EFFECTS OF ROAD SALTING ON STORMWATER AND GROUND-WATER QUALITY AT THE EAST MEADOW BROOK HEADWATERS AREA, NASSAU COUNTY, LONG ISLAND, NEW YORK

by

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ABSTRACT

Water quality in the East Meadow Brook headwaters area was monitored during 1988-93 as part of a study to determine the effects of urban storm runoff on stream and ground-water quality. One of the major sources of contamination at the site was road salt (NaCl). Salt-laden runoff from a winter storm on March 18, 1989, resulted in a 10-fold increase of sodium and chloride concentrations in shallow ground water beneath the stream. Ground-water samples were analyzed for sodium and chloride to estimate the contributions of those ions from road salt and from precipitation.

Loads of sodium and chloride in stormflow reflected the magnitude of the storm and the season and were proportional to the stormflow volume measured at the headwaters area. Dilution of chloride concentrations in stormwater during nonwinter months lowered the sodium and chloride concentrations in shallow ground water adjacent to and beneath the stream channel; most of the salt loads in stormflow and salt concentrations in ground water during nonwinter months resulted from atmospheric deposition. Although chloride concentrations in wetfall were generally higher during the fall and winter than in spring and summer, the chloride contribution to the total loads in stormflow was greatest (7 to 60 percent) during the spring and summer.

After road-salt applications to the Westbury drainage area, large amounts of sodium and chloride entered the stream and ground water and affected the ground-water quality beneath and adjacent to the stream for several months. Concentrations of sodium and chloride in stormwater during a winter storm on March 18, 1989 reached 1,700 mg/L and 2,700 mg/L, respectively. Median concentrations of sodium and chloride in wells affected by road salt were generally several times higher than concentrations in unaffected shallow wells in suburban areas. Bromide-to-chloride ratios were used to identify the vertical migration of road salt within the shallow aquifer.

INTRODUCTION

Most drinking water in Nassau County, N.Y., before the peak of suburban expansion in the 1950's, was obtained from shallow domestic wells and was returned to the ground-water system through septic tanks and leach fields. The widespread urbanization of Nassau County since then has resulted in a decrease in ground-water recharge through the decrease in pervious-surface area and the diversion of stormwater and treated wastewater to coastal waters (Simmons and Reynolds, 1982; Ku and others, 1992); this loss of recharge has caused a lowering of ground-water levels (Franke, 1968) and a decrease in the base flow of streams (Pluhowski and Spinello, 1978). Ground water in urbanized parts of Nassau County contains much higher concentrations of chemical constituents than does ground water in unsewered and rural areas of Long Island (Eckhardt, and others, 1989; Stackelberg, 1995), and one of the major contaminants is road-deicing salt (NaCl), which enters the water-table aquifer as dissolved sodium and chloride during most winters. Although this process is not a major concern at present because it has not yet significantly affected the Magothy aquifer (the major drinking-water source) and is not an immediate threat to human health, it is of interest because extremely high concentrations have been detected in stormwater and in shallow ground water, and because salt concentrations in the deep ground-water system may continue to rise.

East Meadow Brook (fig. 1), the longest stream in Nassau County, flows southward through south-central Nassau County from Hempstead to Great South Bay. The headwaters consist of storm runoff that originates in the Westbury drainage area (fig. 1) and discharges into the stream channel through culverts. Storm runoff that enters the stream channel either infiltrates to the water table or discharges as streamflow to Great South Bay (fig. 1).

During 1988-93, the U.S. Geological Survey (USGS), in cooperation with the Nassau County Department of Public Works (NCDPW), studied the effects of stormwater infiltration on water quality at the headwaters of East Meadow Brook in which a retention basin had been excavated directly east of the streambed to increase ground-water recharge. Road salting within the watershed is a major source of salt loading to ground water, and the effects were investigated as part of that study. This paper (1) discusses the concentrations of sodium and chloride in precipitation and stormwater, and (2) describes the extent of ground water effected by road salt beneath the stream and relates the concentration data to specific storms.

Study Area

The study area consists of a 3.6-hectare 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 storm runoff from part of the village of Westbury, just north of the study area, and discharges into the head of the stream through two culverts at the northern end of the study area. The channel length in the study area was about 460 m, and the stormwater-detention basin (fig. 2), which was constructed in 1992, is about 460 long by 90 m wide.

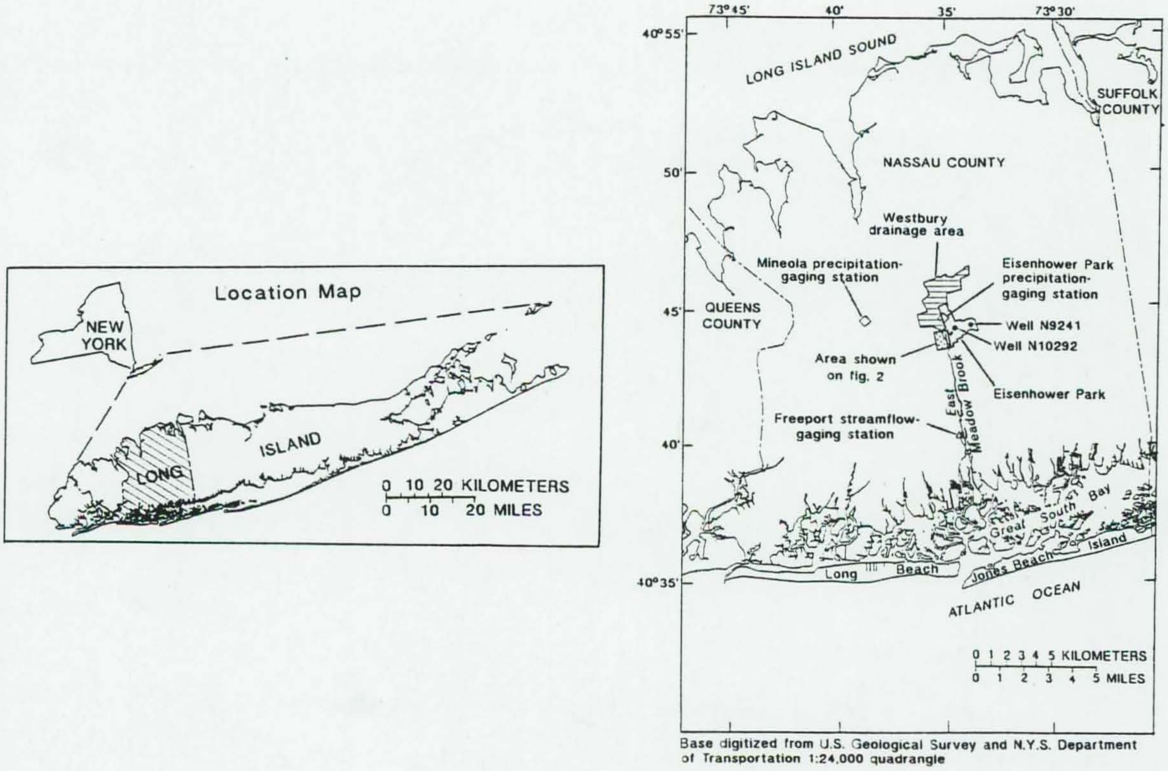


Figure 1. Locations of East Meadow Brook and selected data-collection sites in Nassau County, N.Y.

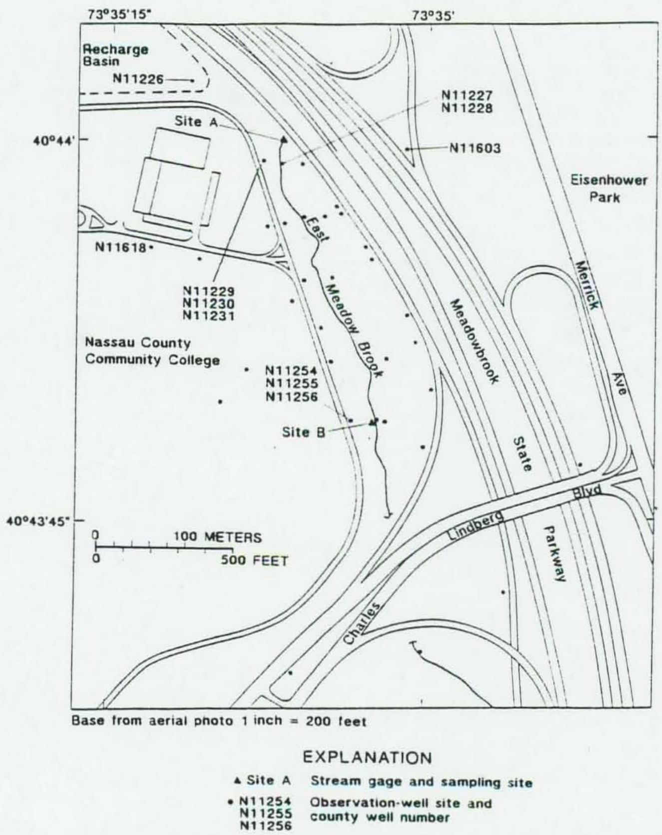


Figure 2. Locations of sampling sites in the East Meadow Brook headwaters, Nassau County, N.Y. (Location shown in fig. 1.)

Previous Studies

Several aspects of the study area were investigated previously as part of the Nassau County Streams and Wetlands Area Management Program. M.P. Scorca (U.S. Geological Survey, written commun., 1994) studied long-term changes in hydrologic conditions near the stream. Frederick Stumm (U.S. Geological Survey, written commun., 1994) examined the response of streamflow to urban runoff and calculated the percentage that becomes recharge during storms at the headwaters site. M.P. Scorca and H.F.H. Ku (U.S. Geological Survey, written commun., 1994) described fluctuations of ground-water levels at the site. Stockar (1994) studied the sources and fate of nitrogen and chloride in urban runoff at the headwaters area. C.J. Brown and others (U.S. Geological Survey, written commun., 1995) studied the effects of stormflow on water quality.

Koppelman and Tanenbaum (1982) observed, during the Nationwide Urban Runoff Program (NURP) study, that chloride loading was seasonal and increased significantly after road-salt application during the winter. Ku and Simmons (1986), in a followup study, calculated chloride loads and indicated that total loads of chloride in stormflow from February through mid-April often exceeded the totals for the rest of the year by as much as 50 percent, presumably as a result of road-salt application during the preceding winter months. Schoonen and others (1995) used chloride-to-bromide ratios to distinguish the chloride derived from halite (road salt) from chloride derived from precipitation.

HYDROGEOLOGIC SETTING

Long Island is underlain by unconsolidated sediments of Late Cretaceous to Quaternary age that overlie a southeastward-dipping bedrock surface. 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 Smolenski 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 aquifer. These deposits are highly permeable and have an average horizontal hydraulic conductivity of 76 m/d (McClymonds and Franke, 1972); the ratio of vertical-to-horizontal anisotropy is about 10:1 (Smolensky and others, 1989). Silt and clay lenses of low hydraulic conductivity are present locally.

The 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 typical of glaciofluvial and glaciolacustrine origin. Several boreholes were drilled and logged near East Meadow Brook to define the stratigraphy (M.P. Scorca and H.F.H. Ku, U.S. Geological Survey, written commun., 1994).

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 except at a few ponds along its length. The start-of-flow point 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, and as far south as the Southern State Parkway in 1992. Seaburn (1969) demonstrated the effects of urbanization on direct runoff along the length of East Meadow Brook. During predevelopment conditions, about 95 percent of the total streamflow at East Meadow Brook was ground-water discharge from the upper glacial aquifer (base flow) (Franke and McClymonds, 1972) and 5 percent consisted of storm runoff. By the late 1980's, the base-flow contribution to East Meadow Brook had declined to about 50 percent, and the contribution of storm runoff had increased proportionately (Scorca, U.S. Geological Survey, written commun., 1994).

The main causes of these hydrologic changes were the construction of roads and other impervious surfaces that prevent infiltration of precipitation, and the construction of storm sewers that carry the runoff directly to the stream through culverts. 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 has been modified by construction of the Meadowbrook Parkway in the 1950's and no longer receives base flow naturally; therefore, the length of the stream channel south of this point that can still receive base flow is 12 km.

The water-table altitude and ground-water flow at the site fluctuate in response to climatic conditions. Water levels were recorded in a well (N9241) east of the site at Eisenhower Park (figs. 1 and 3B). Regional ground-water flow is southwestward, and the vertical hydraulic gradient beneath the site fluctuates with the water table. Base flow in the headwaters area generally was negligible and constituted less than 1 percent of the total flow during monitored storms in this study (Frederick Stumm, U.S. Geological Survey, written commun., 1994).

EFFECTS OF ROAD SALTING ON STORMWATER AND GROUND-WATER QUALITY

Storm runoff from roads and other impervious surfaces can introduce a variety of contaminants to the ground-water system, including nutrients, bacteria, tire and petroleum derivatives, metals, and other substances, but road salt is the major constituent in ground water in the study area. Study of the effects of road salting on ground-water quality in the East Meadow Brook headwaters area required chemical analysis of precipitation, stormwater, and ground water to estimate the amount of sodium and chloride derived from precipitation and from road salt, and to delineate the extent of road-salt migration to the underlying aquifer.

Data-Collection Network

The NCDPW has monitored a rain gage at Mineola, about 5 km west of the study site since 1938 (figs. 2 and 3A). A tipping-bucket rain gage was installed by the U.S. Geological Survey at Eisenhower Park to collect precipitation data for individual storms. Precipitation samples for chemical analysis were collected with a wetfall/dryfall collector by the New York State Department of Environmental Conservation (NYSDEC) and analyzed by the NYSDEC laboratory. Fluctuations in water-table altitude during the study period were measured at well N9241 (figs. 1 and 3B), which is screened in the upper glacial aquifer at Eisenhower Park.

Two streamflow-gaging stations were installed in 1988 at the headwaters of East Meadow Brook. Site A, which is about 15 m south of the main culverts, and Site B, which is about 370 m downstream (fig. 2), were instrumented with data loggers to monitor stage and discharge. Fifty-six monitoring wells were installed during the study, and several previously installed wells were included in the sampling network. Ground-water-sampling procedures at the wells involved the pumping of at least three casing volumes to stabilize temperature and specific conductance of the sampled water. Two well clusters (fig. 2) were sampled for water-quality analysis to determine the vertical extent of ground water effected by road salt: near Site A, wells N11227 and N11228 are screened beneath the streambed near Site A; N11227 is screened from 3.4 to 4.3 m below land surface, and N11228 is screened from 3.7 to 4.6 m below land surface. Near Site B are wells N11254, N11255, and N11256; N11254 is screened from 30.1 to 31.1 m below land surface, N11255 is screened from 8.8 to 9.8 m below land surface, and N11256 is screened from 5.8 to 6.7 m below land surface.

Stormwater samples were collected with automated samplers at about 15-minute intervals during storms. Base-flow and ground-water samples were collected in bottles between storms, and temperature, pH, and specific conductance were measured onsite. Most samples collected during this study were analyzed for "total" (suspended and dissolved) values and generally were not filtered to obtain a separate measurement of the dissolved component. The NCDPW laboratory performed the chemical analyses.

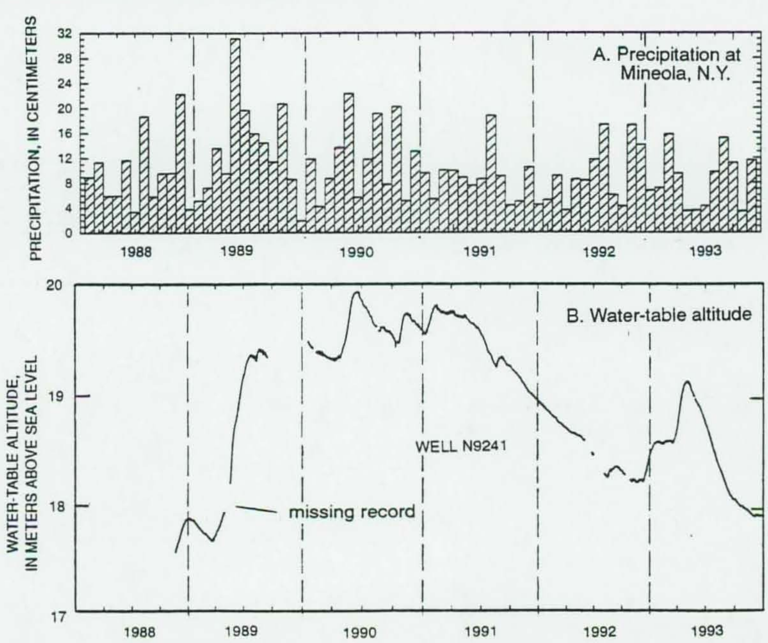


Figure 3. Hydrologic data from study area, 1988-93: A. Monthly precipitation measured at Mineola, N.Y. B. Water-table altitude at a monitoring well screened in the upper glacial aquifer in Eisenhower Park, Nassau County, N.Y. (Locations are shown in fig. 1.)

Sources of Sodium and Chloride

Major sources of sodium and chloride in ground water include precipitation, road salt, fertilizers, sewage, and weathering of soils and sediment. While precipitation loads of sodium and chloride were estimated for this study, it was not possible to quantify loads from other sources. Although sodium and chloride from many of these sources have historically been transported to ground water through the infiltration of precipitation, an increasingly large proportion is introduced by stormwater through streambeds and recharge basins.

Precipitation

The constituent load in atmospheric deposition represents both wetfall and dryfall. Wetfall consists of rain or snow and contains dissolved ions, including chloride, sulfate, sodium, calcium, magnesium, ammonium, and nitrate; dryfall is deposited between storms, and consists of aerosols, coarse particulates, and gases. Dryfall can account for up to 50 percent of the total chemical load in precipitation (Huntington and others; 1994; Art and others, 1974), yet dryfall is often not included because of the difficulty in making accurate measurements. In this study, wetfall was used as a minimum estimate of precipitation load. Sodium and chloride are the major constituents present in wetfall and, on Long Island, which is surrounded by seawater, are the major components of dryfall.

Wetfall loads were calculated as a percentage of total stream load and represent the constituent concentration in precipitation multiplied by the volume of precipitation that entered the stream as runoff at Site A. Because dryfall was not sampled during this study, the estimated wetfall loads represent a minimum value. Chemical loads in precipitation fluctuated throughout the year depending on the season. Although chloride concentrations in wetfall were generally higher during the fall and winter than in spring or summer (probably due to the greater frequency of storms over the ocean during the fall and winter, which results in increased sea spray) chloride constituted a significant percentage of total storm load (7 to 60 percent) during the nonsalting periods (summer and fall). As expected, the contribution of chloride from wet deposition during some road-salting periods formed only a small percentage of the total chloride loading in East Meadow Brook. Estimated chloride concentrations of 1.1 mg/L and sodium concentrations of 0.3 mg/L in wetfall during a storm on April 15, 1989, for example, produced only 0.3 percent of the total chloride and sodium loads in the stream, respectively; the rest was primarily from road salt. Sodium from wetfall generally formed a much smaller contribution to the total storm-runoff load than chloride; this can be partly attributed to the lower molar concentration of sodium than that of chloride in precipitation and in seawater.

Road Salt

Road salt, which in Nassau County consists of NaCl (halite), is a major source of ground-water contamination along roadways and other paved areas in the study area. Road salting during a snow or ice storm increases the concentrations of sodium and chloride and, often, other ions such as calcium and potassium, in runoff and shallow ground water. The increase in concentrations of calcium and potassium in stormflow following road salting indicates that small amounts of impurities, such as calcium chloride and potassium chloride, are mixed with the halite. The U.S. Environmental Protection Agency and the State of New York have set the drinking-water limit at 250 mg/L for chloride but have not set a limit for sodium; the World Health Organization has set a drinking-water limit of 200 mg/L for sodium. 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).

The amount of road salt applied by the NCDPW Highway Division in a given winter depends on several factors, including the number, magnitude, and duration of storms; the temperature; and the ratio of sand to salt used in the mixture. The general formula used is about 560 kg NaCl per center-lane km (0.6 ton per center-lane km) of major roads (Sal Iannucci, Nassau County Department of Public Works, oral commun., 1995). The total length of roads in the Westbury drainage area with storm sewers that discharge into the headwaters area is estimated to be 26.6 km (Stumm, 1992). Given that most roads in the drainage basin are in residential areas and have only 1 to 2 lanes, the road-salt application for a typical snowstorm would be 38,800 to 77,700 kg. If all salt were carried to the stream, the total loads in stormflow at the East Meadow Brook headwaters area would be 15,200 to 30,300 kg for sodium and 23,700 to 47,400 kg for chloride. Estimation of road-salt loading for an individual storm is difficult, however, because the applications contain several variables, as previously mentioned, and because road salt from preceding snow or ice storms may not have been completely washed away.

Stormwater

Surface-water quality was examined both spatially and temporally through frequent sampling at monitoring stations from March 18, 1988 through November 22, 1991, both during and between storms. Although the major source of sodium and chloride in shallow ground water at the site is road salt, these constituents are partly derived from other sources carried by stormwater, including precipitation, sewage, animal waste, and fertilizers.

Chemical Quality

Concentrations of most major ions were lower in stormflow than in base flow or ground water at all times except during periods of road salting. Chloride concentrations generally were higher than sodium concentrations, probably because of the lower sodium-to chloride ratio in road salt and in precipitation than in ground water, and because sodium has a greater tendency to be sorbed to sediments and transported with stormwater than does chloride. Calcium, bicarbonate, and nitrate, which were detected in much higher concentrations in ground water than in stormflow, were probably introduced through fertilization and liming of residential lawns and farms, and from leaking sewers and animal waste. Some constituents, including potassium, organic nitrogen, and bacteria, were detected at higher concentrations in stormflow than in ground water because they tend to be sorbed to suspended sediment or to form colloids and are transported during peaks in precipitation and discharge. Concentrations of certain constituents, including chloride, sodium, and nitrogen species, seem related to seasonal factors and, therefore, can be higher or lower in stormwater than in base flow or shallow ground water (C.J. Brown and others, U.S. Geological Survey, written commun., 1994).

A typical response of sodium and chloride concentrations in the stream to the inflow of storm runoff during losing-stream conditions is shown in the plot of sodium and chloride concentrations and discharge during a storm monitored on May 30, 1991 (fig. 4A). Constituents such as organic nitrogen and bacteria, which are often strongly associated with sediment load during storms, are rarely present in ground water because they are sorbed or filtered out by sediments. Concentrations of sodium and chloride, the major constituents in precipitation, peaked in the initial runoff on this date, then decreased as the storm progressed. The decreases resulted from the rapid flushing of salts from impervious surfaces. During periods of road salting, sodium and chloride concentrations in stormflow were much higher than in ground water. Sodium and chloride concentrations in stormflow increased by more than 2 orders of magnitude during a storm on March 18, 1989, as a result of road salting (fig. 4B).

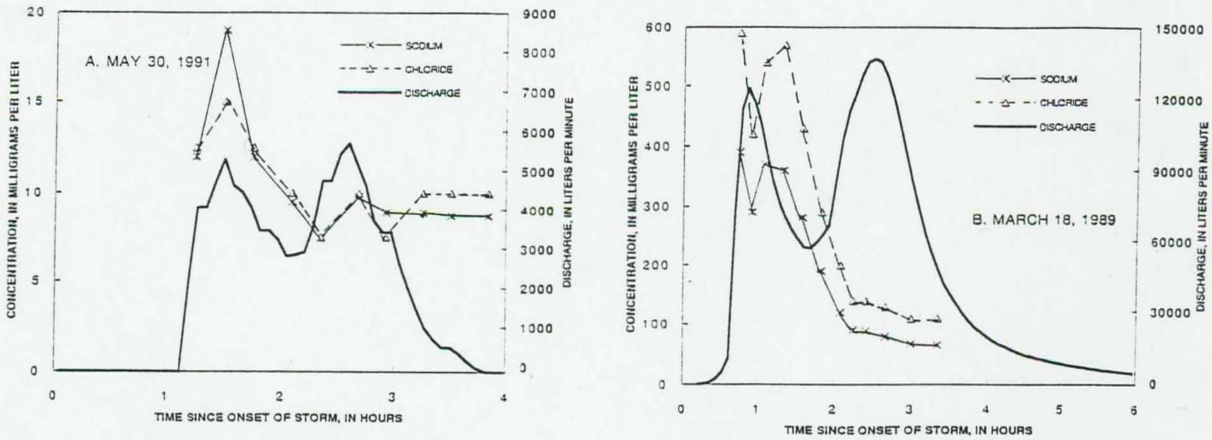


Figure 4. Sodium and chloride concentrations in stormflow, and stream discharge at Site A, during two storms. (Location shown in fig. 1.)

Storm Loads

The loads of selected constituents in stormwater were calculated to determine the contributions from the entire drainage area and to estimate the part that could potentially be transported to ground water. Storm volumes and constituent loads at Site A during four storms in 1989 and one in 1991 are given in table 1. Loads of constituents in runoff from individual storms correlated closely with stormflow volume, and flow volume had a greater effect than concentration on total loads in runoff from a given storm. Loads in stormflow also reflected the season. A decrease in flow volume between Sites A and B during several storms is attributed to infiltration through the streambed; infiltration rates ranged from 1 to 30 percent of the total storm volume, with a median of 16 percent (Frederick Stumm, U.S. Geological Survey, written commun., 1994).

Table 1. Estimated total storm loads for selected constituents at Site A at East Meadow Brook, 1989-91.

[--, no data available. Numbers in parentheses are minimum and maximum loads. All loads in kilograms]

Constituent (total)	Storm date and storm volume (in liters)				
	3-18-89 (1.8×10^7)	4-15-89 (5.3×10^7)	5-10-89 (7.5×10^7)	6-6-89 (1.1×10^7)	11-22-91 (6.0×10^7)
Alkalinity, total as HCO_3	470	740	--	260	170
Chloride, total	4,700	(21-170)	(280-350)	61	(0.6-18)
Sulfate, total	400	(53-660)	(43-750)	(0-109)	52
Sodium, total	3,100	260	320	44	24
Potassium, total	40	37	100	.95	17
Calcium, total	380	400	480	94	62
Magnesium, total	91	120	100	21	18
Nitrate as N, total	17	16	32	11	3.8
Ammonia, total	11	44	10	(0-1.1)	1.8
Organic N, total	40	470	44	(0-1.1)	9.6
Phosphate, total	8	12	(8.1-8.8)	(0-1.1)	2.0

Stream discharge was determined at 5-minute intervals during five storms, and water samples were collected about every 15 minutes. Constituent loads in stormflow 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 stormflow was not sampled because of a delayed response by the automated sampler. The unrepresented loads in such cases were estimated to be small relative to total storm loads; the concentration of the first collected sample was used in load calculations. To account for constituent concentrations that were below detection limits, a minimum and a maximum load were calculated on the assumption that the concentration(s) below the detection limit was equal to zero and equal to the detection limit, respectively.

The loads of sodium and chloride at Site A were 1 to 2 orders of magnitude higher 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 (Frederick Stumm, U.S. Geological Survey, written commun., 1989), were not monitored, and road salt probably was not completely washed from basin surfaces during these events. Arbitrarily assuming only one road-salt application at a rate of 560-kg per lane-km and a total application of 38,800 kg, only 20 percent would have been immediately removed in the March 18, 1989 storm. Although this minimum loading estimate contains considerable uncertainty, it indicates that much of the road salt applied to the basin was likely removed by melting before or by storms after the March 18, 1989 storm.

Ground Water

Several wells in the headwaters vicinity were monitored to determine spatial and temporal changes in water quality. Ground-water quality in the site vicinity is affected by regional ground-water flow and locally by stormwater recharge and other minor ground-water recharge.

Natural Ground Water

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

Regional Water Quality

Shallow ground water was sampled at wells unaffected by channeled stormwater in the East Meadow Brook headwaters area (fig. 2) to define (1) the quality of ambient local water, and (2) the effects of nonpoint contaminant sources and land use. Ground-water quality near the study area varied laterally and with depth as well as seasonally. Previous studies of the relation between land use and shallow ground-water quality in Nassau and Suffolk Counties (Eckhardt, and others, 1989; Leamond and others, 1992; Stackelberg, in press) show significant differences in water-quality between the sewered and undeveloped areas. Concentrations of dissolved inorganic constituents in three suburban areas (one sewered since 1964, one sewered since 1979, and one unsewered), an agricultural area, and an undeveloped area (Stackelberg, 1995), are shown in table 2 along with total inorganic-constituent concentrations at monitoring wells near the East Meadow Brook headwaters.

Table 2. Median values of physical properties and concentrations of inorganic constituents in selected areas on Long Island, N.Y., and in water samples from selected wells in the East Meadow Brook study area.

[Land-use data revised from Stackelberg (1995). Concentrations are in milligrams per liter. µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; --, no data available. Well depths are in meters below land surface; locations are shown in fig. 2]

Property or constituent	Land use (Long Island)					East Meadow Brook well number and depth		
	Suburban							
	Sewered since 1964	Sewered since 1979	Un-sewered	Agri-cultural	Undevel-oped	N11603 (13.7 meters)	N11618 (13.7 meters)	N10292 (15.2 meters)
pH	5.7	5.6	5.6	5.7	5.7	5.8	6.5	5.3
Dissolved oxygen	5.2	6.0	8.7	9.1	10	3.0	2.2	4.0
Calcium	18	14	5.3	28	3.6	8.7	16	10
Magnesium	3.7	2.7	2.8	7.1	1.2	4.1	4.0	3.5
Sodium	17	16	11	8	5	25	53	18
Potassium	2.2	2.1	1.4	3.9	.7	3.5	1.6	3.4
Alkalinity, as HCO_3	20	11	12	15	9.1	22	44	3.7
Chloride	31	23	14	23	8.2	28	80	18
Dissolved solids	159	133	75	193	64	144	216	134
Nitrate (as N)	4.6	4.8	2.6	7.48	.08	3.4	3.7	6.5
Phosphorus (as P)	.02	.05	.04	.07	.03	<0.05	<0.1	<0.05

Ground water in undeveloped areas had much lower concentrations of sodium (8 mg/L), chloride (23 mg/L), and dissolved solids than ground water in other areas (table 2). Median values of most constituents were higher in shallow ground water (15 m or less below land surface) than in intermediate and deep ground waters (30 m or more below land surface) as a result of surface contamination (Stackelberg, 1995). Sodium and chloride concentrations were highest in the area sewered since 1960 and were lowest in unsewered areas.

The chemical characteristics of ground water in the East Meadow Brook headwater vicinity differed from well to well and reflected local contaminant sources and land use. Stiff diagrams of water samples from three monitoring wells in the headwaters area were used to show temporal trends and local chemical differences (fig. 5); these "background" wells were selected as a basis for comparison with ground water affected by stormflow in the stream channel. Water samples from well N10292, at a park 250 m northeast of the site, contained low dissolved-solids, sodium, and chloride concentrations, but relatively high nitrate concentrations (6.5 mg/L, as nitrogen), which are attributed to lawn fertilizers. Shallow ground water in several wells in the site vicinity, including N11603 and N11618 (fig. 5), show evidence of road salting over time as peaks of relatively high sodium and chloride concentrations. Ground water at well N11603 adjacent to the Meadowbrook Parkway, is vulnerable to contamination by road salt, as is ground water at well N11618, west of the headwaters area and downgradient of a Nassau County Community College facility, 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 leaching of the halite to the ground-water system by precipitation.

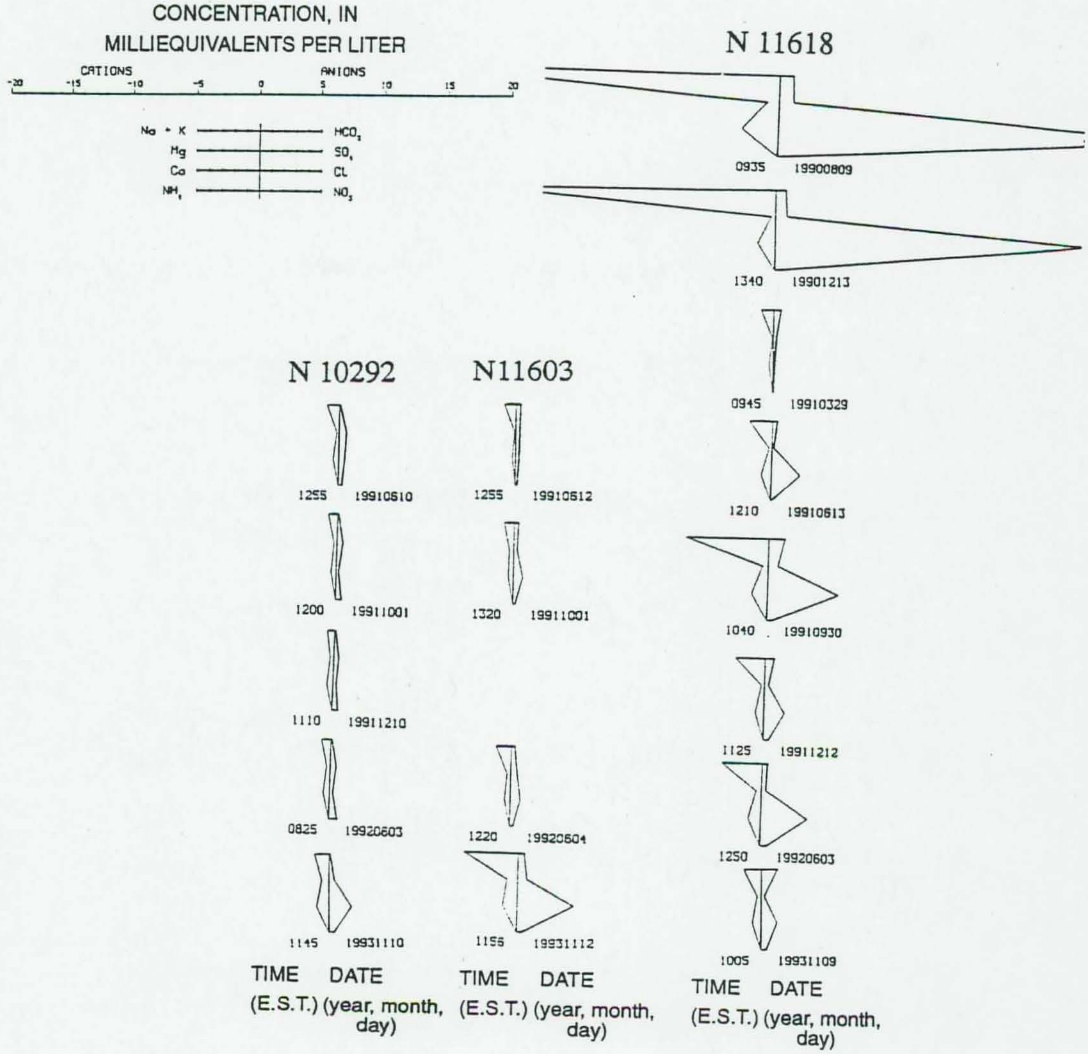


Figure 5. Stiff diagrams of chemical constituents measured in ground water at wells N10292, N11603, and N11618 in the East Meadow Brook headwaters area, Long Island, N.Y. (Locations shown in figs 1 and 2.)

Local Ground-Water Quality

Ground water adjacent to the stream channel was diluted by stormwater except after winter storms accompanied by road salting, when it was contaminated by salt-laden recharge. Ground water in the vicinity of the headwaters generally contained relatively high concentrations of sodium, chloride, calcium, and nitrate; these constituents are derived mostly from anthropogenic sources and partly from natural weathering of aquifer material. In contrast, the runoff from most storms contained relatively low concentrations of most constituents except bacteria. Concentrations of sodium, chloride, and other constituents in stormflow sometimes exceeded those in ground water after winter storms when road salt was used, however, and directly affected shallow ground-water quality. Median concentrations of several constituents, including calcium, magnesium, sodium, bicarbonate, and chloride in shallow ground water at wells at the headwaters area (table 3) were generally higher than median concentrations at background wells (table 2) because local surface contaminants transported in stormflow were not sufficiently diluted by regional flow. Ground water from a shallow monitoring well at the bottom of a small recharge basin north of the site (N11226, fig. 2) had lower concentrations of sodium, chloride, and other ions than did shallow ground water in other locations; this is attributed to dilution by stormwater from the recharge basin, as Ku and Simmons (1986) observed.

Median concentrations of sodium, chloride, and several other constituents in ground-water samples from beneath the stream channel near Site A were much higher than median concentrations in stormwater. A comparison of the range in constituent concentrations shows, however, that concentrations of sodium and chloride in stormwater during some storms were much higher than concentrations in the underlying ground water and affected ground-water quality significantly. Concentrations of sodium and chloride in ground water at deep monitoring wells, such as N11229 and N11254 (table 3; location shown in fig. 2), were lower than those at the shallow well of each cluster as a result of dilution by regional ground-water flow.

Table 3. Median ranges (minimum and maximum) of physical properties and concentrations of constituents in stormwater at Site A and in monitoring wells at the East Meadow Brook headwaters area, Long Island, N.Y.

[Numbers in parentheses represent range. Concentrations are in milligrams per liter. Well locations are shown in fig. 2]

		Well number and depth							
Property or constituent	Site A (stormwater)	N11226 3 meters	N11227 4.3 meters	N11228 4.6 meters	N11229 33 meters	N11230 10 meters	N11254 31 meters	N11255 9.8 meters	N11256 6.7 meters
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)
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)

Road salting generally affected surface- and ground-water quality only a few times per year (after salt applications); yet, these effects sometimes lasted several months. For example, ground-water recharge from stormflow on March 18, 1989, resulted in a 10-fold increase in sodium and chloride concentrations in shallow ground water beneath the stream. Large peaks of sodium and chloride on March 1989 (fig. 6A) were measured in ground water at monitoring well N11227, which is screened 3.4 to 4.3 m below the streambed. Ground water at the slightly deeper well within the cluster, N11228, which is screened 3.7 to 4.6 m below the streambed, contained lower concentrations (fig. 6A) than those in N11227; this indicates a vertical decrease in the effects of stormflow. Relatively low concentrations in stormflow measured on April 15, 1989 resulted in the dilution of shallow ground water after the March 1989 storm; sodium and chloride concentrations in water samples collected in June 1989 decreased to near median values.

The vertical extent of road-salt contamination from the March 1989 storm was studied further through temporal plots of sodium and chloride concentrations in several monitoring-well clusters in the headwaters area, and chloride-to-bromide ratios were used to distinguish chloride from halite (road salt) from chloride in precipitation

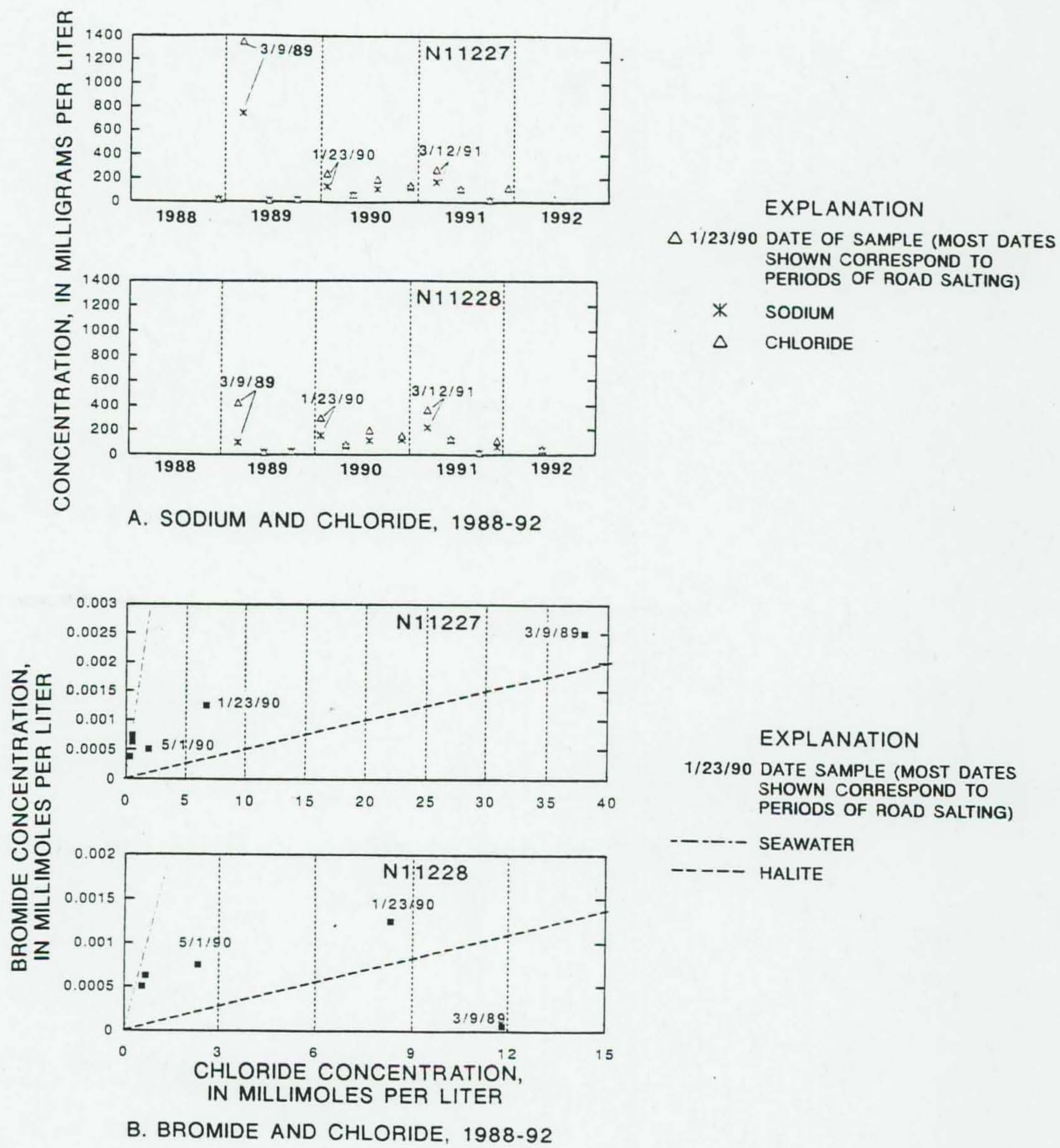
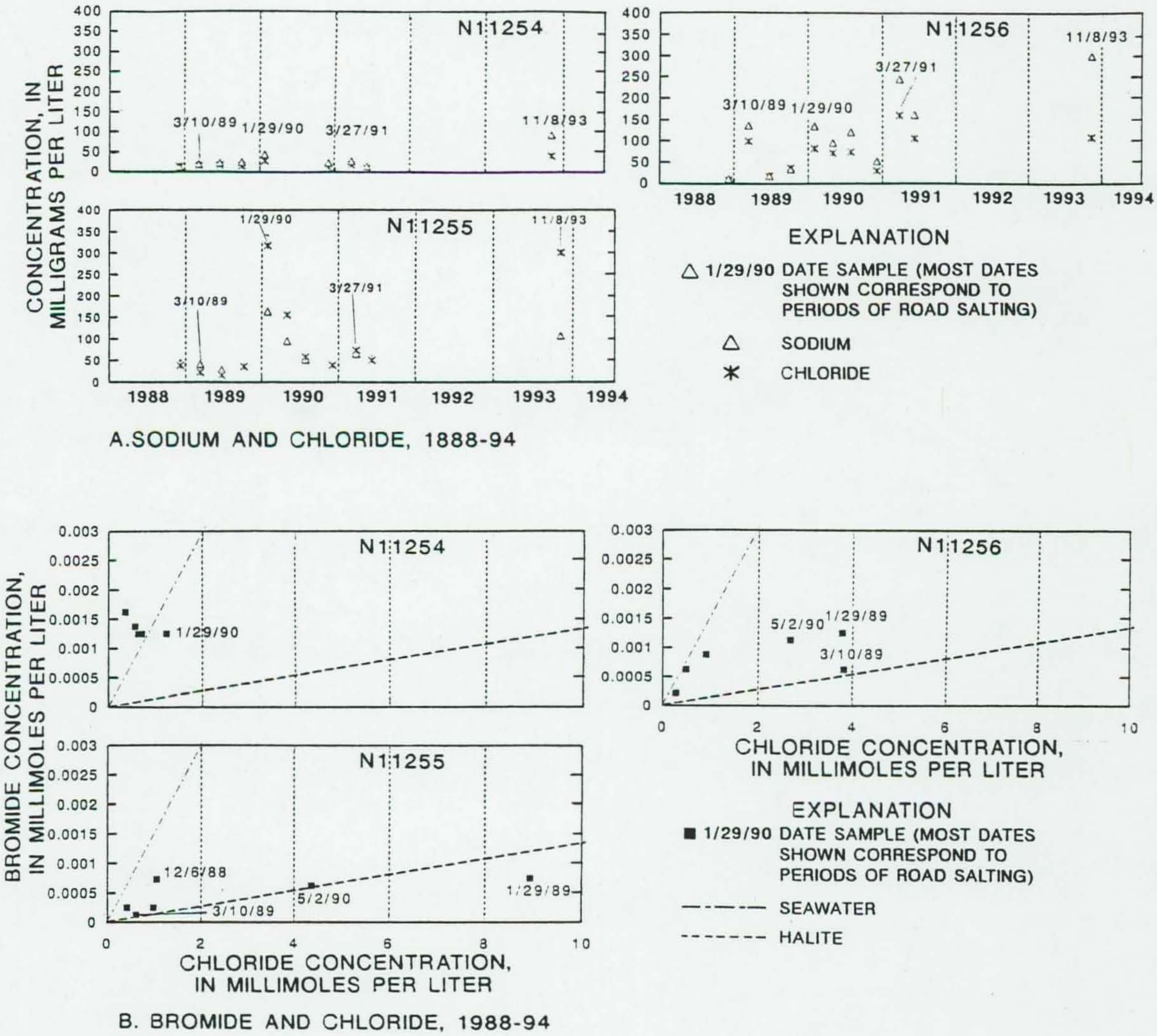


Figure 6. Salt concentrations in shallow ground water at wells N11227 and 11228, screened 3.4 to 4.3 meters and 3.7 to 4.6 meters, respectively. A. Sodium and chloride concentrations, 1988-92. B. Bromide and chloride concentrations, 1988-92.

(Schoonen, and others, in press). Chloride-bromide plots for wells N11227 and N11228 (fig. 6B) 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 6B represents the chloride-to-bromide ratio in halite, the dominant constituent in road salt. Ground-water samples collected after road salting (for example, 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 sea-water line. Ground-water samples that plot between the lines (for example, on May 1, 1990) represent a mixture of precipitation and halite.

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 well cluster at the southwestern part of the site, were used to estimate the vertical extent of road-salt contamination (fig. 7). Sodium and chloride concentrations in ground water at 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. In addition, sodium and chloride concentrations were elevated in ground-water samples collected on November 8, 1993, after completion of the stormflow-detention basin. Data points for wells N11256 and N11255, which lie near the halite line, reflect road-salt contamination, and data points for the deep well (N11254) lie only along the seawater line and reflect the absence of contamination.



CONCLUSIONS

Shallow ground water in urban areas of Nassau County is affected by road salting. Concentrations of sodium, chloride and several other constituents in ground water beneath and adjacent to the East Meadow Brook headwaters area were several times greater than the median concentrations in shallow ground water in nearby areas during the study period. Sodium and chloride concentrations in most stormwater samples collected at the headwaters area (medians of 6.2 and 3.0 mg/L, respectively) were lower than those in ground water, but stormwater sampled directly after road salting had sodium and chloride concentrations as high as 1,700 mg/L and 2,700 mg/L, respectively.

The rate of road-salt application depended on several factors, including the number, magnitude, and duration of storms; the air temperature; and the ratio of sand to salt used in the mixture. Estimates of road-salt load applications for individual storms were difficult to make because the applications have many variables, and because road salt from preceding snow or ice storms might not be completely washed from basin surfaces. The relatively small amount of road salt in stormflow during and following the March 18, 1989 storm, in relation to a minimum application estimate, indicates that much of the road salt applied to the Westbury drainage basin was removed by earlier melting or by later storms. This minimum-loading estimate contains large uncertainty, however.

Major sources of sodium and chloride during the nonwinter seasons include precipitation, sewage, and fertilizers. Wetfall during storms in which road salt was not applied contributed 7 to 60 percent of the total chloride in the storm load. The chloride contribution from precipitation during a storm that followed a road-salt application was only 0.3 percent of the total storm load; the rest was derived from road salt.

Plots of chloride and bromide concentrations in ground water were used to distinguish the sources of chloride derived from road salt (halite) from chloride derived from precipitation. Ground water deeper than 30 m below land surface at the headwaters area generally was unaffected by contaminated stormwater, but the effects were evident to that depth. Water at depths greater than 30 m was diluted by regional ground-water flow.

Stormflow acts as a point source of contamination in localized recharge areas, such as the headwaters area, but elsewhere in Nassau County, road salting on the many roads in the area can be regarded as a nonpoint source of contamination.

ACKNOWLEDGMENTS

Brian Schneider and James Mulligan of Nassau County Department of Public Works provided assistance and suggestions throughout the project, including coordination of well drilling and installation of gaging stations. The NCDPW water-quality laboratory at Cedar Creek performed analyses of inorganic constituents. Patrick O'Connell of the New York State Department of Environmental Conservation provided the analytical results of precipitation chemistry samples collected at Eisenhower Park.

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