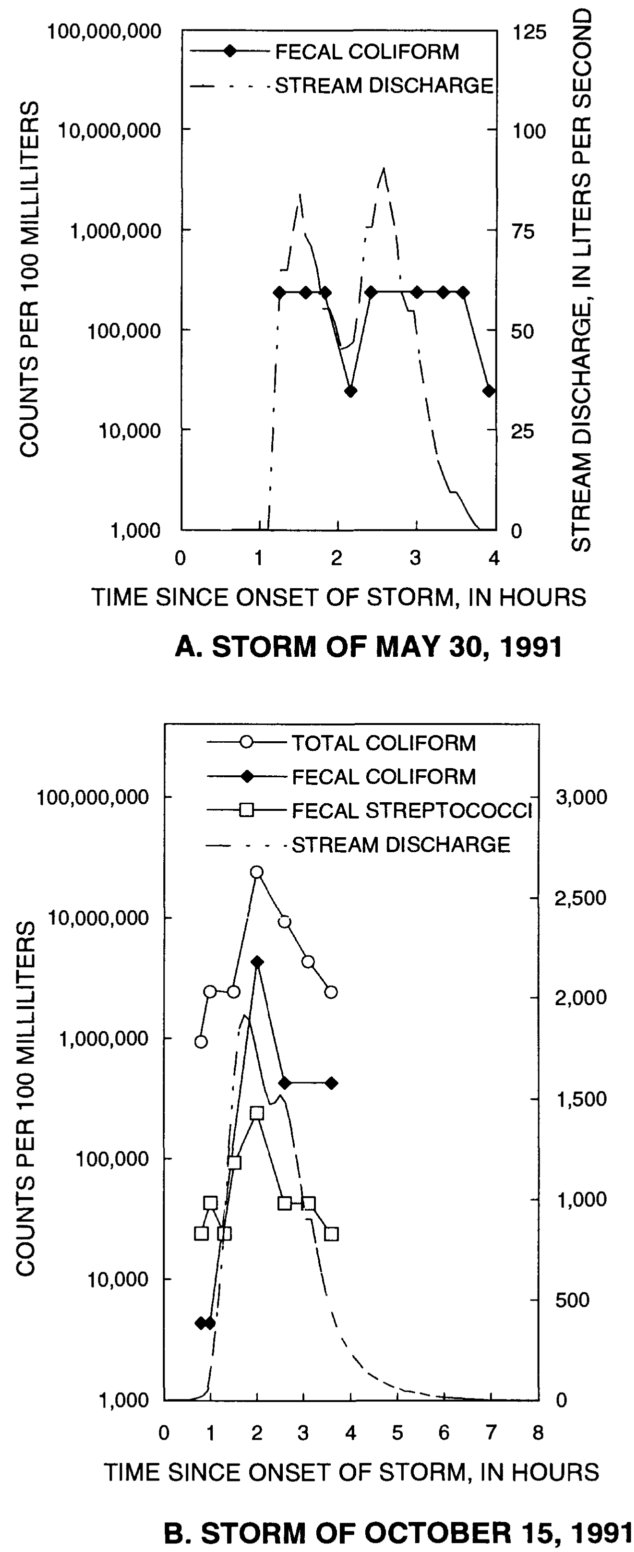

Figure 10. Bacterial counts in relation to stream discharge at Site A in East Meadow Brook headwaters area, Nassau County, N.Y.: A. Fecal coliform during storm of May 30, 1991. B. Total coliform, fecal coliform, and fecal streptococci during storm of October 15, 1991.

of October 15, 1991 (fig. 10B), increased the bacteria count by more than 2 orders of magnitude.

The strong affinity of bacteria for sediment can complicate the interpretation of analytical results because the sorption of bacteria to suspended-sediment particles in stormwater causes the count to decrease as the sediment settles at the end of a storm.

Organic compounds.—Streamflow was sampled during three storms (July 27, 1988, November 1, 1988, and February 3, 1989) during preliminary stages of the project and analyzed for organic compounds, including volatile organic compounds (VOC's); the July 27, 1988 storm samples were also analyzed for pesticides. Concentrations of two VOC's measured in samples from the July 27, 1988 storm exceeded the New York State drinking-water guidelines of 0.005 mg/L; *m*-dichlorobenzene (0.0067 mg/L), and *o*-dichlorobenzene (0.033 mg/L). Concentrations of all measured organic compounds in all other samples were less than 0.005 mg/L. Delay in analysis of samples collected with the automated sampler could have allowed volatilization of VOC's; therefore, the analytical results could be biased low.

Constituent Loads

The loads of selected stormwater constituents were calculated to estimate (1) the contribution from the entire drainage area, and (2) the part of the load that could potentially be transported to ground water. Storm volumes and constituent loads for selected storms between March 1989 and November 1991 at Site A are given in table 5. Data from several storms were excluded because of equipment failure or because the data set for the storm was incomplete. Constituent loads for individual storms were correlated closely with stormwater volume, and stream discharge had a greater effect than concentration on total loads in runoff from a given storm (Stockar, 1994). The loss in storm volume through the streambed between Sites A and B (as discussed in the earlier section, "Headwaters Area") also represents a loss in constituent load. Loads of some stormwater constituents fluctuated seasonally, as discussed below.

Stream stage was recorded, and corresponding streamflow was computed, at 5-minute intervals during all monitored storms at Sites A and B (fig. 2), and water samples were usually collected every 15 minutes. Constituent loads in streamflow were calculated as the discharge for each 5-minute interval multiplied by the concentration in a sample representative of that interval, and the sample loads for each interval were then summed to obtain a total load for the storm. Occasionally the initial pulse of stormwater was not sampled if the automated sampler had a delayed response. The unrepresented loads in such cases were thought to be negligible relative to total storm loads; therefore, the concentration of the first collected sample was used in load calculations.

The base-flow contribution to stormwater was negligible during much of the study period; thus, the base-flow contribution of constituents to the stream was generally considered to be negligible, except in two of the storms analyzed (June 6, 1989, and July 23, 1991), when base flow exceeded about 28 L/s before the beginning of the storms. The concentrations in stormwater, and the corresponding loads, were calculated as the values for stormflow minus the values for base flow.

Storm loads can be affected by storm duration, total precipitation, maximum intensity of precipitation, number of antecedent dry days, total precipitation of the preceding storm, and the season (Ku and Simmons, 1986). These characteristics for 13 storms at Sites A and B are summarized in table 6. The loads of some constituents correlate with stormwater volumes for individual storms (table 5), but the correlations between chloride and nitrogen loads and maximum rainfall intensity, duration of precipitation, total precipitation of the preceding storm, and the number of antecedent dry days for each storm were reported to be poor (Stockar, 1994).

Many constituents, including chloride and nitrate, are quickly washed from impervious surfaces during storms; therefore, storm duration had little effect on the loads of these constituents. The bulk of these constituents would be expected to be washed from impervious surfaces during periods of high rainfall intensity, but graphs of constituent loads as a function of maximum precipitation intensity indicated no correlation for chloride, and moderate to poor correlation for nitrogen species, probably because the loading varies seasonally (Stockar, 1994). Precipitation volume of the preceding storm showed little correlation with loads, probably because the constituents were thoroughly flushed from the basin surfaces; even for storms of moderate size the correlation between preceding precipitation volume and chemical loads was. poor. The amount of dryfall, animal wastes, and other

Table 5. Estimated total storm loads for selected constituents at Site A in East Meadow Brook headwaters, Nassau County, N.Y., 1989-91

[--, no data available. All values are in kilograms]

	Storm date and stormwater volume (liters)					
Constituent	3-18-89 (1.82 x 10^7)	4-15-89 (5.32 x 10^7)	5-10-89 (7.52 x 10^7)	6-6-89 (1.06 x 10^7)	7-23-91 (6.80 x 10^7)	11-22-91 (6.05 x 10^6)
Calcium, total	380	400	480	94	--	62
Magnesium, total	91	120	100	21	--	18
Sodium, total	3,100	260	320	44	--	24
Potassium, total	40	37	102	9.5	--	17
Sulfate, total	400	[1](53-660)	(43-750)	(34-110)	--	52
Chloride, dissolved	4,700	(21-170)	(280-350)	61	(.02-200)	(0.6-18))
Nitrate as N, total	17	16	32	11	73	3.8
Ammonia as N, total	11	44	10	(0-1.1)	16	1.8
Organic N, total	40	470	44	4.8	144	9.6
Phosphate, total	7.8	12	(8.1-8.8)	(0-1.1)	--	2.0
Cadmium, total	(0-.73)	(0-3.2)	(0-.75)	(0-.11)	--	.02
Chromium, total	(0-1.1)	(0-3.2)	(0-.75)	(0-.11)	--	.02
Iron, total	42	44	93	4.0	--	25
Lead, total	.002	(.7-1.1)	(0-3)	(0-0.32)	--	1
Manganese, total	1.9	1.6	4.6	.24	--	.55

[1] To account for constituent concentrations that were below detection limits, a minimum and a maximum load for this range were calculated on the assumption that the minimum concentration below the detection limit was equal to zero, and the maximum concentration below the detection limit was equal to the detection limit.

poor. The amount of dryfall, animal wastes, and other sources of constituents accumulated on impervious surfaces between storms probably has some effect on storm loads, but the seasonal variation in the rate which the sources (such as fertilizers and road salt) are accumulated masked any such correlation.

Wet deposition.—Much of the constituent load in stormwater is derived from atmospheric deposition. Wetfall loads were calculated as the constituent's concentration in precipitation (table 2) multiplied by the runoff volume at Site A (table 7). This more direct method of wetfall-load calculation was used instead of multiplying the wetfall concentration by the basin area because of the urbanized (30 percent impervious) nature of the Westbury drainage area. Dryfall was not sampled during this study; therefore, the wetfall loading estimates represent a minimum value. Wetfall loading varied somewhat throughout the year, depending upon the constituent.

Sperber and Hameed (1986) observed that the wet-deposition concentration of nitrate was somewhat higher during the warmest months (July-September) than at other times. Seasonal patterns could not be determined because wet-deposition nitrate and ammonia loads were not measured during the winter months. Nitrate and ammonia loads from wetfall constituted 29 to 111 percent and 24 to 138 percent of the stormwater loads, respectively; wetfall-derived loads greater than 100 percent of stormwater load suggest utilization by plants, volatilization or oxidation of ammonia, and denitrification or reduction of nitrate, before arrival in the stream. Nitrite was generally not detected in precipitation samples (Stockar, 1994).

The contribution of chloride from wet deposition was only a minor component of the total chloride loading in stormwater during some winter road-salting periods. If wetfall concentrations of 1.1 mg/L and 0.26 mg/L are assumed for chloride and sodium, respec-

Table 6. Characteristics of storms at Sites A and B in East Meadow Brook headwaters area, Nassau County, N.Y., 1989-91

[N/A, not applicable; --, no data available. Locations are shown in fig. 2]

Storm date	Wetfall quantity (centimeters)	Maximum intensity (centimeters per 15 minutes)	Number of antecedent dry days	Location	Streamflow volume (liters)	Loss of volume between Sites A and B (percent)	Estimated recharge volume (liters)	Base-flow contribution (percent)
3/18/89	1.14	0.38	18	Site A Site B	1.82×10^7 1.28×10^7	29.7	0.54×10^7	0
4/15/89	3.18	.3	7	Site A Site B	5.32×10^7 4.72×10^7	11.3	0.60×10^7	0
5/10/89	4.88	.33	4	Site A Site B	7.52×10^7 6.32×10^7	16.0	1.20×10^7	0
6/6/89	.76	.33	1	Site A Site B	1.06×10^7 0.85×10^7	19.8	0.21×10^7	1
9/19/90	1.02	.15	3	Site A Site B	1.07×10^7 1.06×10^7	0.9	0.01×10^7	0
9/22/90	1.90	.20	2	Site A Site B	2.44×10^7 1.53×10^7	37.3	0.91×10^7	0
10/18/90	2.29	.74	5	Site A Site B	5.85×10^7 5.00×10^7	14.5	0.85×10^7	0
4/15/91	.94	--	1	Site A	1.17×10^7	N/A	N/A	0
5/30/91	--	--	1	Site A	5.11×10^5	N/A	N/A	0
7/23/91	2.26	--	9	Site A	6.80×10^7	N/A	N/A	1
10/15/91	--	--	3	Site A	9.40×10^6	N/A	N/A	0
11/22/91	.84	--	10	Site A	6.05×10^6	N/A	N/A	0

Table 7. Estimated wetfall loads from storms at Site A in East Meadow Brook headwaters area, Nassau County, N.Y., 1989-91

[--, no data available. All loads in kilograms]

Constituent	Storm date, wetfall-sampling period, and wetfall quantity (in centimeters)				
	[1]4-15-89 April-May 1989 (3.18)	5-10-89 May 9-16, 1989 (4.88)	6-6-89 June 6-13, 1989 (0.76)	7-23-91 July 16-30, 1991 (2.26)	11-22-91 January 12-26, 1991 (0.84)
Acidity, H^+	3.8	3.2	.71	5.2	0.23
Calcium, total	23	31	.61	33	.46
Magnesium, total	17	19	4.0	3.2	.58
Sodium, total	14	6.4	.88	7.4	4.0
Potassium, total	1.4	--	.15	1.7	1.5
Sulfate, total	150	120	23	230	9.0
Chloride, dissolved	57	40	8.3	15	8.8
Nitrate as N, total	17.7	15	3.2	34	1.6
Ammonia as N, total	12.8	8.3	2.3	22	.83

[1] Wet deposition loads for 4-15-89 were calculated from precipitation-weighted mean concentrations for the second quarter (April-June 1989).

chloride and sodium stormwater loads for the March 18, 1989 storm.

Wetfall loads of sodium generally formed a much lower percentage of the total stormwater load than chloride; this can be attributed partly to the molar ratio of Na to Cl (about 0.7) in precipitation.

Sulfate from wetfall made up 17 to 153 percent of total stormwater load in the storms for which sulfate loads were calculated. Calcium from wetfall constituted from virtually 0 to 6 percent of the total stormwater loads at Site A, magnesium constituted from 0 to 19 percent, and potassium constituted from 0 to 19 percent. The hydrogen-ion loads in wetfall exceeded the total stormwater hydrogen-ion load 9-fold, largely as a result of cation-exchange processes and dissolution of lawn pH adjusters, which greatly decrease the hydrogen ion concentrations after wetfall becomes stormwater.

Road salt.—Road-deicing salts applied during the winter produced occasional large loads of sodium and chloride in East Meadow Brook. Roads are salted by State, county, and town agencies, by institutions, and by private companies. The number of road-salt applications by NCDPW depended on several factors, including the number, magnitude, and duration of storms; the air temperature; and the ratio of sand to salt in the mixture. The general formula used by the NCDPW Highway Division was about 560 kg per center-lane kilometer (km) of road per application; most of the roads maintained by this agency are four-lane roads, thus about 2,240 kg/km is applied (Sal Iannucci, Nassau County Department of Public Works, oral commun., 1995).

The stormwater loads of sodium and chloride at Site A were 1 to 2 orders of magnitude greater during the March 18, 1989 storm than during other storms of comparable volume and were equivalent to 7,700 kg of road salt. At least three deicing events before the March 18 storm—on March 6, March 8, and March 12—were not monitored, and the salt applied on these dates probably was not completely washed from the watershed during these storms. Arbitrarily assuming only one road-salt application at a rate of 560 kg per lane-km and a total application of 38,800 kg indicates that only 20 percent of the salt would have been immediately removed in the March 18, 1989 storm. Although this minimum loading estimate contains considerable uncertainty, it indicates that most of the road salt applied to the basin was probably removed by meltwater before the storm of March 18, 1989 or by storms thereafter; this assumption is supported by the extremely high concentrations of sodium and chloride in the streamwater samples collected on March 6, 1989 (table 4), and in the stormwater sample collected on March 18, 1989 (fig. 8).

Sodium loads for storms sampled at Site A ranged from 24 to 3,100 kg per storm, and chloride loads ranged from below detection to 4,700 kg per storm. Storms with the largest loads of these constituents occurred on March 18, 1989, May 10, 1989, October 18, 1990 (not shown in table 3), and July 23, 1991. The large chloride loads at Site A during the March 18, 1989 storm resulted from road salt; the large loads during the other three storms were due mainly to the large discharge during these storms. Although a strong correlation between winter storms and large salt loads is evident, the paucity of samples obtained during the winter weakens the correlation.

Nitrogen.—Loads of nitrogen compounds in stormwater (table 5) do not show seasonal trends (Stockar, 1994), largely because the frequency of storm sampling was not equal among the four seasons. Storms on April 15, 1989, May 10, 1989, and July 23, 1991, during which high discharges occurred, produced exceptionally large loads of nitrogen compounds. Lawn, park, and golf-course fertilizers, particularly in the spring and fall, probably were the major sources of nitrogen.

Organic nitrogen represented the largest of the nitrogen constituent loads—from 4.8 kg during the June 6, 1989 storm to 470 kg during the April 15, 1989 storm. A high-discharge storm on July 23, 1991 also produced an unusually large organic nitrogen load (144 kg).

Ammonia loads for the sampled storms ranged from an estimated minimum load of zero (below detection limit) in several storms to 44 kg in the April 15, 1989 storm. The large load during this storm is attributed to the relatively large total discharge volume.

Nitrate loads ranged from an estimated 1.7 kg during the storm of May 30, 1991 (not shown in table 3), to 73 kg for the high-discharge storm of July 23, 1991. Large nitrate loads were also observed in the high-discharge storms of May 10, 1989, and October 18, 1990 (not shown in table 5). Nitrite loads (not shown in table 5) for most storms were generally below 2 kg, although the load for the storm of July 23, 1991 exceeded 6.5 kg.

As stated previously, the two major sources of nitrogen in stormwater are animal waste and fertilizers. Stockar (1994) estimated an upper limit of the nitrogen (ammonia plus organic nitrogen) contribution from dog waste in the drainage basin to be from 5.2 to 25.2 kg/d. The organic nitrogen loads calculated from stormwater-sample concentrations and discharge at Site A were lower than estimates calculated from dog-waste contributions in 9 of the 12 storms. The annual load of organic nitrogen to the watershed before volatilization was estimated to be 18,400 kg.

Annual nitrogen loading by fertilizers, calculated from fertilizer-application rates in the pervious areas within the drainage basin, was estimated to be 15,000 kg (Stockar, 1994).

Surface Water Sampled Between Storms

Surface-water samples collected at Site A between storms during gaining-stream (base-flow) conditions consisted mostly of ground water discharging from the aquifer. Base flow was largely absent at Site A during periods of low ground-water levels except in the deepest part of the channel. Samples collected during these periods of low flow probably consisted partly of stormwater remaining from the previous storm; therefore, these data were interpreted conservatively, the samples are referred to as "surface water sampled between storms" rather than "base flow" (table 4).

The ionic strength of stormwater was generally lower than that of surface water sampled between storms, as shown by the specific-conductance values in figure 11. The relatively high specific conductance of ground water that discharges to the stream as base flow is affected by manmade nonpoint sources, such as sewage, road salt, and fertilizers, and also by aquifer weathering.

Sodium and chloride from road salt dominated the chemistry of shallow ground water and surface water sampled between storms during winter periods (fig. 12A, table 4). Concentrations of soluble contaminants derived from nonpoint sources, such as nitrate (fig. 12B), typically are higher in ground water than in stormwater and are diluted during storms, whereas concentrations of less soluble constituents that sorb readily to sediments (for example, ammonia and organic nitrogen) generally are higher in stormwater than in ground water and increase during storms. Fluctuations in calcium were positively correlated with

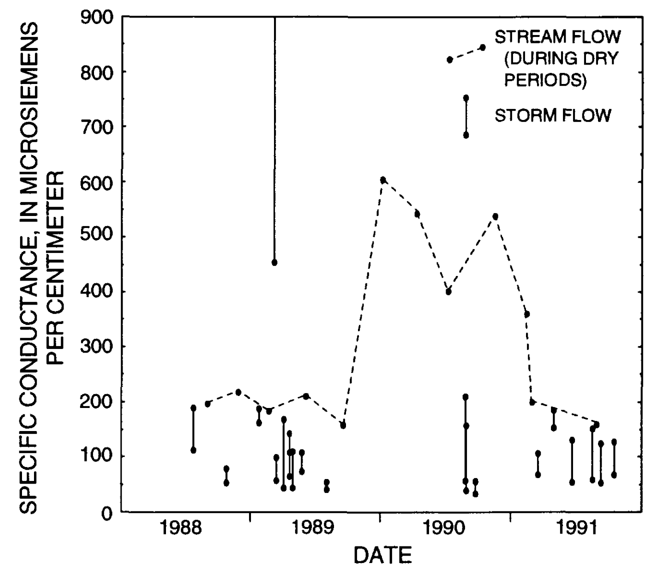

Figure 11. Specific conductance of stormwater and streamflow during dry periods between storms at Site A in East Meadow Brook headwaters area, Nassau County, N.Y., 1988-91.

bicarbonate concentrations during the study period; both constituents were probably derived from pH adjusters ("lime") that are applied to lawns.

Some of the streamflow at Site A after June 1991 consisted of water that was discharged to the headwaters-area culverts from upstream sources. Probable sources include (in chronological order): (1) the previously mentioned water-main break in early 1991, (2) treated water from ground-water-remediation activities at a service station, and (3) ground water from a basement sump at a nearby industrial facility. This added inflow began after the water-main leak began upgradient of the headwaters, and effluent from the ground-water-remediation activities continued to enter East Meadow Brook even after the water main was repaired. Base flow was not observed in East Meadow Brook north of Hempstead Turnpike during this period of artificial streamflow. The effects of the artificial flow on stream chemistry are unknown because the duration and magnitude of artificial flow from the culverts are uncertain.

Ground Water

Several wells in the headwaters area were sampled periodically to define spatial and temporal changes in ground-water quality. Ground-water quality at the

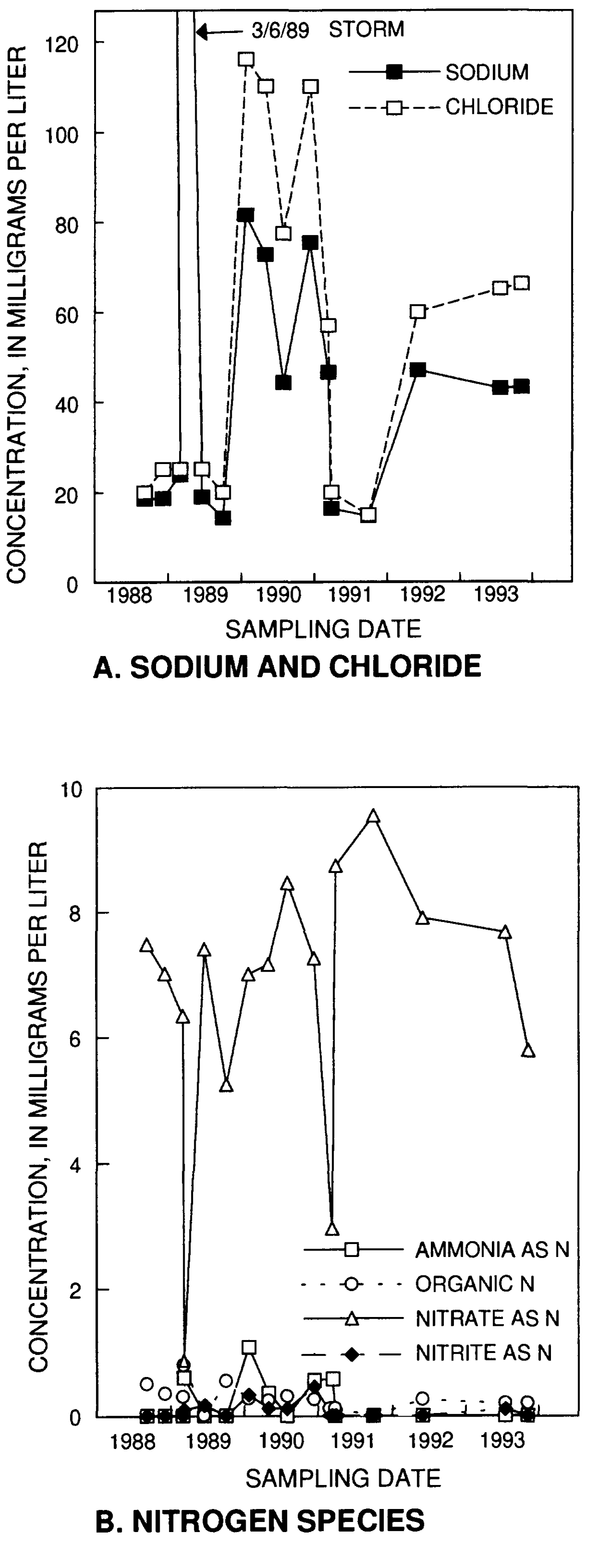

Figure 12. Concentrations of selected chemical constituents in surface water sampled between storms at Site A in East Meadow Brook headwaters area, January 1, 1988 through December 31, 1993. A. Sodium and chloride. B. Nitrogen species.

study site is affected by the regional ground-water flow system, by stormwater infiltration at the headwaters, and by other localized ground-water recharge.

Native (Pristine) Water

The chemistry of ground water under native (pristine) conditions reflects only the chemical composition of precipitation and the composition and solubility of subsurface material. Native water in the upper glacial aquifer generally is slightly acidic, contains low concentrations of bicarbonate, and has low ionic strength. The major cations are sodium, calcium, and magnesium; the major anions are chloride and sulfate.

Ambient Water in Study Area

Shallow ground water was sampled at wells unaffected by channeled stormwater in the East Meadow Brook headwaters area (fig. 2, table 8) to define the quality of ambient, or "background," water. The chemical quality near the study area varied with location, depth, and season. The chemical characteristics of ground water in the headwaters area beyond the

Table 8. Median values of physical properties and concentrations of inorganic constituents in ambient water from selected wells in the East Meadow Brook headwaters area, Nassau County, N.Y., 1989-91

[Concentrations are in milligrams per liter. µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than. Locations are shown in fig. 2]

Property or constituent	Well number and depth (in meters)		
	N11603 (13.7 m)	N11618 (13.1 m)	N10292 (15.2 m)
Specific conductance (µS/cm)	220	359	186
pH (standard units)	5.8	6.5	5.3
Dissolved oxygen	3.0	2.2	4.0
Calcium	8.7	16	10
Magnesium	4.1	4.0	3.5
Sodium	25	53	18
Potassium	3.5	1.6	3.4
Alkalinity, as HCO_3^-	22	44	3.7
Chloride	28	80	18
Dissolved solids	144	216	134
Nitrate, as N	3.4	3.7	6.5
Phosphorus, as P	<0.05	<0.1	<0.05

stream differed from well to well and reflected local contaminant sources and land use. Three such background-quality monitoring wells were selected as a basis for comparison with wells in areas known to be affected by stormwater in the stream channel. Diagrams of the chemical quality of samples from these wells (fig. 13) depict temporal trends and local chemical differences among the three well sites.

Water samples from well N10292, in Eisenhower Park, about 0.9 km northeast of the headwaters (fig. 1),contained low dissolved-solids, sodium, and chloride concentrations, and relatively high median nitrate concentrations (6.5 mg/L, as N); the latter are attributed to lawn fertilizers.

Relatively high sodium and chloride concentrations in shallow ground water indicate long-term contamination from road salt. Water at well N11603, adjacent to the Meadowbrook Parkway (fig. 1), is vulnerable to contamination by road salt, as is water at well N11618, at Nassau County Community College, where road salt was stored in early 1989. The large peaks in sodium and chloride concentrations (680 mg/L and 1,200 mg/L, respectively) in water from well N11618 result from halite that has leached into the ground-water system with precipitation.

Area near Stream Channel

Whereas ambient ground water near the headwaters area generally contains relatively high concentrations of sodium, chloride, calcium, and nitrate, mostly from human-derived sources, ground water adjacent to the stream channel often was diluted by stormwater, except when the stormwater was salt laden. The runoff from most storms during the non-road-salting season contains relatively low concentrations of most constituents except bacteria. During periods of road salting, however, concentrations of several constituents in stormwater generally exceed those in ambient ground water and directly affect the quality of shallow ground water. As a result, median concentrations of calcium, magnesium, sodium, bicarbonate, and chloride in shallow ground water in the headwaters area (table 9) were generally higher than median concentrations at "background" wells (table 8) and were not greatly diluted by regional flow. An exception was a shallow monitoring well at the bottom of a small recharge basin north of the site (N11226, location shown in fig. 2), which had lower concentrations of several constituents than did ambient ground water or ground water adjacent to the stream channel. These lower concentrations are attributed to dilution by stormwater from the recharge basin and only minimal effects of road salt.

Median concentrations of sodium, chloride, calcium, magnesium, and bicarbonate in ground-water samples from beneath the stream channel near Site A (wells N11227, N11228) were much higher than the median concentrations in stormwater (table 9). A comparison of the range in concentrations shows, however, that the concentrations of several constituents were much higher in stormwater during some storms than in the underlying ground water and degraded the ground-water quality. Concentrations of sodium and chloride in deep monitoring wells, such as N11229 and N11254, which are screened at depths of 32 to 32.9 m, and 30.2 to 31.1 m, respectively (table 9; location shown in fig. 2), were lower than those at the shallow well of each cluster probably as a result of dilution by regional ground-water flow.

Road salt and major constituents.—Road salting generally affected the quality of surface water and ground water only a few times per year (after salt applications), yet these effects sometimes lasted several months. For example, infiltration of stormwater in March 1989 caused a 10-fold increase in sodium and chloride concentrations in shallow ground water beneath the stream. High peaks of sodium and chloride on March 9, 1989 (740 and 1,350 mg/L, respectively; fig. 14A) were measured in ground water at monitoring well N11227, screened from 3.4 to 4.3 m below the streambed. Concentrations at the slightly deeper well within that cluster, N11228, which is screened 3.7 to 4.6 m below the streambed, were lower than at N11227 (fig. 14A); this indicates a vertical decrease in the effects of stormwater. Stormwater with relatively low median concentrations of sodium and chloride (8.1 and less than 3.0 mg/L, respectively) on April 15, 1989 diluted the underlying shallow ground water, as evidenced by the decrease in sodium and chloride concentrations at most of the nearby shallow wells by June 1989.

The vertical extent of road-salt contamination from the March 1989 storm was studied further by examination of temporal variability in sodium and chloride concentrations at several monitoring-well clusters in the headwaters area (fig. 14A). Chloride-to-bromide ratios (fig. 14B) were used to distinguish chloride derived from halite (road salt) from chloride

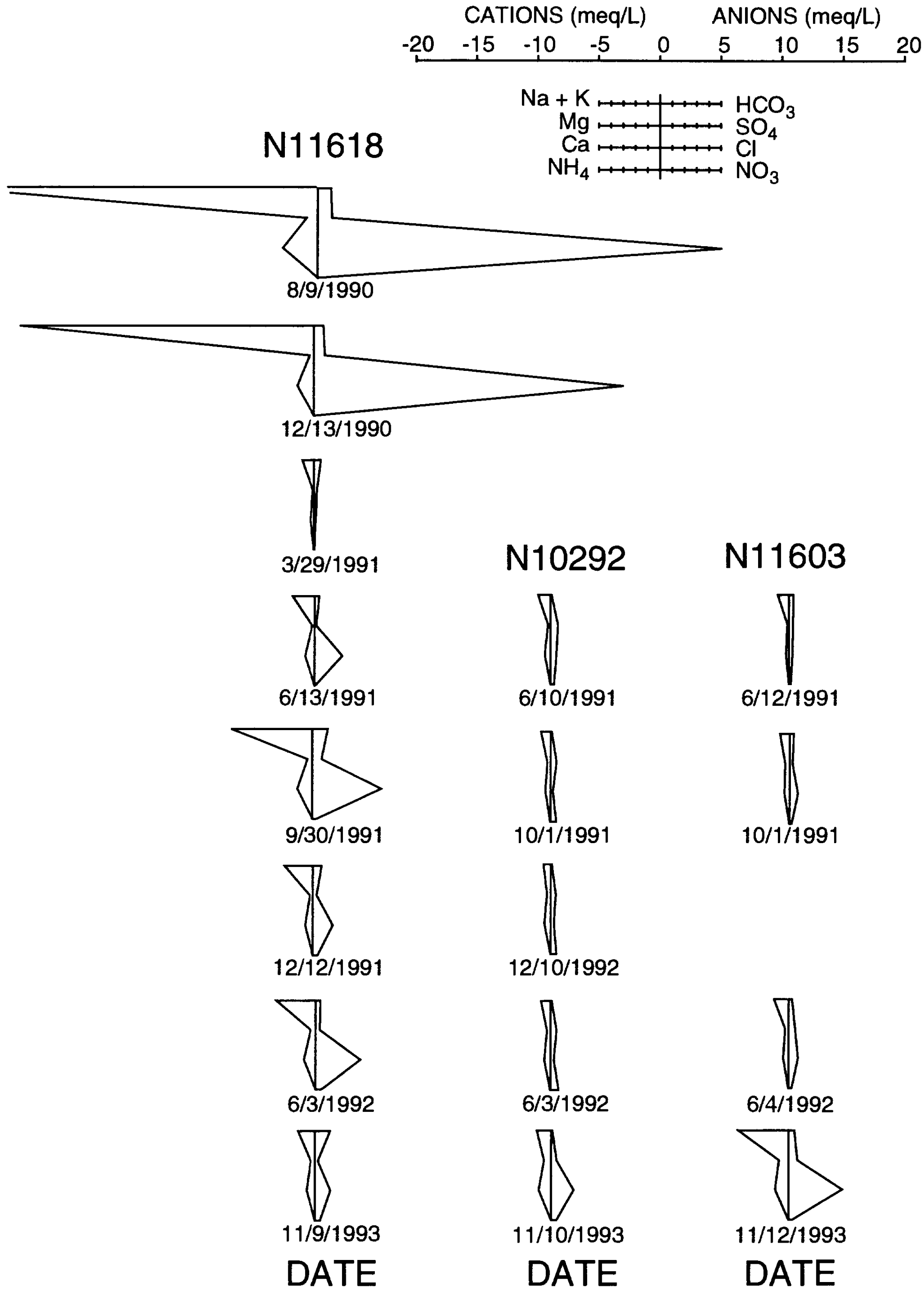

Figure 13. Concentrations of selected chemical constituents in water from wells N10292, N11603, and N11618 in the East Meadow Brook headwaters area, Nassau County, N.Y. (Well locations shown in fig. 2. From Brown and Scorca, 1995, fig. 5.)

derived from precipitation (Schoonen and others, 1995). The graphs of the data for the shallowest wells (N11227 and N11228, fig. 14B) include a dotted line representing the chloride-to-bromide ratio in seawater (the primary source of chloride and bromide in precipitation); water unaffected by road salt would be expected to plot along this line. The dashed line in figure 14B represents the chloride-to-bromide ratio in halite, the dominant constituent in road salt. Groundwater samples collected after road salting (for exam-

Table 9. Median and range of physical-property values and concentrations of constituents of stormwater at Site A in East Meadow Brook headwaters area, and in selected monitoring wells, Nassau County, N.Y.

[Numbers in parentheses represent range. µS/cm, microsiemens per centimeter at 25 degrees Celsius. All concentrations are in milligrams per liter. Locations are shown in fig. 2]

Property or constituent	Site A (stormwater)	Well number and depth, in meters							
		N11226 3.0	N11227 4.3	N11228 4.6	N11229 32.9	N11230 10.1	N11254 31.1	N11255 9.8	N11256 6.7
Specific conductance (µS/cm)	87 (33-8,400)	120 (58-420)	803 (167-4,200)	496 (206-1,430)	728 (499-961)	926 (800-1,000)	168 (130-234)	292 (158-1,060)	516 (114-974)
pH (standard units)	7.0 (6.7-7.8)	6.4 (6.2-6.8)	7.0 (6.7-7.3)	7.0 (6.9-7.3)	5.5 (5.3-5.6)	6.6 (6.3-6.9)	5.3 (5.0-6.1)	6.2 (5.8-6.9)	7.0 (5.9-7.4)
Dissolved oxygen	9.8 (5.0-13)	2.4 (0.4-8.4)	3.0 (0.5-11)	6.5 (.6-9.7)	1.3 (1.0-4.2)	4.1 (2.2-6.0)	3.9 (3.0-7.0)	1.9 (0.8-12)	7.6 (1.0-10)
Calcium, total	8.8 (3.0-64)	4.3 (.5-7.3)	27 (14-84)	25 (13-49)	18 (14-27)	20 (16-27)	5.9 (4.3-9.0)	2.0 (0.3-44)	16 (6.2-43)
Magnesium, total	2.3 (0.6-13)	1.0 (0.1-1.7)	6.5 (3.2-16)	6.2 (3.4-14)	11 (8.7-14)	7.2 (5.5-8.9)	2.9 (2.3-5.2)	.8 (0.1-23)	4.2 (1.5-23)
Sodium, total	6.2 (1.5-1,700)	14 (3.2-88)	88 (13-740)	82 (13-220)	95 (72-130)	130 (120-160)	15 (9.9-41)	52 (28-160)	72 (6.1-160)
Potassium, total	1.7 (0.4-4.9)	.6 (<0.2-2.2)	3.7 (1.1-7.2)	3.4 (0.8-6.0)	2.5 (2.0-3.6)	2.7 (2.0-4.5)	1.1 (0.7-1.5)	1.6 (0.4-7.6)	2.6 (0.6-8.3)
Alkalinity, as HCO_3^-	20 (12-300)	22 (17-29)	59 (24-200)	65 (34-200))	18 (12-21)	35 (23-51)	7.3 (4.9-9.8)	26 (11-33)	48 (12-71)
Sulfate, total	8.4 (3.8-40)	6.2 (5.8-17)	18 (2.5-35)	19 (2.5-33)	46 (31-71)	14 (<10-25)	<10	21 (<10-28)	15 (<10-25)
Chloride, dissolved	3.0 (2.5-2,700)	18 (<3-110)	120 (12-1,400)	120 (18-420)	170 (90-240)	240 (220-270)	22 (12-92)	50 (15-320)	110 (10-300)
Dissolved solids	120 (26-4,600)	59 (46-311)	390 (90-2,500)	210 (130-690)	530 (490-580)	490 (420-640)	125 (120-140)	150 (110-580)	270 (86-510)
Silica, total	2.5 (0.7-10)	1.9 (1.2-43)	6.8 (6.4-7.6)	7.1 (6.2-7.8)	13 (12-14)	4.6 (4.4-4.9)	7.5 (7.4-8.0)	1.7 (1.3-2.0)	3.4 (2.9-4.1)
Nitrate as N, total	1.0 (<0.1-9.6)	.34 (0.1-1.6)	3.4 (1.7-6.3)	3.3 (1.7-5.5)	3.4 (2.6-4.4)	0.93 (0.2-1.8)	7.5 (1.8-9.2)	1.9 (1.0-2.8)	2.2 (0.6-5.2)
Iron, total	.69 (<.01-8.7)	.48 (140-7,900)	.48 (14-5,500)	.36 (60-2,200)	2.5 (1,100-3,600)	11 (1,200-13,000)	.88 (300-1,700)	.86 (200-8,900)	1.4 (150-4,900)
Manganese, total	.05 (<.01-1.3)	.02 (<.01-.39)	.03 (.01-.11)	.04 (<.01-.12)	.04 (<.02-.06)	.16 (.15-.25)	.02 (.01-.04)	.17 (.03-1.7)	.06 (<.02-1.7)

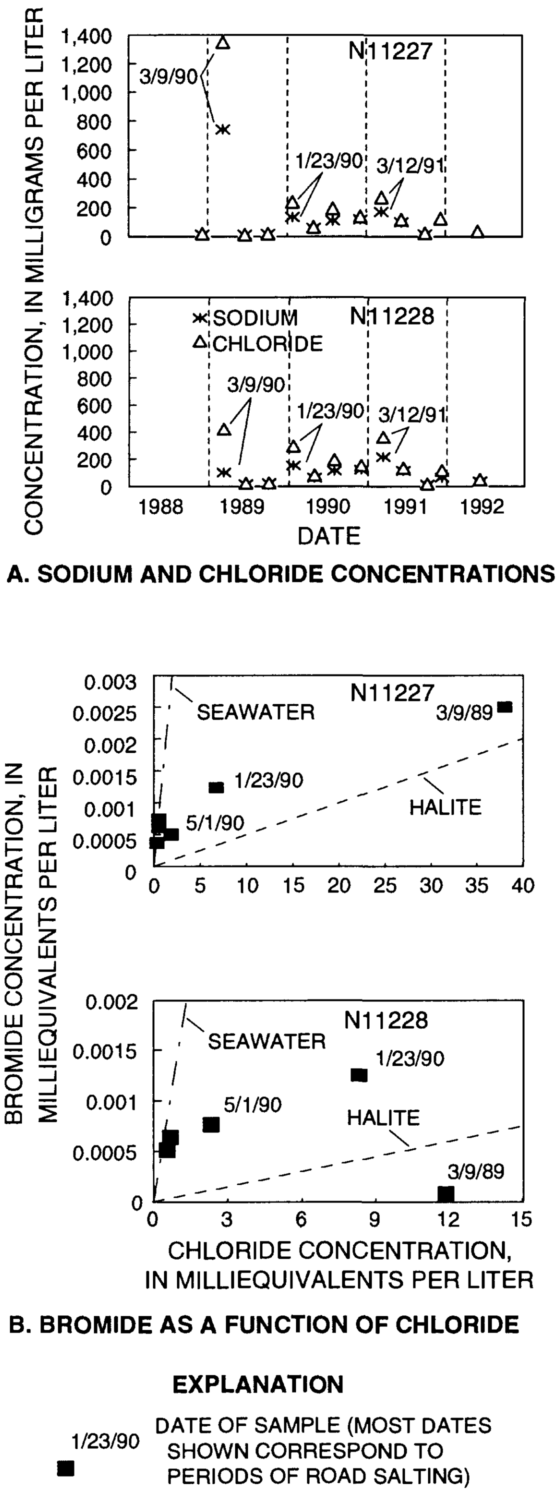

Figure 14. Salt concentrations in ground water at shallow wells N11227 and N11228 in East Meadow Brook headwaters area, Nassau County, N.Y., 1988-92: A. Sodium and chloride. B. Bromide as a function of chloride. (Well locations are shown in fig. 2.)

ple, on March 9, 1989, and January 23, 1990) plot far from the seawater line and near the halite line, whereas ground-water samples collected during the warmer months (not labeled) plot along the seawater line. Samples that plot between the two lines (for example, on May 1, 1990) represent water in which chloride concentration is affected by both precipitation and the halite in road salt.

Mixing of shallow ground water that is affected by road salt with deeper, less-affected water is evident at monitoring wells adjacent to the East Meadow Brook headwaters area. Chemical data from wells N11254, N11255, and N11256, which form a cluster in the southwestern part of the site (fig. 2), were used to estimate the vertical extent of road-salt contamination. Sodium and chloride concentrations in ground water from the shallow well (N11256) show distinct concentration peaks on March 10, 1989, January 29, 1990, and March 27, 1991, after winter storms that were preceded by periods of road salting (fig. 15A). Sodium and chloride concentrations also were elevated on November 8, 1993, after completion of the stormwater-detention basin. Data points for wells N11256 and N11255 plot near the halite line in figure 15B and reflect road-salt contamination, and data points for the deep well (N11254) lie only along the seawater line, indicating that the major source of chloride for the deeper (greater than 30 m) system is areal recharge from precipitation.

Water from wells west of the stream channel also contained elevated concentrations of sodium, chloride, and several other constituents that are probably derived from a salt-storage facility 200 m northwest of the headwaters. The headwaters reach was under losing conditions during this storm period, however; thus, shallow ground water probably did not affect constituent concentrations in the stream.

Nutrients and bacteria.—Organic nitrogen and ammonium concentrations are lower in ground water than in stormwater because they tend to (1) sorb readily to sediments, and (2) oxidize to nitrite and nitrate. Nitrite and organic species of nitrogen are unstable in aerated shallow ground water and are generally considered to be indicators of sewage or organic waste (Hem, 1989). Nitrate, the most stable form of nitrogen in ground water, generally was detected in higher concentrations in ground water than in stormwater (tables 7 and 8). Nitrate concentrations above 1 mg/L as N in ground waters of Nassau County are

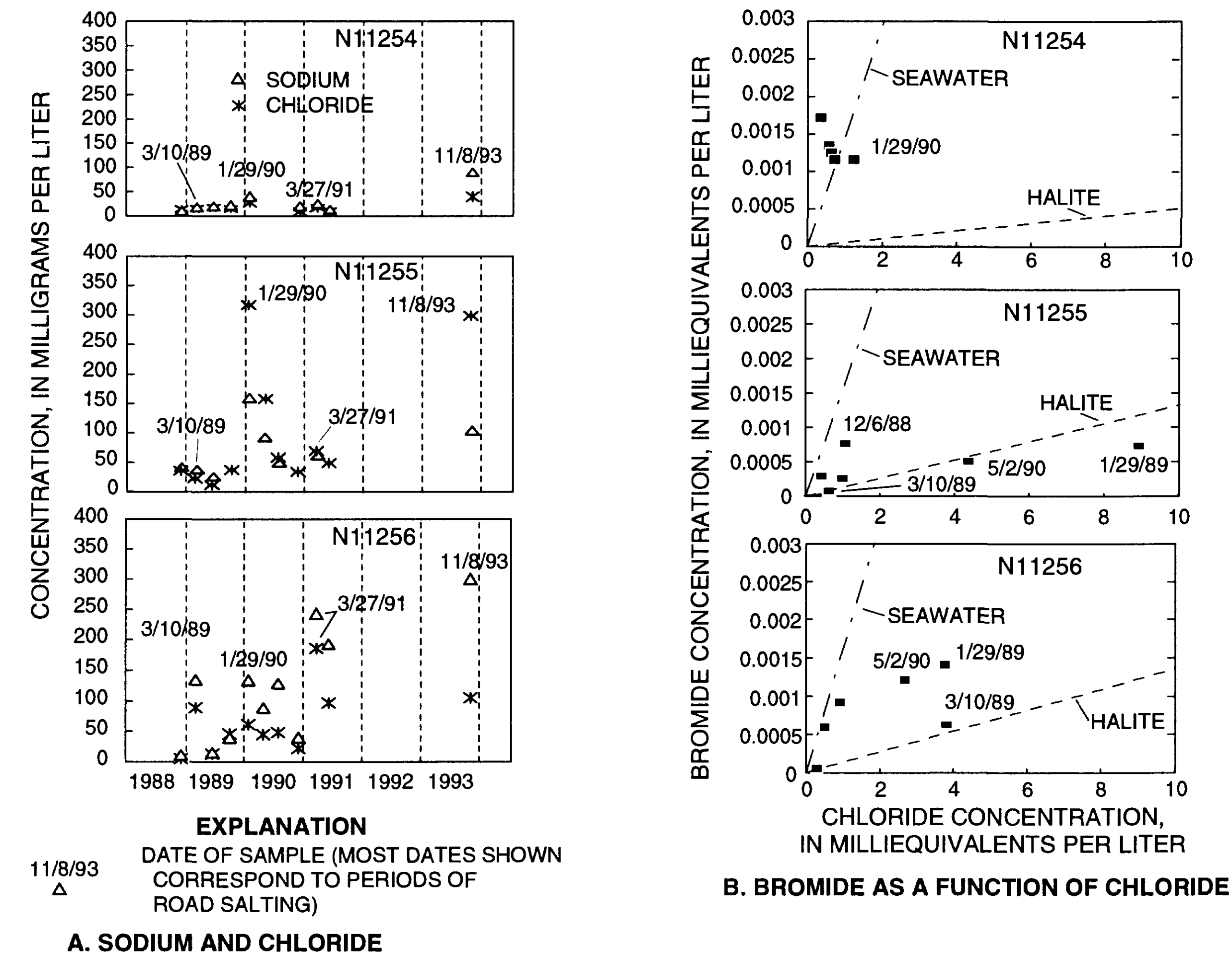

Figure 15. Salt concentrations in ground water at wells N11254, N11255, and N11256 in East Meadow Brook headwaters area, Nassau County, N.Y., 1988-93: A. Sodium and chloride. B. Bromide as a function of chloride. (Well locations are shown in fig. 2.)

attributed mostly to nonpoint sources, such as septic systems and fertilizers, not from stormwater (Ku and Sulam, 1979).

Nitrite and phosphate concentrations were generally below detection limits in ground-water samples at the headwaters area.

Coliform bacteria were generally absent in ground-water samples from the headwaters area because they are filtered or sorbed by the sediment (Katz and Mallard, 1980; Ehrlich, and others, 1979).

Other constituents.—Metals analytes in ground-water samples, except iron and manganese, were generally below detection limits; therefore metals were not considered a major contaminant in the study area. Cadmium was not detected, but a total chromium concentration of 0.06 mg/L, which is above the New York State drinking-water standard of 0.05 mg/L, was measured on one occasion (December 3, 1990) at well N11227. Total lead concentrations (0.06 mg/L) slightly exceeded the New York State drinking-water standard (0.05 mg/L) in N11226 and N11230.

VOC's were not detected in ground-water samples during this study. No analyses were made for other organic compounds, including pesticides, base/neutral-extractables, and acid-extractables.

Effects of Stormwater-Detention Basin

One objective of constructing the stormwater-detention basin in the headwaters area of East Meadow Brook (fig. 2) was to attenuate storm-related contaminant loads. Detention basins and dams that are constructed along the length of a stream should attenuate peak stormflows, increase ground-water recharge through infiltration, and allow settling time for sediment, which results in lowered levels of contaminants, particularly bacteria, that are otherwise discharged downstream. Surface-water and ground-water samples were obtained in the headwaters area of East Meadow Brook after construction of the detention basin to determine its effects on water quality. Samples were obtained from the basin in July 1993 for complete analysis, and in August 1993 for bacteria measurements. Ground-water and surface-water samples were collected during November 1993 for evaluation of surface-water/ground-water interactions.

Detention-Basin Water.

Water samples were collected in the headwaters area on three occasions after construction of the detention basin. Surface-water samples were collected at four locations within the basin in July 1993, and also in August 1993 before a storm (August 17) and for a few days thereafter to determine the effects of stormwater retention on bacteria counts. Total-bacteria counts declined by 2 orders of magnitude, and fecal streptococcus decreased by 3 orders of magnitude within 2 days after the storm (fig. 16).

Surface-water and ground-water samples were collected at several locations near the detention basin during dry conditions on November 8-12, 1993; results of chemical analysis are shown in table 10. Observation-well clusters adjacent to the detention basin also were sampled to determine effects of stormwater infiltration on ground water. Results of the November sampling indicate higher sodium and chloride concentrations in some wells, and lower nitrate concentrations in most wells (table 10) than the preconstruction medians (table 9); concentrations of sodium, chloride, calcium, and magnesium (table 10) at monitoring wells N11254, N11255, and N11256 (fig. 2) also were higher than the preconstruction medians (table 9). VOC concentrations were below drinking-water guidelines in all surface-water and ground-water samples collected at this time.

A water sample from the detention basin at Site E (fig. 2) had very low ionic strength, which is indicative of ponded storm water. Water chemistry at Site D (fig. 2), downstream from the basin, was similar, although total coliform bacteria levels were an order of magnitude greater than in the basin, and fecal coliform bacteria and fecal streptococcus were lower. These differences may reflect a different source of nonenteric coliform bacteria and a greater die-off rate of enteric bacteria at Site D than at the upstream basin.

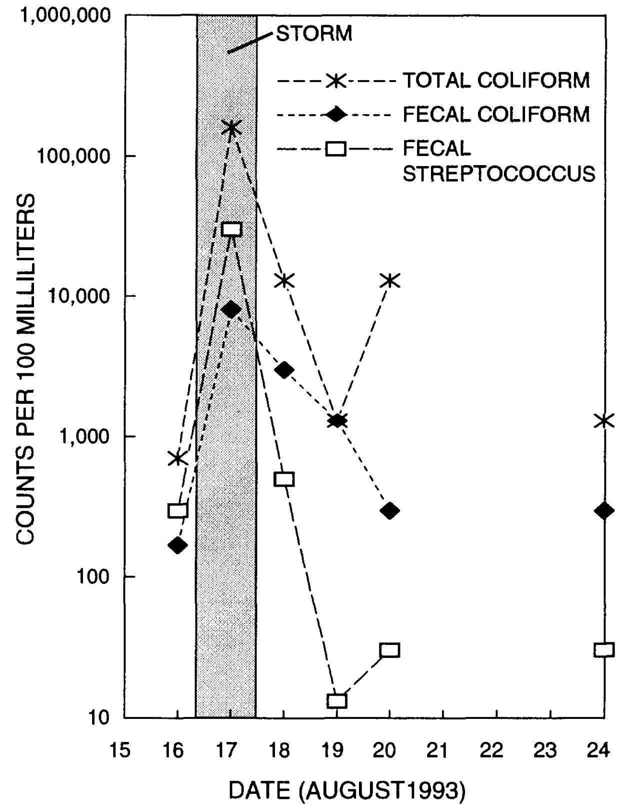

Figure 16. Counts of total coliform, fecal coliform, and fecal streptococcus in stormwater at Site A in East Meadow Brook headwaters area, Nassau County, N.Y., before, during, and for 1 week after a storm on August 17, 1993.

Stream water at Site A, just downstream of the main culverts, had higher concentrations of chloride, sodium, nitrate, and calcium, and a lower level of fecal coliform bacteria than at Sites D and E; this indicates a ground-water source of these constituents upstream of Site A, perhaps the effluent of ground-water remediation operations, as explained earlier.

Water samples from wells adjacent to the basin had similar concentrations of constituents to basin-water samples during base-flow conditions in November 1993, but samples from the basin contained little or no bacteria. Basin influent had much higher nitrate concentrations than the ponded waters, contrary to

Table 10. Physical-property values and concentrations of constituents at Sites A, D, and E, and in monitoring wells at the East Meadow Brook headwaters area, Nassau County, N.Y., during dry conditions on November 8-12, 1993

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; all concentrations are in milligrams per liter. Well and site locations are shown in figs. 2 and 3]

	Surface-water site			Well number and depth (in meters)				
Property or constituent	Site A	Site D	Site E	N11254 (31.1)	N11255 (9.8)	N11256 (6.7)	N 9406.3 (17.7)	N 10292 (15.2)
Specific conductance (µS/cm)	340	99	100	330	1,000	1,030	120	340
pH (standard units)	7.2	6.9	6.8	5.0	5.9	5.9	6.2	4.9
Calcium, total	12	8.7	7.6	9.0	44	43	6.6	20
Magnesium, total	3.5	1.9	1.9	5.2	23	23	1.3	7.0
Sodium, total	43	8.3	9.9	41	107	109	15	25
Potassium, total	2.1	1.5	2.1	.99	7.6	8.3	1.0	3.0
Alkalinity, as HCO_3^-	21	28	23	7.3	10.8	12	21	10
Sulfate, total	14	6.1	7.7	<5	12	12	8.5	21
Chloride, dissolved	66	10	18	92	300	300	10	65
Dissolved solids	220	83	96	220	760	740	71	220
Nitrate as N, total	5.8	.97	1.1	1.8	1.8	1.7	4.2	5.8
Ammonia as N, total	<.1	<.2	<.1	<.1	<.1	<.1	<.1	<.1
Organic N, total	.2	2.6	1.0	.2	.3	.4	.1	.1
Iron, total	.06	.42	.34	1.7	2.2	3.2	.004	<.003
Manganese, total	.13	.03	.07	.01	1.7	1.7	.08	.13

preconstruction results, when stream concentrations were higher than inflow concentrations.

Ground Water

Concentrations of most constituents in shallow ground-water samples collected near the headwaters in November 1993, 1 year after basin completion, were higher than samples collected before basin construction; this suggests that a period of road salting had preceded the November 1993 sampling.

SUMMARY AND CONCLUSIONS

The chemical quality of precipitation, stormwater, and ground water in the headwaters area of East Meadow Brook were monitored during 1988-93 to determine effects of urban stormwater on streamwater and ground-water quality. Stormwater chemistry was monitored during 13 storms, and ground-water samples were collected on 6 to 12 occasions.

Storm loads largely reflected the magnitude of the storm and the season. Large inputs of sodium and chloride to the stream and to ground water generally followed the application of road salt during winter storms. Stormwater during the nonwinter season had relatively low ionic strength and tended to dilute shallow ground water below and adjacent to the streambed. Much of the loading of ions to stormwater and ground water at these times was derived from precipitation.

Concentrations of constituents in the water of East Meadow Brook reflect (1) their chemical source, (2) the relative contribution of base flow (ground-water discharge) to total streamflow, (3) the mechanism of source input into the hydrologic system (for example, nonpoint-source or streambed infiltration), and (4) constituent concentrations in precipitation. Nitrate concentrations, for example, are relatively low in stormwater, but are elevated in base flow and reflect the input of human-related nitrogen to ground water by infiltration with precipitation through soils in the watershed rather than by infiltration of stormwater. The dominant nitrogen species during a period of gaining-stream conditions was nitrate, but during losing-stream conditions the dominant form was organic nitrogen. Potassium, magnesium, sulfate, organic nitrogen, and bacteria, conversely, are in higher concentration in stormwater than in base flow, suggesting that these constituents are washed from surface sources and transported to the stream during storms. Potassium, organic nitrogen, bacteria, and to a lesser extent, magnesium and sulfate are either poorly soluble, tend to be sorbed to suspended sediment, or are colloidal, and are transported during peaks in precipitation and discharge.

Concentrations of most major ions were lower in stormwater than in base flow or ground water except during periods of road salting. The principal sources of three of these ions in base flow—calcium, bicarbonate, and nitrate—are probably fertilizers and lime applied to residential lawns and farms, old septic systems, leaking sewers, and animal waste. Some constituents, including chloride, sodium, and nitrogen species, are related to seasonal factors and, therefore, can be higher or lower in stormwater than in base flow or shallow ground water, depending on the season.

Chloride-to-bromide ratios were used to distinguish chloride derived from halite (road salt) from chloride derived from precipitation and sea spray. Deep ground water (greater than 30 m) was not affected by road salt; thus, road-salt contamination probably extends only to depths of less than 30 m below land surface in this area. Any road-salt affected water that did reach greater depths would be diluted by regional ground water.

Only a few of the chemical constituents measured in ground water beneath the streambed exceeded New York State drinking-water standards. Concentrations of total cadmium and total lead (0.06 mg/L) slightly exceeded the drinking-water limits of 0.05 mg/L in three wells (all screened less than 10 m below land surface), but only in samples collected on one date. Most public-supply wells in Nassau County are screened at depths below the water-table aquifer, thus contamination by stormwater is unlikely to reach such depths beneath the headwaters.

The headwaters detention basin, and probably other detention basins or dams along the length of East Meadow Brook, help to attenuate bacteria counts and decrease chemical inputs to the coastal waters by increasing the infiltration of stormwater and enhancing die-off of bacteria in the ponded waters.

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