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

Effectiveness of Highway-Drainage Systems in Preventing Road-Salt Contamination of Ground Water, Southeastern Massachusetts

USGS

INTRODUCTION

Road-salt contamination of public and private water supplies has become a serious and costly problem, particularly in the Northeast and Midwest. For example, reports of road-salt contamination from 100 of the 351 municipalities in Massachusetts from 1983 through 1990 required an expenditure of about 2.5 million dollars to investigate and remediate. Nationally, an estimated 10 million dollars are spent annually by State and local governments to prevent and remediate road-salt contamination.

One method used by State highway agencies to reduce road-salt contamination of public-water supplies is to divert the salt-laden highway runoff through drainage systems from sections of highway that pass near public-water supplies to less sensitive areas. The U.S. Geological Survey (USGS), in cooperation with the Massachusetts Highway Department (MHD), has conducted an investigation of the relative effectiveness of four highway-drainage systems in preventing road-salt contamination of ground water.

This fact sheet describes the highway-drainage systems tested, the general hydrogeology of the study area, and the methods used to evaluate the drainage systems; and presents preliminary findings of the effectiveness of the systems in preventing road-salt contamination of ground water. These findings are based on data collected from November 1990 through May 1992. The results of this investigation will have wider application than just in the snow-belt regions of the United States, Canada, and Europe, as other contaminants in highway runoff either can be diverted from sensitive areas by drainage systems or allowed to seep into the ground, potentially contaminating ground water.

HIGHWAY-DRAINAGE SYSTEMS

The four types of highway-drainage systems tested were incorporated into the design of a 7-mile, six-lane section of Route 25 in southeastern Massachusetts, which was completed in 1987. Each drainage system represents a different method for controlling runoff from the pavement surfaces, shoulders, and median strip. Test sites designated A, B, C, and D represent the drainage systems in order of increasing highway-runoff control (fig. 1). Test sites A and B represent

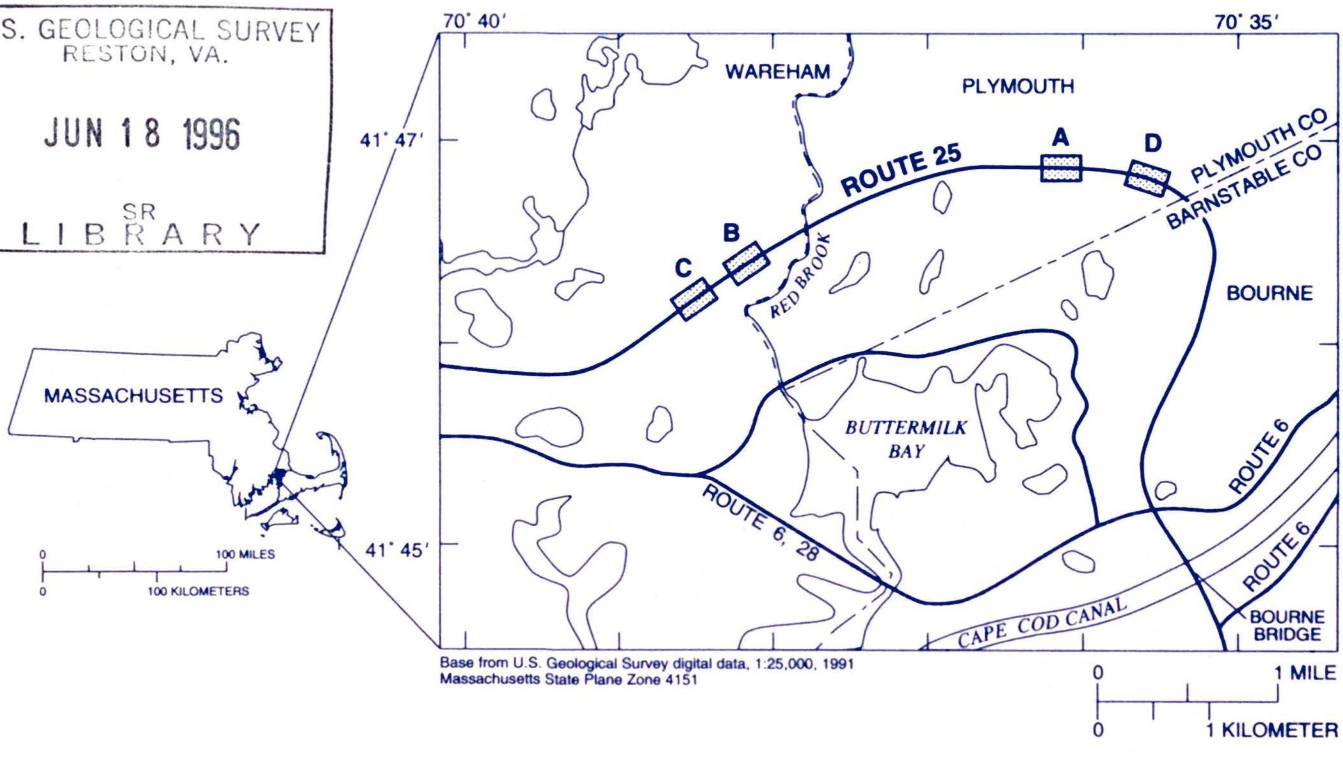

Figure 1. Location of study area in southeastern Massachusetts and test sites A, B, C, and D along Route 25.

standard drainage-system designs and test sites C and D represent new, untested designs.

Site A is an open-drainage system in a fill section of the highway (fig. 2). Runoff is collected in catch basins at the edges of the roadways and in drop inlets in the median strip and is then discharged at the toe of the embankment slopes on both sides of the highway. In effect, all highway runoff—whether from drains, direct overland flow, melting of snow plowed from the roadway surfaces, or spray caused by vehicular traffic—is allowed to infiltrate the soil adjacent to the highway and percolate to the water table.

Site B is a closed-drainage system in a cut section of the highway where catch basins are installed on both edges of both roadways (fig. 2). Highway-surface runoff collected in the catch basins is piped beneath the highway to a trunkline drainpipe beneath the median strip and is then routed to a sedimentation pool. Outflow from the sedimentation pool is discharged into a local stream, Red Brook, about 1 mile upstream from Buttermilk Bay (fig. 1). Additional runoff from the highway shoulders and the median strip can enter the trunkline drainpipe through drop inlets; however, most of the runoff from the shoulders and the median strip infiltrates the soil and percolates to the water table.

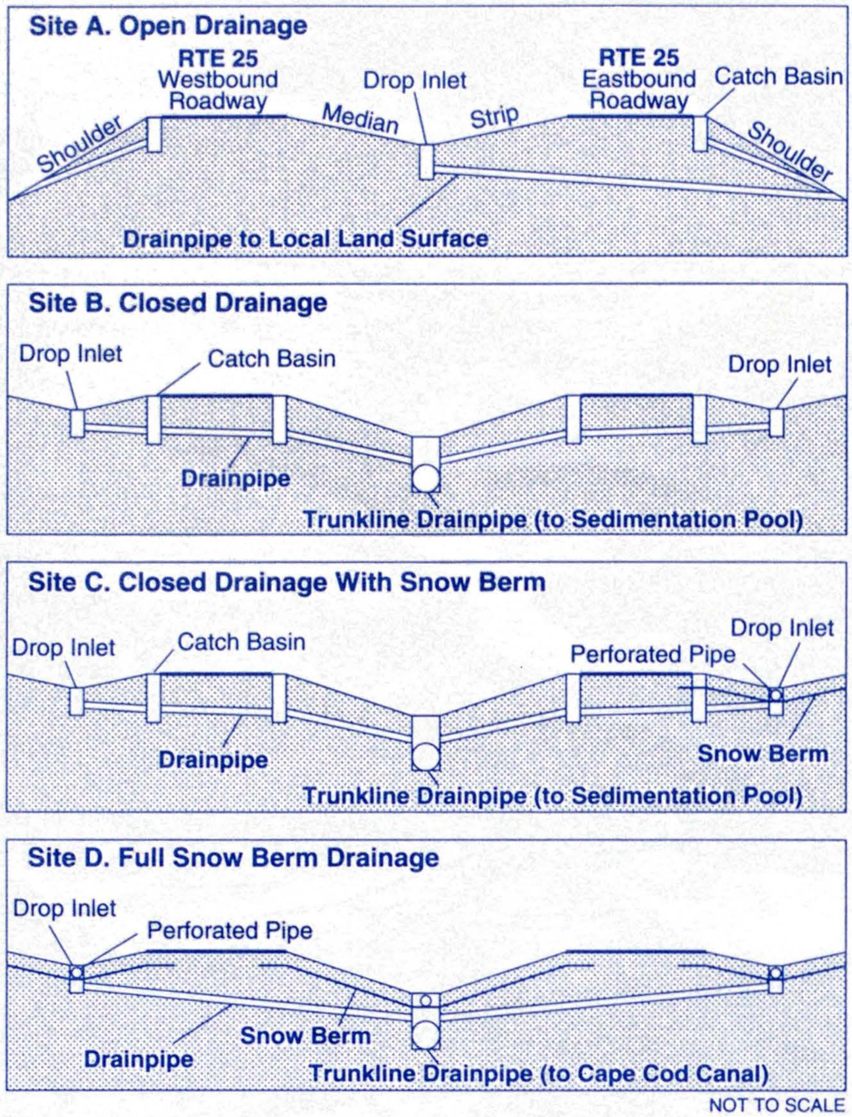

Figure 2. Cross-section views of different highway-drainage designs.

Site C drainage system is in a cut section of highway and contains elements of two designs—a closed-drainage system as at site B, and an impervious-shoulder drainage system referred to as a snow berm (fig. 2). The snow berm consists of a thin layer of bituminous concrete buried beneath the eastbound roadway shoulder. Runoff from the roadway infiltrates the soil that overlies the snow berm. Infiltrated runoff then flows through perforated pipes to drop inlets that are sealed to the snow-berm surface. Runoff from the drop inlets is then piped to the trunkline drainpipe beneath the median strip. The drainage system at site C is designed so that runoff from the roadway and from the eastbound roadway shoulder is diverted from the site, and thus prevented from percolating through the unsaturated zone to the water table. Captured highway runoff at site C enters the same trunkline drainpipe that passes through site B and is discharged into Red Brook.

Site D is a full snow-berm drainage system in a cut section of the highway where both shoulders and the median strip are underlain by snow berms (fig. 2). Runoff from the roadway flows onto the shoulders and the median strip, where it either enters drop inlets as overland flow and is channeled directly to the trunkline drainpipe, or percolates to the impervious snow berms. Infiltrated runoff enters drop inlets from below the land surface through perforated pipe. The trunkline drainpipe under the median strip of the highway discharges into the Cape Cod Canal, a coastal waterway about 2 miles south of the test site (fig. 1).

HYDROGEOLOGY OF STUDY AREA

The test sites along Route 25 site are in a rural area of southeastern Massachusetts in the towns of Wareham and Plymouth (fig. 1). This area is part of a coastal outwash plain bounded by till and bedrock hills to the north and west, and by saltwater bays of the Atlantic Ocean to the south and east. The test sites are underlain by an unconfined sand and gravel aquifer. The sand and gravel deposit ranges in thickness from about 30 to 90 ft (feet) and is underlain by a deposit of fine to coarse sand and silt that extends deeper than the bottoms of holes drilled for installation of monitoring wells. Depth to the water table below the highway ranges from 15 to 60 ft. Water-table depths fluctuate annually by about 1.5 to 2 ft. Hydraulic gradient, the slope of the water table, ranges from about 0.001 to 0.006 ft; ground-water flow is to the south, nearly perpendicular to the highway. Horizontal hydraulic conductivity of the upper 25 ft of the saturated zone is estimated to range from about 100 to 200 feet per day.

STUDY METHODS

Because chloride, the dominant constituent of road salt, is easily transported in water, chloride loads can be used as a measure of road-salt contamination of ground water and of highway runoff. Therefore, preliminary comparisons of the effectiveness of the highway-drainage systems in preventing road-salt contamination of ground water are based on computations of chloride loads in ground water adjacent to the highway and in highway runoff discharged through the drainage systems. The amount of road salt applied to the highway is assumed to be the same at each test site because they are located between the same two interchanges on Route 25.

Analyses of chloride concentrations in water samples collected monthly from wells installed upgradient and downgradient from the highway were used to estimate the monthly road-salt chloride loads in ground water at each test site. Because hydraulic gradients and hydraulic conductivities of the aquifer—the factors that govern the rate of ground-water flow and hence the movement of chloride in the ground water—differ between test sites, monthly concentrations of chloride in ground water were used in conjunction with monthly hydraulic gradients and estimated hydraulic conductivities to determine the rate of transport of road-salt chloride in the ground water downgradient from Route 25 at each test site. Monthly loads of road-salt chloride were determined from the transport rates and expressed in units of pounds (of chloride) per lane-mile of highway for comparison between test sites.

Highway-drainage monitoring stations were installed in the trunkline drainpipes of the highway-drainage systems at sites B, C, and D. Each monitoring station had a calibrated flume cast into a reinforced-concrete vault. Instrumentation for monitoring the transport of road salt in highway runoff through the flumes were contained in equipment shelters on the land surface above the concrete vaults. Flume stage, the depth of the flowing water, and specific conductance, the electrical conductivity of the water, were monitored continuously. Transport of road-salt chloride at each station was determined by applying the recorded stage and specific conductance data to relations developed between stage and water discharge, and between specific conductance and chloride concentrations. These data were then summed for a monthly period to determine the monthly loads of chloride expressed in units of pounds (of chloride) per lane-mile of highway for comparison between test sites.

EFFECTIVENESS OF HIGHWAY DRAINAGE SYSTEMS

Comparison of chloride loads in ground water at each test site from November 1990 through May 1992 shows that the effectiveness of the various highway-drainage systems in preventing road-salt contamination of ground water differ significantly (fig. 3). This interpretation is supported by the data for chloride loads transported through the highway-drainage monitoring stations during the same period. Accumulated monthly chloride load in ground water for the 19-month period at the open-drainage site (A) was

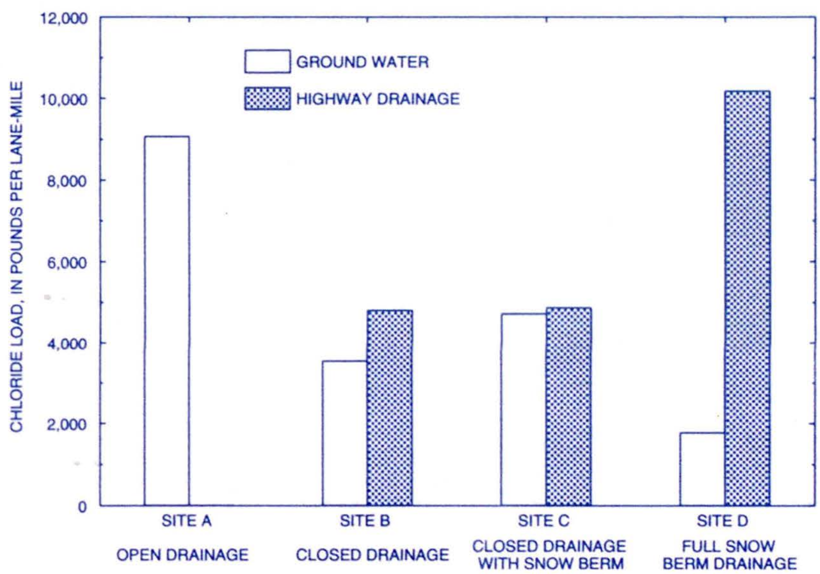

Figure 3. Road-salt chloride loads measured in ground water and discharged through the highway drainage systems, November 1990 through May 1992.

about 2.5 times greater than at the closed-drainage site (B), about 2 times greater than at the closed drainage with snow-berm site (C), and about 5 times greater than at the full-snow berm site (D). In contrast, chloride loads from highway-drainage monitoring stations at the full snow-berm drainage site were about 2 times greater than at the closed-drainage and closed drainage with snow berm sites.

These preliminary findings show that the effectiveness of the closed-drainage (B) and the closed drainage with snow-berm systems (C) in preventing road-salt contamination of ground water are not significantly different from each other. However, the effectiveness of both of these drainage systems are significantly less than that of the full snow-berm drainage system (D), and significantly greater than that of the open-drainage system (A).

REPORTING OF STUDY FINDINGS

The results of this investigation are to be presented in U.S. Geological Survey reports, scientific-journal articles, and at open forums with representatives of the Massachusetts Highway Department and others in the transportation community and the public. The reports listed below address various aspects of the investigation.

Pollock, S.J., 1984, Effectiveness of highway drainage systems in preventing salt contamination of ground water, Route 25 from Wareham to the Cape Cod Canal, Massachusetts: U.S.Geological Survey Water-Resources Investigations Report 84-4166, 22 p.

Church, P.E., and Friesz, P.J., 1993a, Effectiveness of highway-drainage systems in preventing road-salt contamination of groundwater—Preliminary findings: Transportation Research Record, no. 1420, p. 56-64.

Church, P.E., and Friesz, P.J., 1993b, Delineation of a road-salt plume in ground water, and traveltime measurements for estimating hydraulic conductivity by use of borehole-induction logs. In Proceedings of the Fifth International Symposium on Geophysics for Minerals, Geotechnical, Groundwater and Environmental Applications, October 24-28, 1993, Tulsa, Oklahoma, p. Y1-Y16.

Church, P.E., and Granato, G.E., 1996, Bias in ground-water data caused by well-bore flow in long-screen wells: Ground Water, v. 34, no. 2, p. 262-273.

Granato, G.E., (in press), Deicing chemicals as a source of constituents in highway runoff: Transportation Research Record, Preprint 960645.

Granato, G.E, Church, P.E., and Stone, V.J., 1995, Mobilization of major and trace constituents of highway runoff in ground water potentially caused by deicing-chemical migration: Transportation Research Record, no. 1483, p. 92-104.

Warren, L.P., Church, P.E., and Michael Turtora, 1995, Comparison of hydraulic conductivities for a sand and gravel aquifer in southeastern Massachusetts, estimated by three methods: U.S. Geological Survey Water-Resources Investigations Report 95-4160, 16 p.

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