EFFECTIVENESS OF HIGHWAY DRAINAGE SYSTEMS IN PREVENTING SALT CONTAMINATION OF GROUND WATER, ROUTE 25 FROM EAST WAREHAM TO THE CAPE COD CANAL, MASSACHUSETTS

By Samuel J. Pollock

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4166

Prepared in cooperation with the

MASSACHUSETTS DEPARTMENT OF PUBLIC WORKS

RESEARCH AND MATERIALS SECTION for the

COMMONWEALTH OF MASSACHUSETTS

DEPARTMENT OF PUBLIC WORKS and the

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

Boston, Massachusetts

1984

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

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METRIC CONVERSION FACTORS

The following factors may be used to convert inch-pound units to the International System of Units (SI).

Multiply inch-pound units	By	To obtain SI Units
	Length	
inch	25.40	millimeter (m)
	0.254	decimeter (dm)
foot	0.3048	meter (m)
mile	1.609	kilometer (km)
	Velocity	
foot per day (ft/d)	3.048	decimeter per day (dm/d)
	0.3048	meter per day (m/d)
foot per year (ft/yr)	3.048	decimeter per day (dm/yr)
	0.3048	meter per year (m/yr)
	Volume	
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
	0.02832	cubic meter (m^3)
	Flow	
cubic foot per second (ft^3/s)	28.32	cubic decimeter per second (dm^3/s)
	0.02832	cubic meter per second (m^3/s)
cubic foot per day (ft^3/d)	28.32	cubic decimeter per day (dm^3/d)
	0.02832	cubic meter per day (m^3/d)
square foot per day (ft^2/d)	9.290	square decimeter per day (dm^2/d)
	0.0929	square meter per day (m^3/d)

NGVD of 1929 (National Geodetic Vertical Datum of 1929): A geodetic vertical datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level." NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

This report describes a work plan for a project to study the relative effectiveness of specially designed highway drainage features in preventing contamination of ground water by highway-deicing salts with a solute-balance approach. Four different highway drainage designs along a new highway in southeastern Massachusetts will be compared. In one system, no attempt is made to channel runoff from the highway away from the edge of the road, and no attempt is made to prevent percolation of that water into the ground. In a second system, catch basins and drainage pipes conduct highway runoff away from the site for discharge elsewhere. The other two systems use drainage pipes and partial or complete snow berms in which subsurface impermeable layers constructed on the median and shoulders of the roadway prevent percolation of water into the ground.

Two approaches will be used to determine the relative effectiveness of each type of drainage system in preventing salt from entering ground water adjacent to the highway. In the first, a solute-balance approach will be used to quantify the amount of salt applied to the highway with the amount that enters ground water at that site or leaves the highway in surface-drainage outlets at the closed-drainage sites. In the second, or modified solute-balance approach, the quantity of salt in ground water at each site will be compared to the quantity of salt in the ground at a control, the open-drainage site, to determine the capture efficiency of each drainage system. This method assumes that salt is applied to the highway at the same rate per mile of highway at all four highway drainage sites. This method also assumes that the capture efficiency of the open-drainage system in preventing salt from entering the ground water approaches 0 percent.

The amount, or load, of salt in ground water at each of the four test sites will be estimated from the concentration of salt in the water and the volume of water in the aquifer. The concentration of salt will be determined by chemical analysis of water samples from a network of wells adjacent to the highway. The network will be designed so that each well will yield water samples representative of a prescribed volume, or block, of the aquifer. The volume of water within each block will be calculated from the block dimensions and the aquifer porosity as measured from neutron porosity logs and estimated from lithologic samples. The quantities of chloride in all the blocks will be added to determine the quantity of salt entering ground water at each site.

Background data at each test site will be collected for at least 1 year before the highway is opened. After five salting seasons, the capture efficiency of each drainage system will be determined by comparing the salt load spread on the highway with the salt load in ground water and, where possible, in surface drainage.

INTRODUCTION

Background

This article describes a work plan for a joint research project by the Survey (U.S. Geological Survey) and the MDPW (Massachusetts Department of Public Works). The objective of this study is to determine the relative effectiveness of different types of highway drainage systems in preventing highway-deicing salts (sodium chloride and calcium chloride) from getting into ground water adjacent to highways. This research is based on a previous highway salting/runoff study conducted by the Survey and the MDPW (Frost and others, 1981a, 1981b). One conclusion of that study was that highway drainage systems are a major influence in determining where and how much salt enters ground water.

In the current research project, test sites representative of four different types of highway drainage systems have been selected along State Route 25, which is under construction in southeastern Massachusetts (figs. 1 and 2). Data collection will begin at least 1 year before the highway is open and will continue until Route 25 has been open for 5 years. It is anticipated that Route 25 will open during 1986.

The Massachusetts Department of Environmental Quality Engineering requires that public water suppliers warn their customers if water which they deliver contains 20 mg/L (milligrams per liter) or more of sodium because of potential dangers of sodium to people with hypertension or heart disease. Also, the U.S. Environmental Protection Agency (1975) has recommended a 250 mg/L limit for chloride in drinking water. Where public-supply wells have been contaminated by deicing chemicals from highways, reconstruction projects have included special drainage systems designed to minimize future contamination of these wells. In addition, special highway drainage systems to prevent contamination of public and private ground-water supplies are being designed and constructed on new highways to restrict dispersal of highway-deicing chemicals. These chemicals consist of salt (sodium chloride) with as much as 20 percent calcium chloride. Each special drainage system costs between $750,000 and $3,000,000, but the effectiveness of these systems in preventing sodium and chloride from contaminating ground water has not yet been proven.

An evaluation of the effectiveness of various highway drainage systems is needed for State agencies responsible for highway design and protection of public health and water supplies, and consultants who design highways and prepare environmental impact statements.

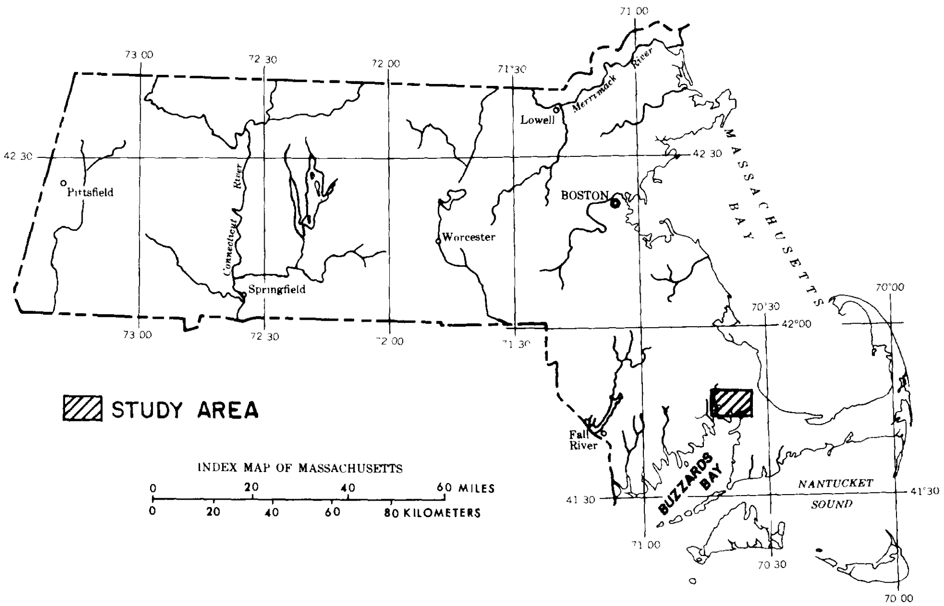
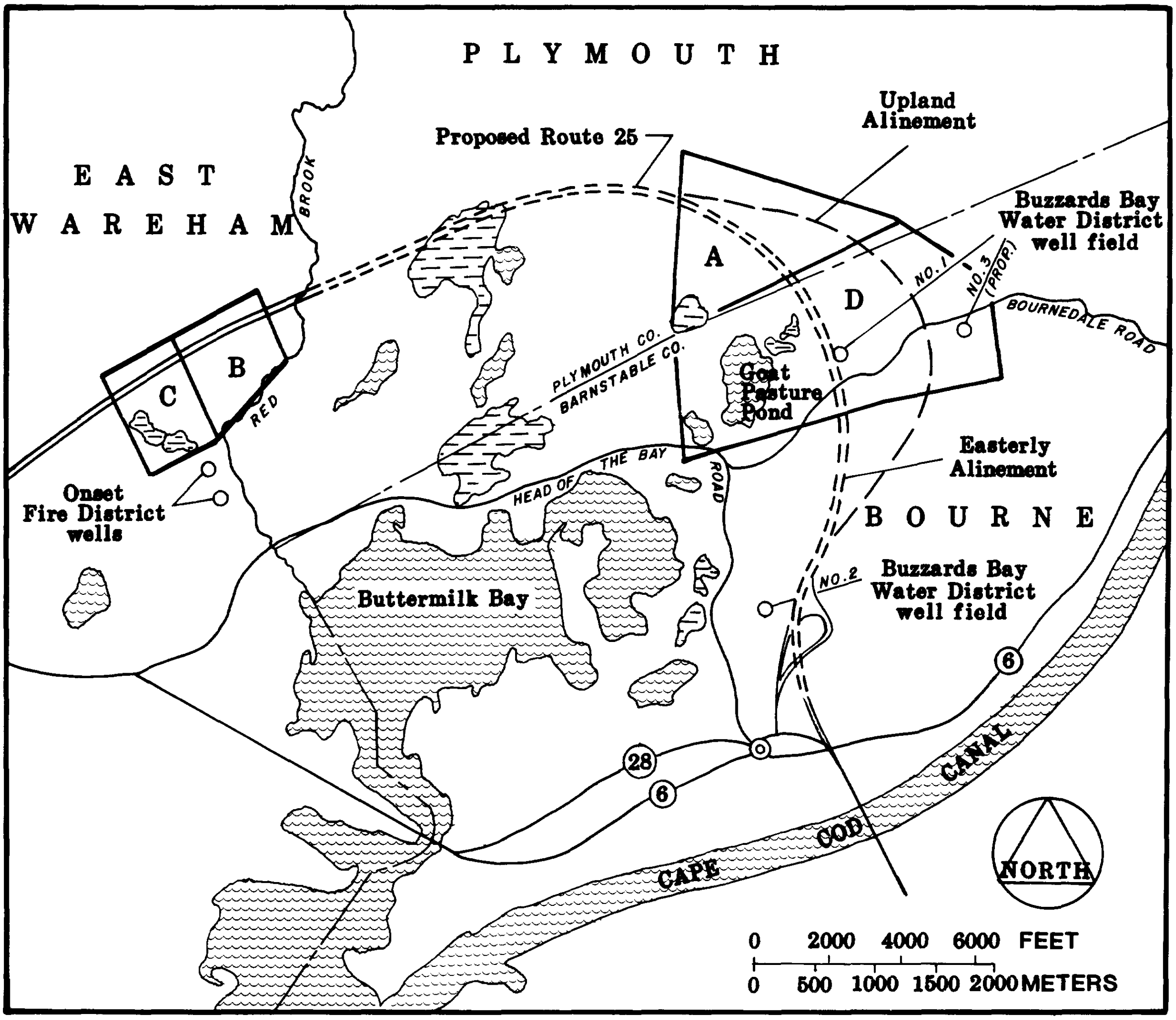


Figure 1.--Location of study area in Massachusetts.



EXPLANATION

[water symbol]	Water
[cranberry bog symbol]	Cranberry bogs
—·—	County boundary
═	Completed section of Route 25 as of 12/1/82
[A]	Test site boundary and identification letter
A	Open-drainage site
B	Closed-drainage site with no snow berm
C	Closed-drainage site with one snow berm
D	Closed-drainage site with full snow berms

Figure 2.-- Location of test sites along Route 25 in southeastern Massachusetts.

Purpose and Scope

The purpose of this report is to describe a planned study to determine the relative effectiveness of four different types of highway drainage systems in preventing highway-deicing salt from getting into ground water adjacent to highways. One system is open drainage in which no attempt is made to channel runoff from the highway away from the edge of the road and no attempt is made to prevent percolation of that water into the ground. A second is closed drainage in which catch basins and drainage pipes conduct highway runoff away from the site for discharge elsewhere. The other two use closed drainage and impermeable materials applied on the median and shoulders along the roadway to prevent percolation of water containing dissolved salt into the ground.

Description of Highway Drainage Systems

"Open drainage" or "country drainage" systems (site A, fig. 2) allow all highway runoff to flow from the pavement into unlined open ditches immediately adjacent to the highway. With open drainage, highway runoff can percolate down to the water table. This highway runoff also can include snowmelt from salt-laden snowbanks that had been plowed off the highway pavement.

"Closed drainage" is a highway drainage system (site B, fig. 2) where the runoff from the paved surface of the highway is conducted away from the highway through the highway drainage system in conduits (pipes and lined ditches) to a single outlet. With this system, salty meltwater from plowed snowbanks adjacent to highway pavement may percolate to the water table beside the highway, but runoff from the pavement is diverted to another location.

"Closed-drainage system with full snow berms" (site D, fig. 2) is the same as the closed-drainage system described above, but with the addition of impermeable snow berms on the median and both shoulders of the highway. "Closed-drainage system with one snow berm" (site C, fig. 2) is the same as the closed-drainage system, but with the addition of an impermeable snow berm on one shoulder of the highway. The term "snow berm" (fig. 3) is used to describe an area adjacent to a highway with a layer of impermeable material and special subdrain. The berm runoff and highway runoff is conducted by the highway drainage system to the highway drainage outlet. With full snow berms, all salt-laden highway runoff or snowmelt should flow into the highway drainage system and be prevented from entering the ground. With one snow berm, only part of the salt-laden highway runoff or snowmelt will be prevented from entering the ground.

EVALUATION OF THE EFFECTIVENESS OF HIGHWAY DRAINAGE SYSTEMS IN PREVENTING SALT CONTAMINATION

Conceptual Model

Effectiveness of the four types of highway drainage systems in preventing salt (sodium chloride and calcium chloride) from entering ground water adjacent to the highway will be determined using the solute-balance approach and a modification of that approach. The solute-balance approach depends on a mass balance equation in which the amount of solute (salt) applied to the highway is assumed to be balanced by the amount of solute leaving by way of the surface-drainage system or stored in the ground-water system adjacent to the highway. In the solute-balance approach, the measured quantity of salt applied to the highway will be compared with the measured quantity of salt in the ground water adjacent to the highway and the measured quantity of salt carried by the highway drainage systems. In the modified solute-balance approach, only the quantity of salt in ground water at each site will be compared to pre-salting conditions and to a control, the open-drainage site, to determine the capture efficiency of each drainage

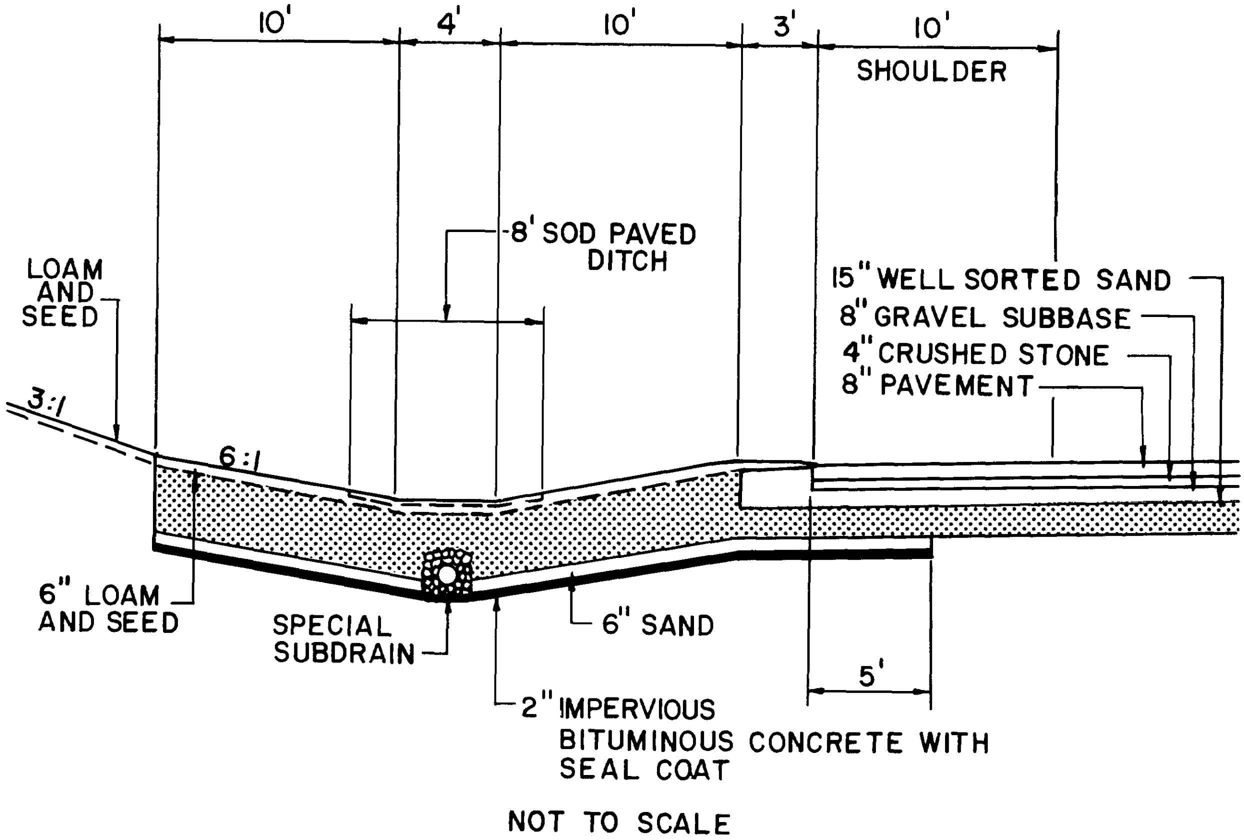


Figure 3.-- Cross section of snow berm along Route 25 in Wareham, Massachusetts.

system. This method assumes that salt is applied to the highway at the same rate and concentration per mile of highway at all four highway drainage sites, and that the capture efficiency of the open-drainage system in preventing salt from moving into ground water is nil. The salt-application rate at all four test sites will be assumed to be the same because similar snow and ice conditions are expected on the 5-mile length of highway that will be serviced and salted by one highway maintenance unit. The highway grade at all four sites is between 0.56 and 2.20 percent, and no steep or north-facing grades that would require extra salting are present.

The general equation for the solute-balance approach is:

$$S_a = S_r - S_{nr} + S_g - S_{ng} + S_s \qquad (1)$$

where:

S_a = the quantity of salt spread on the highway;

S_r = the quantity of salt moving from the highway into the surface streams adjacent to the highway;

S_g = the quantity of salt moving from the highway in ground water adjacent to the highway;

S_{nr} = the quantity of salt naturally occurring in the surface streams adjacent to the highway;

S_{ng} = the quantity of salt naturally occurring in ground water adjacent to the highway; and

S_s = the quantity of salt within the unsaturated zone of the unconsolidated materials adjacent to the highway

It is very difficult to determine accurately the amount of salt applied to a given length of highway, but it is relatively easy to assure that the rate of salt application to a length of highway is uniform; therefore, the modified solute-balance approach was developed. In this approach, the only segment of the general solute equation needed is the amount of salt in the ground water adjacent to the highway that can be attributed to the highway. This amount will be computed in terms of unit length of highway for each of the four sites. The individual values will then be compared to both the presalting loads and to the unit load for the open-drainage system, which is assumed to allow all the salt applied to the highway to enter the ground-water system.

Because both sodium chloride and calcium chloride will be used for deicing, the study will determine quantities of sodium, calcium, and chloride applied to the highway and discharged in surface runoff and in ground water. The chloride ion will be used as a tracer in this study because it is (1) a conservative ion (not adsorbed by the environment through which it moves), (2) found in low concentrations in the local geologic materials and in the ground and surface waters (less than 10 mg/L), (3) the common anion in both highway-deicing chemicals used by the Commonwealth of Massachusetts and local municipalities on their roads, and (4) dissociates (dissolves) completely in water. Sodium and calcium, on the other hand, are not conservative and are involved in ion exchange with earth materials to different degrees. The relative importance of these effects will be determined by comparing the stoichiometric ratios of these elements to chloride in the salt applied with their ratios as measured in the surface water and ground water. Previous studies have indicated that sodium exchanges with calcium in earth materials thereby reducing sodium and increasing calcium in the resultant solution. The MDPW uses a mixture of sodium and calcium chloride which contains about 60 percent of chloride by weight, and, based upon the 1976-81 maintenance records of the MDPW in southeastern Massachusetts. Sodium and calcium chloride was applied at an average annual rate of 10.6 tons per highway-lane mile.

The land on which the highway is being built is wooded, unpopulated, and primarily conservation land where no development has occurred. Therefore, septic tanks, cesspools, and domestic-animal or farm-animal wastes are not additional sources of chloride at these four test sites. In addition, the contribution of chloride from rainfall, sea spray, and wildlife wastes is relatively constant and insignificant compared to the amount applied to the highway for wintertime deicing purposes.

Methodology

Calculations of Velocities and Chloride Loads in Ground Water

The purpose of the ground-water-sampling sites is to determine the quantity of salt that enters the ground water adjacent to the highway at each type of highway drainage system. This is accomplished by calculating the load of chloride in the ground water at each site from the chloride concentration of the water and the volume of water in the aquifer. The network of sampling wells at each site will be designed to provide representative water samples from discrete volumes or blocks of the aquifer from two depths (fig. 4). At each site, the sampling wells, and the blocks which they represent, are based on the geology and hydrology of the unconsolidated materials. Hydraulic conductivity, porosity, velocity, and direction of ground-water flow are determined from an aquifer test, test borings, neutron logs, and water-level elevations. The thicknesses of the upper and lower layers of blocks are selected so that the hydraulic conductivity is relatively uniform throughout each layer. The rows of sampling wells and, therefore, the blocks, are alined downgradient and parallel to the direction of ground-water flow away from Route 25. These wells are spaced such that the ground-water traveltime from one well to the next downgradient well is 1 to 3 months near the highway, and 2 to 6 months further away from the highway. The location of the wells most downgradient from the highway ideally should be at the distance that the salt would reach near the end of the 5 years of data collection. In practice, however, the limiting factor at some sites is the proximity of a pond, stream, bog, or swamp into which the ground water discharges downgradient from the highway and which may be located slightly less than 5 years traveltime from Route 25.

Water removes the chloride from the highway and transports it into the ground water adjacent to the highway. Darcy's law (Ferris and others, 1962) can be used to compute the quantity of ground water flowing in the saturated zone beneath and away from the highway fig. 4).

$$Q = TIW \tag{2}$$

where:

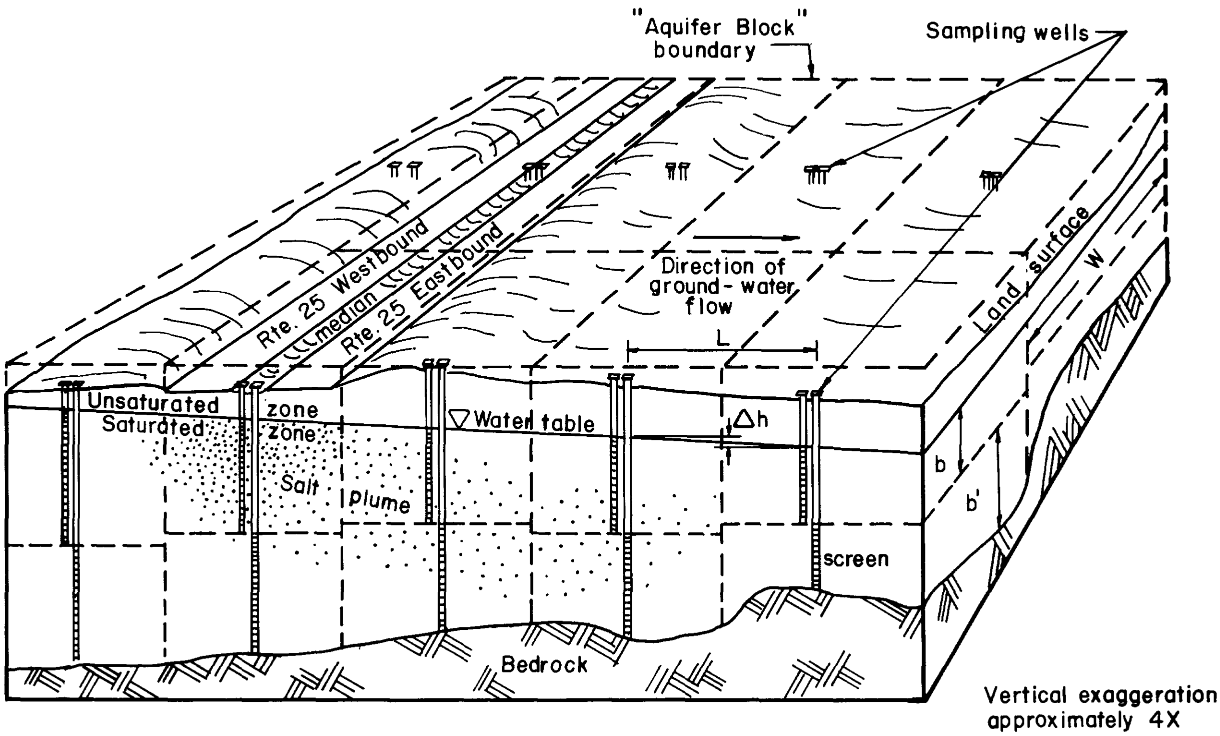
Q = the quantity of water, in cubic feet per day, flowing through a vertical section of an aquifer;

T = the transmissivity of the aquifer material, in square feet per day;

I = the hydraulic gradient across the section, in feet per foot; and

W = the width of the section, in feet.

To apply Darcy's law properly, (1) the hydraulic gradients must be determined along the direction of ground-water flow (perpendicular to the water-table contours), (2) the section must perpendicular to the direction of ground-water flow, and (3) the flow of ground water must be laminar and nearly horizontal.



E X P L A N A T I O N

b, b' = **Saturated thickness of block of aquifer, in feet**

Δh = **Difference in water levels between wells, in feet**

L = **Distance between wells, in feet**

W = **Width of block of aquifer, in feet**

Figure 4.-- Idealized sampling-well network designed to determine the quantity of salt in ground-water discharge and velocity through the aquifer.

Transmissivity is the rate at which water is transmitted through a unit width of aquifer material under a unit hydraulic gradient. It is calculated by multiplying K, the estimated hydraulic conductivity of the unconsolidated material, in feet per day, by b, the saturated thickness, in feet, of each block of aquifer (fig. 4). Aquifer-test analysis was used to estimate hydraulic conductivities directly. In addition, materials samples collected from each test hole can be used to indirectly estimate the hydraulic conductivities of the unconsolidated deposits by comparing the grain sizes with those of known hydraulic conductivity (table 1).

Table 1.--Hydraulic conductivity of aquifer materials[1]

Material	Hydraulic conductivity, K, in feet per day
Gravel:	
Coarse	300-700
Medium	200-300
Fine	180-200
Fine to coarse	150-400
Sand:	
and gravel	200
Coarse	90-150
Medium	70- 80
Fine	20- 30
Fine to coarse	40-150
Fine to medium	40-100
Silt and clay	Less than 10

[1]From Brackley and Hansen, 1977.

Hydraulic gradients, I, are determined from water-table contour maps. The direction of ground-water flow is always downgradient and perpendicular to these contours, assuming that the aquifer is isotropic and that there is no vertical component of flow. Figure 5 is a water-table contour map from which ground-water gradients were determined for two of the test sites.

The bulk velocity of ground water through the aquifer is equal to the area of the cross section through which the flow occurs divided by the quantity of flow per unit time.

$$V_B = \frac{A}{Q} \qquad (3)$$

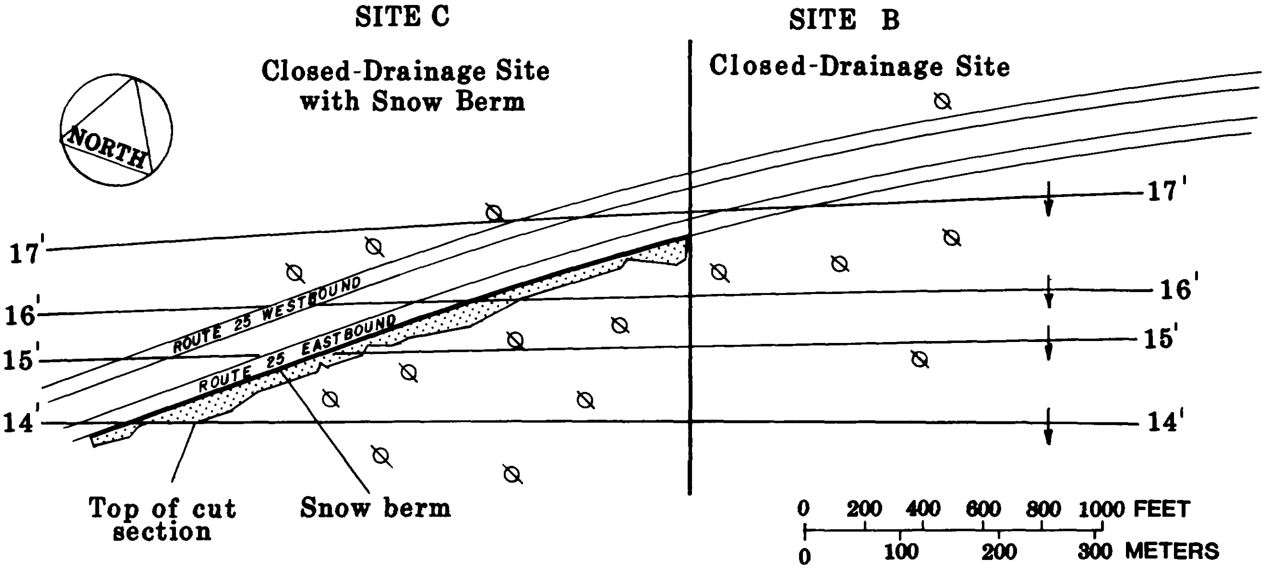
where:

V_B = the bulk velocity of ground-water flow;

A = the area of the vertical cross section (W x b or W x b', in fig. 4) through which that flow occurs; and

Q = the quantity of flow.

In addition, to determine the pore water velocity (V_p), the cross-sectional area "A" must be multiplied by the effective porosity of the material, n, to correct for the area actually occupied by flowing ground water ($V_p = \frac{An}{Q}$). Then, by substituting the right side



EXPLANATION

Observation well

Approximate direction of ground-water flow

14' Water-table contour; shows altitude of water table; contour interval is 1 foot

Figure 5.-- Water-table contours at closed-drainage site (B) with no snow berms and at site (C) with one snow berm, 11/19/79.

of Darcy's equation for Q, and solving for V_p, the resultant equation to compute the velocity of ground-water flow in the pores of the aquifer is:

$$V_p = \frac{K \Delta h}{Ln} \tag{4}$$

where:

V_p = pore velocity of ground water, in feet per day;

K = hydraulic conductivity, in feet per day;

Δh = change in hydraulic head between two points (fig. 4), in feet;

L = length between the two points used to determine hydraulic head, in feet (fig. 4); and

n = effective porosity of the unconsolidated materials.

An aquifer test was made during February 1982 in the vicinity of Buzzards Bay Water District proposed well field 3 (fig. 2). The proposed well field is downgradient from the planned section of Route 25 containing the closed-drainage system with full snow berms. Lithologic logs show that aquifer materials and saturated thickness are similar at the proposed well field and the four sampling sites.

With a hydraulic conductivity of 190 ft/d estimated from this aquifer test, hydraulic gradients determined from water-table maps, and an effective porosity of 0.35 estimated from sediment analyses and other sources, the approximate ground-water velocity for each of the four test sites was computed from equation 4 above. These velocities ranged from 0.8 to 2.2 ft/d and will aid in determining the spacing between observation wells.

Water samples and water-level data will be collected monthly from these wells and analyzed to determine the concentrations of sodium, calcium, and chloride and the water volume in each block. This water-level data will be used in conjunction with depth to the top of the lower block or depth to bedrock, depending on which layer the block is in, to calculate the saturated thickness of that particular block. The quantity of water in each block will then be calculated by multiplying the saturated thickness by its respective effective porosity and its horizontal area. The effective porosity of individual blocks in the aquifer will be estimated from neutron-geophysical logging or from particle-size analyses of samples collected from test borings. Geophysical logging involves lowering a neutron probe into a 2 1/2-inch diameter cased hole drilled through the full thickness of the aquifer and converting the data to porosity using a standardized calibration curve. One such well will be located at each of the four sites.

At any given time, the quantity of chloride (or sodium and calcium) in each block can be calculated based upon the concentrations of chloride and the quantity of water in each block. The quantity of chloride in each block, owing to highway salting, will be calculated as follows:

$$Q_{Cl} = (Cl_L - Cl_b)(n)(V)\,(3.121 \times 10^{-8}) \tag{5}$$

where:

Q_{Cl} = quantity of chloride in each block, owing to highway salting, in tons;

Cl_L = latest concentration of chloride, in milligrams per liter;

Cl_b = background concentration of chloride, in milligrams per liter;

n = effective porosity of the material; and

V = volume of the block of aquifer, in cubic feet.

The quantity of chloride (load) at each of the test sites is the sum of the chloride loads in each of the 16-20 blocks at each site.

Calculations of Chloride Loads in Surface Water

The purpose of the surface-water monitoring stations is to determine the quantity of salt that leaves the highway in water carried by the highway drainage system. Only the sites with closed-drainage systems will have these monitoring stations. The water stage (level), specific electrical conductance, and temperature of the water in the conduit will be recorded on a digital tape every 15 minutes. These data are then converted to flow rates and chloride concentrations before calculating the estimated chloride load.

Specific conductance may be assumed to be directly related to chloride concentration at conductances above about 100 micromhos because sodium chloride and calcium chloride from deicing salts will increase conductance. A predictive equation will be developed by regressing chloride concentration on specific conductance from analyses of samples of highway runoff. With this chloride-versus-conductance relationship, each recorded value of specific conductance will be converted to a chloride concentration from which daily mean chloride concentration will be computed.

The stage of water in the conduit (just above a control point where the height and flow of water are related) is sensed by a servo-manometer, a pressure sensing device, connected to a digital recorder. With a stage-discharge relation developed from periodic, concurrent measurements of stage and discharge at each station, the 15-minute values of stage are converted into discharge from which daily mean discharge will be computed. A crest-stage gage is installed at each station to record peak stages, which might occur between 15-minute recordings on the digital tape, to supplement continuous recorded water levels.

Chloride load, in tons per day, at each surface-water-gaging station will be calculated as follows:

$$Cl_L = Cl_c(D_m)(0.0027) \tag{6}$$

where:

Cl_L = chloride load at each surface-water-monitoring station, in tons per day;

Cl_c = daily mean chloride concentration, in milligrams per liter; and

D_m = daily mean discharge, in cubic feet per second.

The chloride load is then summed for the period over which the solute balance is to be evaluated. During periods of peak runoff, however, the mean quarter hourly discharges and quarter hourly chloride concentrations will be multiplied to obtain quarter hourly chloride loads and summed to obtain a daily chloride load.

Criteria For Site Selection

The selection of sites was based on several factors. Following is a list of the criteria and discussion of how the sites meet each criterion:

1. The sites were selected so that the direction of ground-water movement does not vary more than ±20 degrees from perpendicular to the highway. If the ground-water flow were parallel to the highway, it would be difficult to determine the specific length of highway contributing chloride to the ground water.

2. The sites were selected such that the unconsolidated materials were sand and gravel, typical of that found in the vicinity of public-supply wells in this area and throughout New England. At each of the test sites selected

for this study, the unconsolidated materials are primarily fine to medium sand within the Wareham outwash plain (Williams and Tasker, 1974). This aquifer is generally an excellent source of large supplies of water (Williams and Tasker, 1974). In these materials, the velocity of the ground water should be sufficient to move the chloride at least 1000 feet at each of the sites during the 5-year duration of this study. The zone of contamination can be well defined without necessitating an excessive number of sampling wells.

3. A desirable site characteristic was that the water table be near land surface. An unsaturated zone greater than 50 feet, between land surface and the water table might delay salt movement from the highway to the water table and result in a significant temporary storage of salt in the unsaturated zone. At the selected sites, this zone is thin enough so that salt-free recharge water should flush most of the salt down to the water table between highway-salting seasons. In general, the water table at the test sites varies between 15 and 35 feet below the land surface.

4. The saturated deposits of the aquifer are thick enough to conveniently monitor, but not so thick that the resulting volume of water requires a great number of sampling wells. The aquifer texture and hydraulic properties are relatively homogeneous so that uniform dispersal of the salt is probable. Excessive nonhomogeneity or thickness would require more "blocks of aquifer" and more observation wells to accurately determine the quantity of salt in the water.

5. In the test areas, which are all located along a 5-mile length of Route 25, the salt-application rate is expected to be the same. Only one MDPW maintenance and repair unit will be responsible for this length of highway. This unit will be provided with modern salt spreaders and will keep accurate salt-application records.

6. There are no other significant sources of salt, such as septic systems and dumps, in the vicinity of the test sites. The salt load contributed to the ground water from the highway will be much greater than that contributed by any other background source near the test sites. In addition, the test sites are in a location where no other construction is planned which might disturb the wells, alter the hydrology, or add salt to the ground water during this study. The test sites for this study are mainly on conservation or undeveloped land. The test sites will be sampled and measured for at least 1 year before the highway is opened to determine if there are any significant variations in the background concentration of sodium, calcium, or chloride.

Hydrology and Status of Data Collection at Each Type of Site

Open-Drainage Site, Plymouth

Open drainage is used in areas where the highway runoff will not cause flooding or erosion problems and where there is no anticipated use of ground water. The open-drainage site will be located along either of two highway alinements which have been proposed (fig. 2). Test borings have been made and observation wells installed to evaluate the suitability of either the easterly alinement or the upland alinement for this study. The final selection will be based on the result of pending litigation.

The location of the 11 observation wells that have been installed for site evaluation and design of the sampling-well network along the easterly alinement at the proposed open-drainage site is shown in figure 6. The geologic logs derived from these test borings indicate that sandy till extends from a depth of about 100 feet below land surface to the bedrock surface. Overlying this till is about 25 feet of fine sand which, in turn, is overlain by about 75 feet of medium sand with some gravel. If this type of stratification is encountered downgradient of this site, it will indicate that a two-layered sampling system will be needed: One set of wells screened in the lower fine sand and the other set in the upper medium sand.

Analyses of the data collected at this site indicate that the direction of ground-water movement (fig. 6) varies not more than 20 degrees from perpendicular to both proposed highway alinements as determined from the water-table contour map. Calculations of ground-water velocity based on these preliminary data indicate that ground water is flowing at a rate of about 1.5 ft/d or 550 ft/yr. In addition, analyses of water samples collected from observation wells indicate that the concentration of chloride in the ground water is about 10 mg/L, typical of uncontaminated ground water in this area.

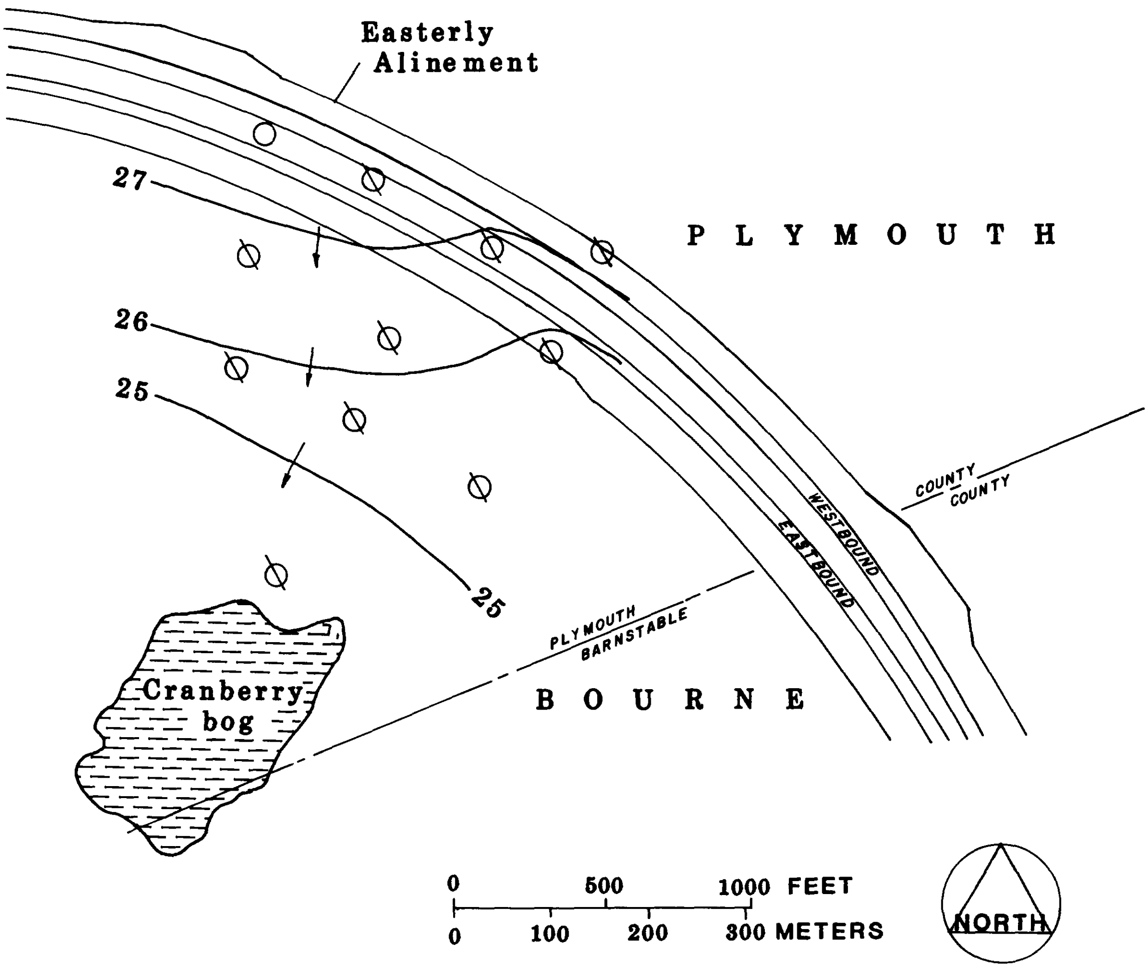
This site generally is suitable for the study, but additional test borings and observation wells are needed to collect sufficient data on the precise direction of ground-water flow and stratification of unconsolidated materials before a sampling well network can be designed. It is planned to make additional test borings and install additional observation wells when the final highway alinement has been selected.

Closed-Drainage Site with No Snow Berms, Wareham

The closed-drainage site with no snow berms is along a section of Route 25 which has been constructed but will not be open to traffic until all of the highway is completed (fig. 2). From this site and the site for the closed drainage with one snow berm, all the runoff from the paved surfaces of the highway flows easterly in conduits to a sedimentation basin at Red Brook (fig. 7). In order to design the sampling well network, five test borings were made to determine the types of unconsolidated material, and five observation wells were installed to determine the water-table elevations and background concentrations of chloride. Figure 8 shows a typical geologic log for the Wareham site. Geologic logs derived from test borings at this site indicate that sandy till is found at a depth of about 100 feet below land surface. Overlying this till is about 25 feet of fine sand which, in turn, is overlain by about 75 feet of medium sand with some gravel. Analyses of water samples from these observation wells indicate that the chloride content of ground water is generally less than 10 mg/L.

Water levels measured in the five observation wells at this test site were used to prepare ground-water contour maps. The maps show that the water table is nearly planar. The direction of ground-water movement is nearly perpendicular to Route 25. Calculations of ground-water velocity based on the analysis of the aquifer-test data, as well as other hydrologic information, indicate water is flowing at a rate of about 2.2 ft/d or about 800 ft/yr at this site. Based on the direction and velocity of ground-water flow (fig. 5) and the two distinct layers of unconsolidated materials (fig. 8), a two-layered sampling network (figs. 4 and 7) was designed. The sampling network and block configuration at Wareham is similar to that shown by the idealized diagram in figure 4.

To measure the discharge from the highway drainage system, two gaging stations will be installed (fig. 7). One will be installed in the main drainage pipe just downgradient from the snow berm. The other will be similarly installed just downgradient from the closed-drainage site. By subtracting the salt load at the downstream gage from that at the upstream gage, the amount of salt leaving the highway pavement and flowing through the highway drainage system will be calculated.



E X P L A N A T I O N

Observation well

Approximate direction of ground-water flow

26 —— Water-table contour; shows altitude of water table; contour interval is 1 foot

Figure 6.--Water-table contours at open-drainage site, Easterly Alinement in Plymouth, Massachusetts, 2/9/80.

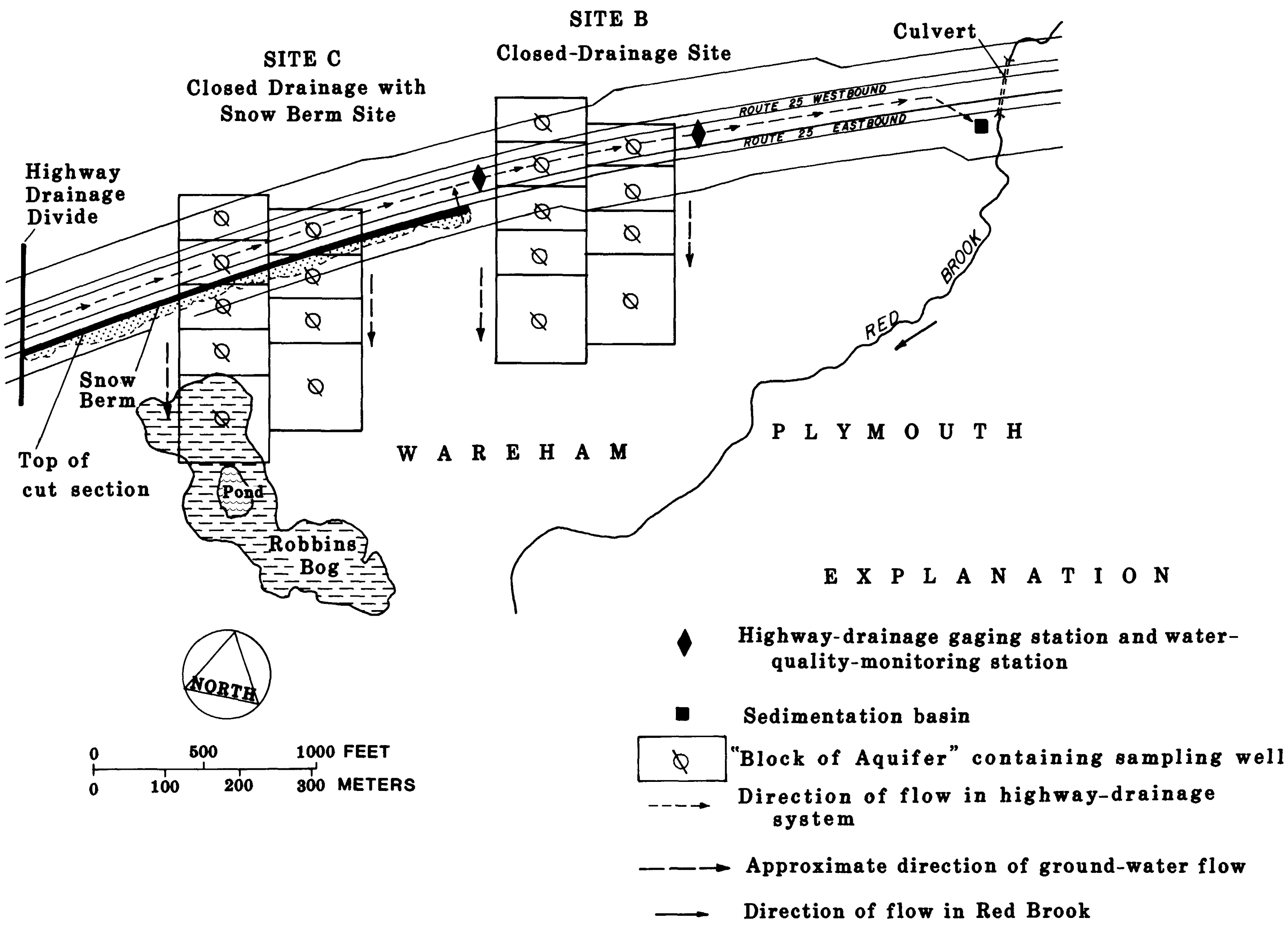


Figure 7.-- Highway-runoff-monitoring sites and sampling wells in Wareham, Massachusetts.

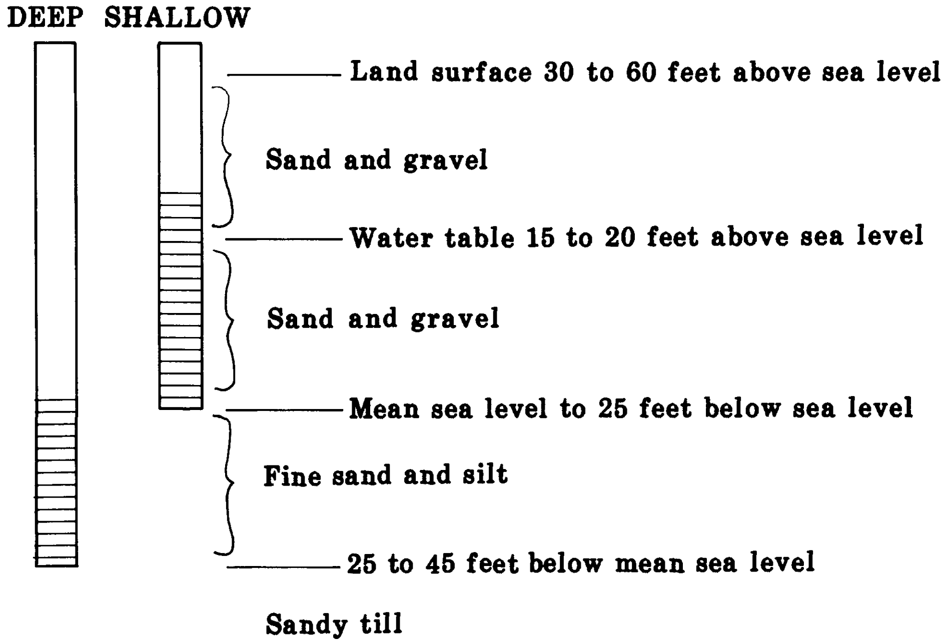


Figure 8.--Typical lithologic log and sampling well construction in Wareham, Massachusetts.

It is anticipated that a flow meter with a specific conductance recorder will be installed at each gaging station. It is planned to have at least 1 year of quantitative specific conductance and chloride data for background purposes at these sites before Route 25 is open to traffic.

Highway runoff from this site flows into a sedimentation basin, which is designed to hold the total potential runoff from approximately 3 inches of precipitation on the area drained before overflowing into Red Brook. The water remaining in the basin seeps through the outlet wall, which is constructed of a filter sand, and flows into Red Brook. Red Brook flows south, emptying into Buttermilk Bay, a saltwater body (fig. 2). The retention time of the highway runoff in the basin is approximately 4 days, and the flow through the outlet wall of the basin that drains the test area is approximately 0.6 ft^3/s. When the basin is full, any additional runoff discharged into the basin will flow over a spillway into Red Brook. Based on 1976-81 precipitation data from the U.S. Weather Bureau Station in East Wareham, Massachusetts, about 2 miles from this site, the sedimentation basins at Red Brook can be expected to overflow about once a year.

Analyses of water samples collected from Red Brook at Route 25, prior to opening the highway, indicate that the background specific conductance is between 45 and 50 micromhos per centimeter at 25°C with a corresponding chloride concentration of around 10 mg/L. This is typical of uncontaminated ground water and surface water in the area of Red Brook.

Closed-Drainage Site with One Snow Berm, Wareham

The closed-drainage site with one snow berm is adjacent to the closed-drainage site with no snow berms, described in the preceding section. The snow berm (fig. 7) was designed to prevent highway runoff from flowing into Robbins Bog, an abandoned cranberry bog that is part of the watershed area of the Onset Fire District municipal water-supply wells (fig. 2). The geology, hydrology, and block layout are similar to that at the closed-drainage site with no snow berms and are described in the preceding section. Ten test borings and observation wells were used to evaluate this site and to design the sampling-well network. The highway drainage from the closed-drainage site with one snow berm flows into the sedimentation basin at Red Brook and will be measured as described in the preceding section.

Closed-Drainage Site with Full Snow Berms, Bourne

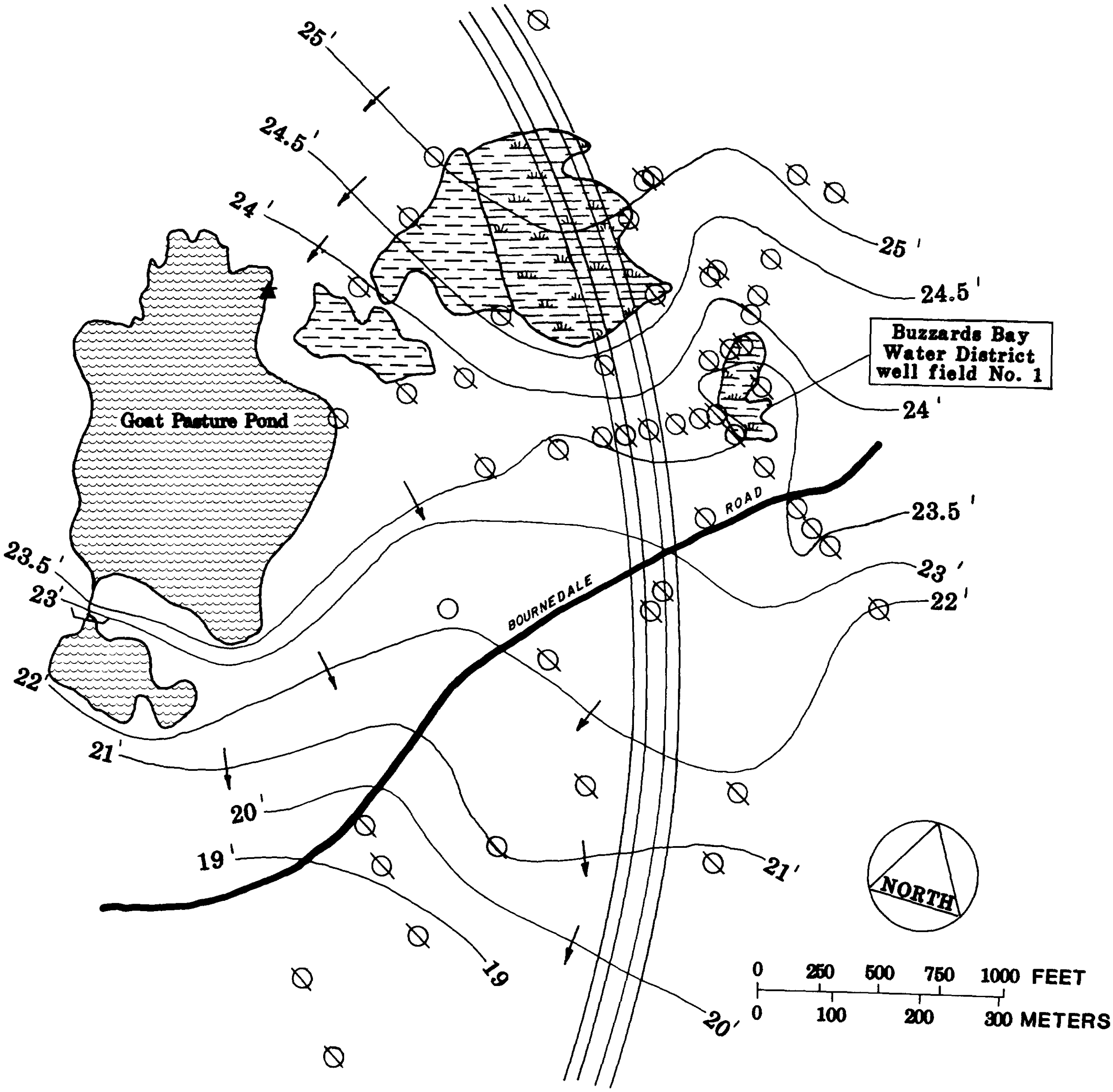
A closed-drainage system with full snow berms has been designed to prevent salt runoff from contaminating the ground water in the vicinity of the Buzzards Bay Water District Well Fields 1 and 2 and proposed well field 3. Two highway alinements, the easterly alinement and the upland alinement, have been proposed along the section of Route 25 that would affect these well fields (fig. 2). As explained under the description of the open-drainage site, only one of these alinements will be built, but neither one has been chosen because of litigation. The closed-drainage site with full snow berms along the Route 25 easterly alinement is shown in figure 9. Thirty-two test borings were made, and observation wells were installed to determine the suitability of the easterly alinement. These were supplemented by 20 wells previously installed for an environmental impact statement. Fourteen wells installed for a supplementary environmental impact statement and 12 test borings and wells made for this study were used to evaluate the suitability of sites along the upland alinement.

North of Bournedale Road, ground-water contours indicate a potentially suitable site northeast of Goat Pasture Pond. The geology and the chloride concentration (10 mg/L) in this area are similar to those of the Wareham sites (closed drainage with no snow berms and one snow berm). It is planned to make additional test borings to obtain geologic logs and to install additional observation wells to collect water-level data and water samples for chemical analysis. These data, and data from all previous test borings and observation wells, will be used to design the sampling-well network for the highway alinement that is finally chosen.

Data from an aquifer test conducted near proposed well field 3 of the Buzzards Bay Water District was used to determine the length of the upland alinement that should be constructed with full snow berms to prevent salt from contaminating the ground water which would be pumped at the proposed well field. Water-table contour maps developed from these data also show that the direction of ground-water flow (fig. 10) is nearly parallel to the upland alinement. Accordingly, if the upland alinement is selected for construction, the sampling-well network will have to be installed at the northern end of the upland alinement, near the Bourne-Plymouth town line where the direction of ground-water flow is more nearly perpendicular to the highway.

The highway runoff for the closed-drainage system with full snow berms for the easterly alinement, north of Bournedale Road, has been designed to flow into Goat Pasture Pond at the location of the northern staff gage shown on figure 9. The runoff will be filtered through a sedimentation basin to remove particulate matter before flowing through a cement-lined ditch to Goat Pasture Pond. The stage, specific conductance, and temperature of water in this ditch will be measured and recorded.

Highway drainage for the closed-drainage system with full snow berms for the upland alinement has not yet been designed. If the upland alinement is selected, a drainage-system design similar to that of the easterly alinement will be prepared, and a similar runoff-monitoring system will be designed.



EXPLANATION

Observation well

20' —— Water-table contour; shows altitude of water table; contour interval varies

Approximate direction of ground-water flow

Water

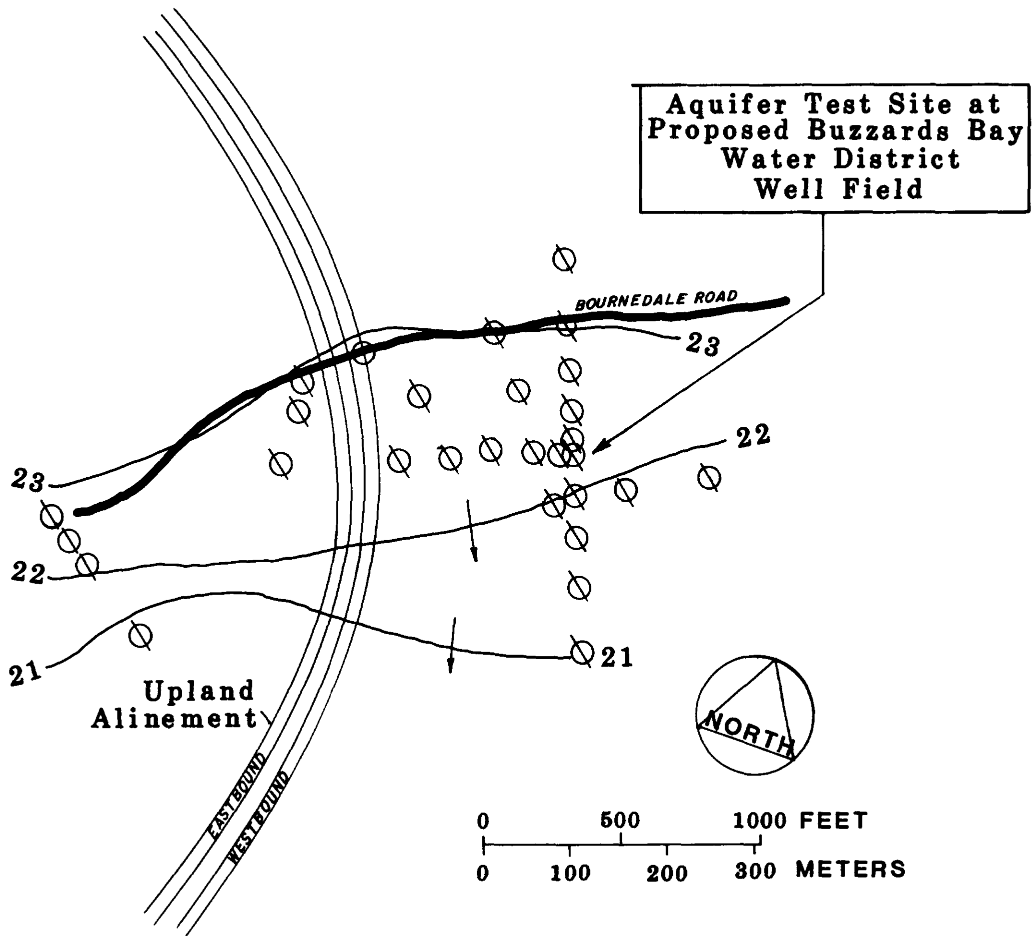
Cranberry bog

Swamp

Dam

Staff gage

Figure 9.-- Water-table contours on 7/7/80 at closed-drainage site (D) with full snow berms, Easterly Alinement in Bourne, Massachusetts.



E X P L A N A T I O N

Observation well

Approximate direction of ground-water flow

23—— Water-table contour; shows altitude of water table on 2/22/82, contour interval is 1 foot

Figure 10.-- Water-table contours at proposed well field, Upland Alinement, Bourne, Massachusetts.

SUMMARY AND CONCLUSIONS

The purpose of this report is to describe a planned study to determine the relative effectiveness of four different types of highway drainage systems in preventing sodium chloride and calcium chloride from entering ground water adjacent to highways. These drainage systems consist of an open-drainage system and three closed-drainage systems, one having no snow berms, one having one snow berm, and one having full snow berms. Snow berms are constructed of impermeable layers with drainage systems on the shoulders or median of the highway to prevent water from infiltrating the ground adjacent to the highway. These sites are located in a rural, wooded area where the ground water is presently uncontaminated by salt. The present chloride concentration in the ground water is about 10 mg/L. The sites are all located along a 5-mile section of State Route 25 in southeastern Massachusetts, which is in various phases of planning and construction.

Two versions of the solute-balance approach will be used to determine the relative effectiveness of each type of drainage system in preventing salt from entering ground water. In one, the direct version, measured quantities of salt applied to the highway will be balanced against measured amount of salt leaving the highway in ground water and in surface drainage thus establishing the capture efficiency of each system. The indirect version assumes that open drainage allows all salt applied to the highway to move into the ground water adjacent to the highway. It also assumes that salt will be applied to the highway at the same rate per mile of highway at all four highway drainage sites. This assumption is presumed to be valid, within the precision of measurement of salt-application rates, because similar snow and ice conditions are expected in this short length of highway which will be serviced by one maintenance section. In the indirect version, the capture efficiency of each drainage system can be determined by comparing the amounts of salt in ground water at the open-drainage site with the amount of salt at the other sites after several salting seasons.

Geology at all four test sites is similar--primarily fine to medium sand having about 80 feet of saturated thickness overlying a layer of till which, in turn, overlies bedrock. A hydraulic conductivity of 190 ft/d, an effective porosity of 0.35, and hydraulic gradients at each site were used to estimate ground-water velocities at the sites of from 290 to 800 ft/yr.

The amount of salt in ground water at each test site will be determined by calculating the load of salt in the aquifer from the sodium, calcium, and chloride concentrations in the water and the volume of water in the aquifer. A network of sampling wells at each site will be designed to provide representative water samples from a discrete volume or block of the aquifer. The network of sampling wells and representative blocks at each site is based on the geologic and hydrologic properties of unconsolidated materials.

Sampling-well networks are presently being installed at two of the sites where Route 25 has been completed but is not yet open to traffic. Sampling-well networks for the other two sites are planned to be installed on a section of Route 25 which has not yet been constructed. At each test site, data will be collected beginning at least 1 year before the highway is opened and will continue for five salting seasons after the highway is opened.

The results of this research will enable highway design engineers to evaluate alternative drainage systems in order to select the most cost-effective method of minimizing or preventing contamination of ground water by deicing salt. This study also will provide data which may aid engineers in designing the most effective methods of alleviating highway-related ground-water contamination problems. The benefit/cost ratio of special drainage systems or other remedial measures can then be determined by comparing the costs of alternative drainage systems, or highway routing alternatives with replacement costs or treatment costs for private and public water supplies. The methodology developed for this study may be useful when applied to other studies of the effects of highway runoff on ground-water quality.

The conclusions of this study will be used by environmental, maintenance, and design units of state highway departments to minimize salt contamination of ground water near highways. These departments can use this information in the (1) design of highway drainage systems for specific sites, (2) comparison of alternative highway locations, (3) evaluation of potential effects of the highway drainage system on surface water and ground water, (4) re-design of highway drainage systems near water-supply wells, (5) selection of remedial measures to alleviate highway-related contamination problems, and (6) selection of approriate snow and ice control measures near water-supply wells.

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-NOTES-