

Prepared in cooperation with the Vermont Agency of Transportation

Effects of Highway Road Salting on the Water Quality of Selected Streams in Chittenden County, Vermont, November 2005–2007



Scientific Investigations Report 2009–5236

Cover. Photograph shows Allen Brook, at the Route 2A crossing, Chittenden County, Vermont (view is upstream).

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By Jon C. Denner, Stewart F. Clark, Jr., Thor E. Smith, and Laura Medalie

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Conversion Factors, Abbreviated Water-Quality Units, and Datums

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
inch (in.)	2.54	centimeter
Area		
square foot (ft ²)	0.09290	square meter
square mile (mi ²)	2.590	square kilometer
Flow rate		
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second
Mass		
pound (lb)	0.4536	kilogram
pound per day (lb/d)	0.4536	kilogram per day
pound per year (lb/yr)	0.4536	kilogram per year
pound per year (lb/yr)	0.0005	ton per year

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
 $^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$

Abbreviated water-quality units used in this report: Concentrations of chemical constituents in water are reported in milligrams per liter (mg/L).

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

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

Effects of Highway Road Salting on the Water Quality of Selected Streams in Chittenden County, Vermont, November 2005–2007

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Abstract

A study of road-deicing chloride (Cl) concentrations and loads was conducted at three streams in Chittenden County, VT, from November 2005 to 2007. This study was done by the U.S. Geological Survey, in cooperation with the Vermont Agency of Transportation. The streams, Alder Brook, Allen Brook, and Mill Brook, were selected to represent different land uses in the upstream watershed, different road types and densities, and different geometric patterns of the roadway draining to the receiving stream to assess the relative contribution of and differences in state road-salt applications to stream Cl concentrations and loads. Water-quality samples were collected and specific conductance was measured continuously at paired stations upstream and downstream from State highways and related to Cl concentrations to assist in determining the effects of road-salting operations during winter maintenance on the levels of Cl in the streams.

Mean concentrations of Cl ranged from 8.2 to 72 mg/L (milligrams per liter) in the water-quality samples collected at sampling stations upstream from State highway bridges and from 7.9 to 80 mg/L in those collected at sampling stations downstream of highway bridges. Mean Cl loads ranged from 1,100 to 4,090 lb/d (pounds per day) at upstream stations and from 1,110 to 4,200 lb/d at downstream stations. Estimated mean annual Cl loads ranged from 402,000 to 1,490,000 lb/yr (pounds per year) at upstream stations and from 405,000 to 1,530,000 lb/yr at downstream stations.

Mean Cl concentrations in samples collected at the three paired stations were lowest at Mill Brook at VT 117 near Essex Junction, VT (7.9 mg/L) and highest at Allen Brook at VT 2A near Essex Junction, VT (80.7 mg/L). None of the monitored Cl concentrations in the water-quality samples collected at the three paired sampling stations exceeded either of the U.S. Environmental Protection Agency's (USEPA) recommended chronic and acute Cl toxicity criteria of 230 and 860 mg/L, respectively.

A fourth stream site, a small tributary draining to Alder Brook between the upstream and downstream stations, was monitored from December 2006 to November 2007. This tributary collected runoff from a state highway and an interchange before flowing through a wetlands retention basin. The mean Cl concentration in water-quality samples collected at the tributary was 449 mg/L. The USEPA recommended chronic toxicity criterion of 230 mg/L was exceeded about 65 percent of the monitoring period. The USEPA recommended acute toxicity criterion of 860 mg/L was not exceeded.

Estimated Cl loads below the State highway bridges exceeded loads above the bridges at all three paired stations during both years of the study. The differences in the annual loads between the upstream and downstream stations were 0.7, 3.0 and 14 percent at Mill, Allen, and Alder Brooks, respectively. Almost all of the difference (92 percent) at Alder Brook was due to the tributary. Cl applied by the State of Vermont for deicing purposes represented less than 20 percent of the annual estimated Cl load in all 3 streams below the state highways.

The highest monthly Cl loads during the first year of the study were observed in January 2006 at all three stream stations because of an early snowmelt event. The highest monthly Cl loads during the second year of the study were observed in April 2007 at all three streams during spring snowmelt and were followed by decrease in Cl loading through the summer. Generally, the relation of Cl loads to runoff was similar at all three streams. In July and October 2007, loads increased slightly with an increase in runoff, indicating that Cl in the soils and groundwater may be contributing to the Cl levels during the summer and fall, well after the road-salting season. Cl loads in all three streams appear to be due primarily to sources in the watersheds upstream of the state highway bridge where road salt was applied and (or) Cl retained in soils and streambed sediments.

Introduction

In 2002, an estimated \$2 billion was spent nationally on chemicals, materials, labor, and equipment for winter maintenance of roads (U.S. Environmental Protection Agency, 2002). Road-salt (sodium chloride (NaCl)) use for deicing and anti-icing of roads has increased steadily since its initial use in the late 1930s and early 1940s. From 1940 to 2004, national sales of salt for deicing purposes increased from 164,000 to 16,014,000 tons annually (Salt Institute, 2004). During this period, salt use was greatest (20,117,000 tons) in 1996. The use of NaCl and other chemicals for road deicing is designed to improve the safety of drivers during winter driving conditions; but there has been an environmental concern in many parts of the United States and other regions of the world because of the use of these deicing materials. Many investigations have been conducted since the 1960s to study the effects of road-deicing materials (Granato, 2000). These investigations have shown that road-deicing activities can have an effect on the receiving environment, including waters, soils, and vegetation. Most of these studies have focused on NaCl, although fewer studies also have assessed the effects of other deicing and anti-icing compounds. These other compounds include calcium chloride (CaCl_2), magnesium chloride, potassium acetate, calcium magnesium acetate, and biobased deicers (Kievit-Kylar, 2004; Staples and others, 2004).

The sources of chloride (Cl) and sodium (Na) to the environment are varied and include rock weathering, precipitation and winds, agriculture, human sewage (on-site disposal systems, municipal wastewater treatment facilities), and road deicing. All surface waters contain a natural amount of Cl and Na. Hanes and others (1970) report that concentrations of Cl in uncontaminated rivers typically range from 0 to 15 mg/L and numerous studies have reported natural Cl levels in rivers to be higher adjacent to coastal waters. Kelly and others (2007), in a study of a rural watershed in New York, found that road salt contributed 91 percent of the total inputs of NaCl to the watershed, and rock weathering and atmospheric deposition combined accounted for less than 2 percent.

NaCl and other deicing chemicals are transported with melting ice and snow onto impervious surfaces, onto adjacent soils and vegetation, and eventually to rivers, streams, and other bodies of water (Environmental Literacy Council, 2005). The actual amount of runoff containing deicing salts that reaches the surface and groundwaters is a function of site-specific characteristics such as soil permeability, vegetative cover, gradients, and highway-drainage techniques (D'Itri, 1992). During and after storms and spring snowmelt, streamflow may contain high concentrations of Na and Cl. These high concentrations are diluted once they enter larger water systems.

Applied deicing salts can follow various pathways from the roadway to receiving waters. Saline wash from the roadbed may flow directly to streams through surface runoff

over impervious surfaces, which may at times include frozen ground. In addition, Cl-enriched water can infiltrate soils near the pavement and subsequently percolate through the unsaturated zone to groundwater. Road salt also can accumulate in snowbanks within the road right-of-way.

Studies of the environmental effects of deicing show that its influence is greatest near the roadway that is salted. From a water-quality standpoint, small drainages from the roadway itself (such as swales) and small streams, lakes, wetlands, and groundwater directly receiving the roadway runoff are most affected. Trowbridge (2007) reported that the effects of road-salting on a number of small streams draining sections of an interstate highway in New Hampshire caused exceedances of the U.S. Environmental Protection Agency (USEPA) recommended chronic Cl toxicity criterion of 230 mg/L for the protection of aquatic life.

Soils and shallow groundwaters also can be affected (Jones and Sroka, 1997), although these environments are less commonly monitored and studied than surface water. The constituents in deicing chemicals affect water quality by increasing total dissolved solids and mobilizing metals by promoting processes such as ion exchange, desorption, complexing, acidification, and mineral dissolution (Shanley, 1994; Granato and others, 1995; Bricker, 1999).

Road salt can accumulate in soil and affect trees and other vegetation. Elevated salt levels in soils inhibit the ability of plants to absorb nutrients and water, impeding long-term growth. Degradation of roadside vegetation also can reduce the ability of roadside areas to act as a buffer to slow the runoff of contaminants into the watershed (Environmental Literacy Council, 2005).

Buttle and Labadia (1999) showed that less than 50 percent of the applied salt was retained in the snowpack during the latter stages of snow-cover development. This finding indicated that 50 percent of the salt was released from the snowpack during mid-winter thaws and rains. The remaining portion was released to surface runoff and soil infiltration during the diminishing snow cover. Blomqvist and Johansson (1999) indicated that the occurrence of salt decreased rapidly with distance from the roadway. Spray transport beyond about 70 ft was determined to be insignificant. Jebb (1988) documented that 98 percent of salt dispersed from the road surface was recovered within about 150 ft of the road edge.

Howard and Haynes (1993) estimated that 45 percent of Cl was removed by overland flow, and the remaining portion entered soil water and groundwater. In a Massachusetts highway study, 55 percent of Cl in deicers was transported in surface runoff and the remaining 45 percent infiltrated through soils into groundwater (Church and Friez, 1993). Toler and Pollock (1974), in another study conducted in Massachusetts, determined that 15 to 55 percent of the annual amount of Cl applied to the highway was initially retained in soil water above the water table. Most of the Cl, however, was leached downward to groundwater with infiltrating rainwater by late fall.

In Vermont, increasing Cl levels have been identified in the Lake Champlain Basin (Shambaugh, 2008). In addition, concerns about road salting were identified in the Vermont Agency of Transportation (VTrans) and the Federal Highway Administration (FHWA) National Environmental Policy Act reevaluation in 2004 for the proposed Chittenden County Circumferential Highway. This proposed highway would pass over a number of streams east of Burlington, VT. In response to this concern, the U.S. Geological Survey (USGS) in cooperation with VTrans, conducted a study of the effects of state roadway-deicing practices on the water quality of selected streams in Chittenden County, VT, from November 2005 to 2007.

Purpose and Scope

This report describes the results of a study to assess the effects of road salting of state highway bridges and connecting roadways on the water quality of three stream sites in Chittenden County, VT (fig. 1; table 1). This report (1) describes the relation between specific conductance values and Cl concentrations, (2) determines the frequency with which Cl concentrations exceeded USEPA recommended chronic and acute toxicity criteria for protection of aquatic life, (3) assesses the relative contribution of state road-salt applications to Cl concentrations and loads in three streams, and (4) compares general water chemistry and chloride concentrations and loads among the three streams. A fourth stream, a tributary to one of the streams studied, was sampled to assess the effects of the tributary on the receiving stream.

The data presented in this report were collected from November 2005 to 2007 and include streamflow; specific conductance; pH; and concentrations of Cl, Na, Ca, potassium (K), magnesium (Mg), sulfate (S), and nitrite plus nitrate ($\text{NO}_2 + \text{NO}_3$). Streamflow and water-quality data collected for the study are stored in the USGS National Water Information System (U.S. Geological Survey, 2003) at <http://nwis.waterdata.usgs.gov/nwis>.

Road Deicing Practices in Vermont

NaCl and sand are primarily used in Vermont for deicing and anti-icing (Gil Newbury and Michael Morissette, Vermont Agency of Transportation, written commun., 2005). During very cold events, CaCl_2 is used with NaCl. The amount of CaCl_2 and other substitutes for NaCl is not quantified by VTrans (Gil Newbury and Michael Morissette, Vermont Agency of Transportation, written commun., 2005). VTrans also uses ferric ferrocyanide, “Prussian Blue,” as an anti-caking agent in the deicing salt.

VTrans has operated a Safe Roads Policy since 1981 that promotes the efficient use of deicing materials on state roads. Under this policy, roads are to be returned to bare pavement after a storm is over on a priority schedule based on the amount of traffic. There is no “bare road” designation

for any State highway during a storm. Vermont is the only state in the Nation that requires an environmental permit for deicing. VTrans obtains an annual permit (10 VSA section 1272) from the Vermont Agency of Natural Resources (VTANR), Department of Environmental Conservation (VTDEC) for deicing roadways and state-owned airport runways. This permit typically defines procedures to follow for the deicing of state roads as described in annually updated VTrans Operations Snow and Ice Control Plans. These plans are structured as a guide to relate winter conditions to levels of deicing service provided by state maintenance crews. The Snow and Ice Control Plans contain standards for correlating recommended salt-application rates to pavement temperatures. The Snow and Ice Control Plans also identify an economic salting range, which extends from 30 to 20°F.

VTrans conducted a study during the winter of 1993–94 of deicing-salt effectiveness at different pavement temperatures called: “Smart Salting: A Winter Maintenance Strategy” (Vermont Agency of Transportation, 1995; Smith and Zogg, 1998). The results of the Smart Salting study indicated that at temperatures greater than 25°F, potential savings in materials exist when a material-application rate curve is used. At lower temperatures, the savings were smaller; therefore, the investigators recommended higher application rates with decreasing temperature.

The Smart Salting study also recommended that winter highway maintenance crews (1) determine pavement temperature through the use of infrared thermometers mounted on supervisors’ vehicles, and (2) determine salt-application rates on the basis of pavement temperature, melting capacity of the salt, and the thickness of the ice or snow on the pavement (Smith and Zogg, 1998). The Smart Salting study created anti-icing and deicing strategies that included application curves relating salt-application rates to snowpack and ice. As the pavement temperature decreases, more salt is needed to melt the ice; therefore, pavement temperature is the controlling factor in the treatment of highways during winter storms (Smith and Zogg, 1998).

The Smart Salting winter maintenance strategy was adopted throughout Vermont during the winter of 1994–95. For anti-icing, action is taken to prevent formation of a strong bond between the ice or snowpack and the pavement. The weight of the expected snowfall prior to plowing is approximated, and then the amount of deicer required to melt from 4 to 6 percent of that weight already bonded to the pavement is calculated.

The VTrans Maintenance Division is responsible for salting, sanding, and plowing more than 6,500 single-lane miles of state-owned roadway. During October 1, 2003–September 31, 2004, VTrans used 89,865 tons of road salt and 76,675 cubic yards of sand statewide (Michael Morissette, Vermont Agency of Transportation, written commun., 2005). From 1981 to 2005, an average annual load of 16.6 tons of road salt per lane-mile was used throughout Vermont. The amount of road-deicing chemicals applied by VTrans from 1981 to 2005 increased from about 12.5 tons per lane-mile in

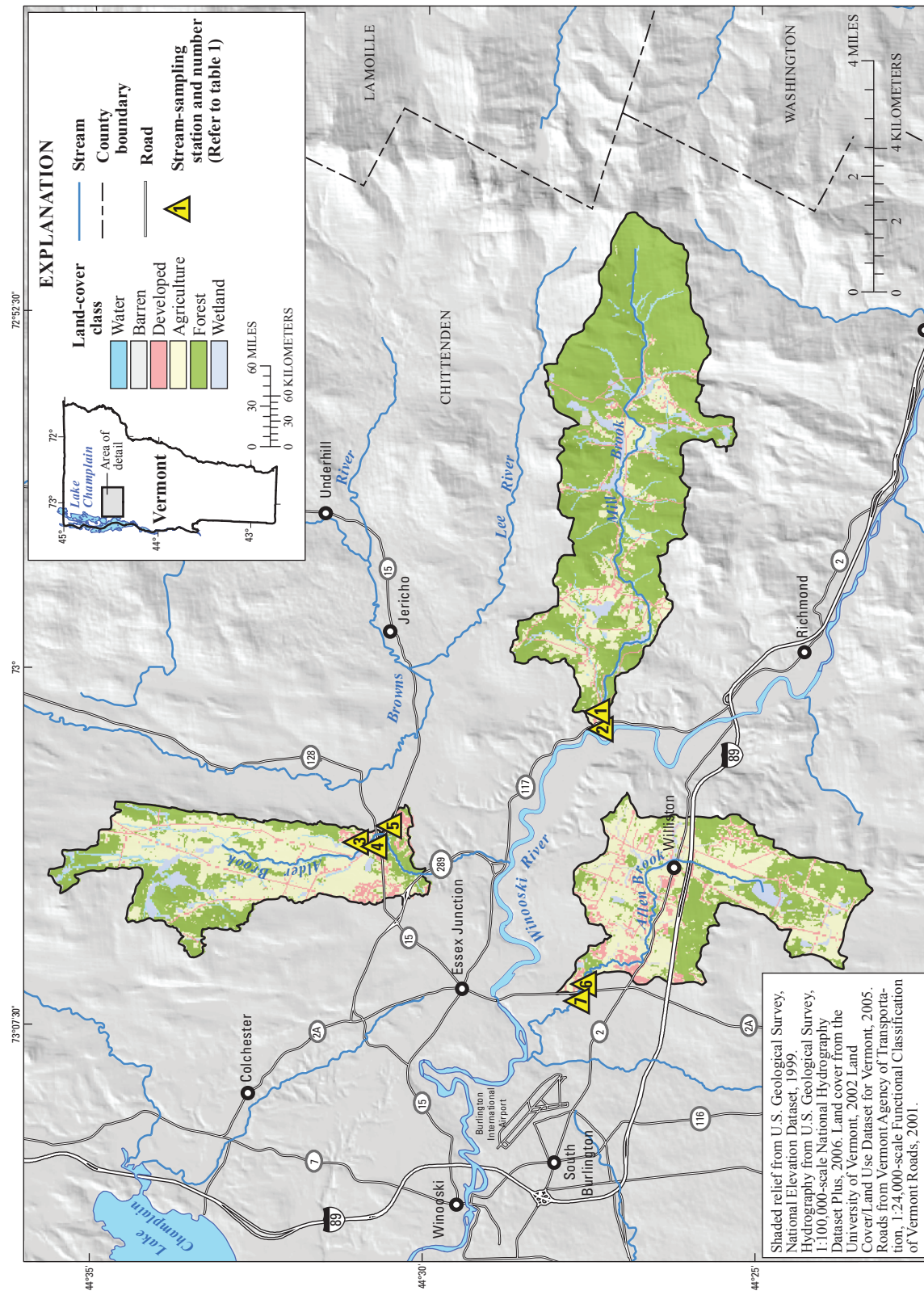


Table 1. Selected characteristics of the three paired stream-sampling stations and the tributary sampling station in Chittenden County, VT.

[Latitude and longitude are given in degrees (°), minutes (′), and seconds (″); USGS, U.S. Geological Survey; mi², square miles; ft³/s, cubic feet per second; Min, minimum; Max, maximum; na, not applicable; mi/mi², miles per square mile; --, not calculated]

Site number (fig. 1)	Site name	USGS station number	Latitude	Longitude	Drainage area (mi ²)	Streamflow (ft ³ /s) ¹		
						Min	Mean	Max
1	Mill Brook above VT 117, near Essex Junction, VT	04289880	44°27′19″	73°01′06″	16.3	na	na	na
2	Mill Brook below VT 117, near Essex Junction, VT	04289881	44°27′19″	73°01′06″	16.4	2.98	37.3	645
3	Alder Brook above VT 289, near Essex Junction, VT	04290160	44°27′19″	73°01′06″	8.87	na	na	na
4	Alder Brook tributary at mouth, near Essex Junction, VT	042901608	44°27′19″	73°01′06″	0.05	0.04	0.17	1.25
5	Alder Brook below VT 289, near Essex Junction, VT	04290161	44°33′01″	73°04′19″	8.93	0.49	16.0	331
6	Allen Brook above VT 2A, near Essex Junction, VT	042903349	44°27′19″	73°01′06″	9.85	na	na	na
7	Allen Brook below VT 2A, near Essex Junction, VT	04290335	44°27′42″	73°06′46″	9.88	0.12	16.2	247

Site number (fig. 1)	Impervious surface ² (percent)	Road density (mi/mi ²)	Septic system density (percent)	Land use, in percent			
				Forest	Developed	Agriculture	Other ³
1	0.48	1.6	--	--	--	--	--
2	0.52	1.7	24	72	4	15	9
3	3.4	3.7	--	--	--	--	--
4	20	40	--	--	--	--	--
5	3.6	3.8	28	34	9	47	10
6	4.7	4.1	--	--	--	--	--
7	4.8	4.2	26	50	13	35	4

¹Streamflow statistics are calculated from the daily mean streamflow for the 2-year study period at the downstream sampling station for Mill Brook, Alder Brook, and Allen Brook, and for the 1-year study period at the Alder Brook tributary-sampling station.

²U.S. Geological Survey, 2003.

³Other consists of wetlands, water, and barren land-use categories.

1981 to about 16.5 tons per lane-mile in 2005. The maximum annual load of road salt used per lane-mile throughout Vermont was 23.9 tons in 1999 and the minimum annual load of road salt used per single-lane mile was 9.2 tons in 1983. Application rates per lane-mile have decreased or remained similar in most areas of the State since implementation of the VTrans Smart Salting Program. Road-salt application rates in Chittenden County (District 5) averaged approximately 15 tons per lane mile per year (average District salt application 1981–2005) (Michael Morrisette, Vermont Agency of Transportation, written commun., 2005).

Weather conditions, road-surface conditions, and the type of road, and changing deicing practices affect the application rate and total amount of road salt used. Recent studies by VTrans have shown increased efficiencies in road deicing with the use of brines (Vermont Agency of Transportation, 2009); such practices may be adopted in the future and would affect the amount of road salts applied. Therefore, the amount of road salt applied to roads in Vermont varies from year to year and from region to region on different stretches of road. In addition to VTrans, many local highway departments and independent private contractors apply deicing compounds to highways in the State. No current (2009) estimates of the amount of deicing material used by these agencies and organizations are available.

Description of the Study Area

Chittenden County was selected for the study because it is the location of the proposed circumferential highway and contains a mix of state road types and land uses representative of the State of Vermont. Chittenden County, VT, encompasses 620 mi² of which about 540 mi² is land and 80 mi² is water (Lake Champlain). It is the most populous county in the state and includes the metropolitan area of Burlington-South Burlington. Topography is characterized by broad lowlands in the western portion of the county and by rolling hills and the Green Mountain range in the eastern portion of the county. Elevations range from about 90 ft near the shore of Lake Champlain to more than 4,000 ft at the summit of Mount Mansfield in the Green Mountains. The county is about 45 percent forest, 26 percent agriculture, 18 percent water, 8 percent developed, and 3 percent wetlands and barren (U.S. Geological Survey, 2001).

The Winooski River, a tributary of Lake Champlain, is approximately 90 mi long and, although it is not Vermont's longest river, it is one of the State's most important, forming a major valley from Lake Champlain to the Green Mountains in Chittenden County. The river's headwaters are in Washington County, north and east of Montpelier. From Montpelier, it flows northwest into Chittenden County, passing north of the city of Burlington. It enters the eastern side of Lake Champlain approximately 5 mi northwest of Burlington. The river was historically used for the transportation of timber for

logging purposes during the 19th century and is now used for a variety of recreational purposes including canoeing, kayaking, fishing, and swimming. Additionally, several hydroelectric dams in the watershed are used for generating electricity. The river valley downstream from Montpelier is used as a corridor for U.S. Highway 2 and Interstate Highway 89.

Bedrock beneath Chittenden County is composed of sandstones, limestones, dolomites, and shales. To the east, shales and sandstones are metamorphosed to phyllites and granofels composed primarily of quartz and mica (Doll and others, 1961; Kim and others, 2007). Easily weathered limestone, dolomite, and calcareous shale contribute dissolved constituents to streamwater in the Allen Brook Basin. The metamorphic rocks underlying the upper Allen Brook, as well as the Alder and Mill Brook Basins, are relatively resistant to chemical weathering and, therefore, contribute fewer constituents to streams than the calcareous shale.

Glacial till and water-transported sediments related to deglaciation cover much of the bedrock throughout the region (Springston and DeSimone, 2007; Wright, 2003). Calcareous rocks in the region have been dragged southeastward by glaciation. Calcareous till and calcareous stratified deposits are found along Alder Brook and calcareous till is found along Allen Brook. The calcareous rocks (Allen Brook) and calcareous glacial till deposits (Allen and Alder Brooks) locally contribute to streamwater chemistry. The headwaters of Mill Brook are in non-calcareous bedrock and flow primarily through fine sands and non-calcareous till (Clark and others, 2005; Ladue, 1982).

Average temperatures in Burlington, VT, range from less than 20°F in the winter to about 70°F in summer. Annual precipitation during the first year of the study (2006) was 47.4 in. (130 percent of normal), and annual precipitation during the second year of the study (2007) was 36.8 in. (104 percent of normal). Snowfall totals for early winter 2006 were near normal through mid-January. Record rainfall in January 2006 completely depleted the snowpack. The snow cover did not recover to any substantial degree during late winter because snowfall was below normal, monthly average temperatures were above normal, and rainfall was frequent. Snowfall totals were below normal for the beginning of the 2007 winter season. No snowfall was recorded in November, and snowfall in December was 65 percent of normal. The snow accumulated in January 2007 and continued to accumulate through early spring because of above-normal snowfall and below-normal monthly average temperatures. Total snowfall in February 2007 was 229 percent of normal. A record monthly total snowstorm accumulation was recorded on February 14–15, 2007. This storm resulted in the second greatest snowfall for the period of record at Burlington (1884–present). Total snowfall during the winter of 2007 was 94.6 in. (130 percent of normal). All climate data were obtained from the National Weather Service in Burlington, VT (<http://www.weather.gov/climate/index.php?wfo=btv>).

Methods of Data Collection and Analysis

The sampling program for this study was designed to determine the frequency with which Cl concentrations exceeded USEPA recommended chronic and acute toxicity criteria and to assess differences in Cl loads upstream and downstream from State highway bridges to determine whether road-salt application affected streamwater Cl levels in the three streams in Chittenden County, VT. Streamflow and specific conductance were continuously monitored at three paired sampling stations to characterize the variations in these parameters during two annual cycles (November 2005–2007) and to establish relations between Cl and specific conductance. Specific conductance is a measure of the capacity of water to conduct an electrical current and is a function of the types and quantities of dissolved substances in water (Wilde and Radtke, 1998b). As concentrations of dissolved ions increase, conductivity of water increases.

Water samples representing the different climatic and hydrologic conditions that can affect constituent concentrations in samples were collected manually approximately monthly, and by using automated sample-collection techniques during thaw and precipitation periods in the winter. These water samples were analyzed for dissolved chloride, dissolved sodium, and dissolved calcium. A reduced number of samples were analyzed for a group of major cations for characterizing basic water chemistry of the streams.

Site Selection

Approximately 10 streams were initially considered as a location for potential sampling stations. The streams were categorized by drainage-basin size, percentage of various land uses, and road density in the watershed. A geographic information system was used to determine watershed characteristics (percent imperviousness, percent land-use types, road density, and septic-system density) (U.S. Geological Survey, 2001). Three streams were selected for this study based on representation of different land uses, road types, the drainage pattern of the roadway to the receiving stream, and the suitability for streamflow and water-quality monitoring (fig. 1). Sampling stations were established upstream and downstream (paired stations) (table 1) from a highway bridge at each of these locations. An additional monitoring station (the Alder Brook tributary) was established in December 2006 at the outlet of a roadway runoff retention basin adjacent to VT 289 and Alder Brook to determine the effects of this tributary on the Cl load in Alder Brook (table 1). The tributary flows into Alder Brook between the upstream and downstream stations.

Hydrologic and Water-Quality Data Collection

Continuously recording streamflow-gaging stations were established at Alder Brook at VT 289 and Mill Brook at VT 117 near Essex Junction, VT, (table 1) using protocols described in Rantz and others (1982). The existing streamflow-gaging station at Allen Brook at VT 2A near Essex Junction, VT, was used (table 1). All discharge measurements in the three streams were made downstream of the highway bridges. Records of stage were obtained using electronic dataloggers and stage sensors. Stage values were recorded every 15 minutes during the study period. Stage readings were related to measurements of streamflow to obtain a stage-streamflow relation used in computing continuous streamflow. An additional streamflow-gaging station was added in December 2006 at the Alder Brook tributary. Streamflow at the Alder Brook tributary station was measured using a 120-degree thin-plate v-notch weir. A theoretical equation was used to rate the streamflow through the weir (Rantz and others, 1982).

Specific-conductance and water-temperature data also were collected continuously at all three paired stations and at the tributary to Alder Brook using published USGS protocols (Wagner and others, 2006). Water temperature and specific conductance were measured at 15-minute intervals during the study period using digital dataloggers.

Water samples were collected approximately monthly at the three paired stream-sampling stations using standard-surface-water sampling protocols (U.S. Geological Survey, variously dated; Wilde and Radtke, 1998a and b). Approximately 25 samples were collected at each of the upstream stations and approximately 40 samples were collected at each of the downstream stations. Automated sampling for Cl was used at the downstream stations to better define the changes in Cl concentrations from daily thaws, freezing precipitation, and snowmelt events. These samples assisted in characterizing the range in Cl concentrations and specific-conductance values in relation to hydrologic and weather conditions at each station. The monthly and automated water-quality sample collection is referred to as “routine” sampling from this point forward in this report. Samples were collected during base flow, rain-on-snow, and snowmelt conditions. Water samples also were collected from December 2006 to October 2007 at the Alder Brook tributary. During each stream-station visit, on-site measurements were made for specific conductance, pH, and water temperature, and water samples were collected for subsequent determination of the concentrations of Cl, Na, and Ca. In addition to the routine sample analysis, samples also were collected four times per year (seasonally) for determination of potassium (K), magnesium (Mg), sulfate (S), and nitrite plus nitrate ($\text{NO}_2 + \text{NO}_3$) concentrations. Water samples were analyzed at the USGS water-quality laboratory in Lakewood, CO, according to methods in Fishman and Friedman (1985) and Fishman (1993).

Data Analysis

For each stream site described in the section “Stream Hydrology and Water Quality,” water-quality conditions are described, and a map and graphs of selected data are presented. Ranges of constituent values not plotted in the graphs are statistically summarized in the text. Mean pH values for samples collected during this study were determined by converting instantaneous pH values to hydrogen-ion (H^+) concentrations, calculating the mean of the instantaneous H^+ concentrations, and converting the mean H^+ concentrations back to pH units (Radtke and others, 2003).

For each stream site, the illustration begins with a map of the stream showing the major stream network, monitoring stations, the State road network, and a photograph. Information about land cover and the road network assists in the understanding of natural and anthropogenic factors that affect water quality.

On the second page of illustrations, two graphs describe the distribution of water-quality samples in relation to streamflow for both the upstream and downstream stations and specific-conductance values in relation to Cl concentrations for each year (2006 and 2007). In the first graph, daily mean streamflow for the data-collection period as well as dates and instantaneous streamflow values for the associated water-quality samples are presented. The distribution of water-quality samples with respect to time also is represented. Because the water-quality samples are displayed with the corresponding instantaneous-streamflow values, these points do not always fall on the line representing the daily mean discharge. In the second graph, daily mean specific conductance for the data-collection period and Cl concentrations for the water-quality samples are presented for the paired stations.

On the third page of illustrations, the first graph shows the linear relation between specific-conductance values and Cl concentrations. These relations were used to develop regression equations for estimating daily mean Cl concentrations at the downstream-sampling stations. The concentrations of constituents in surface water commonly are related to other constituent concentrations and factors such as hydrologic conditions, season, and location. One constituent concentration can be expressed in terms of another constituent concentration using simple regression equations (Helsel and Hirsch, 1992). Regression analysis is commonly used to define the mathematical relation between specific conductance and dissolved constituents, such as Cl (Hem, 1992). The second graph on the third page of illustrations for each stream shows the estimated daily mean Cl concentrations for the study period relative to individual measured Cl concentrations and the USEPA recommended chronic toxicity criterion for Cl (230 mg/L) (U.S. Environmental Protection Agency, 1988).

The first graph on the fourth page of illustrations shows the effects of rain-on-snow on Cl concentrations and stream stage during January 2006. The second graph shows the effects of snowmelt on Cl concentrations and streamflow during

March 2007. These two graphs represent important runoff and snowmelt periods during the two years of study. The fifth page of illustrations for each stream contains a graph comparing estimated stream loads of Cl to estimated loads of Cl applied as road deicing material by VTrans during each winter season.

The LOAD ESTimator (LOADEST) computer program (Runkel and others, 2004) was used to estimate Cl loads at the sampling stations. LOADEST is based on a regression equation in which time series of streamflow and concurrent Cl concentrations from the upstream and downstream stations are used as calibration data for the estimation of constituent loads. For this study, a user-defined model that included two explanatory variables (streamflow and specific conductance) was used. Two explanatory variables in the calibration and estimation files are useful in the formulation of the regression for load estimation.

The number of pounds of Cl applied to State highways in the study area was estimated from data provided by VTrans (Michael Morissette, Vermont Agency of Transportation, written commun., 2007). Snowplow drivers were required to record dates and application rates for each trip during which NaCl was applied. Markers were set on the roadway at the basin boundaries to define the road-surface lengths traversed by snowplows within the watershed of the stream stations. From these data, pounds of Cl applied to state highways per lane-mile were calculated. Conversion of NaCl loads applied to roadways to Cl loads was necessary for comparison to data in this study and is a function of atomic weight of Cl relative to salt. Sodium and Cl ions are monovalent, thus the conversion is obtained by dividing the NaCl load by 1.648. The result is the load of Cl. All descriptive statistics were calculated using Excel and SAS statistical software (Microsoft, 2003; SAS Institute, Inc., 1998, 2000).

A ternary plot (Helsel and Hirsch, 1992) was used to describe the general water chemistry (with respect to cation composition) at the three sampling stations. The ternary plot is trilinear and shows the difference in cation distribution among the stations. Concentrations were converted to milliequivalents and used to determine the percentage of cation composition. Boxplots were used to compare the range in chloride concentrations and instantaneous yields among the three paired sampling stations.

Quality-Control Procedures

Field quality-control procedures included the collection of replicate and blank samples. Field-blank samples provided information on bias or the potential for contamination as a result of sample collection, processing, and analysis. Analytical results from the field-blank samples showed that concentrations of constituents discussed in this report were less than the laboratory reporting level. Replicate samples provided information on the variability of analytical results caused by sample collection, processing, and analysis. Relative differences in concentrations in environmental and replicate

samples were less than 3 percent for constituents discussed in this report. These results indicate that sample collection, processing, and analysis did not introduce any variation in the environmental data to affect the interpretation of results.

Quality-control procedures for the collection of continuous specific-conductance data followed procedures in Wagner and others (2006). The sensors were cleaned during each field visit for measuring streamflow or the collection of water-quality samples. Field calibration was performed if the cleaned sensor readings obtained during the calibration check differed by more than the calibration criteria (Wagner and others, 2006).

Stream Hydrology and Water Quality

Local streamflow conditions during the study were above normal based on 78 years of streamflow record (1929–2007) at the USGS streamflow-gaging station Lamoille River at East Georgia, VT (station 04292500). Normal streamflow is defined as annual mean streamflow that falls within the 25th- to 75th-percentile streamflow duration. The normal range of streamflow statistics for the period of record for the Lamoille River at East Georgia, VT, is 1,082 ft³/s at the 25th percentile and 1,408 ft³/s at the 75th percentile. Mean streamflows for water years 2006 and 2007 were 1,910 and 1,540 ft³/s, respectively (<http://wdr.water.usgs.gov/>). Annual mean discharge for 2007 was less than the annual mean discharge for 2006, reflecting a decrease in annual precipitation in 2007.

Total annual runoff (based on the annual average volume of water in each stream normalized for drainage area) for 2006 at the three paired stations was 28.6 in. for Alder Brook, 24.3 in. for Allen Brook, and 37.5 in. for Mill Brook. Total annual runoff for 2007 was 17.9 in. for Alder Brook, 17.2 in. for Allen Brook, and 24.7 in. for Mill Brook. Total runoff for the Alder Brook tributary station was 39.9 in. (partial year) and was greater than expected possibly due to unaccounted for drainage to the station. These comparisons show that total annual runoff in the watersheds of Alder and Allen Brooks was similar and total annual runoff in the Mill Brook watershed was greater than runoff in the other two watersheds. The difference was likely the result of lower topographic relief in the Alder and Allen Brook watersheds than in the Mill Brook watershed. The headwaters of Mill Brook originate on the western slopes of the Green Mountains. Precipitation also tends to be greater in the higher altitude mountainous terrain than in the lower altitude areas.

Mean concentrations of Cl in the routine water-quality samples collected at upstream-sampling stations ranged from 8.2 to 72 mg/L and those in samples collected at downstream stations ranged from 7.9 to 80.7 mg/L. Mean Cl loads in samples collected at upstream stations ranged from 1,100 to 4,090 lb/d and those in samples collected at downstream stations ranged from 1,110 to 4,200 lb/d. Estimated mean annual Cl loads at upstream stations ranged from 402,000 to

1,490,000 lb/yr and those at downstream stations ranged from 405,000 to 1,530,000 lb/yr (table 2).

In the following sections describing hydrology and water quality for each stream, concentrations of selected constituents and loads of Cl are summarized. Relations of streamflow to specific conductance and Cl concentrations are also summarized. Comparisons are made between (1) measured and estimated Cl concentrations to USEPA recommended chronic toxicity criteria to determine the frequency and duration of exceedances, and (2) the VTrans Cl application rates for winter maintenance to the estimated Cl load measured at each of the downstream stations.

Estimated loads and yields of Cl at the sampling stations for the 2-year study period are presented in table 2 along with the 95-percent confidence intervals of the mean load, the standard error of prediction, and the ratio of the standard error of prediction to the mean load. The ratio of the standard error of prediction to the mean load standardizes the model error and provides a comparison among stations having large differences in load estimates. The prediction error ranged from 2.0 to 6.1 percent of the mean loads. This indicates that the model error for the estimates of Cl loads was low. Mean streamflow, estimated loads and yields, and the 95-percent confidence intervals for Cl loads for individual years (2006 and 2007) for each station are presented in table 3.

Mill Brook at VT 117 near Essex Junction, VT, Stations 04289880 and 04289881

The Mill Brook stations above and below VT 117 near Essex Junction, VT, represent drainage from a two-lane highway in a rural setting. The Mill Brook watershed is predominantly a forested and agricultural area. The two-lane rural State highway VT 117 crosses Mill Brook between the upstream and downstream stations and serves traffic from interstate I-89 going to the rural communities of Jericho, Underhill, and parts of Essex, VT (fig. 2). The contributing drainage basins for the upstream and downstream stations are 16.3 and 16.4 mi², respectively (fig. 2). The downstream station on Mill Brook has the lowest road density (1.7 mi/mi²) and percent impervious surface (0.52 percent) of the three downstream stations (table 1). Land use in the Mill Brook watershed is about 72 percent forest, 15 percent agriculture, 9 percent wetlands, water, and barren, and 4 percent developed (table 1; fig. 1).

Annual mean discharge for the years 2006 and 2007 was 45 and 30 ft³/s, respectively. Daily mean streamflow and time distribution for water-quality samples are shown in figure 3A. The minimum and maximum streamflow at which water-quality samples were collected was 3.7 ft³/s and 217 ft³/s, respectively.

Continuous specific-conductance values and concentrations of Cl in the routine water-quality samples are shown in figure 3B and summary statistics are presented in tables 4 and 5. The minimum and maximum specific-conductance value at

Table 2. Estimated mean annual loads, yields, confidence intervals, standard error of prediction, and the ratio of the standard error of prediction to the mean annual load for chloride at sampling stations for the 2-year sampling period in Chittenden County, VT.

[Numbers have been independently rounded; USGS, U.S. Geological Survey; lb/d, pounds per day; lb/yr, pounds per year; (lb/mi²)/yr, pounds per square mile per year]

Site number (table 1; fig. 1)	USGS station number	Station name	Mean load		Yield (lb/mi ²)/yr	95-percent confidence interval		Standard error of prediction (lb/yr)	Ratio of standard error of prediction to mean load (percent)
			(lb/d)	(lb/yr)		Lower (lb/yr)	Upper (lb/yr)		
1	04289880	Mill Brook above VT 117, near Essex Junction, VT	1,100	402,000	24,600	387,000	420,000	8,400	2.1
2	04289881	Mill Brook below VT 117, near Essex Junction, VT	1,110	405,000	24,700	391,000	423,000	8,030	2.0
3	04290160	Alder Brook above VT 289, near Essex Junction, VT	1,940	708,000	79,800	628,000	799,000	43,400	6.1
4	042901608	Alder Brook tributary at mouth, near Essex Junction, VT	280	93,800	1,900,000	92,100	98,800	1,710	1.8
5	04290161	Alder Brook below VT 289, near Essex Junction, VT	2,220	810,000	90,700	767,000	854,000	22,600	2.8
6	042903349	Allen Brook above VT 2A, near Essex Junction, VT	4,090	1,490,000	152,000	1,400,000	1,590,000	50,000	3.4
7	04290335	Allen Brook below VT 2A, near Essex Junction, VT	4,200	1,530,000	155,000	1,470,000	1,600,000	34,300	2.2

^aTime period is from December 15, 2006, to November 15, 2007.

Table 3. Estimated annual loads, yields, and confidence intervals for chloride by year at sampling stations in Chittenden County, VT.[Numbers have been independently rounded; USGS, U.S. Geological Survey; lb/d, pounds per day; lb/yr, pounds per year; (lb/mi²)/yr, pounds per square mile per year]

Site number (table 1; fig. 1)	USGS station number	Station name	Year	Mean streamflow (in thousands of acre-feet)	Chloride			
					Load (lb/d)	Load (lb/yr)	Yield (lb/mi ²)/yr	95-percent confidence interval
								Lower (lb/yr) Upper (lb/yr)
1	04289880	Mill Brook above VT 117, near Essex Junction, VT	2006	32,600	1,290	471,000	28,900	449,000 489,000
			2007	21,400	920	336,000	20,600	321,000 347,000
2	04289881	Mill Brook below VT 117, near Essex Junction, VT	2006	32,600	1,300	475,000	28,900	453,000 493,000
			2007	21,400	930	339,000	20,700	329,000 354,000
3	04290160	Alder Brook above VT 289, near Essex Junction, VT	2006	13,600	2,420	883,000	99,600	767,000 1,010,000
			2007	8,540	1,470	537,000	60,500	482,000 599,000
4	042901608	Alder Brook tributary at mouth, near Essex Junction, VT	2007	116	280	93,800	1,900,000	92,100 98,800
5	04290161	Alder Brook below VT 289, near Essex Junction, VT	2006	13,600	2,670	975,000	109,000	913,000 1,040,000
			2007	8,540	1,770	646,000	72,300	613,000 675,000
6	042903349	Allen Brook above VT 2A, near Essex Junction, VT	2006	12,800	4,830	1,760,000	179,000	1,640,000 1,890,000
			2007	9,050	3,350	1,220,000	124,000	1,150,000 1,300,000
7	04290335	Allen Brook below VT 2A, near Essex Junction, VT	2006	12,800	4,960	1,810,000	203,000	1,730,000 1,900,000
			2007	9,050	3,450	1,260,000	141,000	1,200,000 1,310,000

Time period is from December 15, 2006, to November 15, 2007.

which water-quality samples were collected was 58 and 184 $\mu\text{S}/\text{cm}$, respectively. Mean specific conductance of the routine water-quality samples was 118 $\mu\text{S}/\text{cm}$ at the upstream station and 110 $\mu\text{S}/\text{cm}$ at the downstream station. Continuous specific conductance measurements found little difference between the upstream and downstream stations over the 2-year monitoring period (table 5).

Mean Cl concentrations in the routine samples were 8.2 mg/L at the upstream station and 7.9 mg/L at the downstream station (table 4). The relation between specific-conductance values and Cl concentrations (fig. 4A) was used to estimate daily mean Cl concentrations on the basis of the continuous specific-conductance data collected at the station (fig. 4B); this regression relation had an R^2 of .91. The estimated mean Cl concentrations based on this relation were 8.2 mg/L at the upstream station and 8.3 mg/L at the downstream station for the 2-year study period (table 5). The highest estimated daily mean Cl concentrations in 2006 (12.6 mg/L upstream and 12.8 mg/L downstream) (table 5) occurred during periods of summer low flow in August following an intense summer rainstorm of 1.61 in. Possible explanations of higher Cl concentrations in the summer and fall is that road salt may be retained in soils and leached during precipitation events, and or other Cl sources are present in the stream watershed.

The highest estimated daily mean Cl concentrations in 2007 also occurred during a period of summer low flow and following a period of below-normal rainfall in September (16.0 mg/L at both stations) (table 5). In contrast, the lowest estimated daily-mean Cl concentrations occurred following rainstorms in October 2006 (2.4 mg/L downstream and 2.1 mg/L upstream) and in April 2007 (2.3 mg/L downstream and 2.2 mg/L upstream), likely as a result of dilution. None of the Cl concentrations in the routine water-quality samples or the estimated daily mean Cl concentrations in samples from either the upstream or downstream stations exceeded the USEPA recommended chronic toxicity criterion of 230 mg/L or the acute toxicity criterion of 860 mg/L (U.S. Environmental Protection Agency, 1988) (fig. 4B; tables 4 and 5).

The January 2006 rain-on-snow event and its effects on concentrations of Cl in relation to stage are shown in figure 5A. Stage was used as a surrogate for discharge because ice in the stream affected the instantaneous-streamflow values and precluded the use of streamflow in the analysis. This event resulted in only a very slight rise in Cl concentrations (fig. 5A). Estimated maximum instantaneous Cl concentrations during this event were 8.9 mg/L upstream and 8.6 mg/L

downstream (fig. 5A). The stage rise (apparent discharge increase) at the end of the day was attributed to ice jams (fig. 5A).

The March 2007 snowmelt event and its effects on concentrations of Cl in relation to streamflow from March 2 to March 5 are shown in figure 5B. The estimated maximum instantaneous Cl concentrations during this event were 12.9 mg/L on March 3 at the downstream station and 13.0 mg/L on March 2 at the upstream station (fig. 5B). Streamflow was stable during the melt period, decreasing slightly as Cl concentrations increased. The decrease in streamflow was likely the result of minor ice jams upstream from the Mill Brook stations. The reduced discharge may have contributed to slightly higher concentrations because of reduced dilution.

The difference in the estimated Cl loads upstream and downstream of the state highway were calculated by subtracting the estimated upstream Cl load from the estimated downstream Cl load. This difference was 4,000 lbs in 2006 and 3,000 lbs in 2007 (table 6; fig. 6). The portion of Rte 117 draining to Mill Brook had an estimated 11,600 lbs of applied Cl from VTrans snowplow operations in the winter of 2006 and 7,560 lbs in the winter of 2007 (table 6; fig. 6). VTrans maintained 0.47 lane-miles in the Mill Brook Basin, but an additional 0.17 lane-miles of other non-state roads in the watershed also are maintained and are not accounted for in the road-salt application estimate. The applied Cl amount from State deicing operations represents about 2 percent of the total annual Cl load downstream of the highway crossing. State applications were greater than the gain in Cl loads between the upstream and downstream stations in both years. Because the amount of applied Cl by VTrans is greater than the difference in Cl loads between the upstream and downstream stations, the applied Cl is likely being sequestered in the surrounding soils and vegetation.

Overall, since only about 2 percent of the total Cl load in Mill Brook may be attributed to VTrans road salt applications, inputs derived from other sources in the watershed account for nearly all of the Cl measured in samples collected at the Mill Brook stations. Low Cl concentrations in Mill Brook may result from two important basin characteristics, that is, the watershed is minimally urbanized and the highway density is relatively low. Moreover, the watershed area and discharge are twice those of the other study streams (table 1). Therefore, salt runoff from road-stream crossings can be diluted rapidly by relatively high streamflow and or assimilated into adjacent soils.

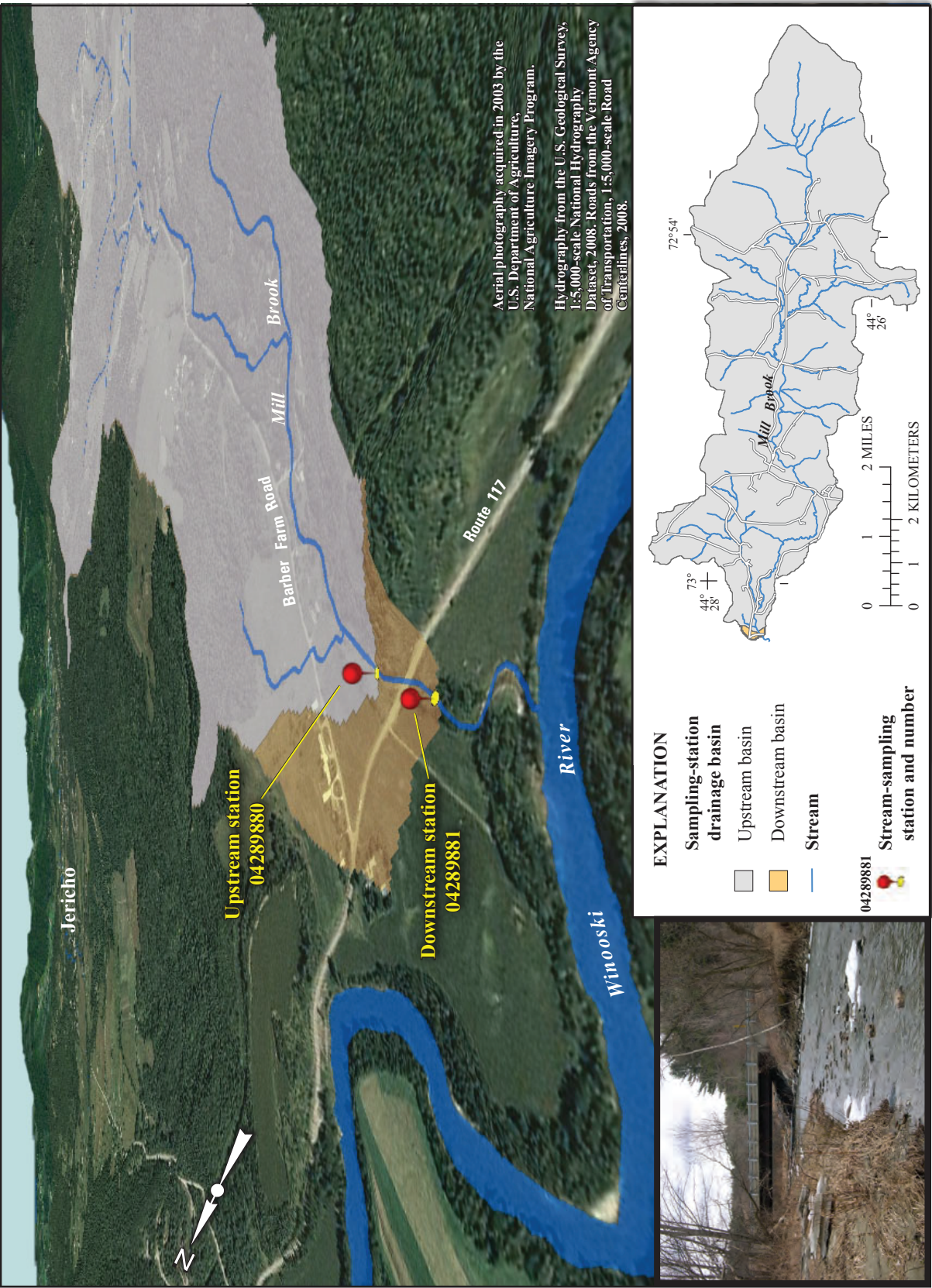


Figure 2. Location of upstream- and downstream-sampling stations, basin delineations, state road network, and photograph of the downstream-sampling station for Mill Brook at VT 117 near Essex Junction, VT, stations 04289880 and 04289881 (Refer to table 1 and figure 1 for additional station information).

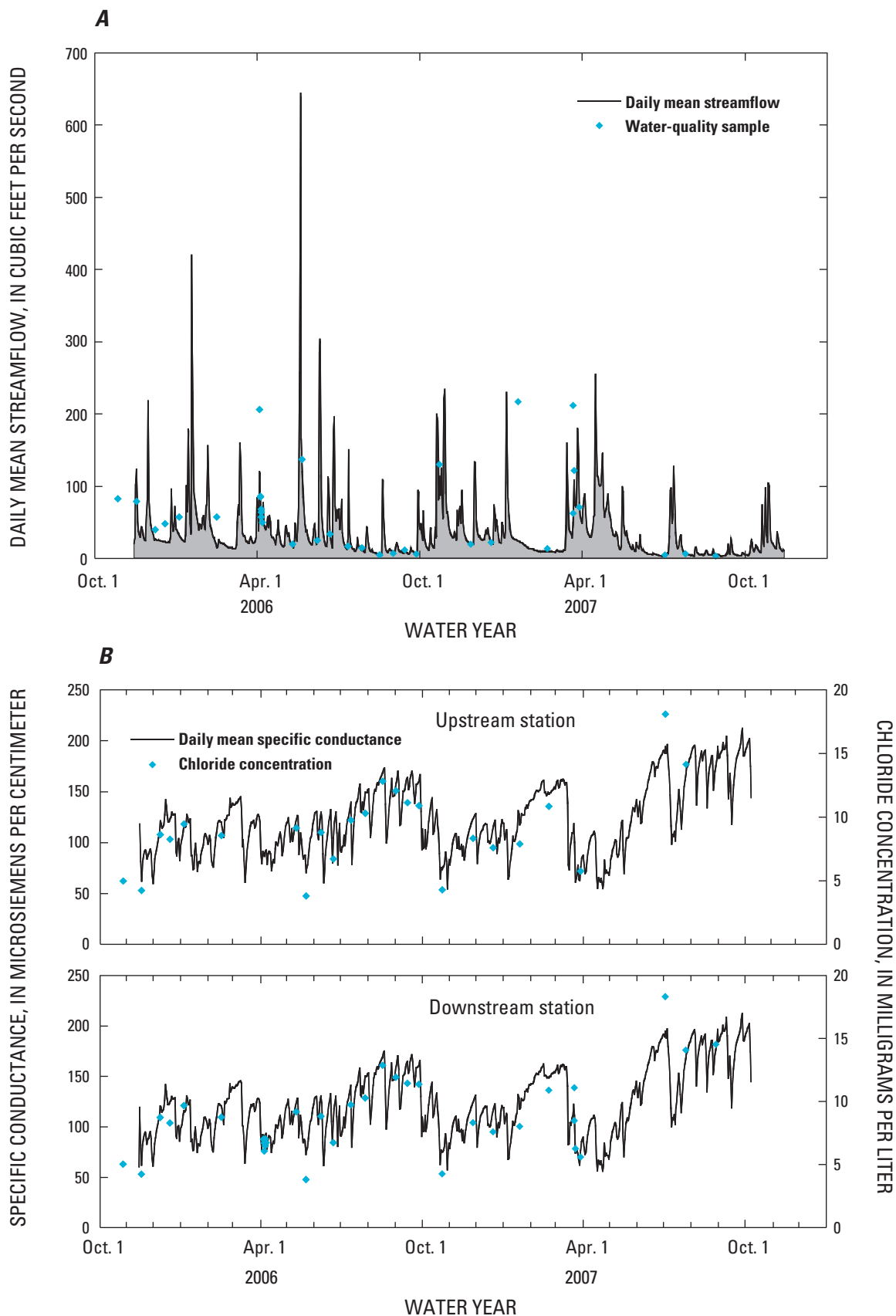


Figure 3. (A) Daily mean streamflow and time distribution of water-quality samples and (B) daily mean specific conductance and concentrations of chloride for Mill Brook at VT 117 near Essex Junction, VT, stations 04289880 and 04289881.

Table 4. Summary statistics for values of specific conductance and pH and concentrations of chloride, sodium, calcium, potassium, magnesium, sulfate, and nitrite plus nitrate for routine water-quality samples collected at Mill Brook at VT 117, near Essex Junction, VT.

[Min, minimum; Med, median; Max, maximum]

Water-quality constituent ¹	Upstream site, station 04289880					Downstream site, station 04289881				
	Number of samples	Min	Mean	Med	Max	Number of samples	Min	Mean	Med	Max
Specific conductance	24	58	118	118	183	35	58	110	114	184
pH	20	6.6	7.4	7.5	8.1	32	6.6	7.4	7.6	8.2
Chloride	24	3.0	8.2	7.9	17	35	3.0	7.9	7.5	17
Sodium	24	2.46	5.64	5.55	10.9	35	2.44	5.25	5.21	11.1
Calcium	24	6.32	12.8	12.6	20.1	35	6.27	11.6	11.5	20.5
Potassium	7	0.45	0.73	0.79	0.96	7	0.44	0.74	0.76	1.01
Magnesium	7	1.21	2.19	2.36	3.32	7	1.20	2.26	2.42	3.58
Sulfate	7	4.4	5.7	5.9	6.9	7	4.4	5.6	5.8	6.9
Nitrite plus nitrate	5	0.09	0.29	0.29	0.50	5	0.10	0.28	0.28	0.50

¹All constituents are dissolved and reported as milligrams per liter except specific conductance, which is reported as microsiemens per centimeter at 25 degrees Celsius, and pH, which is reported as standard units.

Table 5. Daily mean summary statistics for continuous specific conductance and estimated continuous chloride concentrations at Mill Brook at VT 117, near Essex Junction, VT.[$\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; Min, minimum; Med, median; Max, maximum]

Water-quality constituent	Upstream site, station 04289880				Downstream site, station 04289881			
	Min	Mean	Med	Max	Min	Mean	Med	Max
Specific conductance ($\mu\text{S}/\text{cm}$)	45	113	109	201	45	114	110	202
Chloride (mg/L)	2.2	8.2	7.8	16	2.3	8.3	8.0	16

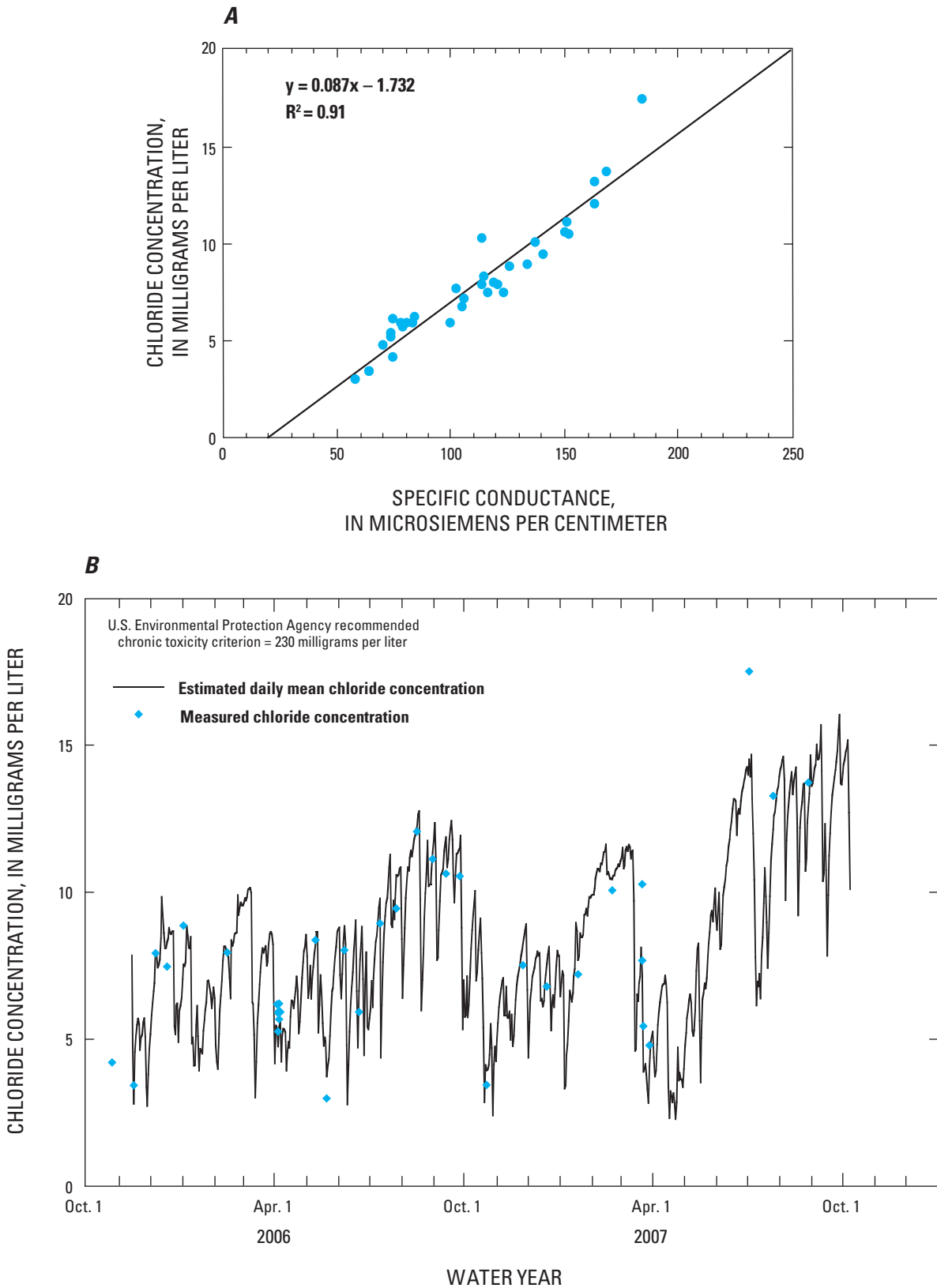


Figure 4. (A) Relation between specific conductance and chloride concentration in routine water-quality samples and (B) estimated daily mean chloride concentrations and chloride concentration in routine water-quality samples for the study period at Mill Brook at VT 117 near Essex Junction, VT, station 04289881.

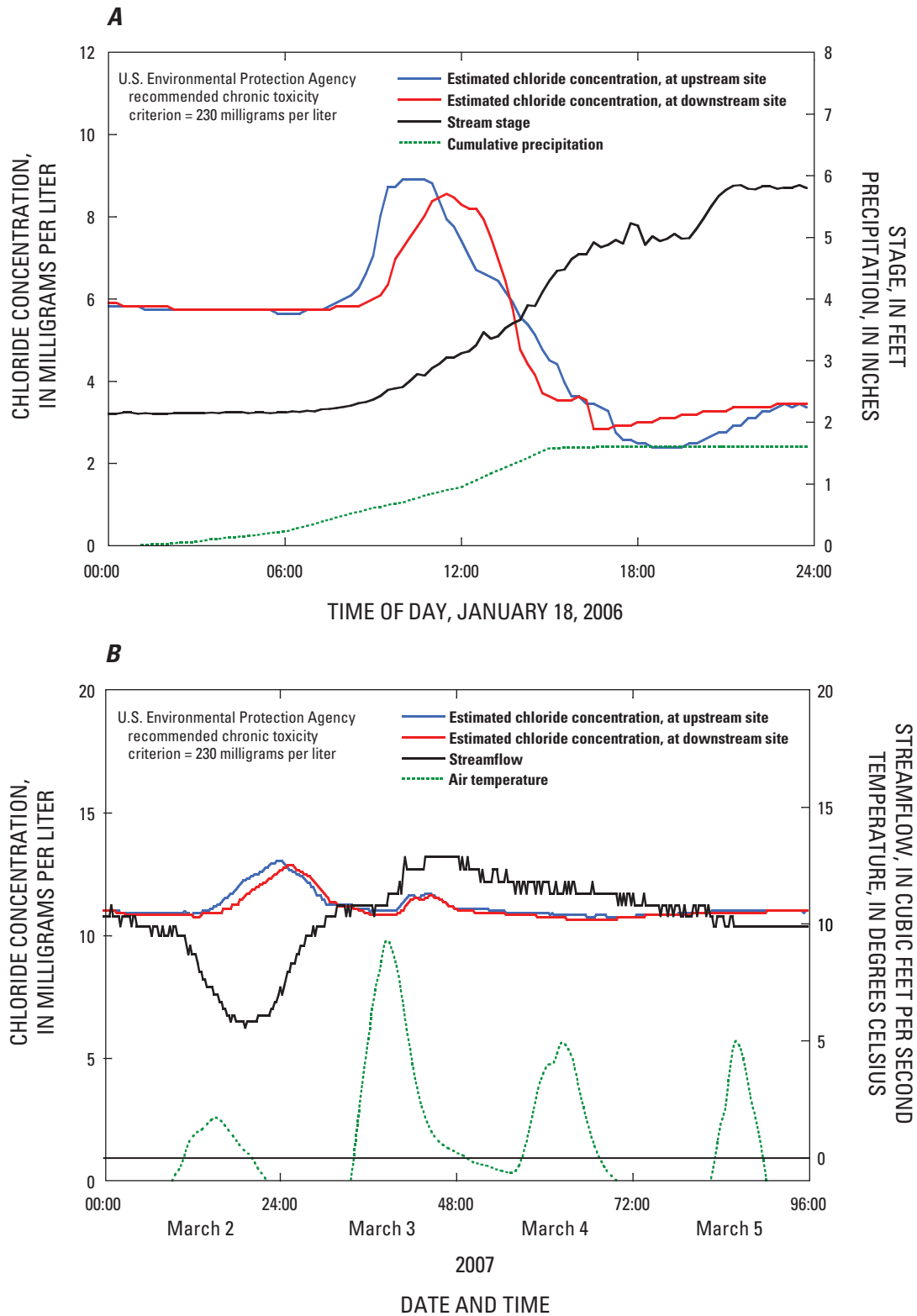


Figure 5. Relation of estimated chloride concentration to (A) stream stage during a rain-on-snow event (January 18, 2006) and (B) streamflow during a snowmelt event (March 2007) at Mill Brook at VT 117 near Essex Junction, VT, stations 04289880 and 04289881.

Table 6. Difference in the estimated annual stream chloride load at upstream and downstream sampling stations and estimated Vermont Agency of Transportation (VTrans) applied chloride load at sampling sites in Chittenden County, VT.

[Numbers have been independently rounded; USGS, U.S. Geological Survey; lb/yr, pounds per year]

Site number (table 1; fig. 1)	USGS station numbers (upstream, downstream)	Station name	Year	Difference in chloride load ¹ (lb/yr)	Estimated VTrans load ² (lb/yr)
1	04289880, 04289881	Mill Brook at VT 117, near Essex Junction, VT	2006	4,000	11,600
			2007	3,000	7,560
3	04290160, 04290161	Alder Brook at VT 289, near Essex Junction, VT	2006	92,000	55,700
			2007	109,000	67,800
6	042903349, 04290335	Allen Brook at VT 2A, near Essex Junction, VT	2006	50,000	12,000
			2007	40,000	8,660

¹Downstream load minus upstream load.
²Estimated chloride load applied by Vermont Agency of Transportation (source of data).

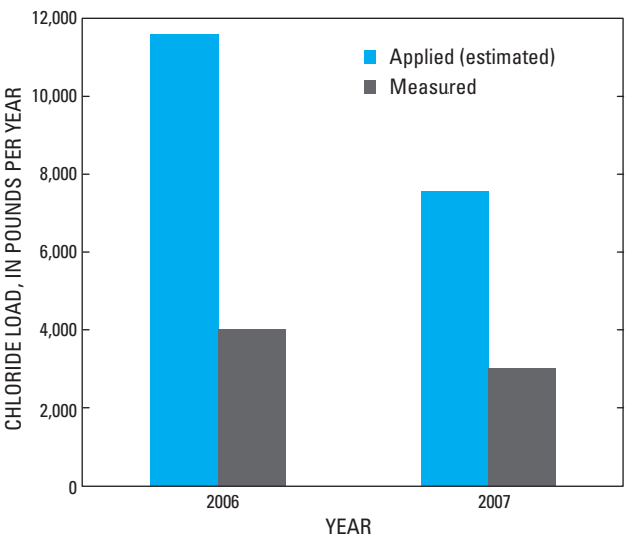


Figure 6. Estimated applied road deicing and measured chloride load for Mill Brook at VT 117 near Essex Junction, VT, station 04289881.

Alder Brook at VT 289, near Essex Junction, VT, Stations 04290160 and 04290161

Alder Brook above and below VT 289 near Essex Junction, VT, are stations that represent drainage from a two-lane State highway, constructed on a four-lane right-of-way. The highway was opened in October 1993 and is a segment of the proposed Chittenden County Circumferential Highway. The completed segment links VT 117 to VT 2A in Essex. The upstream station has a drainage area of 8.87 mi² and is upstream from both a highway culvert and the confluence of a small tributary, and the downstream station has a drainage area of 8.93 mi² (table 1; fig. 7). The drainage area of the downstream station on Alder Brook has a greater road density (3.8 mi/mi²) and percent impervious surface area (3.6 percent) than the downstream station on Mill Brook and a similar road density and percent impervious surface to the downstream station on Allen Brook (table 1). The Alder Brook watershed is predominantly an agricultural and forested area. Land use in the Alder Brook watershed is about 47 percent agricultural, 34 percent forested, 10 percent wetlands and water, and 9 percent developed (table 1; fig. 1).

Annual mean discharge for the years 2006 and 2007 was 18.8 and 11.8 ft³/s, respectively. Daily mean streamflow and time distribution for water-quality samples are shown in figure 8A. The minimum and maximum streamflow at which water-quality samples were collected was 0.70 and 121 ft³/s, respectively.

Continuous specific-conductance values and concentrations of Cl in the routine water-quality samples are shown in figure 8B and summary statistics are presented in tables 7 and 8. The minimum and maximum specific-conductance value at which water-quality samples were collected was 148 and 727 μ S/cm, respectively. Mean specific conductance of the routine water-quality samples was 349 μ S/cm at the upstream station and 380 μ S/cm at the downstream station. Mean continuous specific conductance measurements (table 8) were similar to the mean specific conductance values of the routine water-quality samples at both the upstream and downstream stations. The mean continuous specific conductance value over the 2-year monitoring period was 12 percent greater downstream than the upstream mean value (table 8).

Mean Cl concentrations in the routine samples were 39.3 mg/L at the upstream station and 52.3 mg/L at the downstream station (table 7). The relation between specific-conductance values and Cl concentrations at the downstream sampling (fig. 9A) was used to estimate daily mean Cl concentrations on the basis of the continuous specific-conductance data collected at the station (fig. 9B); the regression relation had an R² of 0.86. Estimated mean Cl concentrations during 2006–2007 generated from this relation were 46.9 mg/L at the upstream station and 54.3 mg/L at the downstream station (table 8). The highest estimated daily mean Cl concentration in 2006 for the downstream station (112 mg/L) occurred during a period of summer low flow in

August (fig. 9B) following an intense summer rainstorm. This indicates that Cl may be stored in streambed sediments and nearby soils, or that there are other sources of Cl in the Alder Brook Basin.

The greatest estimated daily mean Cl concentration at the downstream station in 2007 (128 mg/L) occurred during a period of snowmelt in March (fig. 9B). Estimated Cl concentrations greater than 100 mg/L were observed at Alder Brook in August 2006 and October 2007 following intense rainstorms. In contrast, the lowest estimated daily mean Cl concentration at the downstream station (7.7 mg/L) also occurred following a rainstorm in October 2006. The low concentration was likely a result of dilution. None of the Cl concentrations in the routine water-quality samples or the estimated daily mean Cl concentrations in samples from either the upstream- or downstream-sampling stations exceeded the USEPA recommended chronic toxicity criterion of 230 mg/L or the acute toxicity criterion of 860 mg/L (figs. 8B and 9B; tables 7 and 8).

The January 2006 rain-on-snow event and its effects on concentrations of Cl in relation to stream stage are shown in figure 10A. Stream stage was used as a surrogate for discharge, in this case, because of the effects of ice. The stage measurement reading did not change substantially during the beginning of the event, indicating that runoff was small. Cl concentrations increased at the downstream station prior to an increase at the upstream station, possibly indicating that runoff containing a higher Cl concentration was discharging to the stream between the two stations. The estimated maximum instantaneous Cl concentration during this event was 219 mg/L at the downstream station (fig. 10A). The highest Cl concentration was observed just prior to the large rise in stream stage. The Cl concentration decreased as streamflow increased as a result of dilution (fig. 10A).

The March 2007 snowmelt event and its effects on concentrations of Cl in relation to streamflow from March 2 to March 5 are shown in figure 10B. The small increase in Cl concentration at the downstream station only (fig. 10B) indicates that Cl inputs from melting snow along the highway were discharging to Alder Brook below the upstream station. An increase in Cl concentration was observed concurrently at both stations on the evening of March 2. Chloride concentrations decreased (fig. 10B), and snowmelt did not occur again until mid-day on March 3, as air temperature increased (fig. 10B). A slight increase in Cl concentration was again observed at the downstream station, prior to the large increase in Cl concentrations at both stations (fig. 10B). The estimated maximum instantaneous Cl concentration during this event was 232 mg/L at both stations (fig. 10B). These similar concentrations indicate that the dominant source(s) of Cl was further upstream from the stations. The USEPA recommended chronic toxicity criterion of 230 mg/L was slightly exceeded during the event, but the associated USEPA 4-day average criterion was not exceeded (U.S. Environmental Protection Agency, 1988) (fig. 10B).

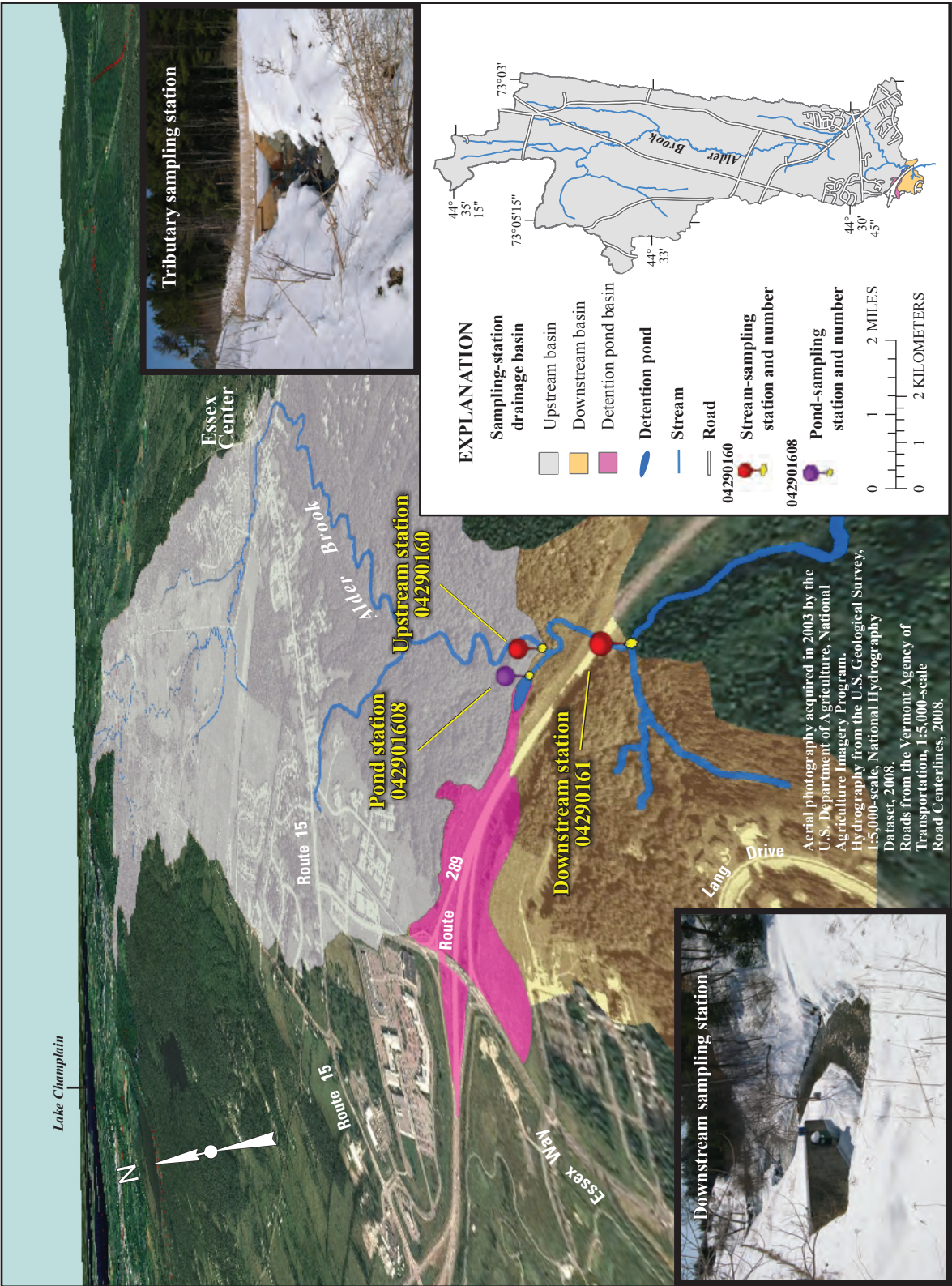


Figure 7. Location of upstream- and downstream-sampling stations, basin delineations, state road network, and photograph of the downstream- and tributary-sampling stations for Alder Brook at VT 289 near Essex Junction, VT, stations 04290160, 042901608, and 04290161 (Refer to table 1 and figure 1 for additional site information).

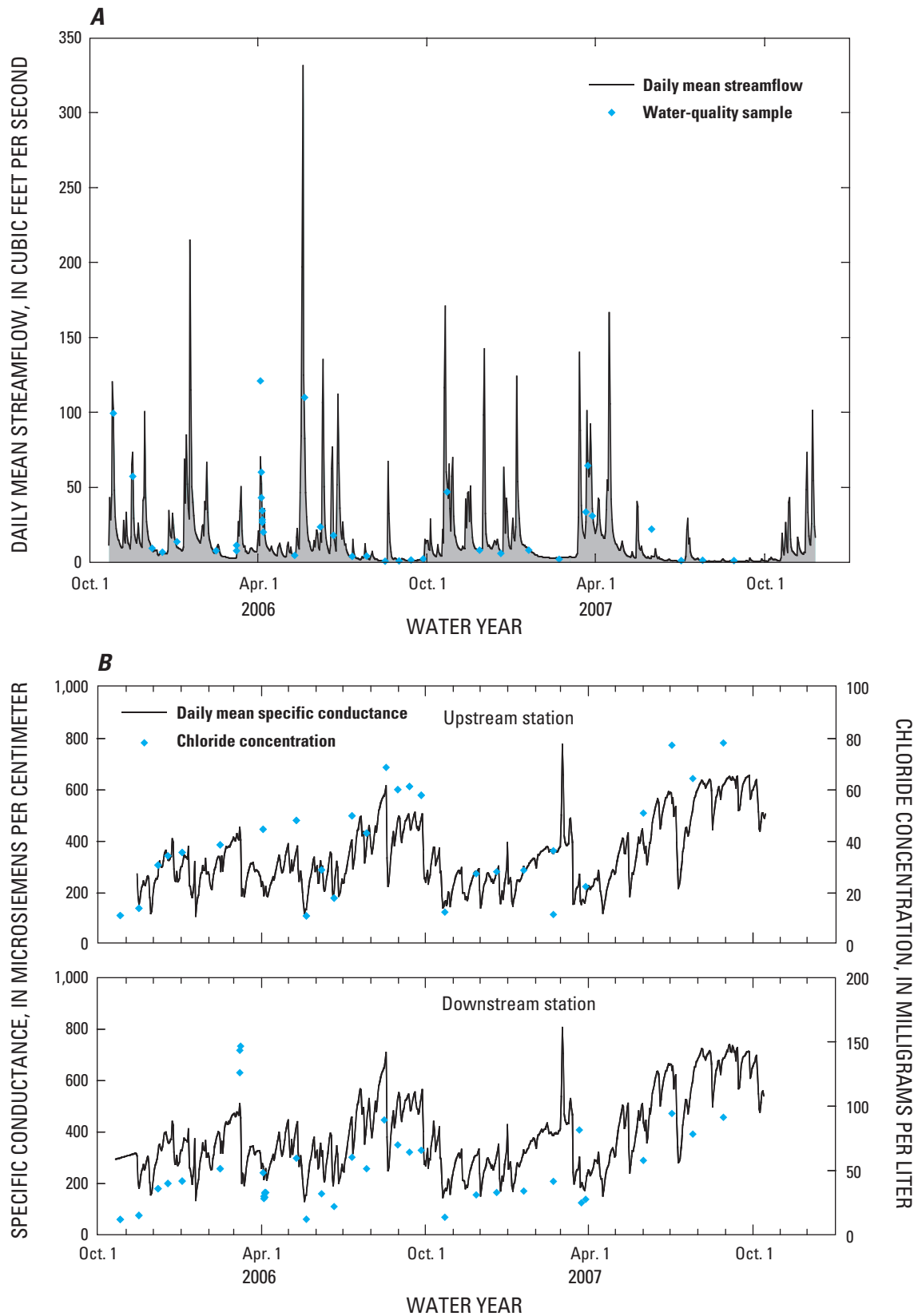


Figure 8. (A) Daily mean streamflow and time distribution of water-quality samples and (B) daily mean specific conductance and concentrations of chloride for Alder Brook at VT 289 near Essex Junction, VT, stations 04290160 and 04290161.

Table 7. Summary statistics for values of specific conductance and pH and concentrations of chloride, sodium, calcium, potassium, magnesium, sulfate, and nitrite plus nitrate for routine water-quality samples collected at Alder Brook at VT 289, near Essex Junction, VT.

[Min, minimum; Med, median; Max, maximum]

Water-quality constituent ¹	Upstream site, station 04290160					Downstream site, station 04290161				
	Number of samples	Min	Mean	Med	Max	Number of samples	Min	Mean	Med	Max
Specific conductance	28	148	349	338	620	38	155	380	349	727
pH	24	7.3	7.7	7.8	8.9	33	6.7	7.5	7.7	8.7
Chloride	28	11.1	39.3	36.1	78.2	38	12.2	52.3	41.0	147
Sodium	28	8.1	24.4	22.8	45.3	38	9.0	29.8	24.7	80.9
Calcium	28	13.2	32.1	31.7	59.5	38	14.0	30.5	29.4	61.8
Potassium	8	0.99	1.61	1.72	1.97	7	1.00	1.57	1.61	1.94
Magnesium	8	3.12	8.10	7.15	15.4	7	3.26	7.89	7.06	16.9
Sulfate	8	5.3	12.0	11.5	21.4	7	5.74	13.2	11.9	25.5
Nitrite plus nitrate	6	0.18	0.35	0.30	0.68	5	0.19	0.36	0.31	0.68

¹All constituents are dissolved and reported as milligrams per liter except specific conductance, which is reported as microsiemens per centimeter at 25 degrees Celsius, and pH, which is reported as standard units.

The difference in the estimated Cl loads upstream and downstream of the State highway were 92,000 lbs in 2006 and 109,000 lbs in 2007 (table 6; fig. 11). The state highway draining to Alder Brook received an estimated 55,700 lbs of applied Cl from VTrans snowplow operations in the winter of 2006 and 67,800 lbs in 2007 (table 6; fig. 11). VTrans maintained 1.32 lane-miles but an additional 0.76 lane-miles of other non-state roads in the watershed are maintained and are not accounted for in this estimate. The applied Cl amount from State snowplow operations represents about 9 and 17 percent of the total annual Cl load downstream of Rte 289 in 2006 and

2007, respectively, and about 60 percent of the difference in the loads at the upstream and downstream stations. Comparison of the estimated Cl loads in Alder Brook to Cl applications by VTrans indicate that most of the Cl loads in the Alder Brook watershed likely originates from other sources. Some of the Cl in the stream may also be originating from shallow groundwaters and nearby soils that have retained Cl applied in previous years. Another possible source of salt to Alder Brook between the upstream and downstream stations is the Alder Brook tributary. Streamflow and Cl concentrations and loads from this tributary are described in the following section.

Table 8. Daily mean summary statistics for continuous specific conductance and estimated continuous chloride concentrations at Alder Brook at VT 289, near Essex Junction, VT.

[μS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; Min, minimum; Med, median; Max, maximum]

Water-quality constituent	Upstream site, station 04290160				Downstream site, station 04290161			
	Min	Mean	Med	Max	Min	Mean	Med	Max
Specific conductance (μS/cm)	109	349	320	777	131	390	357	805
Chloride (mg/L)	3.8	46.9	41.6	124	7.7	54.3	48.3	128

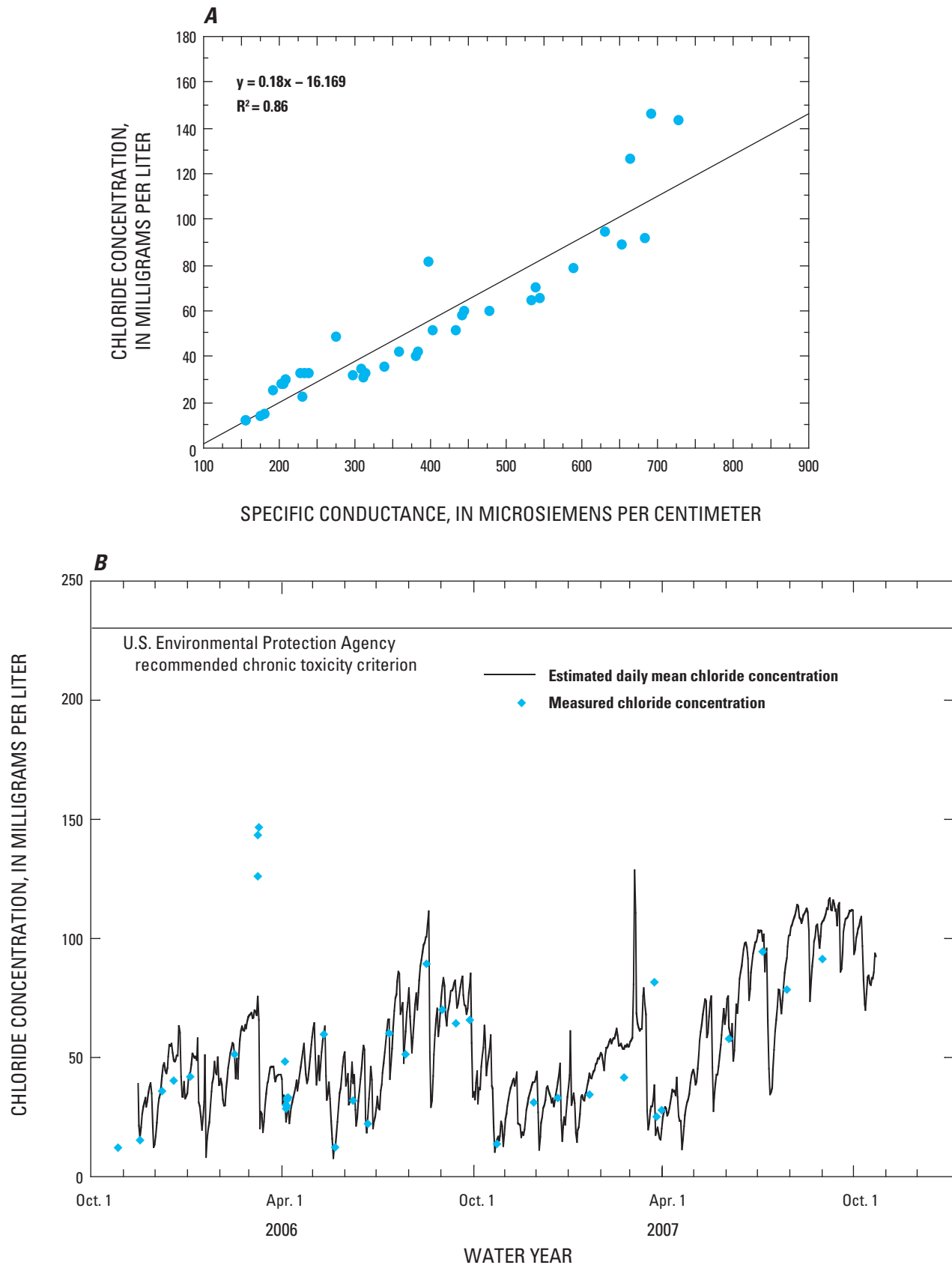


Figure 9. (A) Relation between specific conductance and chloride concentration in routine water-quality samples and (B) estimated daily mean chloride concentrations and chloride concentration in routine water-quality samples for the study period at Alder Brook at VT 289 near Essex Junction, VT, station 04290161.

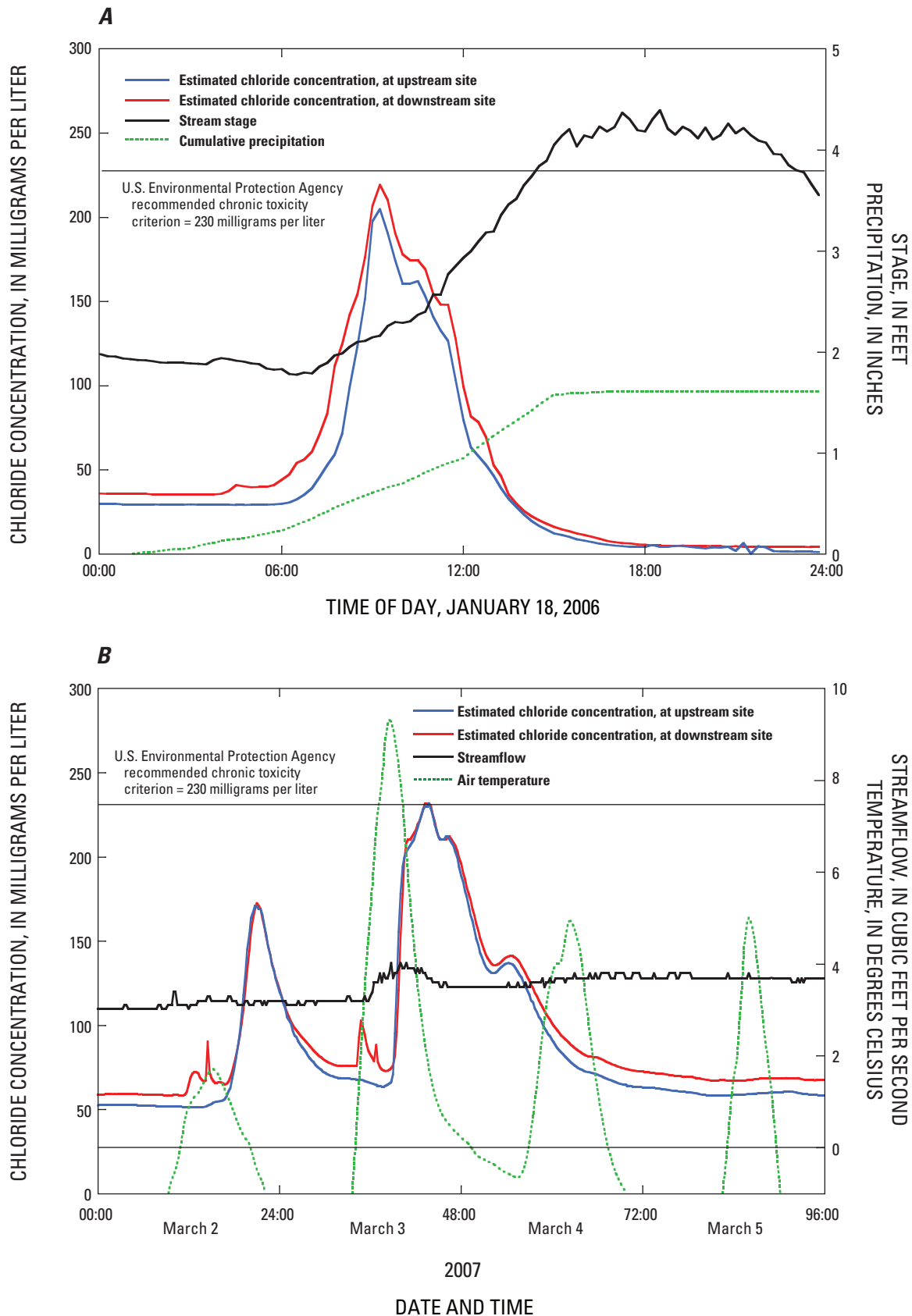


Figure 10. Relation of estimated chloride concentration to (A) stream stage during a rain-on-snow event (January 18, 2006) and (B) streamflow during a snowmelt event (March 2007) at Alder Brook at VT 289 near Essex Junction, VT, stations 04290160 and 04290161.

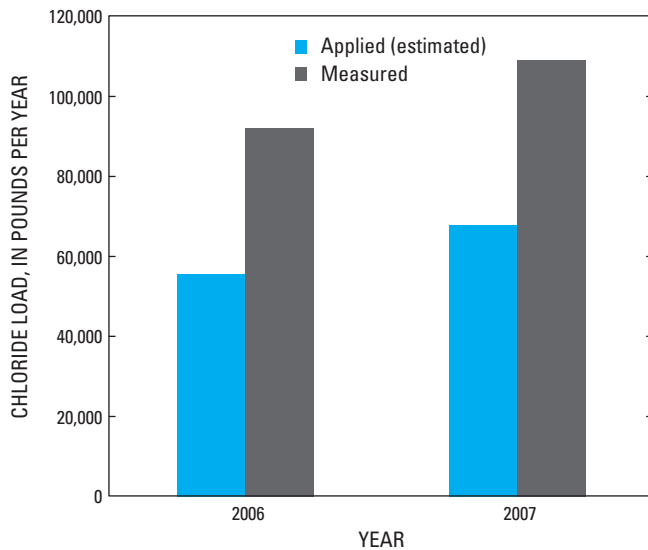


Figure 11. Estimated applied road deicing and measured chloride load for Alder Brook at VT 289 near Essex Junction, VT, station 04290161.

Alder Brook Tributary at Mouth near Essex Junction, VT, Station 042901608

The Alder Brook tributary station was established in December 2006 to expand and supplement data collected at the paired Alder Brook stations. The Alder Brook tributary is a constructed culverted drainage system and retention basin with a topographically defined drainage area of 0.05 mi². The area draining to the Alder Brook tributary has the highest road density (40 mi/mi²) and percent impervious surface (20 percent) of all the stations monitored (table 1). Direct overland flow from the highway can enter the culverted system. This water then discharges to a ditch about 250 ft upstream from a retention basin (also known as a sedimentation pool); the surface area of the retention basin is about two-thirds aquatic vegetation. The retention basin collects drainage from a highway interchange area. Water flowing from the outlet of the retention basin discharges into Alder Brook upstream of VT 289, just downstream from the upstream Alder Brook station (fig. 7).

Mean discharge from December 2006 to November 2007 was 0.17 ft³/s. Daily mean streamflow and time distribution for water-quality samples are shown in figure 12A. The minimum and maximum streamflow at which water quality samples were collected was 0.08 and 0.98 ft³/s, respectively.

Continuous specific-conductance values and concentrations of Cl for the routine water-quality samples are shown in figure 12B and summary statistics presented in tables 9 and

10. The minimum, mean and maximum specific-conductance value at which water-quality samples were collected was 1,095, 1,810 and 2,330 μ S/cm, respectively.

The mean Cl concentration in the routine water-quality samples was 449 mg/L (table 9). The relation between specific-conductance values and Cl concentrations (fig. 13A) was used to estimate daily mean Cl concentrations on the basis of the continuous specific-conductance data collected at the station (fig. 13B); this regression relation had an R² of 0.93. The estimated mean Cl concentration was 292 mg/L during the 1-year monitoring period (table 10). The highest estimated daily mean Cl concentration was 721 mg/L in March 2007 (fig. 13B), during a snowmelt period and 3 days after a peak in streamflow. The minimum estimated daily mean Cl concentration (31.0 mg/L) occurred in October 2007, following an intense fall rainstorm indicating that Cl concentrations were diluted at this time. The USEPA recommended chronic toxicity criterion of 230 mg/L was exceeded about 65 percent of the monitoring period (fig. 13B). The recommended acute toxicity criterion of 860 mg/L was not exceeded (fig. 13B).

Samples collected in March 2007 were used to describe the effects of snowmelt on Cl concentrations in the tributary (fig. 14). An increase in the estimated Cl concentration at Alder Brook tributary was observed on March 4. The estimated maximum instantaneous Cl concentration during this event was 460 mg/L (fig. 14). During the period of March 15–22 instantaneous Cl concentrations were greater than 600 mg/L with a maximum instantaneous concentration of nearly 800 mg/L. The dominant source of Cl was most likely from highway runoff and other sources in the drainage area. The USEPA recommended chronic toxicity criterion of 230 mg/L was exceeded during the event and for the remainder of the month of March and the snowmelt period (fig. 14).

There are no VTrans estimates of the road-salt applied in the drainage area of the tributary. The estimated Cl load from the Alder Brook tributary from December 2006 to November 2007 is 93,800 lbs (table 2), this load amount is 86 percent of the difference in the upstream and downstream loads at the paired monitoring stations in 2007. As such, the Alder Brook tributary appears to be a major contributor to the increase in Cl loads in Alder Brook.

Streamflow and runoff data indicate that the actual contributing drainage area to the Alder Brook tributary may be at least two times the topographically defined drainage area. Watershed boundaries were redefined by high-resolution light-detection and ranging (LiDAR) data. The use of LiDAR data, with its increased terrain detail, did not result in any substantial change in the watershed area. This indicates that some unaccounted-for sources of flow and Cl, such as additional parking lots and roads may be present in the tributary watershed or some runoff entering swales (possibly originating outside of the defined drainage area) may infiltrate soils and percolate to groundwater.

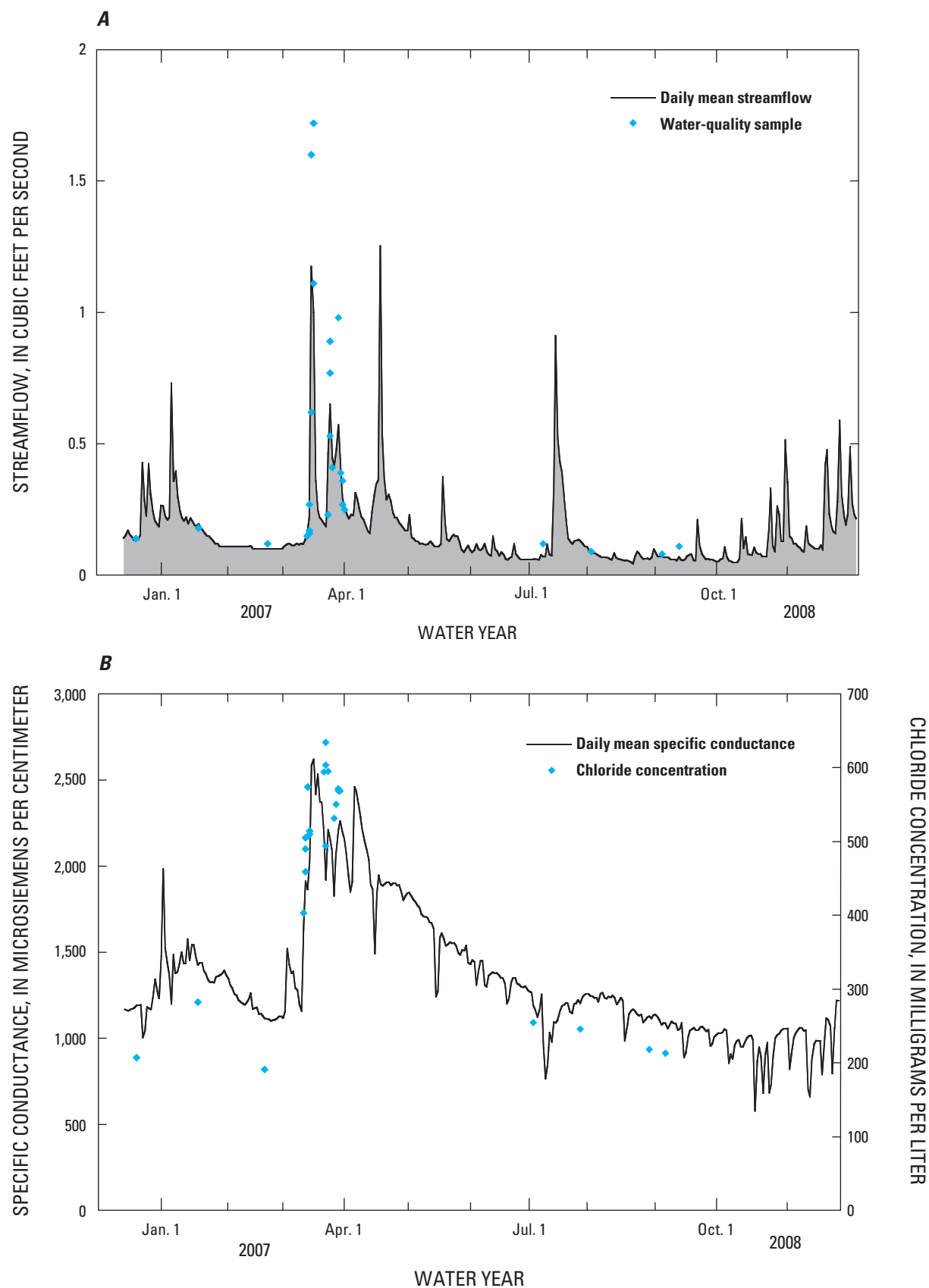


Figure 12. (A) Daily mean streamflow and time distribution of water-quality samples and (B) daily mean specific conductance and concentrations of chloride for Alder Brook tributary at mouth near Essex Junction, VT, station 042901608.

Table 9. Summary statistics for values of specific conductance and pH and concentrations of chloride, sodium, calcium, potassium, magnesium, sulfate, and nitrite plus nitrate for routine water-quality samples collected at Alder Brook tributary at mouth near Essex Junction, VT.

[Min, minimum; Med, median; Max, maximum]

Water-quality constituent ¹	Number of samples	Min	Mean	Med	Max
Specific conductance	24	1,095	1,810	1,980	2,330
pH	24	7.5	7.9	7.9	8.4
Chloride	24	191	449	506	634
Sodium	24	99	232	260	321
Calcium	24	34.8	82.6	85.8	103
Potassium	3	1.44	1.76	1.59	2.25
Magnesium	3	18.8	20.7	21.2	22.0
Sulfate	3	50.2	56.6	56.6	63.2
Nitrite plus nitrate	2	0.15	0.39	0.39	0.64

¹All constituents are dissolved and reported as milligrams per liter except specific conductance, which is reported as microsiemens per centimeter at 25 degrees Celsius, and pH, which is reported as standard units.

Table 10. Daily mean summary statistics for continuous specific conductance and estimated continuous chloride concentrations at Alder Brook tributary at mouth near Essex Junction, VT.

[$\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; Min, minimum; Med, median; Max, maximum]

Water-quality constituent	Min	Mean	Med	Max
Specific conductance ($\mu\text{S}/\text{cm}$)	578	1,350	1,240	2,620
Chloride (mg/L)	31.0	292	255	721

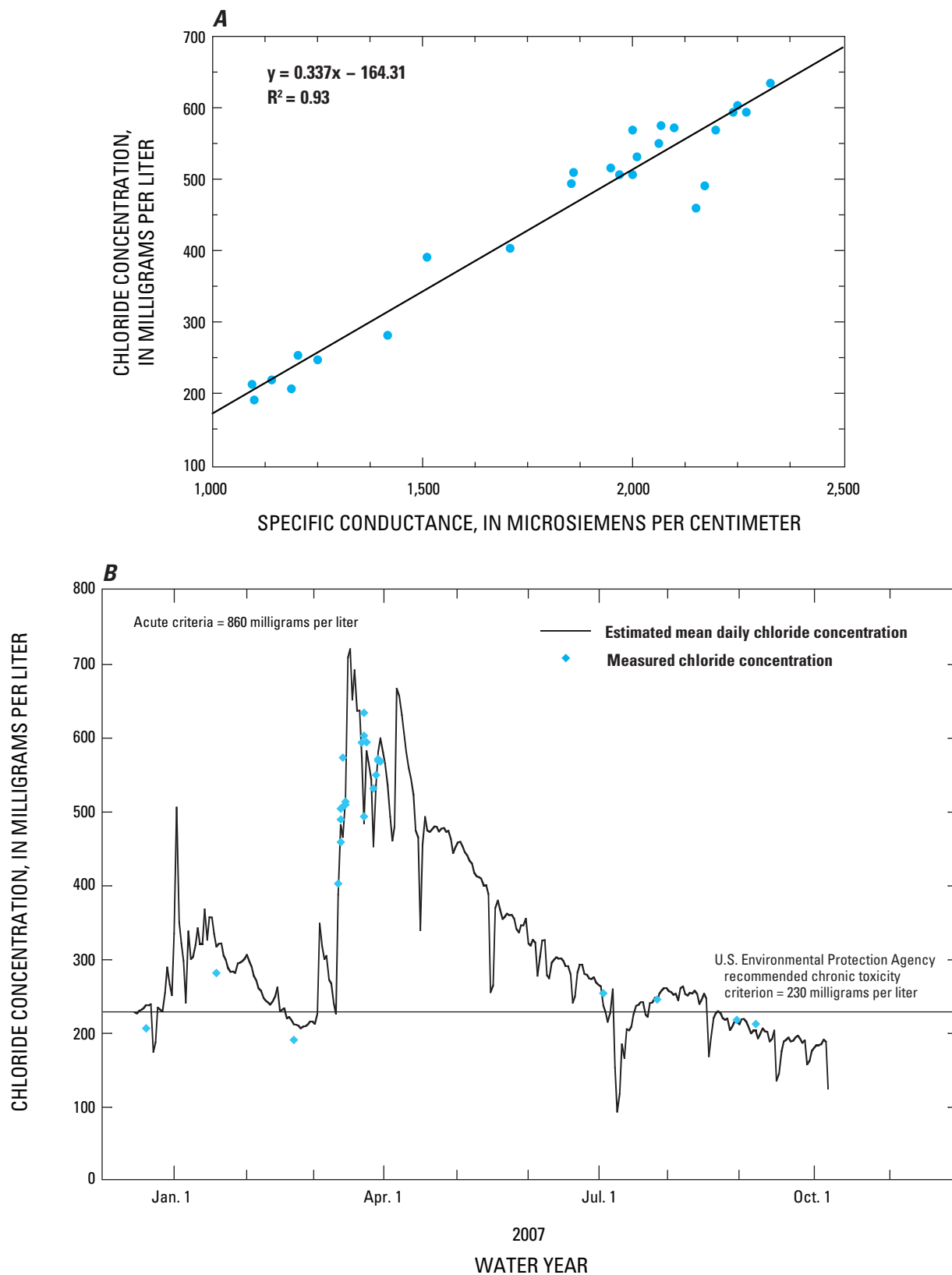


Figure 13. (A) Relation between specific conductance and chloride concentration in the routine water-quality samples and (B) estimated daily mean chloride concentrations and chloride concentration in routine water-quality samples for the study period at Alder Brook tributary at mouth near Essex Junction, VT, station 042901608.

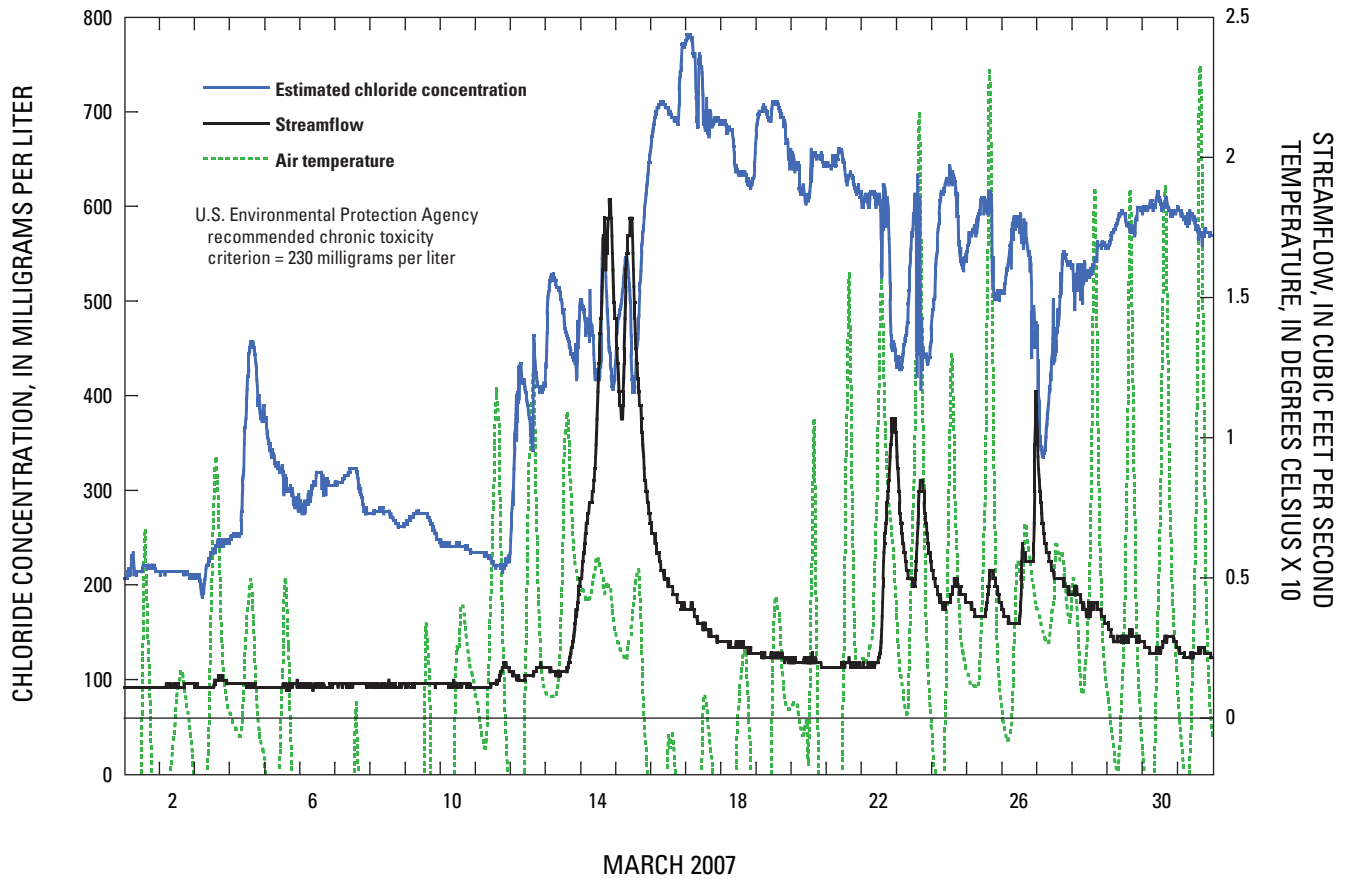


Figure 14. Relation of estimated chloride concentration to streamflow during a snowmelt event (March 2007) at Alder Brook tributary at mouth near Essex Junction, VT, station 042901608.

Allen Brook at VT 2A near Essex Junction, VT, Stations 042903349 and 04290335

Allen Brook sampling stations above and below VT 2A near Essex Junction, VT, represent drainage from a two-lane State highway that is the major road corridor between Interstate I-89 and the village of Essex Junction. The Allen Brook drainage basin is predominantly agricultural and forested, but the lower part of the watershed along VT 2A near Tafts Corner, VT, has experienced extensive growth and development in the last 2 decades. The contributing drainage basins for the upstream and downstream stations are 9.85 and 9.88 mi², respectively (fig. 15). The area draining to the downstream station on Allen Brook has a higher road density (4.2 mi/mi²) and percent impervious surface (4.8 percent) than the drainage to the downstream station on Mill Brook and a similar road density compared to the downstream station on Alder Brook (table 1). Land use in the Allen Brook watershed is about 50 percent forest, 33 percent agriculture, 13 percent developed, and 4 percent wetlands and barren (fig. 1).

Annual mean discharge for the years 2006 and 2007 was 17.7 and 12.5 ft³/s, respectively. Daily mean streamflow and time distribution for water-quality samples are shown in figure 16A. The minimum and maximum streamflow at which water-quality samples were collected was 0.22 and 268 ft³/s, respectively.

Continuous specific-conductance values and concentrations of Cl in the routine water-quality samples are shown in figure 16B and summary statistics are presented in tables 11 and 12. The minimum and maximum specific-conductance values at which water-quality samples were collected was 268 and 800 μ S/cm, respectively. Mean specific conductance of the routine water-quality samples was 503 μ S/cm and 500 μ S/cm at the upstream and downstream stations, respectively. There was a minor increase (less than 1 percent) in the mean of the continuous specific conductance values between the upstream and downstream stations.

Mean Cl concentrations in the routine samples were 72.7 mg/L at the upstream station and 80.7 mg/L at the downstream station (table 11). The relation between specific-conductance values and Cl concentrations (fig. 17A) was used to estimate daily mean Cl concentrations on the basis of the continuous specific-conductance data collected at the station (fig. 17B); this regression relation had an R² of 0.87. Estimated mean daily Cl concentrations based on this relation were 82.1 mg/L at the upstream station and 83.1 mg/L at the downstream station for the 2-year study period (table 12). Allen Brook had the highest estimated mean Cl concentrations and was the most urbanized of the three streams studied. Urbanization or road density and Cl concentrations can be positively

correlated (Nimiroski and Waldren, 2002), which may explain the elevated Cl levels in Allen Brook. The highest estimated daily mean Cl concentrations in 2006 (122 mg/L upstream and 124 mg/L downstream) were measured during August (fig. 17B) indicating that a continuous upstream source and (or) reduced dilution influences the maximum concentrations in Allen Brook.

The highest estimated daily mean Cl concentration in 2007 at the downstream station was 161 mg/L during a period of summer low flow (fig. 17B). Summer base flow was lower in 2007 than in 2006 because rainfall was lower. In contrast, the lowest daily mean Cl concentrations at the downstream station (25.0 and 23.3 mg/L) occurred following rainstorms in May 2006 and December 2007, respectively. None of the Cl concentrations in the routine water-quality samples or the estimated daily mean Cl concentrations at the downstream station exceeded the USEPA recommended chronic toxicity criterion of 230 mg/L or the acute toxicity criterion of 860 mg/L (fig. 17B; tables 11 and 12).

The January 2006 rain-on-snow event and its effects on instantaneous concentrations of Cl in relation to stream stage are shown in figure 18A. Stream stage was used as a surrogate for discharge, in this case, because the stream was ice-affected. Estimated Cl concentrations at the downstream station increased prior to an increase in the Cl concentration at the upstream station. This initial increase in Cl concentration at the downstream station is likely the result of direct runoff of salt from the bridge and roadway. However, Cl concentrations at both monitoring stations eventually increased with a gradual increase in stage (fig. 18A) indicating other watershed sources of Cl were contributing to the observed Cl concentrations. Estimated maximum instantaneous Cl concentrations during this event were 149 mg/L at the upstream station and 156 mg/L at the downstream station (fig. 18A). Cl concentrations decreased sharply as streamflow increased. Maximum streamflow occurred about 8 hours after the maximum Cl concentration was observed. Instantaneous Cl concentrations did not exceed the USEPA recommended chronic toxicity criterion of 230 mg/L during this event.

The March 2007 snowmelt event and its effects on instantaneous concentrations of Cl in relation to streamflow from March 2 to 5 are shown in figure 18B. A slight increase in Cl concentration was observed on March 2. Because this increase occurred long after the daily maximum air temperature was reached, it is likely that the Cl concentration increased in response to Cl sources upstream. The estimated maximum instantaneous Cl concentrations were 195 mg/L at the upstream station and 184 mg/L at the downstream station on March 3 (fig. 18B). Instantaneous Cl concentrations did not exceed the USEPA recommended chronic toxicity criterion of 230 mg/L during this event.



Figure 15. Location of upstream- and downstream-sampling stations, basin delineations, state road network, and photograph of the downstream-sampling station for Allen Brook at VT 2A near Essex Junction, VT, stations 042903349 and 04290335 (Refer to table 1 and figure 1 for additional site information).

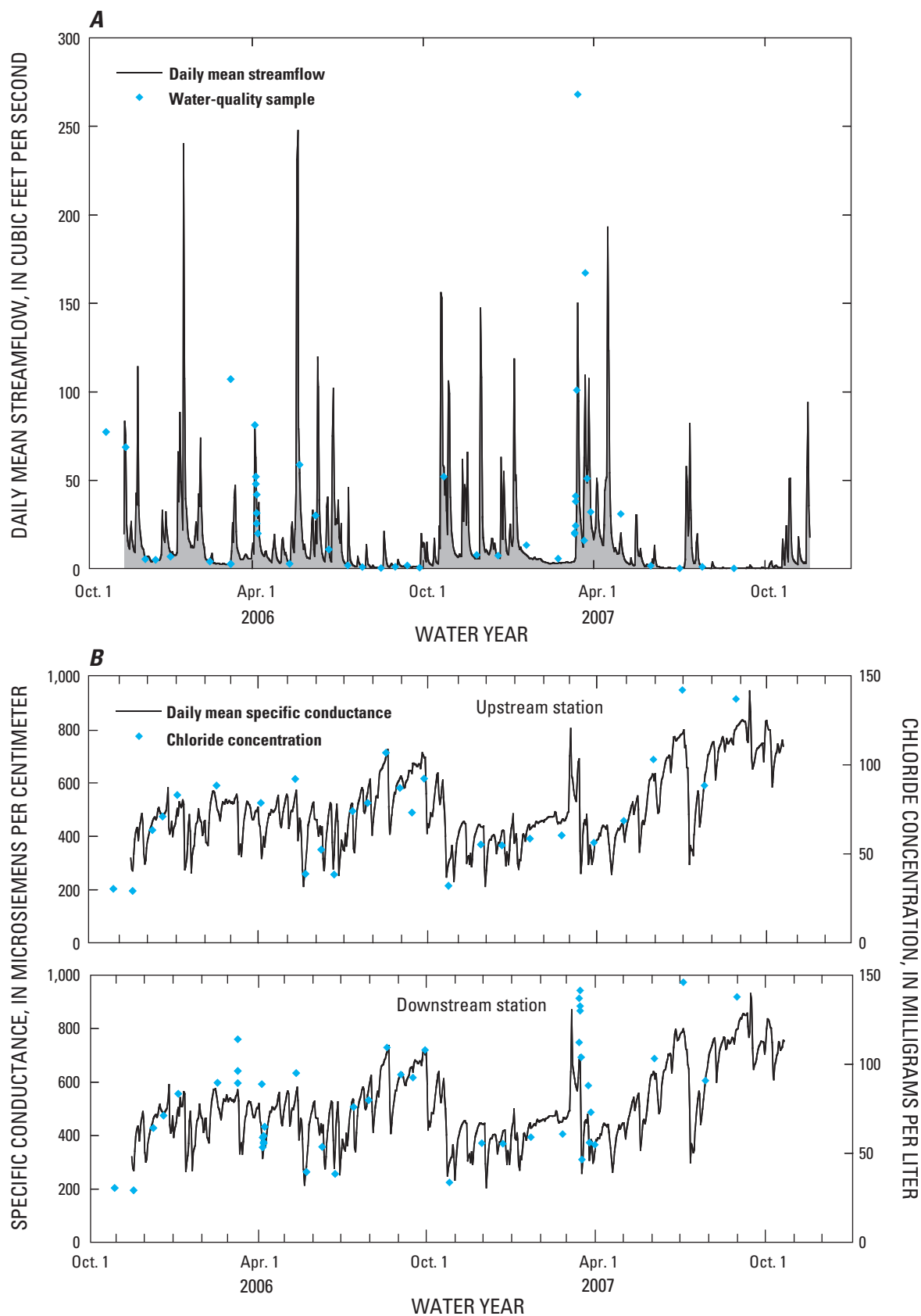


Figure 16. (A) Daily mean streamflow and time distribution of water-quality samples and (B) daily mean specific conductance and concentrations of chloride for Allen Brook at VT 2A near Essex Junction, VT, stations 042903349 and 04290335.

Table 11. Summary statistics for values of specific conductance and pH and concentrations of chloride, sodium, calcium, potassium, magnesium, sulfate, and nitrite plus nitrate for routine water-quality samples collected at Allen Brook at VT 2A, near Essex Junction, VT.

[Min, minimum; Med, median; Max, maximum]

Water-quality constituent ¹	Upstream site, station 042903349					Downstream site, station 04290335				
	Number of samples	Min	Mean	Med	Max	Number of samples	Min	Mean	Med	Max
Specific conductance	28	268	503	500	798	46	269	500	491	800
pH	25	7.4	7.8	7.9	8.5	42	7.1	7.6	7.7	8.5
Chloride	28	29.4	72.7	72.1	142	46	29.3	80.6	77.9	146
Sodium	28	19.0	43.6	42.4	79.4	46	7.7	45.5	43.2	83.7
Calcium	28	21.7	39.2	39.1	60.6	46	15.9	35.0	37.1	60.3
Potassium	8	1.29	1.95	1.92	3.01	7	1.34	1.94	1.81	3.11
Magnesium	8	5.14	9.62	8.98	16.8	7	5.15	9.12	8.96	17.3
Sulfate	8	8.1	12.9	13.5	16.9	7	8.2	12.7	13.4	16.5
Nitrite plus nitrate	6	0.06	0.26	0.26	0.56	5	0.04	0.30	0.31	0.57

¹All constituents are dissolved and reported as milligrams per liter except specific conductance, which is reported as microsiemens per centimeter at 25 degrees Celsius, and pH, which is reported as standard units.

The difference in the estimated Cl load upstream and downstream of the State highway was 50,000 lbs in 2006 and 40,000 lbs in 2007 (table 6; fig. 19). The Allen Brook study area received an estimated 12,000 lbs of applied Cl from VTrans snowplow operations in the winter of 2006 and 8,660 lbs in the winter of 2007 (table 6; fig. 19). VTrans maintained 0.87 lane-miles but an additional 0.73 lane-miles of other non-state roads in the watershed are maintained and are not accounted for in the VTrans application rates. The applied Cl amount from State snowplow operations represented (1) less than 1 and about 3 percent of the total annual Cl load

downstream of Rte 2A in 2006 and 2007, respectively, and (2) about 20 percent of the difference between the upstream and downstream Cl loads. All of the Cl being applied by VTrans does not appear to be transported to Allen Brook during snowmelt events and may be stored in soils adjacent to the roadway. This stored Cl is likely released throughout the year and may be partially responsible for greater concentrations of Cl in the brook during low-flow periods. The dominant sources of Cl in Allen Brook at the monitoring stations are not known, but may include other roads and areas deiced in winter months and septic systems that are upstream of the stations.

Table 12. Daily mean summary statistics for continuous specific conductance and estimated continuous chloride concentrations at Allen Brook at VT 2A, near Essex Junction, VT.

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; Min, minimum; Med, median; Max, maximum]

Water-quality constituent	Upstream site, station 042903349				Downstream site, station 04290335			
	Min	Mean	Med	Max	Min	Mean	Med	Max
Specific conductance (µS/cm)	212	506	480	942	204	511	486	930
Chloride (mg/L)	24.6	82.1	76.8	163	23.3	83.1	77.8	161

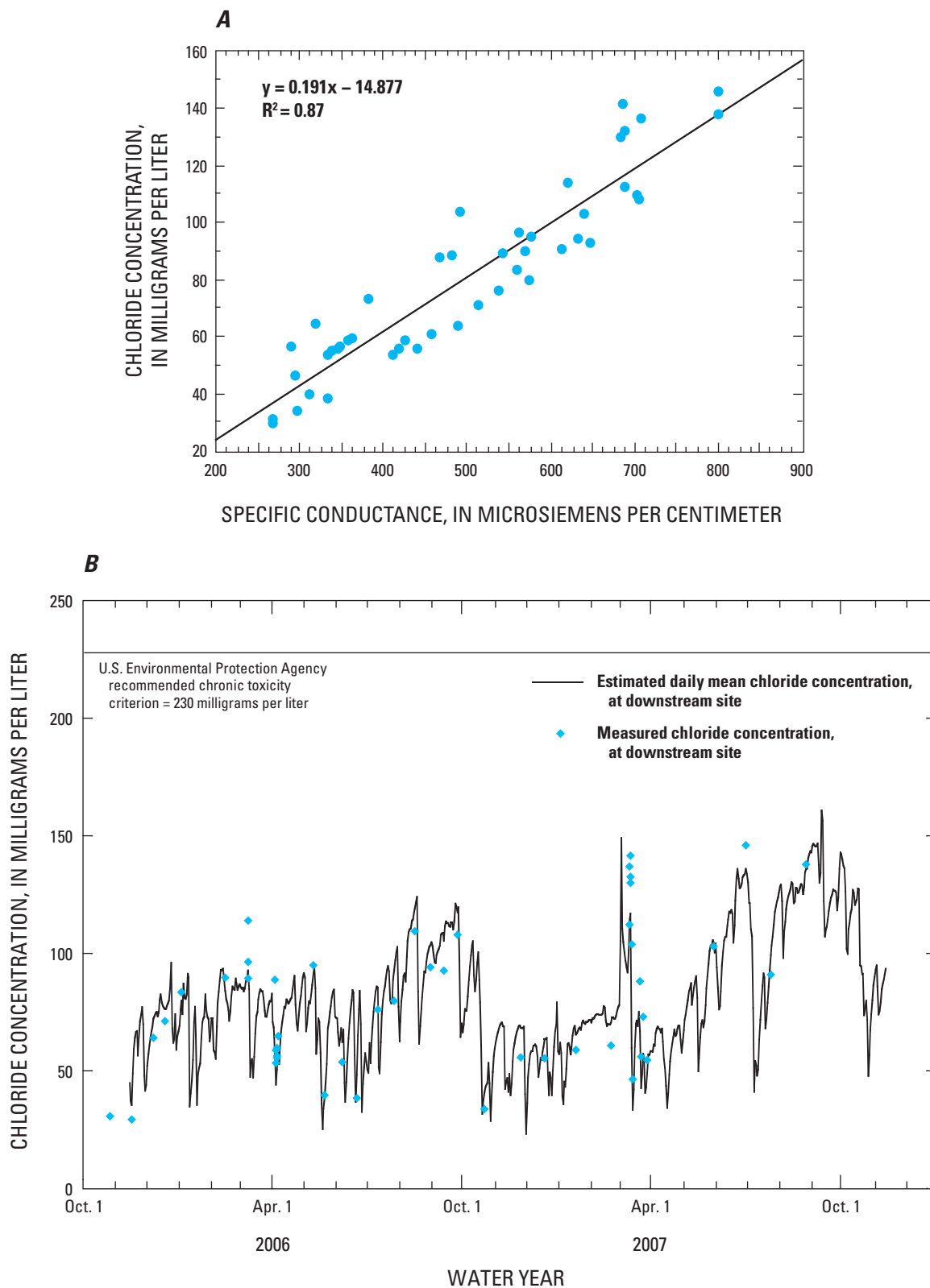


Figure 17. (A) Relation between specific conductance values and chloride concentration in routine water-quality samples and (B) estimated daily mean chloride concentrations and chloride concentration in routine water-quality samples for the study period at Allen Brook at VT 2A near Essex Junction, VT, station 04290335.

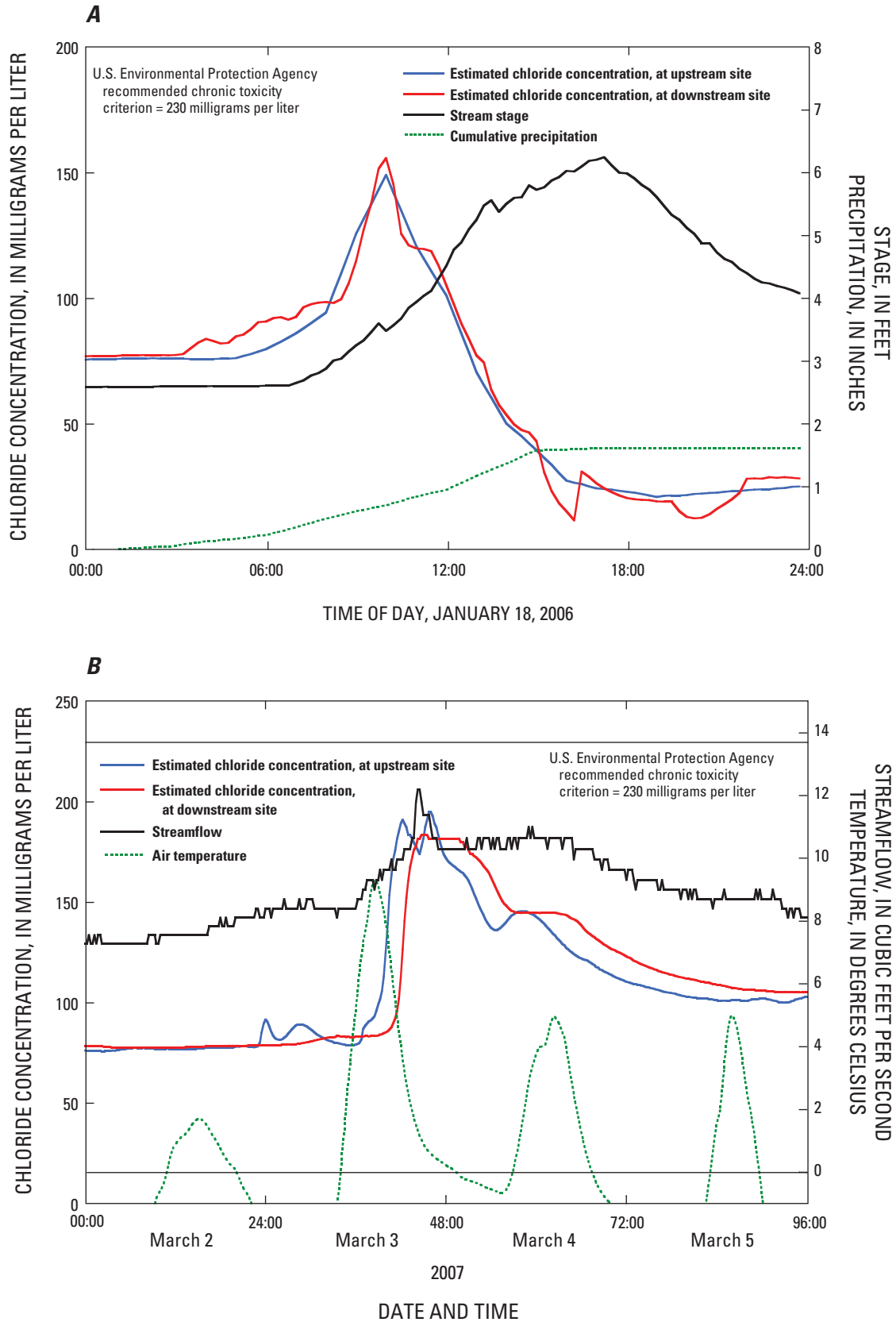


Figure 18. Relation of estimated chloride concentration to (A) stream stage during a rain-on-snow event (January 18, 2006) and (B) streamflow during a snowmelt event (March 2007) at Allen Brook at VT 2A near Essex Junction, VT, stations 042903349 and 04290335.

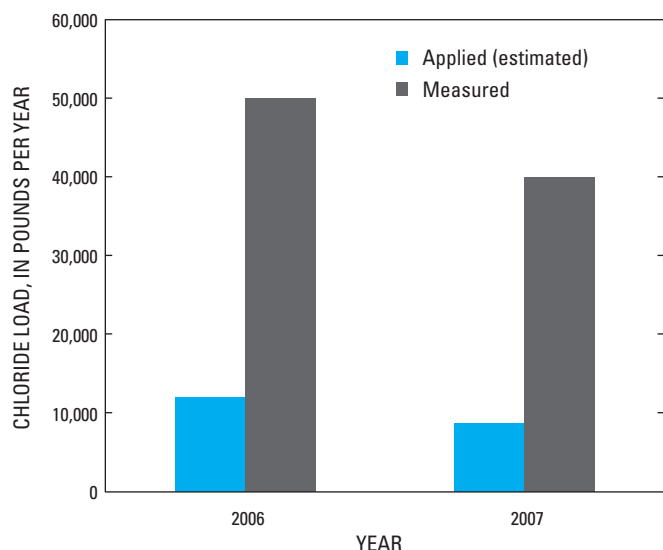


Figure 19. Estimated applied road deicing and measured chloride load for Allen Brook at VT 2A near Essex Junction, VT, station 042903349.

Effects of Highway Road Salting on Water Quality

The median cationic composition of water samples collected at the downstream stations in this study is shown in figure 20. All of the samples clustered around the median value for each of the stream stations; therefore, the median value is plotted to represent the cationic composition of water at the three streams. The trilinear plot represents 100 percent of the cation composition (Ca, Mg, Na plus K), and the coordinates of a point plotted on the diagram add to 100 percent. The water type, as represented by cations, at all three stations was similar with respect to magnesium (about 20 percent). However, variations in composition with respect to Ca and Na plus K were observed. Samples collected at Mill Brook were dominated by Ca (about 60 percent) and contained a smaller percentage of Na plus K (about 20 percent) than samples collected at Alder and Allen Brooks. In samples from the Alder and Allen Brook watersheds, where highway density is greater than in the Mill Brook watershed, the percentage of Ca was smaller and Na plus K was greater than in the Mill Brook samples. Samples collected at Allen Brook, the most urbanized of the three basins, contained a higher percentage of Na plus K (about 40 percent) than samples collected at Mill Brook and Alder Brook (about 32 percent). A decrease in the ratio of Ca to Na plus K may be indicative of anthropogenic inputs to the stream. The difference in the ratio of Ca to Na plus K

indicates that the difference in water composition among the three stations is likely a result of anthropogenic inputs. Collectively, these data suggest that the Mill Brook watershed is less affected by anthropogenic activities than the Alder and Allen Brook watersheds.

Cl concentrations tended to vary inversely with streamflow—that is, as streamflow increased, Cl concentrations decreased. For example, nonpoint sources of Cl, such as widely dispersed road salt, are diluted by snowmelt and rainwater. However, Cl concentrations can increase with increasing flows during the initial part of storm or snowmelt runoff, and then generally decrease through dilution. The range in Cl concentrations among the three paired stations and the tributary station is shown in figure 21. At Mill Brook, Cl concentrations in samples collected at the upstream and downstream stations were similar, but at Alder and Allen Brooks, Cl concentrations were slightly higher in samples collected at the downstream station than in those samples collected at the upstream station (fig. 21). Cl concentrations were highest in samples collected at the Alder Brook tributary station (fig. 21). None of the Cl concentrations in the routine water-quality samples from the three paired stations exceeded either of the USEPA recommended chronic and acute toxicity criteria of 230 and 860 mg/L, respectively (U.S. Environmental Protection Agency, 1988) (fig. 21). Cl concentrations in samples collected at the Alder Brook tributary station generally fell between the USEPA recommended chronic and acute toxicity criteria (fig. 21), but the Cl concentrations from the tributary are diluted upon entering Alder Brook.

Elevated Cl concentrations were observed each winter as a result of two different hydrologic events at all three paired sampling stations. Intense rainfall occurred in January 2006 and a rapid late-winter snowmelt event occurred in March 2007. Intense rainfall can quickly wash off deicing salts previously deposited on roadways. Cl-rich meltwater can be transported from the road surfaces and pavement-edge snowbanks, by way of ditches and swales, to receiving waters. Streamflow was low at the beginning of March; therefore, dilution of Cl inputs from roadway drainage pathways was small.

Cl concentrations were elevated during periods of base flow at all three paired stations. The persistence of elevated Cl concentrations during low flows in late summer and early fall indicates input from groundwater discharge or other continuous sources. Stream samples collected in a small basin during base flow periods can provide a composite sample of shallow groundwater discharge. The quality of groundwater discharge may indicate the presence of nonpoint-source contamination, such as road salt (Heisig, 2004). Elevated concentrations during base flows may also be indicative of a continuous source to the stream, such as a permitted wastewater discharge. However, no known wastewater discharges are present in the watersheds of the three streams.

Monthly Cl loads and runoff at the downstream-sampling stations are shown in figure 22. The highest monthly chloride loads during the first year of the study were observed in January 2006 at all three streams (figs. 22A, B and C).

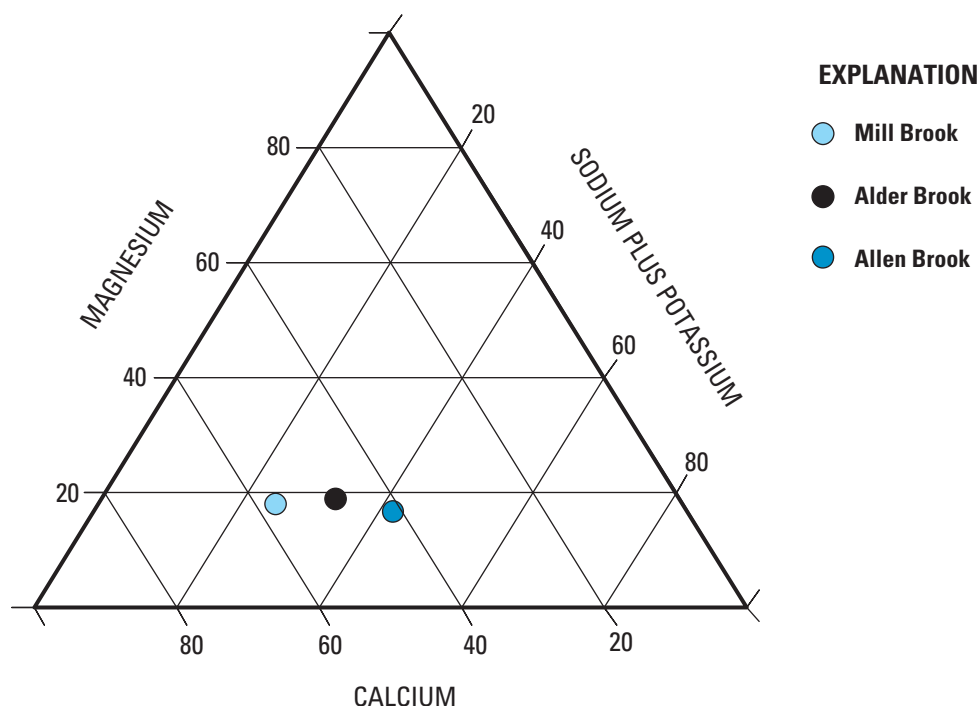


Figure 20. General cation composition (in percent) for Mill Brook at VT 117, Alder Brook at VT 289, and Allen Brook at VT 2A near Essex Junction, VT.

The highest monthly chloride loads during the second year of the study were observed during spring snowmelt in March and April 2007 at all three streams and were followed by decreases in Cl loads through the summer. Generally, the relation of Cl load to runoff followed a similar pattern at all three streams in 2007. In July and October 2007, loads increased slightly with an increase in runoff, again indicating that salt in the soils and groundwater may be contributing to the Cl levels during the summer and fall, well after the road-salting season.

Monitoring and assessment of Cl concentrations and loads in the three streams indicate that VTrans road-deicing practices do not appear to have a large influence on Cl concentrations and loads in the streams studied. Cl loads downstream of the state highways were greater than the loads upstream of the highways, but Cl applications for road deicing by VTrans were a small component (from less than 1 to 17 percent) of

the total downstream Cl loads. The increase in Cl downstream of the state roadways is likely due to Cl usage on the state highways. The one exception would be the Alder Brook tributary where highway and interchange drainage appears to be an important component of the tributary's flows and Cl loads. Sequestering of Cl by adjacent soils and streambed sediments appeared to be occurring in the drainages studied because the largest observed in-stream concentrations occurred generally during low-flow conditions and at times of the year when Cl applications were not occurring.

Results of the study also imply that most of the Cl loads in the three streams studied are originating farther upstream in the watersheds and possibly from Cl stored in the soils and shallow groundwater near the State highways. Other sources of Cl in these watersheds could include deicing of local roads, private roads and parking areas, household use of deicing salts, septic systems, fertilizers, and pet wastes.

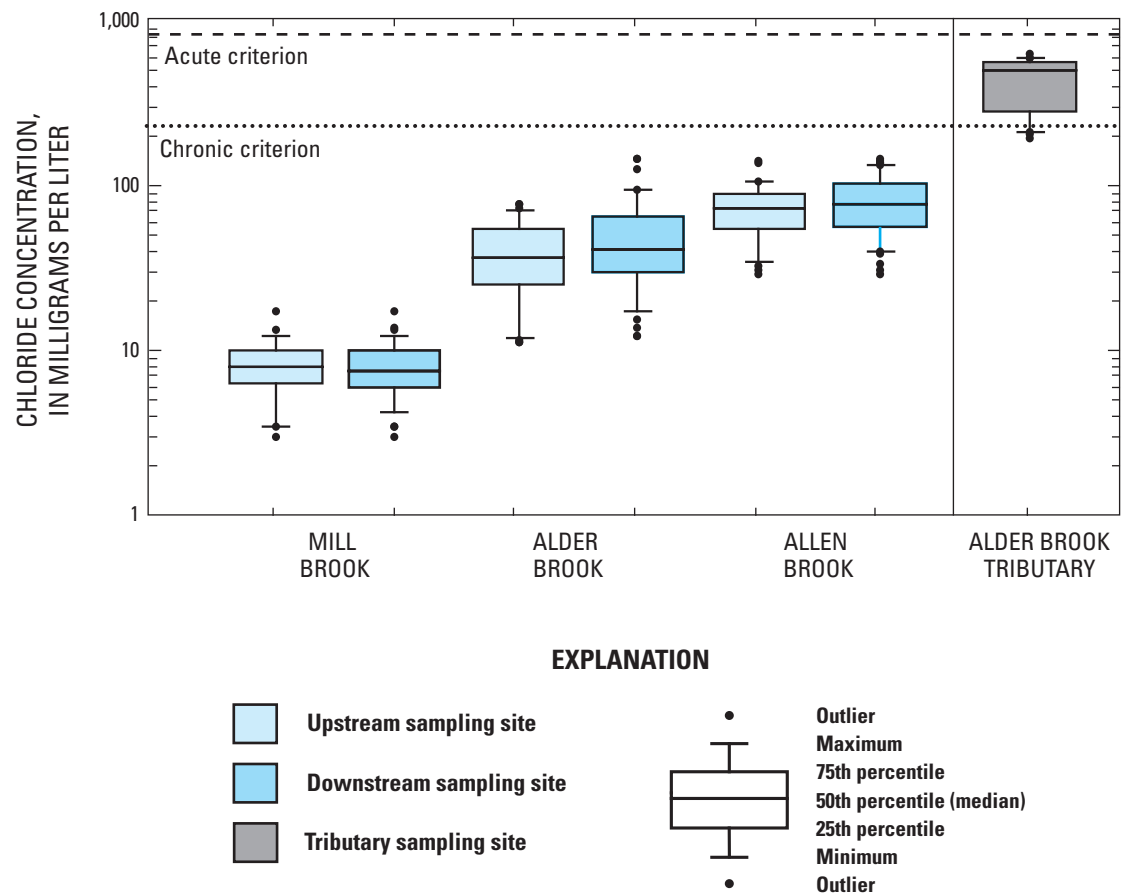


Figure 21. The range in chloride concentrations in the routine water-quality samples for the paired sampling stations at Mill Brook at VT 117, Allen Brook at VT 2A, Alder Brook at VT 289, and Alder Brook tributary at mouth near Essex Junction, VT.

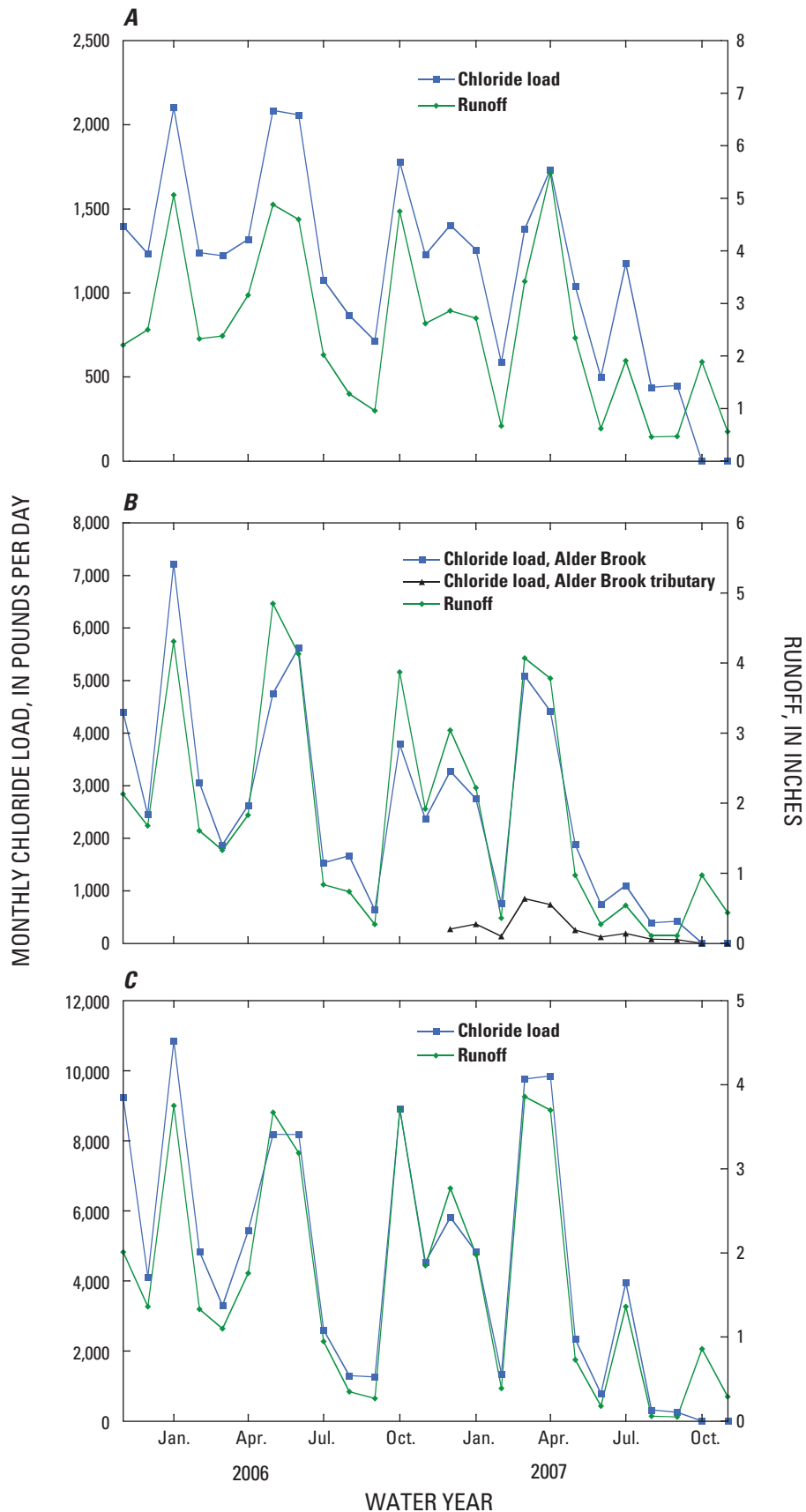


Figure 22. Estimated monthly chloride loads and measured runoff for (A) Mill Brook at VT 117 near Essex Junction, VT, station 04289881, (B) Alder Brook at VT 289 near Essex Junction, VT, station 04290161 and (C) Allen Brook at VT 2A near Essex Junction, VT, station 04290335.

Summary and Conclusions

The use of road salt (sodium chloride (NaCl)) for deicing of roads has increased steadily since its initial use in the late 1930s and early 1940s. NaCl and sand are primarily used in Vermont for deicing and anti-icing, respectively, and Vermont is the only state in the Nation that requires an environmental permit for deicing. The sources of chloride (Cl) and sodium (Na) to the environment are varied and include rock weathering, precipitation and winds, agriculture, human sewage (on-site disposal systems, municipal wastewater-treatment facilities), and road deicing. Excess NaCl in streams can be harmful to aquatic life. This report describes the results of a study by the U.S. Geological Survey, in cooperation with the Vermont Agency of Transportation (VTrans), designed to determine the degree to which road-deicing practices affected Cl concentrations and loads in selected streams in Chittenden County, VT. The sampling program was designed to assess differences in Cl concentrations and loads above and below State highways to determine whether road-salt application affects Cl concentrations and loads in streams.

A combination of continuous monitors and water-quality sampling was used to assess the surface-water hydrology and water quality of three paired stream-sampling stations over 2 years. Streamflow and specific conductance were measured continuously at locations upstream and downstream on Mill Brook at VT 117, Alder Brook at VT 289, and Allen Brook at VT 2A, all near Essex Junction, Chittenden County, VT, from November 2005 to 2007. Water samples were collected routinely for determination of chloride (Cl), calcium (Ca), and sodium (Na) concentrations and seasonally for determination of Cl, Ca, Na, potassium, magnesium, sulfate, magnesium, and nitrite plus nitrate concentrations from November 2005 to October 2007. Water quality and streamflow data were collected at a tributary to Alder Brook from December 2006 to November 2007.

Local streamflow conditions during the study were above normal and mean annual discharge for 2007 was less than mean annual discharge for 2006 as result of lower annual precipitation in 2007. Most of the snowfall in 2006 occurred early in the winter followed by warm temperatures and a large snowmelt in January 2006. In 2007 snowfall was greatest during February and March, with melt occurring in March and April.

Mean concentrations of Cl in the water-quality samples collected at upstream and downstream stations ranged from 8.2 to 72 mg/L and 7.9 to 80.7 mg/L, respectively. Mean Cl loads ranged from 1,100 to 4,090 lb/d (pounds per day) at upstream stations and from 1,110 to 4,200 lb/d at downstream stations. Estimated mean annual Cl loads ranged from 402,000 to 1,490,000 lb/yr (pounds per year) at upstream stations and from 405,000 to 1,530,000 lb/yr at downstream stations, respectively.

Chloride concentrations were similar between samples collected at the paired upstream and downstream stations for

each stream. Mean Cl concentrations in samples collected at the three paired stations were lowest at Mill Brook at VT 117 near Essex Junction and highest at Allen Brook at VT 2A near Essex Junction, VT. Mean Cl concentrations were highest in samples collected at the Alder Brook tributary; however, concentrations were diluted as the tributary entered Alder Brook. None of the Cl concentrations in the water-quality samples collected at the three paired stations exceeded the U.S. Environmental Protection Agency's (USEPA) recommended chronic or acute toxicity criteria of 230 and 860 mg/L, respectively.

The mean Cl concentration in water-quality samples collected at the Alder Brook tributary was 449 mg/L. The highest estimated daily mean Cl concentration was 721 mg/L in March 2007, 3 days after a peak in streamflow. The minimum estimated daily mean Cl concentration (31.0 mg/L) occurred in October 2007, following an intense fall rainstorm. The USEPA recommended chronic toxicity criterion of 230 mg/L was exceeded about 65 percent of the period monitored. The USEPA recommended acute toxicity criterion of 860 mg/L was not exceeded.

Samples collected in January 2006 and March 2007 were used to describe the effects of rain and snowmelt on Cl concentrations during the deicing season. Cl concentrations in samples collected at Mill Brook during rain and snowmelt events were lower than those in samples collected at Alder and Allen Brooks. In only one instance did an estimated Cl concentration (232 mg/L) during a snowmelt event in March 2007 at Alder Brook reach the USEPA recommended chronic toxicity criterion at both the upstream and downstream stations; however, the period of exceedance was short and the concentration did not exceed the USEPA 4-day average criterion.

The highest monthly Cl loads during the first year of the study were observed in January 2006 at all three streams. The highest monthly Cl loads during the second year of the study were observed in April 2007 at all three streams during spring snowmelt and were followed by decreases in salt loads through the summer. Generally, the relation of salt loads relative to runoff in 2007 was similar at all three streams. In July and October 2007, Cl loads increased slightly with an increase in runoff, indicating that salt in the soils and groundwater may have been contributing to the Cl levels during the summer and fall.

Estimated Cl loads below the State highway bridges exceeded loads above the bridges at all three paired stations during both years of the study. The differences in the annual loads between the upstream and downstream stations were 0.7, 3.0 and 14 percent at Mill, Allen and Alder Brooks, respectively. Almost all of the difference (92 percent) at Alder Brook was due to the tributary. Cl applied by the State of Vermont for deicing purposes represented less than 20 percent of the annual Cl load in the streams below the state highways; however, the Cl applications comprised from 20 to 100 percent of difference in Cl loads between the upstream and downstream stations.

The differences in water composition, Cl concentrations, and Cl loads among the three paired stations indicated that the land use in each of the watersheds affected the water-quality data collected at each station. The Mill Brook watershed was selected to represent a rural two-lane-highway segment and a predominantly forested watershed. Samples collected at Mill Brook had the lowest concentrations and loads of Cl and an ionic water type representative of more natural conditions compared to the other two streams. The Alder and Allen Brook watersheds contained two-lane State highways and had high Cl concentrations and loads and higher ratios of Ca to Na plus K, indicating a difference in general water composition. The higher concentrations of Cl and the difference in general water chemistry at these streams indicate that anthropogenic inputs to these watersheds may be affecting water quality.

State highway salt applications for snow and ice removal did not represent a major source of the Cl loads in the three streams monitored. Other sources of Cl must be present in the three watersheds, and may include Cl in soils and stream-bed sediments, other non-state deicing activities, and septic systems.

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