A Method of Predicting Road Salt Runoff in New Hampshire

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A predictive method is developed to forecast the "worst case" amount of sodium (Na^+) and chloride (Cl^-) ions added to surface waters as a result of highway deicing chemicals. Assumptions are based upon hydrological, topographical and meteorological characteristics specific to the central New Hampshire region. This worst case model is a seasonal method which is based upon all salt running off during a six month salting season (November-April). Specific geographical names are omitted as the project for which this model was developed is not finalized at this writing.

The preparation of an Environmental Impact Statement (EIS) to identify potential effects associated with a proposed federal action which will significantly affect man s environment is required by the National Environmental Policy Act of 1969. The EIS must address all of the probable effects, both positive and negative, likely to be anticipated. These include social, economic and environmental considerations.

In the study of proposed new roadways, effects upon water quality often become a major issue. In particular, there is a need to identify the potential changes in water quality following construction and opening of the roadway. For instance, questions arise with regard to toxic heavy metals such as zinc, cadmium, lead and mercury, often found in vehicular coolants, fuels, lubricants and wearing parts (1). These elements will be incident upon the roadway pavement and find their way to runoff waters in sufficient concentrations to inhibit biological productivity.

Of all potential pollutants during the winter season, deicing compounds are the most obvious (2, 3). Two elements--sodium and chloride--lend themselves to direct quantification of runoff concentrations, except that the analyses are so complex that results obtained are largely estimates based upon professional judgment.

In New Hampshire, where relatively severe weather conditions and heavy snowfalls occur during winter, extensive road plowing and salting operations take place. Therefore, during the preparation of a recent Environmental Impact Statement for a proposed new roadway in that State, a method of predicting the runoff of road salt derived by the New Hampshire Department of Public Works and Highways, was used to evaluate the likely effects upon the many streams to be traversed by the new road. Described below are the existing conditions of the study area, the methodology employed in predicting road salt runoff concentrations and utilization of those predictions to define the probable impacts. This paper considers the potential salt impacts of the proposed roadway extension in central New Hampshire. The names of lakes, ponds and streams have been deleted as the outcome of the project is undecided and is facing divided public opinion.

Study Area

The study area is totally within the Merrimack River Basin (R) Watersheds of the Rivers A and B make up the headwaters of River R. (See Figure 1). River A flows through the corridor in a southerly direction near the west end of the proposed road. The path of River B is generally parallel to the proposed road across the southern portion of the study area.

Natural drainage in the region is reflected in the distribution of lakes, low areas and meandering streams. The terrain of the adjacent reaches of Rivers A and B is gradual with elevations ranging from 120 to 300 meters above mean sea level. All roadway drainage is directed into the closest downhill receiving stream. The number of lane miles of highway section is known for each drainage basin to be crossed.

Climatology

The watersheds in the study area have a variable climate characterized by moderately warm summers, cold winters and ample rainfall. The weather is especially severe in the upper tributaries of River A where it flows out of high mountains. The project lies in the path of prevailing winds from the west and cyclonic disturbances that cross the country, from the west and southwest toward the east and northeast.

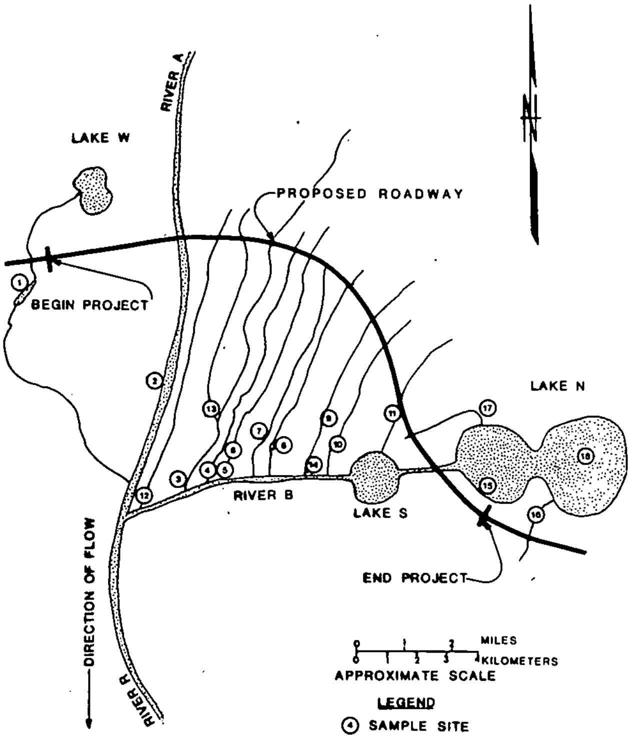


FIGURE 1
WATER BODIES IN STUDY AREA
(schematic)

Temperature

The average annual temperature in the basin is about 7°C. The average monthly temperatures vary widely throughout the year, between 18°C and 21°C in July and August to -4°C and -3°C in January and February. The extremes range from highs in the +30°C range to lows of -34°C.

Precipitation

Precipitation data was obtained from the U.S. Weather Bureau's Climate Survey (4) and is summarized for the study area in Table 1. Precipitation amounts are distributed equally throughout the year. It ranges from a low of 67mm in February to a high of 101mm in November. The mean and median precipitation is 86mm per month.

Table 1. Total average precipitation at a study area station.

Month	Average Precipitation (mm)
January	83
February	67
March	81
April	87
May	99
June	92
July	91
August	75
September	96
October	75
November	101
December	86
Annual	1030
Average Annual Snowfall (mm)	1750

Elevation of Station (m) 119 Period of Record 1931-1960

Lakes And Ponds

The study area has several small ponds, three major lakes and many streams. Lake W, located on the western end of the project, is a natural water body. The surface area is 248 hectares with an approximate maximum depth of 12 meters.

Lake S is also a natural water body. It is fed by waters of River B at the outlet of Lake N. Its depth ranges up to approximately 8 meters with a surface area of 72 hectares.

Lake N is by far the largest water body in the study area. It has two segments--an upper lake and a lower lake, connected by a channel. The upper lake has a depth of 52 meters and the lower lake of 18 meters. The upper and lower lakes have a combined surface area of 1,726 hectares.

Many smaller ponds are located throughout the study area.

For one year the various water bodies were sampled one day per month. The samples were analyzed within one day after retrieval to determine existing water quality. Table 2 lists 18 sample sites and respective drainage areas.

Table 2. Drainage area at sample sites

Site Number	Street Name	Drainage Area (Approximate hectares)
1	Pond i	4,940
2	River A	259,620
3	Tributary a	430
4	Tributary b	215
5	Brook a	310
6	Pond ii	35
7	Tributary c	50
8	Pond iii	400
9	Brook b	1,305
10	Tributary d	180
11	Tributary e	125
12	Brook c	615
13	Tributary f	410
14	Tributary g	215
15	Cove a	375
16	Brook d	910
17	Brook e	1,200
18	Lake n	116,610

Deicing Compounds

In New Hampshire, one of the major pollutants in highway runoff is deicing salt. The method used for this study in approximating salt impact involves estimating the total amount of additional salt to be applied for the proposed action within each of the small watersheds involved. This does not include any reduction of salt application to the existing system unless a section of the existing road is to be abandoned.

To approximate the "worst case" situation for environmental impact analyses the total amount of salt applied is assumed to reach the outflow of the watershed under study at the sample sites. Sample sites are located immediately downstream of the proposed location of the roadway. Two periods of the year are used to calculate the anticipated concentrations for the chloride (Cl^-) and sodium (Na^+) ions.

The first period is November through April. This is the assumed salting application season. Analysis for this six-month period assumes all applied salt (NaCl) is diluted by the total volume of runoff for these months and that no salt is held over throughout the summer season.

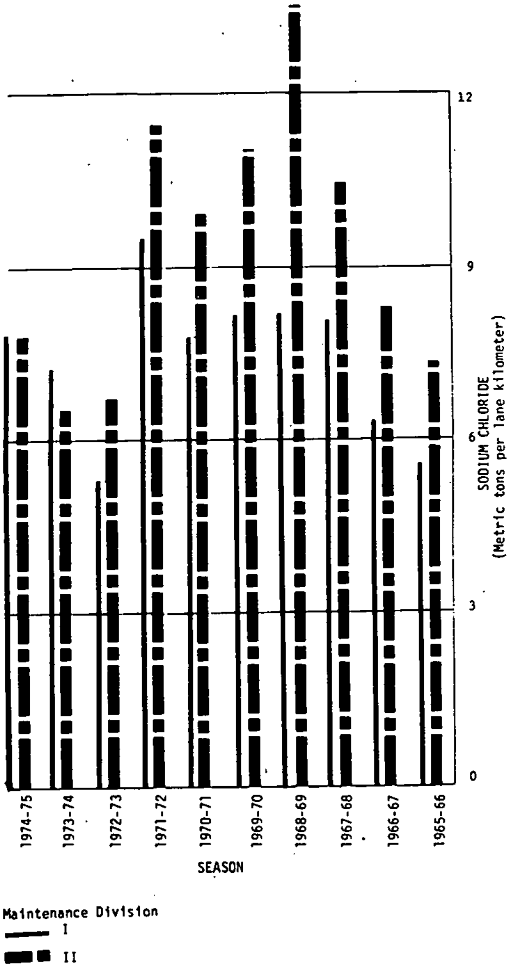
The second period assumes the total salt applied to new improvements is diluted by the total yearly runoff. This assumes that salt reaches surface water bodies throughout the year.

Depending on the assumptions and input data either method of calculating could yield higher ion concentrations. To determine the "worst case" situation, both methods are used. The higher value for a given month is then used as the worst output figure. The results in salt intrusion analysis indicate the former method may, as a rule of thumb, be considered a "worst average case."

Salt Application

The project overlaps two New Hampshire Department of Public Works and Highways maintenance divisions. Application rates for sodium chloride (NaCl) were obtained for these two divisions for the seasons of 1965-1966 through 1974-1975. The average application was found to be approximately 7.9 metric tons per kilometer per year. These are shown in Figure 2. The average application figure may now be considered high as the Department altered its policy on salt application just prior to the 1972-1973 season. Since then the amount of salt put on roadways has been reduced due to changes in the rate and method of application. These changes are reflected in Figure 2.

Figure 2. History of NaCl application in project area



The sodium chloride (NaCl) is further assessed (by atomic weight) to dilute into 60 percent chloride (Cl^-) ions and 40 percent sodium (Na^+) ions. All of the salt is assumed to be dissolved and carried in the runoff. This may be considered a worst case assumption as sodium ions often bond with soil particles for an indeterminate time, ions percolate into the groundwater system or are lost to aerosol formation.

Potential Loadings - Unknown Stream Discharge

The following is the method used in computing the potential loads for chloride (Cl^-) and sodium (Na^+) ions in the watersheds were average discharge is not known. In the study area, area average discharge is known only for Rivers A and B at sample sites 2 and 18, respectively. All original calculations were in English and only recently converted to Metric. Thus the units may be unfamiliar.

1. Conversion factors

454,000 mg = 1 pound (1)
28.32 liter = 1 cubic foot (2)

2. Average salting rate

7.9 metric tons NaCl per lane kilometer per year. (Note: Average application rate since 1972 is less than 6.8 metric tons per lane kilometer per year).

3. Salting season

November through April

4. Rainfall (See Table 1)

Yearly Average = 1,030mm (3)
Salting season = 505mm (4)

5. Restrict use of this procedure to areas where average discharge is not known. That is, it is not used on Rivers A and B.

6. Application of salt

Salt application: Assume 7.9×10^9mg/lane kilometer.

7. Salt dilution

NaCl will dilute to ± 60.7 percent into Cl^- and ± 39.3 percent into Na^+ by weight.

8. Salt application season concentrations

a. Runoff - Runoff (in liters) is computed in terms of Drainage Area (DA), (which is expressed in hectares). It is liberally assumed, for a worst case analysis, 80 percent of precipitation will result in surface runoff (5, 6). Groundwater recharge, evapotranspiration and sublimation are some sources of lost runoff.

$$\text{Seasonal runoff (liters)} = (\text{DA ha}) \times (10{,}000 \text{ square meter/ha}) \times (0.8) \times (505\text{mm}) \frac{1}{1000} \frac{\text{m}}{\text{mm}} \times (1000 \text{ liters/cubic meter}) = 4.04\text{DA}\times10^6 \quad (5)$$

b. Chloride concentration

Cl^- (mg/l/lane km)

$$= \frac{7.90\text{x}10^{9}\ (\text{NaCl mg/lane kilometer})}{4.04\ \text{DAx}10^{6}\ (\text{liter})}$$

$$\text{x } 0.607 = \frac{1187}{\text{DA}} \qquad (6)$$

c. Sodium concentration

Na^+ (mg/l/l/lane km)

$$= \frac{7.90\text{x}10^{9}\ (\text{NaCl mg/lane kilometer})}{4.04\ \text{DAx}10^{6}\ (\text{liter})}$$

$$\text{x } 0.393 = \frac{768}{\text{DA}} \qquad (7)$$

9. Average annual concentrations

a. Runoff - It is assumed 44 percent of precipitation will result in runoff due to surface cover a hydrologic characteristic of central New Hampshire (7).

Annual runoff (liters) = (Da ha)

x (10,000 square meter/ha)

x (0.44) x (1030mm/1,000mm/m)

x (1,000 liters/cubic meter)

$= 4.53\ \text{DAx}10^{6}.$ (8)

b. Chloride concentration

Cl^- (mg/l/lane km)

$$= \frac{7.90\text{x}10^{9}\ (\text{NaCl mg/lane kilometer})}{4.53\ \text{DAx}10^{6}\ (\text{liter})}$$

$$\text{x } 0.607 = \frac{1{,}059}{\text{DA}} \qquad (9)$$

c. Sodium concentration

Na^+ (mg/l/l/lane km)

$$= \frac{7.90\text{x}10^{9}\ (\text{NaCl mg/lane kilometer})}{4.53\ \text{DAx}10^{6}\ (\text{liter})}$$

$$\text{x } 0.393 = \frac{685}{\text{DA}} \qquad (10)$$

Potential Loadings - Known Stream Discharge

For large areas where Q stream discharge (liters per second) is known, an average annual daily dilution by discharge can be calculated. Though the value of Q varies widely over the season no other source of daily discharge information was available.

Runoff per year = (Q) x (24 hours/day)

x (60 minutes/hour)

x (60 seconds/minute) (11)

x (365 days/year) = 3.15 $\text{Qx}10^{7}$ liters

The computation of chloride and sodium concentrations adhere to the following:

1. Chloride concentration

Cl^- (mg/l/l/lane km)

$$= \frac{7.90\text{x}10^{9}\ (\text{NaCl mg/lane km}) \text{ x } 0.607}{3.15\ \text{Qx}10^{7}\ (\text{liters})}$$

$$= \frac{152}{\text{Q}} \qquad (12)$$

2. Sodium concentration

Na^+ (mg/l/lane km) = $7.90\text{x}10^{9}$ (NaCl

$$= \frac{7.90\text{x}10^{9}\ (\text{NaCl mg/lane km}) \text{ x } 0.393}{3.15\ \text{Qx}10^{7}\ (\text{liters})}$$

$$= \frac{98.6}{\text{Q}} \qquad (13)$$

At River A the salt is assumed to be diluted by the average annual daily discharge. This is approximately $5.89\text{x}10^{4}$ liters per second. In this case the formulae reduce to:

Chloride Cl^- concentration (mg/l/lane km)

$= 2.58\text{x}10^{-3}$ (14)

Sodium Na^+ concentration (mg/l/lane km)

$= 1.67\text{x}10^{-3}$ (15)

At Lake N the salt is assumed to be diluted by average annual daily discharge supplying Lake N, approximately $1.51\text{x}10^{4}$ liters per second. In this case the formulae reduce to:

Chloride Cl^- concentration (mg/l/lane km)

$= 1.01\text{x}10^{-2}$ (16)

Sodium Na^+ concentration (mg/l/lane km)

$= 6.53\text{x}10^{-3}$ (17)

The maximum loads of chloride (Cl^-) and sodium (Na^+) ions that may be expected over the average year of salting season are outlined below.

Impact Analysis

If one assumes the average annual concentration or average seasonal concentrations of salt (NaCl) could occur at any instantaneous moment when the diluted concentrations are highest, the maximum degree of impact may be observed. As higher concentrations of sodium ions are normally experienced in the summer months it could be concluded, however, this period of the year could become critical to stream biota.

Table 3 (8, 9) tabulates the amount of annual chloride and sodium concentrations that could be added to each watershed throughout the year. Also shown are seasonal computations if one assumes all roadway salt applied is removed by runoff by the end of April. If one assumes total thawing in a short duration then the salt would be further diluted and thereby reduce the amount of concentrations.

Table 3. Summary of salt (NaCl) concentrations.

Site No.	Maximum[a] Lane Distance	Drainage Area (hectares)	(mg/l)							
			Potential Increase				Existing Annual Means		Total Expected Annual[b]	
			Seasonal		Annual					
			Cl^-	Na^+	Cl^-	Na^+	Cl^-	Na^+	Cl^-	Na^+
1	3.2	4,940	0.8	0.5	0.7	0.4	5.7	3.9	6.4	4.3
2	25.8	259,620	T	T	0.1	T	6.4	5.0	6.5	5.0
3	8.4	430	22.9	14.8	20.4	13.2	4.9	4.0	25.3	17.2
4	4.5	215	24.4	15.8	21.7	14.0	9.1	6.0	30.8	29.8
5	3.2	310	12.2	7.9	10.8	7.0	14.2	8.1	25.0	16.1
6	3.2	35	109.7	71.0	97.4	63.1	11.9	7.7	109.3	70.8
7	3.2	50	74.6	48.3	66.3	42.9	18.8	11.9	85.1	54.8
8	24.5	400	71.6	46.3	63.6	41.2	11.7	7.7	75.3	48.9
9	7.7	1,305	6.9	4.5	6.2	4.0	32.3	17.5	38.5	21.5
10	6.5	180	41.4	26.8	36.8	23.8	7.7	5.9	44.5	29.7
11	5.2	125	48.1	31.2	42.7	27.7	6.9	3.2	49.6	30.9
12	6.5	615	12.3	8.0	10.9	7.1	13.7	8.4	24.6	15.5
13	8.4	410	24.0	15.5	21.3	13.8	4.6	3.0	25.9	16.8
14	6.5	215	35.2	22.8	31.3	20.2	11.8	6.1	43.1	26.3
15	9.7	375	30.2	19.6	26.9	17.4	8.3	4.9	35.2	22.3
16	3.2	910	4.2	2.7	3.7	2.4	12.2	8.3	15.9	10.7
17	3.2	1,200	3.1	2.0	2.8	1.8	7.7	5.7	10.5	7.5
18	19.4	116,610	0.2	0.1	0.2	0.1	12.4	7.4	12.6	7.5

T = Trace

[a] Includes Potential Interchange ramps and cross roads.

[b] Standards: Chloride not to exceed 250 mg/l in drinking water as per U.S. Public Health Service and a desirable level of 25 mg/l in water used for certain industrial purposes as per U.S. Department of the Interior. Sodium not to exceed 22 mg/l in drinking water for persons on low salt diets as per American Heart Association

To derive a relative degree of impact the annual mean concentration levels for chloride and sodium are added to the annual concentrations. The results of these comparisons are shown in Table 3.

Impact Evaluation

The U.S. Public Health Service (USPHS) recommends a maximum level of chloride in drinking water of 250 mg/l (10). The U.S. Department of the Interior lists 25 mg/l as a desirable level for certain industrial uses (8).

USPHS has not set standards for sodium content in water. However, the American Heart Association (AHA) recommends a level of 22 mg/l of sodium should not be exceeded for those persons on low salt diets.

No evidence exists that drinking water is taken directly from surface runoff at any location in the study area, including the sampled streams.

Further, it is recognized these are waters classified by New Hampshire as suitable for public water supply only after adequate treatment.

The impact classification adheres to the following:

Critical - Contamination of public supply of drinking water.

Great - Projected chloride levels exceed 250 mg/l limit in drinking water.

Moderate - Projected chloride levels equal or exceed desirable concentrations of 25 mg/l or projected sodium levels exceed desirable 22 mg/l levels.

Based upon this analysis it is anticipated eight samples will exceed the AHA recommended limit for sodium. No sample sites will exceed the USPHS's level for chloride, however. The long term cumulative effects of this added salt is unknown.

Conclusion

Pursuant to requirements to identify and evaluate potential impacts associated with planned public works projects, a method to analyze road clearing operations was developed by the New Hampshire Department of Public Works and Highways. This was particularly important in view of the many water bodies which could be detrimentally affected.

The salt intrusion relationships of deicing compounds, runoff and soil conditions are complex. They do not readily lend themselves to simple analysis for environmental impact purposes. Therefore, during the preparation of a recent environmental impact statement, a simplified seasonal procedure to predict road salt runoff to determine probably "worst average case" effects was used. With appropriate modifications to reflect local climate, topographic and hydrologic conditions the method may be applied elsewhere for impact analyses.

References

1. Fish, Charles D. and Robert E. Christensen, 1973, Cadmium, Nickel and Zinc in Earthworms from Roadside Soil, Environmental Science and Technology, Vol. 7.
2. Terry, Robert C. 1974, Road Salt Drinking Water and Safety. Bullinger Publ. Co. Cambridge, Massachusetts. 161 p.
3. Hall, Francis, R. 1975, Chlorine in Natural Waters of New Hampshire, NH. Agri. Exper. Sta., Univ. of NH. 25 p.
4. United States Weather Bureau, 1961, 1931-1960 Climate Survey for New Hampshire, Washington D.C.
5. American Society of Agricultural Engineers, 1972, Erosion and Sediment Control on Urban and Construction Sites - An Annotated Bibliography, Am. Soc. Agri. Eng., St. Joseph, Michigan, 13 p.
6. Wischmeier, W. H., and J. V. Mannering, "Relation of Soil Properties to Its Erodibility," Soil Sci. Soc. Am., 33(1), 131-137 (1969).
7. United States Geodetic Survey, 1970, Survey Atlas HA7.
8. Highway Research Board, 1970 Effects of Deicing Salts on Water Quality and Biota, Report 91, National Cooperative Highway Research Program, Washington, D.C.
9. Federal Water Pollution Control Administration, 1968, Water Quality Criteria: Technical Report of the National Technical Advisory Committee to the Secretary of the Interior, U.S. Department of the Interior, Washington, D.C. April.