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Foreword

Today, our society and economy depend upon all-weather use of our streets and highways. The already alarming record of accidents is sensitive to inadequacies in snow and ice control programs. Sodium chloride and/or calcium chloride have yielded generally excellent results in clearing snow-covered or icy pavements at minimum costs. The savings in accident damages, personal injuries and human lives dwarf any real or suspected brine damage to vegetation, water supplies or wildlife, no matter by what standards they are measured.

Nonetheless, with the growing concentrations of population and the increasing concern for land use throughout the United States, highway agencies, as others, must be increasingly responsive to the needs for pollution prevention in all of their activities. The information developed by the five research reports in this RECORD indicates that in the future pollution control will be an item of increasing concern in highway snow and ice control activities as it is in most other industries today. The reports also indicate, however, that the cries of the alarmist—promising immediate disaster to vegetation, wildlife and water supplies—are not based on facts.

There are several challenges presented by the information developed in these research reports. One lies in improved maintenance practices. The over-application of chlorides where conditions do not warrant, poorly regulated spreading equipment which scatters material beyond the pavement edges, improperly located and improperly protected stockpiles of sodium chloride and/or calcium chloride which leech away during periods of precipitation, all of these wasteful practices must be measured against the need for pollution prevention, as well as operating economy.

Another challenge lies in the area of additional study and research. Present knowledge shows some potentially useful correlations but many gaps exist. The interrelationships between quantities of chloride applied to the highway, the annual inches of precipitation, the chloride ion concentrations in the soils adjacent to the highway, the types of vegetation along the highway, and other applicable variables must be established. Reliable information is needed on recovery rates or rates at which chloride concentrations are reduced by natural processes acting on soils and water supplies. Conversely, tolerance levels or rates at which sodium chloride or calcium chloride could be introduced to the soil or water supply without building up an increased concentration would be valuable guides in planning winter maintenance operations on our highway systems.

Hutchinson and Olson report on the sodium and chloride ion levels in soils adjacent to highways in Maine. Relationships were established between the levels of both ions and the proximity to the road edge of the soil sample and the number of years that salt had been used on the highway for snow and ice control.

The presence of sodium chloride ions in the soil at one highway sampling location in Connecticut is discussed by Prior and

Berthouex. Significant seasonal variations in salt concentrations were reported but the seriousness of the concentrations was minimal.

Schraufnagel offers a comprehensive review of the properties of chlorides and their presence in various effluents and soils in Wisconsin, particularly as related to the use of rock salt and calcium chloride in snow and ice control on highways. Although the concentrations found were below the harmful level, chlorides have been increasing in receding waters in Wisconsin, particularly in the southeastern part of the state.

Weigle's abridgment offers a brief discussion of the phenomena involved in groundwater contamination by highway salting. His studies indicate that chloride concentrations in groundwater near a salted highway fluctuate strongly and the fluctuations are in annual cycles. He found that generally the chloride concentration in the groundwater is much less than the 250 ppm detectable by taste.

In the final report, Roberts and Zybura note that soluble salt determinations made on soils samples taken along Interstate 80 in Iowa indicate concentrations of sodium chlorides sufficiently high to affect grass growth up to ten feet from the pavement. Of ten grasses studied, Kentucky 31 fescue was best suited for use where roadside soils were contaminated by salt.

—L. Gary Byrd

Contents

The Relationship of Road Salt Applications to Sodium and Chloride Ion Levels in the Soil Bordering Major Highways

F. E. HUTCHINSON and B. E. OLSON
    Respectively, Associate Professor of Soil Science, and Technical Assistant,
    Department of Plant and Soil Sciences, University of Maine, Orono

Sodium and chloride levels in soils adjacent to salted highways were measured during July and October 1965, and April 1966, at 27 sites to determine the effect of salting for periods ranging from zero to 18 years. Levels of both ions were raised as a result of this practice, with the effect greatest at the edge of the road embankment and also where salting had been practiced for the longest period of time. Salting increased sodium and chloride levels more at the 6-in. than at the 18-in. depth, and sodium levels were raised to a higher value than were the chloride levels. Although levels of these ions were highest at the edge of the highway, the levels were raised at a distance of 60 ft from the highway in some instances. Wells near some of the highways contained chloride levels in excess of the recommended maximum.

•THE application of chloride salts to highways for ice removal during winter months has become a common practice throughout the northeastern section of the United States. Although some experimental uses were attempted earlier, the practice has become a general one during the past 20-yr period.

During the fiscal year 1964-65, the State of Maine purchased 87,000 tons of chloride salts for application to its highways. Additional purchases by individual cities and towns brought the total up to at least 100,000 tons.

The fate of these chloride salts after they are applied to highways is of considerable importance since they are considered to be pollutants in soil and water supplies. Their continued use may result in a serious loss of potable water supplies and of soils suitable to support growth of desirable vegetation along our major highways.

Groundwater samples taken from populous areas of eastern Massachusetts have shown an increase in salt content (6). In New Hampshire, a recent study (5) has indicated that the decline of roadside maple is correlated with a high salt concentration in the soil. The toxicity of chlorides to plants has been thoroughly demonstrated by several investigators (1, 2, 3). Although the tolerance varies from species to species, all plants are susceptible to this ion when it is present in relatively large concentrations.

OBJECTIVES

This study was initiated with the following objectives:

1. To determine the levels of sodium and chloride ions present in soils adjacent to salted highways at random points.

2. To determine the distance from the edge of a highway over which salt applications affect levels of sodium and chloride ions present in the soil.

3. To determine the relationship of sodium and chloride levels in the soil to the number of years that road salt has been applied.

4. To determine the extent to which road salt applications have affected well water purity.

PROCEDURE

To determine the relationship of road salt applied to highways for varying periods of time to the sodium and chloride levels in the soil along the road, intensive sampling sites were established in five sections of the Maine Turnpike and Interstate 95 which exhibited a range from 0-18 years. These sites were chosen at random within each section with the exception that each one had to meet the criterion of sloping away from the highway with less than a 10 percent slope. At each intensive site, soil samples were collected at 6 and 18-in. depths in 5-ft increments from the edge of the road embankment out to a distance of 45 feet by use of a Nasco soil sampling tube with 1-in. diameter. A minimum of 12 borings were composited for each sample to avoid error.

Twenty-two extensive sites were established along the major highways of the state by the criterion described. At these sites, soil samples were collected at 6 and 18-in. depths at distances of 0, 30 and 60 feet from the road embankment.

Soil samples were collected at all sites during July and October of 1965 and again in April 1966. Samples were air dried and sieved through a 2-mm screen to remove the coarse materials. Sodium and chloride ions were extracted from the soil by leaching with 1 N NH_4OAc solution, as described by Jackson (4).

Well water samples were collected at random along highways wherever they were found in close proximity to the road. At each site, a one-pint sample was dipped out and placed in a plastic bottle.

Sodium was measured with a Coleman flame photometer, Model 21, and chloride by a Dohrmann halide analyzer equipped with automatic integration.

RESULTS

The soil samples collected at the intensive site along Interstate 95 in Stillwater provide an excellent comparison of the sodium and chloride levels in the soil after one winter
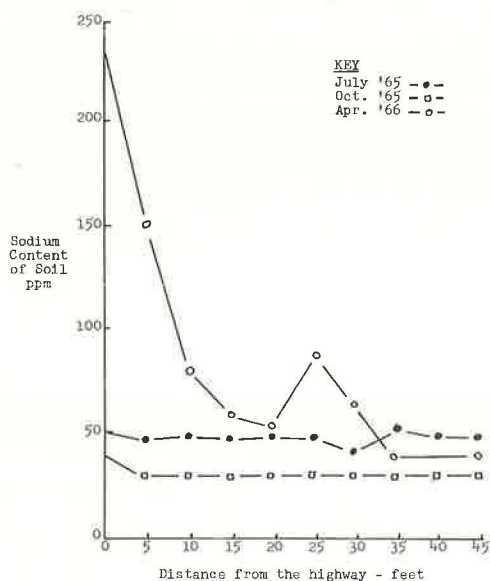

Figure 1. Sodium content of soil along Interstate 95 at Stillwater, Maine, before and after one winter of road salt applications.
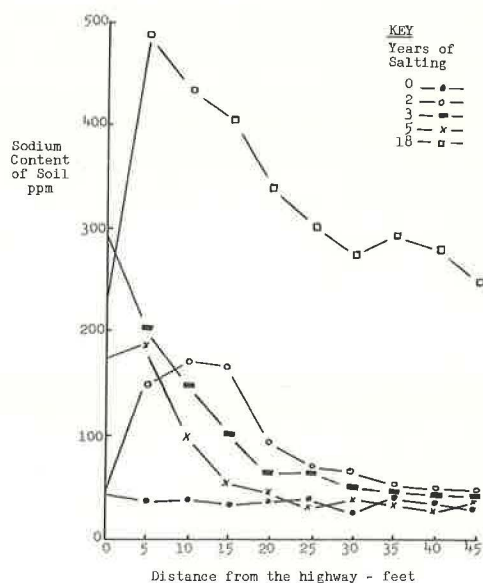

Figure 2. Sodium content of soil at five sites along the Maine Turnpike and Interstate 95.

TABLE 1

SODIUM LEVELS IN SOIL SAMPLES COLLECTED ALONG A SECTION OF
INTERSTATE 95 IN STILLWATER, MAINE, BEFORE AND AFTER
ONE WINTER OF ROAD SALT APPLICATION[a]

Date	Depth (in.)	Distance From Highway (ft)										Avg.
		0	5	10	15	20	25	30	35	40	45	
July '65	6	50	48	50	49	50	49	41	52	49	49	48.7
	18	39	43	43	43	48	36	41	43	46	41	42.3
Oct. '65	6	39	30	30	30	30	30	30	30	30	30	30.9
	18	23	25	36	27	23	25	25	23	30	18	25.5
April '66	6	235	150	81	58	53	87	64	39	—	39	87.3
	18	133	97	58	39	37	37	35	32	35	30	53.3

[a]Sodium values reported as parts per million (ppm).

of road salt applications with the levels present in the soil before any salt was applied. This comparison is possible because this section of highway was not opened for use until October 1965.

Sodium and chloride data shown in Figure 1 and Tables 1 and 2 indicate that following one year of salting, the levels of both ions were raised appreciably in the soil. Sodium values at the 6-in. depth exhibit an increase up to a distance of 30 feet from the edge of the road embankment, with the increase being nearly fivefold at the zero distance and decreasing with distance. Sodium content of the soil was also influenced at the 18-in. depth by salting for one winter, but the effect is evident over a smaller distance of approximately 10 feet.

Chloride values at the Stillwater site were increased markedly over the entire distance of sampling, although the levels accumulated near the roadside were less than for sodium. This is explainable on the basis that the sodium cation is attracted to the negatively charged soil colloids where it is held from leaching to a considerable extent, whereas the chloride anion is repelled by the colloids and leaches readily if the soil material is such that percolation occurs.

The sodium and chloride values for the soils sampled at five intensive sites along the Maine Turnpike and Interstate 95 are shown in Figure 2 and Tables 3 and 4. These samples afford the opportunity for comparisons between sites which have been salted annually for 0, 2, 3, 5, and 18 years since this highway was constructed and opened for use by sections. The soil series were identified at each site and all were found to be originated from marine sediments which adds uniformity to the results obtained in this study.

TABLE 2

CHLORIDE LEVELS IN SOIL SAMPLES COLLECTED ALONG A SECTION OF
INTERSTATE 95 IN STILLWATER, MAINE, BEFORE AND AFTER
ONE WINTER OF ROAD SALT APPLICATION[a]

Date	Depth (in.)	Distance From Highway (ft)										Avg.
		0	5	10	15	20	25	30	35	40	45	
July '65	6	T	T	T	T	T	T	T	T	T	T	T
	18	T	T	T	T	T	T	T	T	T	T	T
Oct. '65	6	T	T	T	T	T	T	T	T	T	T	T
	18	T	T	T	T	T	T	T	T	T	T	T
April '66	6	97	150	174	112	102	30	58	50	—	41	90.4
	18	100	81	107	54	65	45	49	45	46	38	63.0

[a]Chloride values reported as parts per million (ppm).
T = Trace (less than 1 ppm).

TABLE 3

SODIUM LEVELS IN SOIL SAMPLES COLLECTED AT FIVE SITES ALONG THE
MAINE TURNPIKE AND INTERSTATE 95 CHOSEN TO EXHIBIT A RANGE IN
TIME FOR WHICH ROAD SALT HAS BEEN APPLIED[a]

Site No.	Years of Salting	Distance From Highway (ft)										Avg.
		0	5	10	15	20	25	30	35	40	45	
10[b]	0	40	39	40	39	40	40	36	41	39	39	39.3
10[c]	0	31	34	40	35	36	30	33	33	38	30	34.0
5	2	61	148	177	169	96	73	70	55	51	49	94.9
5	2	51	96	123	103	66	66	54	49	52	44	70.4
1	3	293	205	149	102	64	67	54	47	47	46	107.4
1	3	128	72	70	47	41	50	47	33	41	36	56.5
7	5	176	187	101	57	47	39	41	40	31	41	76.0
7	5	77	89	70	54	51	48	51	47	47	44	57.8
13	18	247	488	434	408	341	302	275	297	282	252	332.6
13	18	272	307	276	192	229	207	181	186	149	178	217.7

[a] Sodium values reported as parts per million (ppm) for the average of April, July and October samplings.
[b] Data for 6-in. sampling depth.
[c] Data for 18-in. sampling depth.

Using the range of 30 to 40 ppm of sodium found at site 10 as a base level where no salt has been applied, it is obvious that salting has increased soil sodium levels at the remaining 4 sites. This influence appears to be directly related to the number of years of salting, with the exception of site 7. Subsequent on-site inspection has shown a slight variation in the microrelief at this sight which tends to prevent surface flow of water across the plot at a right angle to the highway and consequently, less salt is moved into the soil at this site than would be expected.

At sites 5 and 13, the sodium levels are much less at the point where the first sample was collected than they are at the 5-ft distance because the first sample was collected in material which was part of the "fill" used as a base for the highway. This material was much coarser than the adjacent soil and it did not contain as many colloidal particles to prevent leaching of the sodium ions.

TABLE 4

CHLORIDE LEVELS IN SOIL SAMPLES COLLECTED AT FIVE SITES ALONG
THE MAINE TURNPIKE AND INTERSTATE 95 CHOSEN TO EXHIBIT A RANGE
IN TIME FOR WHICH ROAD SALT HAD BEEN APPLIED[a]

Site No.	Years of Salting	Distance From Highway (ft)										Avg.
		0	5	10	15	20	25	30	35	40	45	
10[b]	0	T	T	T	T	T	T	T	T	T	T	T
10[c]	0	T	T	T	T	T	T	T	T	T	T	T
5	2	46	42	54	67	63	26	18	24	20	23	38.3
5	2	29	32	37	31	32	22	19	16	13	11	24.2
1	3	100	67	59	73	37	21	21	14	12	15	41.9
1	3	97	80	48	31	16	12	19	13	12	11	33.9
7	5	74	89	36	16	15	12	17	14	11	11	29.5
7	5	29	46	31	22	T	11	10	9	10	6	17.4
13	18	113	204	217	183	154	128	116	154	117	115	150.1
13	18	75	139	122	120	105	84	66	54	71	45	88.1

[a] Chloride values reported as parts per million (ppm) for the average of April, July, and October samplings.
[b] Data for 6-in. sampling depth.
[c] Data for 18-in. sampling depth.

Levels of the sodium at the sites which had been salted for 2 and 3 years indicate an increase ranging from four to eightfold at the 6-in. depth near the edge of the highway. This increase drops steadily with distance from the highway until it is insignificant at 35 feet. The sodium levels in the soil at these sites at a depth of 18 inches is considerably less than at the 6-in. depth but there is a consistent increase which is three or fourfold at the edge of the highway in comparison to those for the untreated site. The levels at the lower depth are also higher to a distance of approximately 30 feet.

The sodium levels at site 13, where salting has been practiced for 18 years, are extremely high at the edge of the highway and they continue at a high level across the total distance sampled, although the levels decrease with distance similar to the other sites. At this site, sodium levels are fifteen times higher at the 6-in. depth near the edge of the roadbed than they are in surrounding fields of the same soil. Even at a distance of 45 feet, these values are eight times greater than normal. Values for the 18-in. depth follow a pattern identical to the 6-in. samples with the exception that they are approximately one-third smaller at this lower depth.

Chloride levels for the five intensive sites shown in Table 4 exhibit the same relationships as are evident for sodium, but the levels are considerably lower because of the nature of the ions. Following 2 and 3 years of salting, the chloride levels at the 6-in. depth were raised to 46 and 100 ppm, respectively, at the edge of the highway. These levels decreased steadily with distance to 25 feet and then stabilized at approximately 12-24 ppm. The levels at site 7 were raised by salting, but the results are confounded because of the microrelief at the site.

The soil content of chloride ions following 18 years of salting was far less than the sodium content, with the values for the 6-in. depth being only about one-half as large

TABLE 5

SODIUM AND CHLORIDE LEVELS FOR SOIL SAMPLES
COLLECTED AT TWENTY-TWO RANDOMLY SELECTED
SITES ALONG MAJOR HIGHWAYS IN MAINE

Site No.	Sodium[a] (dist. from highway)			Chloride[a] (dist. from highway)		
	0 Ft	30 Ft	60 Ft	0 Ft	30 Ft	60 Ft
2	144	66	73	95	45	32
3	785	701	384	715	449	263
4	274	104	47	247	36	T
6	43	29	46	65	T	T
8	314	144	44	118	30	T
9	11	20	20	T	T	T
11	563	134	71	118	33	T
12	106	166	37	8	6	T
14	404	171	160	114	63	15
15	110	39	32	T	T	T
16	300	181	22	9	T	T
17	293	77	34	35	T	T
18	259	68	42	51	T	T
19	270	181	182	82	53	33
20	310	95	74	84	34	T
21	18	96	34	22	35	T
22	185	129	49	57	70	26
23	535	152	60	70	T	T
24	37	43	37	21	9	T
25	321	24	11	101	T	T
26	395	364	266	97	114	67
27	371	174	95	94	24	T
Avg.	275.3	143.5	82.7	100.1	45.5	19.8

[a]Reported as parts per million to 6-in. depth.

as they were for sodium at all distances. At the 18-in. depth, this difference was even larger.

Data are presented in Table 5 for the sodium and chloride levels in the soil at 22 extensive sites randomly selected along various major highways in Maine. The number of years of salting is not known specifically for these sites along secondary roads, but salting of highways in this state for ice removal was initiated shortly after World War II and has been continued at an increasing intensity ever since.

It is apparent that the levels of both ions exhibit a wide variation, with sodium ranging from 11 to 785 ppm and chloride from a trace (less than 1 ppm) to 715 ppm. The levels of the two ions are consistently related because each site with a low level of sodium also contains a low level of chloride ions. Sites 9 and 21 are examples of this consistent relationship.

The average levels of the ions for all sites are of particular interest because they indicate that the soil content of each has been markedly influenced by salting. The average values of 275 ppm of sodium and 100 ppm chloride found at the edge of the highways are six and one hundred times greater than are normal for the soils in the state. Furthermore, this effect is appreciable at a distance of 60 feet from the highway on the average. Considering the width of a highway right-of-way, these figures indicate that private properties are undoubtedly being affected.

The sodium level of the soil at site 3 is an example which should be considered in detail. Assuming a cation exchange capacity of 20 meq/100 grams for the Buxton soil series at this site, and employing the equivalent weight of sodium as 23, it can be seen that the cation exchange capacity of the soil is 17 percent saturated with sodium cations. The importance of this value can easily be related to the conditions in the arid portions of the United States where a soil with a sodium saturation greater than 15 percent is designated as an alkali soil.

Sodium and chloride levels in well water samples collected at various points over the area of the state are listed in Table 6. The levels of these ions in samples collected from within 15 feet of the highway exhibit a consistent influence of salting, with the levels of chloride ions higher than those for sodium. This difference would be expected for the same reason that has been previously explained for the higher levels of sodium ions in the soil samples.

The average values for the wells close to highways are far above those for the wells that were more than 50 feet from the highway with sodium averaging 72 ppm and chloride, 174 ppm in the salt-affected wells. It appears that normal well water samples contain 1-3 ppm and a trace, respectively, of these ions.

The highest level of 461 ppm of chloride was found in a well in Madison. This value is considerably above the 250-ppm maximum suggested for potable water supplies by the U. S. Public Health Service.

CONCLUSIONS

Levels of sodium and chloride ions in soils along highways in Maine where road salt has been applied have been increased considerably over the levels found in unaffected soils. These levels tend to be influenced most near the edge of the road embankment and the effect decreases with distance from the highway. Levels of both ions increase with the length of time for

TABLE 6

CONCENTRATION OF SODIUM AND CHLORIDE IONS IN WATER SAMPLES COLLECTED FROM WELL LOCATED WITHIN FIFTEEN FEET FROM THE EDGE OF MAJOR HIGHWAYS[a]

Location	Sodium (ppm)	Chloride (ppm)
Lisbon	78	144
Gorham	33	67
Gardiner	55	96
Whiting	180	310
Madison	102	461
Lewiston	105	156
Milford	65	231
Gardiner	22	87
Forks	11	14
Avg.	72.3	174.0
Hanover[b]	2	T
Richmond[b]	3	T
Ripogenus[b]	1	T

[a]All wells were sampled during April 1966.
[b]These wells were selected for comparison because they were more than 50 feet from a highway.

which salting has been practiced, and this increase occurs over a greater distance with time.

Since high concentrations of sodium ions have an adverse effect on soil physical properties by causing dispersion of colloidal particles, alkali soils lack aggregation and are poorly drained, structureless soils. It appears the sodium levels found at some sites in this study would suggest that road salt applications may be resulting in poorer drainage of the soils along the highways. Furthermore, the sodium and chloride levels present in these soils are rapidly approaching a point where they may be toxic to some of the desirable vegetative species growing in the area.

ACKNOWLEDGMENT

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A Study of Salt Pollution of Soil by Highway Salting

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•HEAVY applications of sand-salt mixtures to highways for snow and ice removal are common in New England, where several tons of salt per mile may be applied during a winter. The fate of these quantities of salt after being plowed or splashed from the highway is important. How does this salt affect the environment near the highway? This report provides general answers regarding changes in soil salinity during the course of a year.

The salt applied to a highway must either be carried by surface runoff into streams or by infiltration into the ground. Once salt-bearing water has infiltrated, the salt may become associated with the soil grains by adsorption or ion exchange, or it may remain in solution. Excessive salt infiltration might cause a reduction in soil fertility with resulting damage to plants, and an increase of salts in the groundwater to a level where shallow wells produce unpalatable water.

The fact that plants are unable to thrive in highly saline soils is well established and information for many species of plants and different soil conditions is recorded in agricultural literature. This information is of great value to engineers dealing with problems related to salts. Although some results from this study were referred to existing data on plant tolerance to salts, no attempt was made to supplement this type of information.

The main problem in highway deicing is, "How much salt may be applied without interfering with the environment?" Many related questions must also be answered: What concentrations of salt occur in soils near highways? How does the salt concentration fluctuate during the year? What is the capacity of different types of soil to retain salt as it is applied and to release it during spring and fall rains? How does the salt concentration vary with depth and distance from the highway? This study provides some answers to these related questions based on a 1-yr field study.

The ultimate question remains unanswered, however. Is there some amount of salt that may be applied to a highway during a winter without spoiling the environment near the highway? Considerably more work is required to answer this question.

LITERATURE REVIEW

Introduction

Many researchers have investigated salt with respect to its effect on plants and its occurrence and movement in soil. In considering the effects on plants, the total soluble salt content or salinity is of importance as well as the quantity of the various ionic species. Symptoms of injury would include foliar coloration, marginal leaf scorch and defoliation and death of the tree. These symptoms are similar regardless of whether injury is due to drought, salinity, sodium or chloride (1, 2). This, along with the fact that salt gives rise to salinity, sodium and chloride, makes it difficult to determine the extent of damage caused by each factor.

Salinity

Salinity interferes with the mechanism by which a plant absorbs moisture from the soil (2, 3, 4). Since water enters the root through a membrane, an osmotic pressure gradient is established across the membrane, the magnitude of which depends on the difference in salt concentration on either side of the membrane. The direction of the gradient is such as to cause water to flow naturally across the membrane toward the higher salt concentration. Increasing salinity in the soil, therefore, makes it increasingly more difficult for water to be taken in by the plant. Osmotic pressures up to 17 atmospheres have been reported (3).

Since osmotic pressure is a concentration phenomena, the effect of a given quantity of salt per unit weight of soil depends on the moisture content of the soil. The salts become more concentrated, and therefore more detrimental, as the wilting percent moisture is approached. The wilting percentage of a sandy soil is lower than that of a finer textured soil. At the wilting percentage, a given quantity of salt is more harmful in a coarse textured soil (2, 4, 5).

Jackson (4) has presented a salinity scale (Fig. 1) which classifies the salinity of a soil according to the specific conductance and percentage of salts in the saturation extract of the soil. The percent moisture at saturation is four times the wilting percent moisture, so the salinity scale makes salinity comparisons in different textured soils more meaningful. Figure 1 also gives the crops suited to various salinity ranges and some of the effects on crops sensitive to salinity. Button (2) has indicated salt tolerances which are similar to those given in Figure 1. Others have also indicated the relative tolerance of various tree species (1, 2, 3, 6). In addition to the immediate damage of saline soils, there is evidence that low salinity may cause small but cumulative damage to trees over a period of years (2). In general, other factors being equal, growth is retarded by increasing salinity due to lack of water or, conversely, more water is required to obtain similar growth characteristics (3, 7).

Sodium

The sodium ion has two characteristics of importance. It changes the character of the soil and has a toxic effect on plants.

Soil has the ability to adsorb cations from solution, with the clay particles having the greatest capacity to do so. The adsorbed ions are in equilibrium with those in the surrounding water. If a sodium salt is applied to the soil, an ion exchange results with

SPECIFIC CONDUCTANCE OF THE SATURATED EXTRACT OF SOIL, MICROMHOS/CM

0	2000	4000	8000	16000
Nonsaline	Very slightly saline	Moderately saline	Strongly saline	Very strongly saline
Salinity effects mostly negligible	Yields of very sensitive crops may be restricted	Yield of many crops restricted. Alfafa, cotton sugar beets, cereals, and grain sorghums adapted.	Only tolerant crops yield satisfactory. Bare spots because of injury to germination.	Only a few very tolerant crops yield satisfactory. Only salt tolerant grasses, herbaceous plants, shrubs, and trees grow.
0	0.1	0.3	0.5	1.0

PERCENTAGE OF SALTS IN MOISTURE SATURATION EXTRACT

Figure 1. Salinity scale [reproduced from (4) by permission of publisher].

sodium replacing calcium on the soil grains. After this exchange of ions, the soil frequently becomes less permeable (2, 4, 6, 7, 8). The loss of calcium from the soil may also be injurious to plants since it is an essential nutrient (2).

There has been some indication of the sodium ion being toxic to trees. It has been shown to cause leaf tip burn in almond trees. In a comparison with calcium chloride, sodium chloride was shown to be the more toxic to elm and white pine (2).

Trees receiving drainage from a highway showed higher levels of sodium in their leaves and twigs than those not receiving the drainage (1). Maples appeared to be particularly sensitive to sodium in this case.

Sodium is generally considered nonessential to plant growth. There are indications, though, that it may interfere with potassium, an essential element, while in other cases it may function in the place of potassium (1, 2, 6).

Chloride

The effect of the chloride ion is especially important in relation to highway salting because it is present in both the salts used, i. e., sodium chloride and calcium chloride. Chloride is not reported to have any deleterious effects on soil characteristics, except as an anion contributing to the salinity, but it is important in relation to groundwater. The U. S. Public Health Service Drinking Water Standards (9) recommend a maximum of 250 mg/l as chloride for drinking water. These standards do not set any particular limits for sodium or calcium except that the total dissolved solids should not exceed 500 mg/l.

Chloride has been found to exert a toxic effect on plants. Excessive chloride is evidenced by its accumulation in the leaves and causing leaf burn (1, 2, 6, 10). Studies in New Hampshire (1) indicate chloride may not be as damaging as sodium since it tends to accumulate only in the leaves which fall off each year, while sodium is also found in the twigs which are a permanent part of the tree. However, in a limited study, Button (10) found that chloride accumulates in twigs as well as in leaves.

Calcium

Calcium is an element commonly found in soils and is essential for plant growth (2, 4). It is added to soil when lime is applied for pH control and also as gypsum to replace excessive quantities of sodium. High concentrations of calcium, however, will cause excessive salinity and may be specifically toxic (2).

Temperature

Temperature can have an effect on the extent of salt injury to plants (6). At lower temperatures plants consume less water through transpiration, and therefore lesser quantities of salts are brought into the plant. Higher temperatures also decrease the moisture content of the soil, which in turn intensifies the salinity problem (4).

Freezing temperatures may markedly affect the infiltration characteristics of soil and, consequently, the extent to which salt intrudes or is excluded, depending on the type of cover, type of soil, and rate of freezing (11). Almost normal infiltration was found in forest soil frozen to a depth of four inches, while corn and pasture areas showed almost no infiltration when frozen to a similar depth. Heavy-textured soil gave less infiltration when frozen than light-textured soil. Slow freezing is conducive to the formation of an ice with low permeability.

After a 7-yr study, Holmes (6) observed no injury to trees where salt was applied only during the winter, concluding that most of the salt was removed with surface run-off and did not penetrate the frozen soil. Grass died in some areas, however, apparently as a result of the salting.

Salt Movement in Soil

Salts are carried from one point to another by the movement of soil moisture (12). As previously indicated, frost formation may, to various degrees, impede the movement of water through the frozen layer. The frozen surface has been found to have a
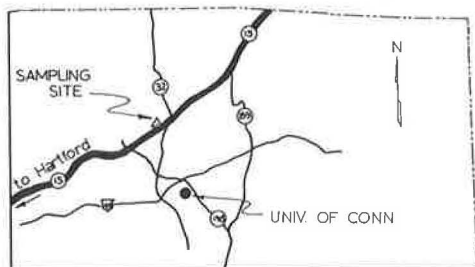
Figure 2. Sampling location on Route 15 in northeastern Connecticut.

higher moisture content than unfrozen soil beneath (11). This is the result of moisture moving up to the frozen area from the lower layers.

In nonfrozen soil the direction of moisture and salt movements depends on the moisture content of the soil (12). With moisture at or near field capacity, movement is toward the groundwater. With low moisture conditions, moisture moves to the surface and evaporates. When the water table is near the surface, large quantities of water evaporate from the soil surface. When water moves to the surface to evaporate or is transpired, salt moves upward also and accumulates near the surface (3, 5, 12). The rate of upward movement depends on the soil permeability. Dissolved salts in low permeability soils did not readily move to the surface, while with higher permeability, higher salt concentrations were found at the surface (5).

Controlled field experiments, in which KCl was applied once to Panoche clay loam and displaced with applications of water, have revealed that chlorides are effectively displaced by intermittent applications of water (18). Relatively small quantities of water displaced chlorides from the top 2 feet to a depth of about 3 feet; however, greater quantities were required to displace the chloride through the lower depths. As the chlorides were displaced from the top 2 feet a bell-shaped chloride-depth profile was produced. The maximum chloride concentration decreased as it moved downward. At a depth of 5 feet only a small increase in chloride concentration was observed as the salt was leached from the soil. For a given total water application, the frequent application of small quantities most efficiently displaced chlorides from the top 2 feet of soil.

More limited information is available on horizontal movement of salts. This factor will depend primarily on local runoff conditions. Studies in New Hampshire (1) showed above-normal concentrations of sodium in the soil only within 30 feet of the highway. Observations at one location in Connecticut (Fig. 2) showed trees above the pavement on the slope of a cut, but within 10 feet laterally, received chloride from the splashing of vehicles and wind-blown mist (10). The level of accumulation, however, was insufficient to cause apparent damage. Only those trees which received brine drainage from the pavement showed injury.

Fifteen sets of samples were collected between January 4 and April 27, 1966, and three additional sets of samples were collected in October 1966. Three snowfalls and salt applications had occurred before the first samples were obtained in January. The samples collected in October 1966, are useful as a base of comparison. It is expected that conditions during the fall of 1965 were quite similar to those during the fall of 1966. Of course, long-term field observations would be required to determine whether or not the salts decrease during the spring and summer to the same level each year.

Samples were excavated in two ways. At first a split spoon sampler was used, but this was difficult to handle and extremely time consuming. Also, in order to obtain a sufficiently large sample for the chemical analyses, it was necessary to use soil from several inches above and below the desired depth. A 6-in. power auger was later used to dig a 3-ft deep hole. The sides of the hole were brushed to remove disturbed soil and the samples were then taken from the sidewall. This method was faster and easier, and samples of any desired size could be collected. Samples were transported and stored in covered, unwaxed paper cups.

All holes were refilled after the samples had been collected in order to preserve the original drainage pattern in the area. Sampling on subsequent days required moving parallel to the highway to a location several feet from any refilled holes. Visual examination of the samples indicated that the same type soil was always obtained.

Collecting a set of 20 samples consumed about 8 man-hours when the power auger was used.

SOIL CHEMICAL ANALYSES

All soil samples were analyzed for total soluble salt, chloride, and sodium. The techniques used resulted in measurement of the salt present in both the soil and the soil water when the samples were collected.

Soil salinity is commonly used by agriculturalists to indicate the total soluble salt level, and the salt tolerance of plants is specified in terms of salinity. Since the salts applied to highways are sodium chloride and calcium chloride, the chloride ion serves as a convenient tracer and is used here as a measure of the salt originating from the highway. There is evidence that both cation concentration and cation type in soil are critical. Specifically, the sodium ion has been shown harmful to plants. Most soils show a tendency to exchange normal cations such as calcium for sodium. Therefore, sodium ion concentration was also measured.

Total Soluble Salt

Total soluble salt was measured using a Betz Conducto-Bridge, Model X 50. This instrument measures the ability of a solution to conduct a current. As the soluble salt concentration is increased, the solution becomes a more effective conductor. The specific conductance of a solution is the conductance that would be measured at 25 C between electrodes 1 sq cm in cross section and placed 1 cm apart. The units associated with this measurement, as indicated by the instrument, are micromhos per centimeter. A temperature adjusting circuit is part of the meter so all results are in terms of 25 C.

The Conducto-Bridge must be calibrated against standard solutions of sodium chloride. A typical calibration curve is shown in Figure 3. The instrument calibration was checked frequently. The electrodes required replatinizing (recoating) occasionally to retain proper instrument response.

Basically, the total soluble salt measurement consisted of agitating a mixture of 100 milliliters of distilled water and 50 grams of soil to dissolve the salts, filtering this mixture, and measuring the conductance of the filtrate (13). A few of the early samples were too small to permit the use of a 50-gram sample. In such cases a 35-gram soil sample was agitated with 70-ml distilled water. At least 70 ml of filtrate was needed to submerge the conductivity electrode to the required extent. With the aid of the calibration curve the conductance reading was converted to a total soluble salt concentration as milligrams of sodium chloride per kilogram of soil, or parts sodium chloride per million parts soil (ppm). A more detailed procedure is presented in Appendix A of this report.
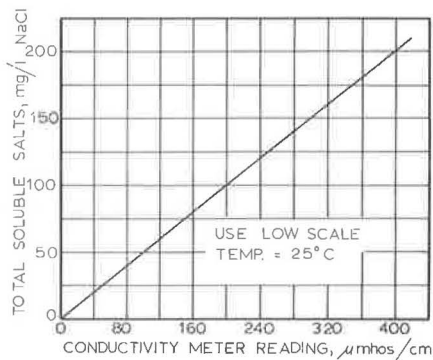
Figure 3. Conductivity meter calibration curve.

Chloride

The filtrate which was analyzed in the soluble salt test was also used for the chloride analysis. Chloride ion concentration was determined using the Mercuric-Nitrate test as described in "Standard Methods for the Examination of Water and Wastewater" (14). This is a rapid, accurate titration technique using mercuric nitrate as a titrant and diphenylcarbozone as an end point indicator. Results are reported as milligrams of chloride per kilogram of soil, or parts chloride per million parts soil (ppm).
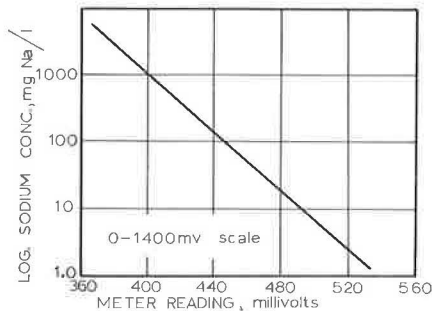
Figure 4. Sodium electrode calibration curve.

Sodium

Three methods for sodium analysis were considered: gravimetric analysis, flame photometry, and electrometric. Gravimetric analyses are extremely time consuming and require considerable skill. Work by Bower (15) and Fehrenbacher (16) has shown that the results of flame photometric measurements compare with those made electrometrically using a sodium specific electrode. The sodium electrode method can be used over a wider range of sodium without dilutions, and is simpler and more rapid than a flame photometer. For these reasons the sodium ion concentration was measured using a sodium sensitive electrode.

A Beckman Zeromatic pH Meter was converted to a "sodium meter" by replacing the hydrogen sensitive electrode with a Beckman 39137 Cationic Electrode which is sensitive to sodium ions.

This electrode is effective over a concentration range of 1.0 to 0.0001 Normal, a temperature range of 0 to 80 C, and a pH range of 9 to 13. The reference electrode is the standard saturated KCl-calomel half-cell with a fiber-type salt bridge. The glass sodium electrode tip is sensitive to differences in ionic activity. When connected to the pH meter circuit, the activity difference between the test sodium solution and the reference solution is indicated as a voltage. The meter is calibrated using standard sodium chloride solutions so that the indicated meter voltage may be converted to sodium ion concentration. A typical calibration curve is shown in Figure 4.

The sodium electrode is also sensitive to several monovalent cations other than sodium. Interference from hydrogen ions is easily avoided by adjusting the pH of the sample so that the H^+ concentration is less than one ten-thousandth the sodium concentration to be measured. The pH of all samples analyzed for sodium was adjusted to pH 10.

Sodium was extracted from the soil using a solution of sulfuric and hydrochloric acid. Activated carbon was also added to adsorb organics extracted from the soil (17). The mixture was agitated and then filtered and the sodium analysis made on the filtrate. A more detailed procedure is presented in Appendix B.

RESULTS AND DISCUSSION

Before examining the results of this study, it would be useful to review the salting procedures and quantities of salt applied by the Connecticut State Highway Department. This information was obtained from Mr. J. Bauer at the Department's local headquarters in Willington, Connecticut.

Records are maintained by the crews responsible for snow and ice control, and consist of the cubic yards of sand, tons of salt and the number of salt applications for each storm. The salt application rate used on Route 15 is 800-1000 lb/mi, while secondary routes receive 500-600 lb/mi. Additional salt is also mixed with the sand. The crew responsible for Route 15 at the sampling site is assigned 35.8 mi of the route beginning at exit 100 and extending to the Massachusetts line. The sampling site was between exits 101 and 102. In addition, this crew is responsible for 58.2 mi of secondary roads in the area. Records for total sand and salt used by this crew are given in Table 1. The sections assigned to each crew are not rigidly fixed and it is possible that at times another crew may have also applied salt at the sampling site.

The salt used is primarily sodium chloride with some calcium chloride being mixed in for use when the temperature is 26 F or less. Salt is applied at the beginning of a storm and also after the storm when necessary to remove any snow and ice packed on the highway.

TABLE 1

SALTING RECORD FROM
CONNECTICUT HIGHWAY DEPARTMENT

Date	Sand (cu yd)	Salt (ton)	No. Salt Applications
Dec. 20, '65	845	255	
Dec. 26	193	41	
Jan. 2-3, '66	160	270	
Jan. 6	283	47	
Jan. 8-9	522	208	2.5
Jan. 13	207	113	2
Jan. 19	108	57	1
Jan. 21	197	33	1
Jan. 23-24	233	427	5
Jan. 27	216	94	1
Jan. 30	346	209	4
Feb. 3-4-5	387	213	3
Feb. 13	108	57	1
Feb. 16-17	153	27	1
Feb. 19-20	162	18	
Feb. 24-25-26	396	284	4
Mar. 12	256	354	3

As anticipated, the greatest salt concentrations were found near the highway (Fig. 5). Some salt travels more than 100 ft laterally from the highway, even when the ground is very gently sloped. In general, the salt concentrations decrease farther from the highway and the fluctuations in concentration are smaller. After February the tendency for salt to travel laterally even 25 ft appears considerably reduced. This was probably the result of lesser amounts of frost allowing more infiltration of snow melt and rainwater.

The greatest salt concentrations were at the soil surface regardless of the distance from the highway. The highest salt concentration measured was 450 ppm at the soil surface 5 ft from the pavement on February 10. Unfortunately, a complete record at the 5-ft distance was not obtained. The maximum concentration at the other distances occurred in January so concentrations greater than 450 ppm probably had occurred at the 5-ft distance, but were not observed. The soil saturation moisture percentage was approximately 50 percent for the topsoil and 25 percent for the subsoil. Therefore, the maximum observed salt concentration in the saturation extract was 900 mg/l for the topsoil, well within the limit for a nonsaline soil on the salinity scale shown in Figure 1. The highest level recorded in the subsoil was 164 ppm, or 656 mg/l in the saturation extract. The complete total soluble salts data record is presented in Table 2.

By March 1 most of the salt had been leached from the top 3 ft of soil at distances 25 ft or more from the highway. By April 1 this was true 5 ft from the highway also. After March or April only small changes in salt concentration were observed, as shown in Figures 6 and 7. The concentration at all distances from the highway and depths continued to decrease slightly during the summer. Small fluctuations, such as observed after about April 1, probably reflect the effect of having to obtain samples from a slightly different location each day and are considered insignificant.

Although certain trends were observed, insufficient data were obtained to precisely follow salt movements and establish the rates of movement. To do this would require frequent analyses of soil water obtained from undisturbed soil.
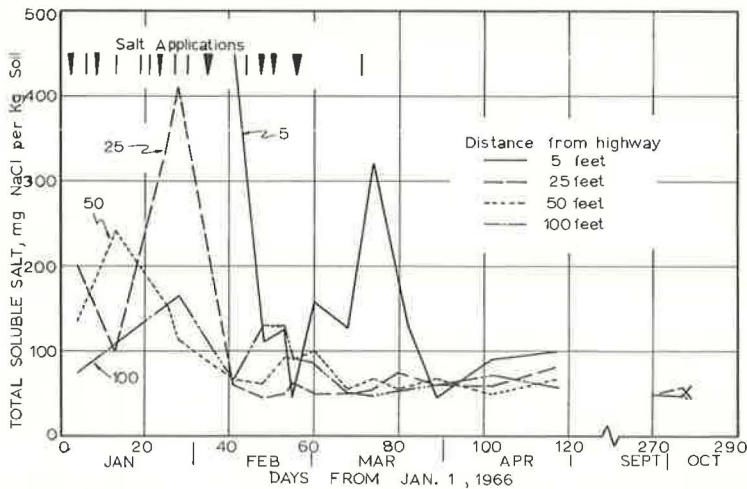

Figure 5. Total soluble salt concentration at soil surface several distances from highway.

TABLE 2
TOTAL SOLUBLE SALTS CONCENTRATION,
mg NaCl PER Kg SOIL (ppm)

Date	Depth (ft)					Date	Depth (ft)				
	Top	0.5	1	2	3		Top	0.5	1	2	3
(a) 5 ft from edge of paved shoulder						(c) 50 ft from edge of paved shoulder					
1-4-66						1-4-66	135	44	42	38	36
1-13-66	No samples taken from this location until 2-10-66					1-13-66	240	82	42	33	34
1-24-66						1-24-66	164	105	—	—	—
1-28-66						1-28-66	114	64	38	34	68
2-10-66	450	270	86	164	110	2-10-66	68	96	52	66	39
2-17-66	110	105	105	160	82	2-17-66	63	72	42	87	51
2-22-66	125	86	41	110	63	2-22-66	91	54	66	44	35
2-24-66	45	99	37	120	52	2-24-66	90	33	30	44	41
3-1-66	158	70	56	57	140	3-1-66	100	67	48	33	56
3-9-66	127	44	62	140	68	3-9-66	56	30	34	35	35
3-15-66	320	43	50	56	60	3-15-66	68	39	30	31	38
3-23-66	130	110	85	79	60	3-23-66	56	45	35	30	26
3-29-66	46	56	62	100	60	3-29-66	68	25	40	29	32
4-12-66	91	82	78	75	62	4-12-66	50	35	36	27	—
4-27-66	100	125	84	135	97	4-27-66	68	53	50	—	50
9-27-66	50	52	55	65	78	9-27-66	48	35	37	36	30
10-4-66	48	60	54	64	58	10-4-66	50	66	40	34	34
10-6-66	60	54	48	44	54	10-6-66	44	30	28	28	30
(b) 25 ft from edge of paved shoulder						(d) 100 ft from edge of paved shoulder					
1-4-66	201	136	38	58	35	1-4-66	74	—	56	46	56
1-13-66	100	105	48	43	48	1-13-66	—	67	60	—	—
1-24-66	322	124	—	—	—	1-24-66	150	80	—	—	—
1-28-66	410	78	69	34	30	1-28-66	166	108	44	40	39
2-10-66	60	45	60	46	37	2-10-66	65	52	93	52	51
2-17-66	45	42	38	58	63	2-17-66	130	92	45	122	50
2-22-66	50	38	34	34	32	2-22-66	130	128	52	75	42
2-24-66	62	50	32	48	45	2-24-66	92	45	43	46	50
3-1-66	50	52	46	34	37	3-1-66	84	50	38	42	38
3-9-66	50	22	30	20	25	3-9-66	51	29	33	35	61
3-15-66	56	47	24	32	28	3-15-66	48	34	30	37	35
3-23-66	75	60	44	39	32	3-23-66	55	30	30	34	28
3-29-66	61	43	35	32	22	3-29-66	61	40	35	38	31
4-12-66	60	47	52	36	35	4-12-66	73	46	50	40	25
4-27-66	82	44	45	48	45	4-27-66	60	43	35	47	43
9-27-66	49	32	32	34	30	9-27-66	50	43	45	48	40
10-4-66	58	37	34	34	33	10-4-66	47	34	32	34	34
10-6-66	45	35	35	29	31	10-6-66	43	33	39	32	34

In general, the salt concentration decreased with depth, and the fluctuations in salt concentration were smaller at lower depths. This should be expected since the salt is both diluted and dispersed as it moves through the soil. Samples taken 5 ft from the
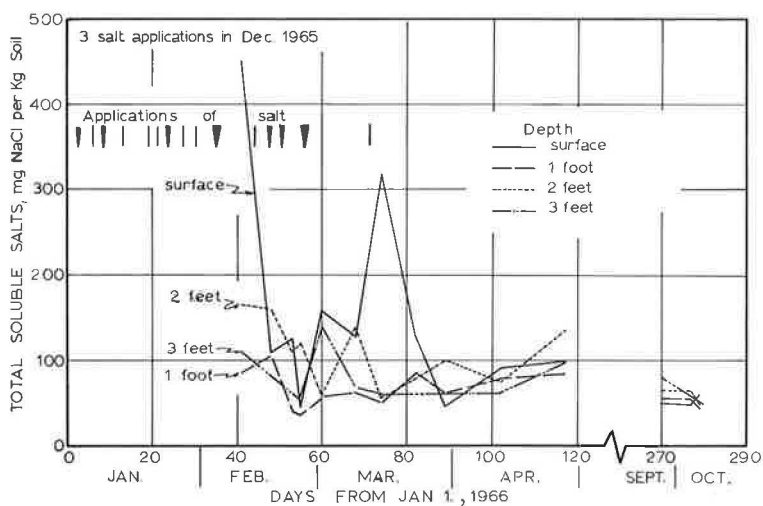

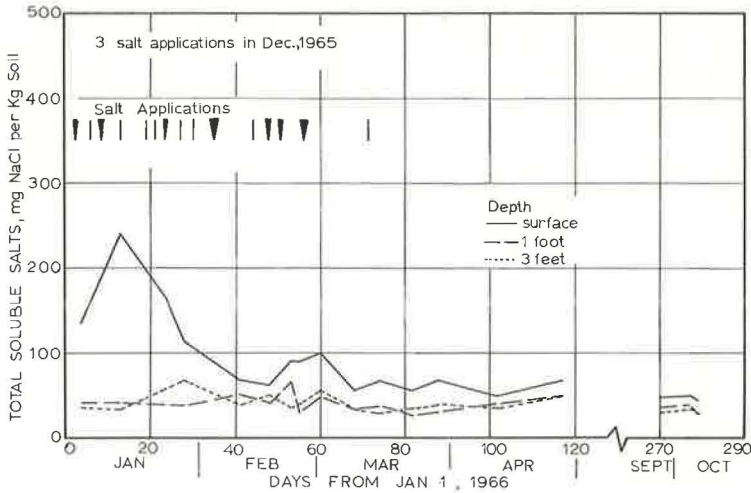Figure 6. Total soluble salts at several depths 5 ft from highway.

Figure 7. Total soluble salts at several depths 50 ft from highway.

highway revealed that the concentration at the 2-ft depth was often greater than that at the $\frac{1}{2}$ and 1-ft depths. The pattern observed may result from the irregular spacing of salt applications and sampling times. The soil at the 2-ft depth may absorb salts more readily than other depths, although visually the soil at all depths appeared similar. Differing compaction during construction of the highway may also have resulted in sufficiently different permeabilities to give the results obtained. Most likely a combination of factors results in the salt being rapidly transported to the 2-ft depth and then gradually dispersed and diluted from there.

Figure 8. Depth profile of total soluble salt concentration.

During the highway salting season large variations of salt concentration with depth were observed, while at other seasons little variation was found. Figure 8 compares a depth profile observed shortly after a salt application with one existing about six months later, after spring rains and snow melts had leached most of the salts from the soil. On February 10 the effects of two salt applications are evident at a distance of 5 ft from the highway. The salt from the earlier application has been leached below the 1-ft level and shows as a peak concentration at the 2-ft depth. A subsequent application has only begun to penetrate the soil and is concentrated mostly at the surface, possibly because of frozen ground conditions. At other distances from the highway the concentration at any depth may be greater or less than that at another depth. Insufficient information is available to define or predict the rates of travel which produced these results, but the observed conditions are in accordance with the observations of Miller et al (18).
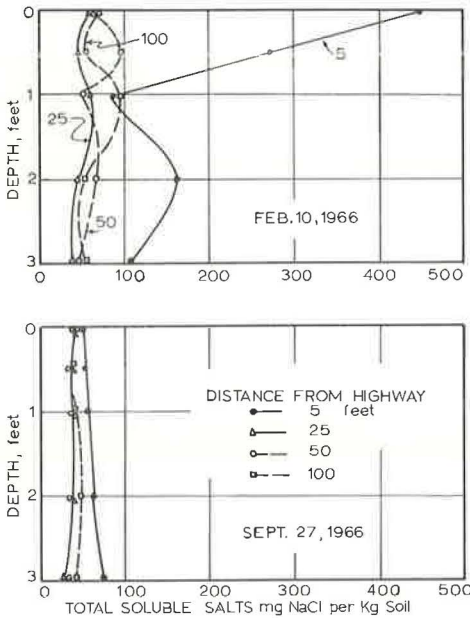
In general, the concentrations of chlorides showed the same fluctuations as the

total soluble salts, and graphical representations of chloride data would be similar to those already presented. The same trends would be revealed and the same conclusions would be indicated. Complete chloride data are presented in Table C-1 of Appendix C.

Sodium concentration data did not fit the pattern established by the chlorides and total soluble salts. Early in the study some scattered high values of sodium were observed, but not as frequently as in the total soluble salts and chloride data. After mid-February, however, the sodium concentration rarely exceeded 25 ppm. This may be related to the exchange of sodium by the soil particles, or to the extraction procedure used in the sodium analysis, but no explanation is evident. The sodium data are presented in Table C-2.

CONCLUSIONS

The maximum concentrations of salts may be found at the soil surface and nearest the highway. These studies indicate that the soil salinity problem resulting from highway salting is minimal for similar field conditions. Adverse drainage conditions, however, could create more serious problems and should be avoided.

There is some tendency for salts to travel laterally away from the highway, but the most prevalent movement is downward into the soil. As infiltration proceeds, the salt concentration is markedly decreased from that at the surface. The salt concentrations in the subsoil are generally decreased as depth increases, but occasionally this pattern may not appear. Salts are readily leached from the top several feet of soil and by April the majority of the salts have disappeared. The salt concentrations continue to decrease gradually through the summer and reach a low level before salt applications are resumed again the following winter.

Chloride measurements are generally proportional to total soluble salts measurements. Sodium ion concentrations, however, appear to establish a pattern somewhat different than the total salts.

Further work is required to define the seasonal pattern of changes in soil salinity more carefully and to ascertain whether the salt levels decrease to their former level over the summer season. Rates of movement of salts through soils of all types must be known in order to better understand the patterns observed in certain depth profiles, and to be able to predict the concentrations which will result at various depths and distances from the road. In order to answer the question of how much salt may be applied in any specified situation without causing damage, answers must be obtained. Soil type, drainage patterns, salt application rates, infiltration rates, frequency of salt and water application, and frost conditions are all involved in the problem. At present, even the most simple cases involving salt applications to unfrozen ground are not entirely understood.

ACKNOWLEDGMENTS

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Appendix A

TOTAL SOLUBLE SALT ANALYSIS

A Betz Conducto-Bridge, Model X 50, was used to measure the conductance of a soil extract solution. This instrument has two ranges of conductance which may be used. The lower range, which indicates 0 to 150 micromhos per centimeter, was used since the salt concentrations found were relatively low.

Calibration of Conductivity Meter

Prepare a series of sodium chloride solutions of known concentration. Determine the meter conductance reading corresponding to each of these concentrations according to the procedure given in the "Instrument Operation" paragraph. Construct a graph of conductance, micromhos per centimeter, versus concentration, mg/l NaCl. The instrument should be recalibrated periodically.

If the black coating of the electrodes becomes thin or chipped, the instrument readings will not be reliable. The electrodes may be renewed by replatinizing. This procedure is described in the Conducto-Bridge Instruction Manual.

Preparation of Soil Samples (13)

Weigh out 50 grams of soil which has been passed through a 2-mm sieve. Place this sample in a 250-ml Erlenmeyer flask and add 100-ml distilled water. Agitate this mixture with an Eberbach shaker for 20 min and then allow 20 min for clarification. Filter the supernatant through Whatman's No. 1 filter paper. The filtrate conductance is then measured using the Conducto-Bridge.

Use of the Conductivity Meter

Measure the temperature of the sample and set the temperature compensating dial on the meter. Set the conductivity range for the low readings. Immerse the electrode so that the perforations in the casing are submerged. Adjust the scope to the largest dark band and record the observed conductivity reading. Convert this reading to total salt concentration, as mg/l NaCl, with the aid of the calibration chart. This value can be related to the soil as ppm by multiplying by two. Rinse the electrode well with distilled water between readings.

Appendix B

SODIUM CONCENTRATION MEASUREMENT

A Beckman Zeromatic pH Meter may be modified to measure sodium electrometrically by replacing the hydrogen sensitive electrode with a Beckman 39137 Cationic Electrode. The cationic electrode, which is sensitive to sodium, was paired with a standard calomel reference electrode. The "sodium meter" was operated to measure millivolts over the 0 to 1400-mv range. The procedure for accomplishing this is stated in the pH meter instruction manual.

Calibration of the Sodium Electrode

The electrode actually measures ionic activity and not concentration. Therefore, the electrode calibration must cover the range of concentrations that are to be measured. The pH of the calibration standards should be the same as that to which the soil sample extracts are to be adjusted.

Prepare a series of standard sodium chloride solutions. A tenfold dilution factor between standards is convenient. Solutions of 0.1 to 0.0001 molar sodium were used and the pH of each dilution was adjusted to 10.

Immerse the electrodes in each of the standard solutions and record the observed millivolt readings. Construct a calibration curve by plotting millivolts versus the sodium ion concentration of each standard solution.

Preparation of Soil Samples (17)

The sodium must be extracted from the soil with an acid solution. Prepare an extracting solution consisting of 12-ml concentrated sulfuric acid, 73-ml hydrochloric acid, and sufficient distilled water to make 18 liters.

Place 20 grams of soil which has been passed through a 2-mm sieve in a 250-ml Erlenmeyer flask. Add 80 ml of extracting solution and about 0.8-grams activated carbon. Agitate this mixture on an Eberbach shaker for 5 min and filter through Whatman's No. 1 filter paper.

Immerse the electrodes in the filtrate and measure the sodium ion response in millivolts. With the aid of the calibration chart convert the millivolts reading to sodium ion concentration, as mg/l Na. This value can be related to the soil as ppm by multiplying by four. Rinse the meter electrodes thoroughly with distilled water between measurements.

Appendix C

TABLE C-1

CHLORIDE CONCENTRATION, mg Cl⁻ PER Kg SOIL (ppm)

Date	Depth (ft)					Date	Depth (ft)				
	Top	0.5	1	2	3		Top	0.5	1	2	3
(a) 5 ft from edge of paved shoulder						(c) 50 ft from edge of paved shoulder					
1-4-66						1-4-66	36	—	8	10	8
1-13-66	No samples taken from this location until 2-10-66					1-13-66	66	22	12	12	12
1-24-66						1-24-66	48	30	—	—	—
1-28-66						1-28-66	33	13	13	9	18
2-10-66	204	136	27	88	60	2-10-66	17	27	9	14	6
2-17-66	34	51	50	98	36	2-17-66	26	22	15	27	15
2-22-66	64	46	13	66	34	2-22-66	25	12	20	13	15
2-24-66	12	28	12	71	12	2-24-66	22	10	12	14	10
3-1-66	47	24	18	20	87	3-1-66	30	18	12	16	14
3-9-66	55	17	30	86	24	3-9-66	16	12	11	16	14
3-15-66	20	30	30	29	27	3-15-66	22	14	12	16	14
3-23-66	55	44	22	20	38	3-23-66	12	9	12	10	8
3-29-66	19	22	24	56	27	3-29-66	19	9	9	8	12
4-12-66	28	38	20	39	17	4-12-66	18	12	15	9	—
4-27-66	22	25	18	10	22	4-27-66	13	12	12	25	11
9-27-66	10	12	17	18	27	9-27-66	12	7	8	9	8
10-4-66	12	18	12	14	12	10-4-66	13	15	10	16	10
10-6-66	20	16	12	20	20	10-6-66	16	12	12	10	12
(b) 25 ft from edge of paved shoulder						(d) 100 ft from edge of paved shoulder					
1-4-66	48	41	12	16	8	1-4-66	15	—	15	10	6
1-13-66	36	24	11	12	13	1-13-66	—	11	54	—	—
1-24-66	105	40	—	—	—	1-24-66	34	22	—	—	—
1-28-66	104	20	28	12	13	1-28-66	36	27	13	18	12
2-10-66	16	15	18	15	9	2-10-66	15	12	14	14	14
2-17-66	14	28	16	25	14	2-17-66	30	28	12	26	15
2-22-66	16	10	14	16	14	2-22-66	36	30	13	18	16
2-24-66	17	12	12	14	10	2-24-66	22	14	12	12	16
3-1-66	18	10	14	12	16	3-1-66	26	16	10	10	12
3-9-66	12	8	8	8	9	3-9-66	10	10	9	10	12
3-15-66	16	10	10	8	8	3-15-66	16	9	10	16	14
3-23-66	20	16	14	12	8	3-23-66	16	10	8	8	8
3-29-66	18	12	12	10	8	3-29-66	15	15	12	12	7
4-12-66	18	12	14	12	12	4-12-66	20	18	16	15	8
4-27-66	26	12	11	16	14	4-27-66	12	10	9	10	16
9-27-66	8	18	8	7	6	9-27-66	19	10	4	7	7
10-4-66	13	12	8	12	16	10-4-66	13	12	12	9	8
10-6-66	14	10	16	14	12	10-6-66	16	12	14	12	12

TABLE C-2

SODIUM ION CONCENTRATION, mg Na PER Kg SOIL

Date	Depth (ft)					Date	Depth (ft)				
	Top	0.5	1.0	2.0	3.0		Top	0.5	1.0	2.0	3.0
(a) 5 ft from edge of paved shoulder						(c) 50 ft from edge of paved shoulder					
1-4-66						1-4-66	—	6.6	—	—	3.2
1-13-66	No samples obtained from this location until 2-10-66					1-13-66	23.9	1.2	—	2.0	—
1-24-66						1-24-66	106.0	45.2	—	—	—
1-28-66						1-28-66	172.0	70.0	70.0	14.8	—
2-10-66	138.0	—	23.9	14.8	41.3	2-10-66	106.0	12.0	14.7	106.0	1.5
2-17-66	23.9	14.8	9.2	14.8	14.8	2-17-66	23.9	2.0	9.2	14.8	3.2
2-22-66	5.5	14.8	9.2	5.5	3.2	2-22-66	9.2	2.0	6.0	3.2	9.2
2-24-66	19.8	14.8	4.4	5.5	3.2	2-24-66	54.4	14.8	9.2	1.2	5.6
3-1-66	14.8	9.2	1.9	6.6	5.5	3-1-66	9.2	5.5	2.0	3.2	2.0
3-9-66	14.8	2.0	1.2	5.5	9.2	3-9-66	14.8	5.5	3.2	6.6	3.2
3-15-66	41.1	9.2	3.2	5.5	5.5	3-15-66	14.8	9.2	9.2	2.0	5.6
3-23-66	14.8	9.2	5.5	3.2	5.5	3-23-66	14.8	9.2	9.2	14.8	5.6
3-29-66	9.2	3.2	4.4	2.6	14.7	3-29-66	14.8	3.2	3.2	9.2	12.0
4-12-66	14.8	9.2	9.2	9.2	5.2	4-12-66	9.2	5.6	5.6	5.6	—
4-27-66	12.0	23.9	9.2	5.5	3.2	4-27-66	9.2	9.2	4.4	5.6	3.2
9-27-66	3.2	3.2	8.4	3.2	3.2	9-27-66	—	—	18.4	8.4	18.4
10-4-66	—	—	5.1	—	1.4	10-4-66	—	—	—	8.3	5.1
10-6-66	—	—	—	—	—	10-6-66	23.2	18.4	23.2	23.2	18.4
(b) 25 ft from edge of paved shoulder						(d) 100 ft from edge of paved shoulder					
1-4-66	9.2	—	—	—	—	1-4-66	—	—	14.7	64.4	23.8
1-13-66	5.5	0.8	1.2	—	—	1-13-66	—	106.4	39.1	—	—
1-24-66	285.0	9.2	—	—	—	1-24-66	138.0	59.0	—	—	—
1-28-66	—	83.0	50.5	24.0	24.0	1-28-66	—	49.4	41.2	—	49.4
2-10-66	14.8	3.2	9.2	24.0	24.0	1-10-66	1.6	23.8	9.2	14.8	106.4
2-17-66	14.8	4.4	3.2	9.2	1.2	2-17-66	83.0	14.8	5.5	14.8	14.8
2-22-66	3.2	4.4	5.2	5.2	3.2	2-22-66	9.2	3.2	5.5	5.5	0.8
2-24-66	9.2	5.2	1.2	4.4	5.2	2-24-66	14.8	5.4	5.4	9.2	12.0
3-1-66	9.2	5.2	2.0	2.0	3.2	3-1-66	14.8	3.2	3.2	5.4	3.2
3-9-66	2.0	2.0	1.4	—	1.2	3-9-66	9.2	9.2	6.6	3.2	9.2
3-15-66	23.7	3.2	3.2	9.2	3.2	3-15-66	12.0	5.6	6.7	18.4	5.6
3-23-66	23.7	12.0	9.2	5.2	5.2	3-23-66	23.8	23.8	23.8	9.2	5.6
3-29-66	9.7	2.5	6.6	5.5	3.2	3-29-66	9.2	3.2	9.2	4.4	3.2
4-12-66	23.9	9.2	2.5	5.5	1.9	4-12-66	14.8	18.4	5.6	14.8	9.2
4-27-66	12.0	1.5	4.4	14.8	14.8	4-27-66	4.4	14.8	6.6	14.8	9.2
9-27-66	3.2	3.2	3.2	5.1	—	9-27-66	—	—	18.4	3.2	—
10-4-66	—	8.3	—	1.3	—	10-4-66	1.2	—	—	—	1.2
10-6-66	—	—	—	—	—	10-6-66	—	—	—	—	—

Pollution Aspects Associated
With Chemical Deicing

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•THERE ARE a number of chemicals that might be used for deicing. About the only requirements are that the substance be soluble in and lower the freezing point of water. Some chemicals have an additional advantage for deicing by giving off heat as they go into solution.

Chemical deicers may range from urea to rock salt. Cost is a big factor in the selecting of a deicer and this alone points to an overwhelming use of salt. However, the chemical used must be compatible with its intended objective. As an example, for "gas line freeze" the chemical must be soluble in both gasoline and water and not impair engine operation.

STREETS AND HIGHWAYS

In 1965, the U.S. use of rock salt for road deicing was estimated at 4 million tons or twice the amount used in 1960. The total 1965 salt consumption in the U.S. for all purposes was estimated at 34.7 million tons compared with about 26 million tons in 1960 (1).

The use of rock salt and calcium chloride in Wisconsin for winter road maintenance dates back about 20 years. At first they were used, mainly mixed at a rate of 75 to 100 lb/cu yd of sand, to prevent freezing and increase abrasion. The treated sand was applied generally on hills, curves and intersections. For a number of years there has been a shift toward direct application of chemicals. Calcium chloride can substantially lower the freezing point more than salt and in addition heat is evolved as it goes into solution. From a practical standpoint, rock salt loses its effectiveness around 20 F and with lower temperatures the proportion of calcium chloride must be increased. Generally, use of chlorides is restricted to above zero weather.

The Wisconsin Highway Commission, starting in the winter of 1956 and 1957, began a "bare pavement" program of winter highway maintenance with full-scale use of chlorides. Most of the chloride now used is rock salt. Generally the amount of calcium chloride used on state highways is less than 5 percent of the total chemical applied. About 90 percent of the chlorides are now used "straight" and not mixed with sand.

Table 1 is a summary of the amount of chlorides purchased by the State of Wisconsin for use on its trunk highways beginning with the 1955-56 season (2, 3). While it is difficult to make yearly comparisons because of different snowfall and freezing rain patterns, it appears that Wisconsin's use of chlorides is trending upwards.

A previous report (4) shows that state trunk highways in Milwaukee County received by far the most chlorides and have the highest application rates per mile. During the winter of 1964-65 chloride use in that county reached an all-time high of 77,012 tons. Of this, the state's use amounted to 18,536 tons, the City of Milwaukee applied 33,104 tons, other municipalities used 21,670 tons and the county used 3,702 tons.

Among the other counties in Wisconsin using the largest amounts and having the highest rates of application are Kenosha, Racine, Waukesha and Rock Counties, all of which are located in the southeastern section of the state. Not only is this area more

TABLE 1

CHLORIDE PURCHASES (TONS) FOR DEICING
WISCONSIN STATE HIGHWAYS

Winter	Sodium Chloride	Calcium Chloride	Total	Avg. Tons per Mile
1955-56	5,797	1,344	7,141	0.6
1956-57	23,740	1,091	24,831	2.3
1957-58	45,111	3,055	48,166	4.4
1958-59	57,888	2,222	60,110	5.9
1959-60	87,845	1,720	89,565	9.0
1960-61	54,857	1,128	55,985	5.5
1961-62	108,815	1,948	110,763	10.9
1962-63	78,038	2,012	80,050	7.9
1963-64	79,852	2,182	82,034	8.1
1964-65	149,330	2,196	151,526	15.0
1965-66	111,634	3,130	114,764	11.4

populated but it contains more multilane highways where the amounts and rates would necessarily be higher. Although chloride usage was determined in 2 counties, it is difficult to determine the state, county, municipal and town applications for all of Wisconsin's 72 counties. However, as an estimate, the total amount of chlorides applied to all roads in Wisconsin is somewhere in the vicinity of twice that used on the state trunk highways.

CHLORIDES—GENERAL

The two chemical agents applied to highways for ice removal are rock salt and calcium chloride. Although they are used in relatively unrefined states, rock salt is 94 to 97 percent sodium chloride. The latter, NaCl, is 39.3 percent sodium and 60.7 percent chloride while calcium chloride, as such, contains 36.1 percent calcium and 63.9 percent chloride. The ASTM specification followed requires a minimum of 94 percent $CaCl_2$ in the material used for deicing. Cost of the commercial grades used on highways has been about $10 per ton for rock salt delivered and $47 per ton for calcium chloride delivered in bag lots. In these times of rising prices it is interesting to note that the cost of rock salt is down 20-25 percent since 1960. The price of calcium chloride is also less now than it was in 1960, and it may be possible that bulk rather than bag shipments will result in further economies.

Chlorine is one of the approximately 100 elements. In its elemental state, it is an active gas and as such is never found free in nature. Chlorides are chemical combinations of chlorine with another element or radical. The earth's crust averages about 0.15 percent chloride and sea water contains approximately 1.9 percent. Extensive deposits of chlorides are scattered about the continents, but the element is ubiquitous with essential concentrations being maintained by precipitation. Annual additions from this source may range from hundreds of pounds per acre in coastal areas to 10 pounds per acre at locations far inland. Chlorides are important in physiological processes and recognized as a vital micronutrient for plant life.

The Mohr method (5), in which the sample is titrated with silver nitrate to the chromate endpoint, is commonly used for chloride analyses of waters and wastes. This determination is relatively accurate and rapid. The minimum level of detection by this method is about 0.5 to 1 milligram per liter. The expression shows the weight in a unit volume of solution and is frequently abbreviated mg/l. Sometimes chloride results are expressed in parts per million (ppm) which is a weight per unit weight relationship. Results on a sample with a density equal to that of water will yield the same numerical value in mg/l or ppm. Occasionally these terms are used interchangeably.

The California Water Quality Control Board's publication, "Water Quality Criteria," indicates the following chloride concentrations as not being harmful for the specified beneficial uses: domestic water supply, 250 mg/l; industrial water supply, 50 mg/l;

irrigation, 100 mg/l; for stock and wildlife, 1500 mg/l (6). Several references are cited concerning harmful levels of chloride to fish life varying from a low figure of 400 mg/l for trout found by one investigator to a range of 8100 to 10,500 mg/l for small bluegills reported in another study. A considerable variation in critical chloride levels might be expected depending on the kind of fish involved as well as the entire chemical makeup of the water when a given species is considered. Some fish are anadromous and during their life cycle are subjected to drastic changes of chloride from about 19,000 ppm in the oceans to near nil in fresh water streams.

Where a better public water supply is available the Public Health Service (PHS) indicates an upper limiting chloride concentration of 250 mg/l (7). Waters with 2000 mg/l of chloride have been used for domestic purposes without adverse effects once the human system adjusted to these waters (8). It should be pointed out that the PHS considers physical characteristics in addition to those qualities directly affecting health. Restrictions on the chloride content of drinking water are generally based on taste rather than health. However, excessive chlorides may be harmful to some people with diseases of the heart or kidneys (6).

Chlorides have been implicated in the corrosion of metals including stainless steels. After a 2-yr study, the Ohio River Valley Water Sanitation Commission recommended that the chloride concentration of the main stem never exceed a monthly average of 125 mg/l based on the minimum monthly average 10-yr flow and that the maximum concentration never exceed 250 mg/l. Health aspects were not involved in proposing these limits but rather corrosive damage to industrial structures was the primary concern. An industry spokesman indicated that increasing the salinity average above the then 40 to 50 mg/l or lengthening the periods of high salinity would increase corrosion of all metals used in the water handling system (9).

In 1952, Mackenthun (10) reported on a review of the literature concerning materials affecting biological life in streams and sewage treatment processes. References were cited for sodium chloride solutions indicating that a concentration of 2500 ppm in standardized dilution water was the minimum lethal value for minnows; that a level of 3680 ppm in Lake Erie water for a 64-hr period caused a 50 percent immobilization to Daphnia and that 50,000 ppm in sludge retarded or inhibited digestion at treatment plants. A 2775-ppm concentration of calcium chloride in distilled water was lethal to minnows over a 2 to 4-day period and was the lowest level of the three shown. The tolerance of Daphnia was tested under the same conditions as those reported for sodium chloride; however, the critical level found for calcium chloride was 920 ppm. Personnel of Madison's Health Department added sodium chloride to Lake Mendota waters. Four goldfish placed in these waters, having a chloride concentration of 1200 mg/l, were not noticeably affected during a 24-day test period (11).

In nature there may be adaptations to high chloride concentrations by fish and other aquatic life or other constituents in the water might mitigate conditions. The previous references were based on laboratory studies but what about findings in situ? Large amounts of chlorides discharged by industrial plants have resulted in fish kills in the Werra River, Germany (12). Tolerance to chlorides was greater at low temperatures with fish kills occurring in the winter when the salt content exceeded 12,000 mg/l. In the saline stretches immediately below discharges, insect larvae disappeared and there was a reduction of other fish food organisms. A year-round study of biological conditions in a brine-polluted stream was reported (13). Chloride concentrations ranged from 20,000 mg/l in the headwaters to 100 mg/l in the lower section. The 34 species of organisms found in the stream throughout the year were classified according to chloride tolerance. The greatest difference in stream life was the absence of fish life where chloride exceeded 1000 mg/l. However, this was in the upper section where water depth may have restricted the habitat.

Calcium and sodium in their elemental states are whitish, reactive metals but are always combined in nature. The earth's crust contains 3.6 percent calcium and 2.6 percent sodium, and these rank fifth and sixth, respectively, in the earth's elemental composition.

Calcium is vital to life and its compounds are widely and usually abundantly spread over the earth's surface. In its natural forms it is unlikely that harmful quantities of

calcium would be ingested. The main objections to calcium in domestic water supplies are hardness and the fouling of utensil and hot water heater surfaces. One part of calcium is equivalent to $2\frac{1}{2}$ parts of hardness. Sodium compounds are generally very soluble in water. The element is necessary for life but nearly all of sodium-related problems occur because of excessive amounts rather than deficiencies.

Salt is one of our commonest chemicals and we are all familiar with its use in the preparation and seasoning of foods. About 80 percent of the soluble solids in ocean water is sodium chloride. The sodium and chloride contents of sea water are approximately 10,560 and 18,980 ppm, respectively. In addition to its occurrence as dissolved material in oceans, seas and salt lakes, it is found in beds of rock salt which are mined.

Calcium chloride is a deliquescent substance with an affinity for water. As such, the chemical is used on dirt roads to allay dust and also as a dessicant and dehumidifying agent. It is quite soluble in water and natural deposits are not common, but rather it is chiefly a by-product of the chemical industry and is also extracted from natural brines.

The solubility of sodium chloride is 35.7 parts per 100 parts of water at a temperature of 32 F compared with calcium chloride's solubility of 59.5 parts under the same conditions. In aqueous solution these chemicals ionize and lower the liquid's freezing point. The sodium chloride molecule ionizes to form a sodium ion and a chloride ion while the calcium chloride molecule forms a calcium ion and two chloride ions. A solution of the latter would, therefore, be expected to have a lower freezing point. The eutectic temperature or the minimum freezing point for a solution of sodium chloride is -6 F compared with a eutectic temperature of -67 F for a calcium chloride solution. When most chemicals dissolve, heat may be either given off or taken up during the process. Sodium chloride has a heat of solution of -1.18 kilo-calories per gram mole compared with calcium chloride's value of 3.01 kilo-calories per gram mole (14). In effect this indicates that when sodium chloride dissolves it requires about 36 Btu (British thermal units) per pound while calcium chloride liberates about 49 Btu per pound when it goes into solution.

Soils have negative electrical charges on their surfaces and adsorb positively charged ions (cations) including those of calcium, magnesium, hydrogen, ammonium, potassium and sodium. Although in a sense the adsorbed cations are chemically combined with the soil particles, they may be replaced or exchanged by other cations. Each soil has a definite capacity to adsorb cations. Sodium ions are not as tightly held as some of the others but a concentrated sodium solution can replace some of the other cations adsorbed on the soil. When about 15 percent or more of a soil's exchange capacity is made of sodium ions, an alkali soil develops. The soil then loses its natural characteristics and productivity is impaired. Excessive ions in the soil solution other than sodium may affect plant growth by interfering with water uptake. The latter is referred to as a saline soil condition.

The chloride ion has a negative charge and it is not attracted by the soil adsorption sites, nor are chloride ions precipitated by soil reactions. Consequently, we would expect chloride ions to move en masse with the groundwater although there may be a substantial change in the makeup of the accompanying cations.

Calcium chloride is used to a certain extent in Wisconsin to minimize road dust problems. Not enough information was available to arrive at a figure for the amount used, but it appears to be less than the calcium chloride involved in deicing. Rock salt also might be mixed with the calcium chloride for dust control. Still another road use of these chlorides is as roadbed stabilizers, but this practice is presently infrequent in Wisconsin. Dust control entails an application of about 1 to 2 lb/sq yd (6 to 12 tons/mi for about a 20-ft wide road). Roadbed stabilization requirements are about the same per inch of compacted depth—a 6-in. compacted depth on an approximately 20-ft wide road would require 36 to 72 tons/mi.

CHLORIDES—WATER SUPPLIES

Indicating the concentrations that are naturally present in waters and showing other sources of chlorides will help put them in better perspective.

TABLE 2

WISCONSIN PUBLIC WATER SUPPLIES

Chloride (mg/l)	No. of Supplies	Chloride (mg/l)	No. of Supplies
0-10	309	51-100	14
11-20	102	131	1
21-30	23	141	1
31-40	10	154	1
41-50	10		

Public water supplies in Wisconsin generally have low chlorides. Tabulated data for 471 separate sources revealed an arithmetic average chloride concentration of 12.6 mg/l. The median value was 7 mg/l with 248 sources having 7 mg/l or less and 223 supplies having 8 mg/l or more. Nearly two-thirds or 309 had a concentration of 10 mg/l or less (15).

High chloride content may be found in some areas, particularly in deeper wells in the northern and southwestern Wisconsin mining areas and in the eastern part of the state (16).

Ryling's report on saline waters in the bedrock aquifers of eastern Wisconsin indicates that in 97.9 percent of the area mapped the chloride concentration was 0 to 100 mg/l; 1.6 percent of the section had concentrations of 101 to 200 mg/l; 0.1 percent of the section surveyed ranged from 201 to 250 mg/l; and 0.4 percent of the area had concentrations in excess of 250 mg/l (17). A sample of mine pumpage at Hurley from the 32nd and 34th levels, about one mile below the ground surface, was found to contain 19,500 mg/l of chloride.

CHLORIDES—SEWAGE AND WASTES

The chloride content of sewage remains substantially unaltered as wastes flow through the treatment processes. Nearly all municipal sewage treatment plants discharge to surface waters, and sizeable chloride increases can occur where little dilution is available. Chloride is not altered or significantly taken up in surface waters either so that other chloride sources only add to the total amount in the stream.

Body wastes, particularly urine, contain chloride in an amount similar to that ingested in the food and liquid intake. The excreta averages about 6 grams of chloride per person daily and adds a concentration of about 15 mg/l to the total sewage flow (8). The chloride contained in sewage from residential areas contains about 50 mg/l of chloride (18). The difference is probably because of other household sources of chloride as well as that in the water supply initially.

Sizeable quantities of salt used for household water softening in municipally sewered areas eventually discharge to a surface water. During softener regeneration the sodium ions of the concentrated salt solution displace the calcium and magnesium ions, the hardness contributors, from the ion exchange bed. Under operational conditions the calcium and magnesium ions in the water supply displace the sodium ions from the exchange median. Madison, Wisconsin has a water hardness of around 300 mg/l (17 to 18 grains/gal). Softening of the household hot water supply involves use of about 50 to 60 lb of salt per person per year. This can easily raise the average chloride concentration in wastes from these homes by 100 mg/l.

A composite sample of the effluent from Madison's Nine-Springs sewage treatment plant in April 1965, had a chloride content of 287 mg/l. This represented about 46 tons per day of salt. Madison's chloride discharge is high, but one industry accounts for one-third to one-half of the total. Madison's wells, which provide the municipal water supply, do not have high amounts of chloride. In late 1960 and early 1961, chemical analyses were made of 18 Madison municipal wells. Five of the wells had no detectible chloride and only three had a concentration of more than 5 mg/l. The maximum concentration found in the municipal wells was 26.5 mg/l and the average for all the wells was 5.9 mg/l.

Sodium chloride is used in the preparation and preservation of foods. Typical chloride values found in some food processing wastes follow: meat packing, 1000 mg/l; cheese making, 400 mg/l; and pickle and kraut canning, 2000 to 3000 mg/l. A sample from a spent cucumber brine tank had 100,000 mg/l of chloride associated with a BOD of 15,500 mg/l.

RUNOFF AND SURFACE WATER SAMPLING

In 1956-57, sampling stations were set up in the vicinity of Chippewa Falls, Wisconsin Rapids, Green Bay and Madison, Wisconsin to study the runoff from chloride-treated highways. In the Chippewa Falls area, samples of road runoff with chloride concentrations of up to 10,250 mg/l were found, although the maximum concentration found in the surface water was 45.5 mg/l. Summer samples of road runoff had chloride concentrations ranging up to 16 mg/l, while at the same time, the streams had concentrations of 0.5 to 2 mg/l. During the winter of 1959, samples from Beaver Dam Lake at Cumberland in Barron County suggested a density stratification of chlorides with depth. Near the surface the chloride concentration was 8 mg/l and this increased to 33 mg/l near the lake bottom at a depth of 15 ft below the surface.

Since 1957, with one exception, samples from the Suamico River and Duck Creek tributaries near Green Bay receiving roadside runoff had chloride concentrations of less than 50 mg/l. In January 1965, the Duck Creek tributary below State Trunk Highway 54 in the Town of Hobart had a chloride concentration of 255 mg/l. Stream samples from Mosquito and Mill Creeks, north of Wisconsin Rapids, did not indicate unusual chloride increases during periods of runoff.

In the Madison area, samples were taken of street runoff at various locations and also of Lake Wingra and Murphy Creek which connects Lake Wingra to Lake Monona. The maximum chloride concentration found in runoff was 3275 mg/l but, as with the other high values, was associated with little snow melt and flow. Street runoff reaches Murphy Creek at several points along its 2½-mi length. The maximum chloride concentration found in this stream was 165 mg/l. BOD and suspended soils determinations were also made on some of the runoff samples. As might be expected, a considerable amount of sand and silt is washed off the streets. The maximum suspended solids concentration found was 3852 mg/l. Of the approximately one dozen BOD determinations of street runoff, most were in the range of 20 to 30 mg/l, although three were about 100 mg/l. Samples of melt from a large snow pile along Lake Monoma showed chloride concentrations of 77.5 and 1130 mg/l. A sample of runoff from another snow pile had a chloride content of 285 mg/l.

Lake Wingra, located at Madison, is a spring-fed lake with a surface area of 0.5 sq mi. The lake, however, receives runoff from nearby streets. During the winter of 1959, the chloride content of the lake increased to 18 mg/l on March 19. In late July 1959, the lake was sampled at four stations lengthwise of the lake at both the 0.2 and 0.8 depths. The chlorine content of these samples ranged from 9 to 11 mg/l indicating it was fairly well dispersed and decreasing. In the spring and summer of 1965, the Lake Wingra outlet was sampled on three occasions with concentrations of 43, 41 and 40.5 mg/l being found on May 21, June 9 and July 1, respectively.

In early 1962, the Madison City Council requested their Rivers and Lakes Commission to make a study regarding the effects on the Madison lakes of the chemicals used for deicing roads. The Commission made an intensive study that spring and reported to the Council in June. Their data showed, that since the 1940-47 period, there had been a rise in chloride concentrations in Lakes Mendota, Wingra and Monona, but a decrease was found in Lakes Waubesa and Kegonsa. Comparisons of concentrations found in the lakes in the spring of 1962, with those of 1940-47, are given in Table 3.

TABLE 3

MADISON LAKES CHLORIDE CONCENTRATIONS (mg/l)

Lake	1940-47 Range, Yearly Average	1962 Range, Individual Samples
Mendota	2-3	5-10
Wingra	4-5	6-14
Monona	6-12	13-15
Kegonsa	29-38	10
Waubesa	34-57	14

The lower concentration in Lakes Waubesa and Kegonsa resulted from diversion of Madison's treatment plant effluent around the lower lakes beginning in December 1958. Their conclusions indicated that, although the use of chemicals had raised the chloride concentrations in the upper Madison lakes, it was not felt that these values were detrimental to aquatic life (11).

It is interesting to compare the findings on Lake Wingra over the years. During 1940-47, about 10 samples were taken yearly. Chloride values ranged between 2 and 17 mg/l but the annual averages were nearly uniform with a value of either 4 or 5 being reported for each of the 8 years. Although the chloride level currently in Lake Wingra is apparently not significant insofar as water uses are concerned, it represents a quadrupling since 1959, and an eightfold increase since the 1940-47 series of samples. In 1965, a sample was obtained from a spring discharging to the west side of Lake Wingra and it contained a chloride concentration of 18.5 mg/l. This indicates chloride is now getting into the lake from a shallow aquifer in addition to drainage from streets.

Surface water samples are generally taken once a month at 37 locations about the state as part of Wisconsin's stream monitoring program. Review of the data, for the years 1961-64 (19), shows several significant features and trends. During the period the average annual chloride concentration increased each year at 18 of the 37 stations. The 1964 data show that 11 of the 12 stations near the east and south perimeter of the state from Green Bay to Beloit had average chloride concentrations of more than 10 mg/l. In contrast, only 2 of the 25 other stations had averages of more than 10 mg/l. One of these stations, the Wisconsin River near Necedah, had an average 1964 chloride concentration of 11.3 mg/l and the other, the Montreal River near Saxon, averaged 55.6 mg/l. For the 1961-64 period the latter station, which was receiving mine pumpage, exhibited the highest over-all chloride content. Mining in the Hurley area ceased early in 1965. Since that time, there has been a substantial decrease in the Montreal River's chloride concentration.

The highest chloride value found in a surface water was 370 mg/l. This was in the Milwaukee River north of Milwaukee at Brown Deer Road on March 6, 1963. Further chemical determinations on the sample indicate that a "slug" of calcium chloride was involved. The next highest chloride value found at this station during the 4-yr period was 46.5 mg/l. Consideration was given to correlating chloride concentrations with stream runoff. There has been a general decrease in runoff rates from 1961-64. However, conflicting factors interfere with interpreting the results. At lower runoff rates there is less dilution water available and, therefore, higher concentrations would be expected but lower runoff rates from the roads would indicate less chlorides are being flushed into streams.

RELATED PROBLEMS

A few years ago well pollution problems by chlorides were reported in Michigan. Runoff from chemically treated roads and seepage from uncovered salt and salt-sand stockpiles were involved (20). New items were also noted concerning pollution of water supplies in some eastern states by chlorides. Inquiry was made of New Hampshire officials regarding the problem in their state. They supplied a comprehensive report (21).

The State of New Hampshire has been using chlorides for winter highway maintenance since the mid-1940's, and up to now have used more than one million tons on approximately 3800 miles of roads. In 1953, four water supplies that had been adversely affected by chlorides were replaced with new wells. Since that time, increasing numbers of replacements have been made yearly with 37 being provided in 1964. Most of the well pollution problems have been of shallow-dug wells within 100 feet of a chloride source. The normal chloride content of New Hampshire groundwaters is less than 10 mg/l which simplifies tracing of chlorides. Occasionally affected wells in that state revealed chloride contents of up to 3500 to 3800 mg/l. Over 90 percent of the replacement wells were of drilled construction and produced a satisfactory supply. A calculation shows that the average chloride application rate in New Hampshire for the past 20 years was somewhat over 13 tons/mi. Last winter's application rate was about 31

tons/mi. Their over-all application rate is substantially higher than that applied to Wisconsin state highways. A news clipping (22) indicated that 200 wells in New Hampshire had been involved and the cost to the state of replacing them amounted to more than $200,000. Another news item (23) indicated that the State of Massachusetts used about 100,000 tons of salt during the winter of 1964-65, but did not reveal the amount of miles involved. Groundwaters there near some highways were reported to have chloride concentrations approaching the limit of 250 mg/l.

From the standpoint of well pollution problems, Wisconsin is in a better position than New Hampshire. First of all, our chloride usage has not been as high and second, but of more importance, is the adoption and enforcement of Wisconsin's Well Construction Code which reduces the danger from surface pollution. Other factors in our favor would include public water supplies serving many of our suburban areas and small villages and probably a further set-back of homes from highways in Wisconsin.

The use of chlorides in Wisconsin is not without hazard to well water supplies. In 1960, a group of five wells were affected by leaching from a sand-salt stockpile. The area involved is underlain with limestone, and groundwaters used for supplies normally have less than 12 mg/l of chloride. Table 4 is a summary of the conditions and findings (24).

In 1965, a new well was constructed near a salt-sand stockpile in the southeast part of Wisconsin. Initially, 75 ft of casing was placed in the well, but the water was too salty to drink. A liner was placed in the well to 110 ft and then the water reportedly became potable (25). A high chloride sample was recently investigated and traced to a defective water softener. The well was satisfactory but there was a chloride content of 2090 mg/l in water from the softener (26).

In addition to shallow-dug wells, it would appear that driven point supplies located in previous sand and gravel areas would be susceptible to chloride pollution from highways. Surface water runoff rates would tend to be higher during cold weather with frozen soil and little vegetation. Under such conditions more chlorides would reach surface waters and less seep into groundwaters. Where storm sewers are available, practically all the street runoff discharges directly to surface waters.

During the winter of 1958-59, wildlife mortalities occurred in Wisconsin which were attributed to salt poisoning from the sodium chloride used for deicing highways (27). In a 40-mi radius of Madison, salt poisoning was diagnosed in wild rabbits, pheasants, a quail and a pigeon. Additional reports were received of similar cases, mostly in rabbits. The gizzard contents of the affected quail were blue-stained from insoluble ferric ferrocyanide used with the salt. However, this additive was not implicated. The symptoms were produced experimentally by single doses of 3 grams of sodium chloride to adult pheasants and rabbits weighing from 1100 to 1400 grams each. This dosage usually produced death within 24 hr in the test specimens, particularly when water intake was limited, and the test specimens showed similar disorders as those in naturally occurring cases. It was believed that the heavy snows and cold weather of that winter accentuated the problem by creating "salt hunger" and restricting water intake.

TABLE 4

POLLUTION OF WELLS FROM A SAND-SALT STOCKPILE

Well	Type	Casing Depth	Distance From Salt-Sand Pile (ft)	Well Chloride (mg/l)
A	6-in. drilled	42 ft	40	1345
B	4-in. drilled	30 ft	200	172
C	Drilled	?	300	18.5
D	Dug	To rock	400	24
E	6-in. drilled	50 ft	600	186

ADDITIVES

Various substances may be added to rock salt and calcium chloride to prevent caking, inhibit corrosion and for marking. The chlorides used for deicing are comparatively innocuous but what about the additives?

Previously mentioned in this report was the additive ferric ferrocyanide, or Prussian blue, $Fe_4[Fe(CN)_6]_3$, which was not considered involved in the wildlife mortalities. In 1959, rock salt thus treated was added to water to obtain an over-all concentration of 9600 mg/l of the commercial grade deicer. Blunt-nosed minnows did not appear to be affected at this concentration during a 48-hr test period. Ferric ferrocyanide is insoluble in water and does not release cyanide upon acidification. Prussian blue, or Berlin blue as it is sometimes called, is used as a laundry bluing agent. At one time, it was used as a tonic in doses of 3 to 5 grains (0.20 to 0.32 grams), repeated several times daily [28].

Another ferrocyanide, that of sodium, is sometimes added to rock salt as an anticaking agent to prevent the crystals from sticking or freezing together. Sodium ferrocyanide's common name is Yellow Prussiate of Soda and its chemical formula is $Na_4Fe(CN)_6 \cdot 10H_2O$. It is soluble in water, but little other information appears to be available regarding properties we are interested in. However, a sodium compound will often react similar to its potassium counterpart. Potassium ferrocyanide, or Yellow Prussiate of Potash, is also soluble in water. Insofar as ingestion is concerned, potassium ferrocyanide is practically non-toxic; but where the stomach is highly acidic, enough cyanogen may be split off to exert a posionous effect [28]. Although reports indicate that 2000 mg/l of potassium ferrocyanide is not toxic to fish, extensive mortalities have occurred where the initial concentration was only 1 to 2 mg/l because of photo-decomposition and release of cyanide [29].

Tests were conducted at the State Laboratory of Hygiene to determine if sodium ferrocyanide would also release cyanide. A solution of sodium ferrocyanide, initially containing 15.5 mg/l, after ½-hr exposure in sunlight contained approximately 3.8 mg/l of cyanide; this concentration remained fairly constant on subsequent checks. There was some deterioration of a similar sodium ferrocyanide solution not so exposed but the reaction appears to be triggered by sunlight [30].

Cyanide has been shown to be toxic to fish life in concentrations of 0.1 to 0.3 mg/l [6]. The presence of cyanide in a concentration exceeding 0.2 mg/l constitutes reason for rejection of a water supply [7]. If sodium ferrocyanide were used as an additive at a rate of 2 lb/ton of salt, and assuming that the amount of cyanide released is equal to about one-fourth the additive's concentration, an 800-mg/l concentration of rock-salt deicer would present a hazard to fish life and water supplies because of the accompanying cyanide. This is equivalent to about 500 mg/l of chloride, a value which is frequently exceeded in road runoff but to our knowledge has not been exceeded in surface waters even where little dilution was available. An estimated one-half to two-thirds of the rock salt used in Wisconsin for deicing is treated to prevent caking.

In Michigan, during the winter of 1955-56, a chromium base rust inhibitor was added to calcium chloride for use on roads. Fortunately the hazard was recognized and the practice promptly discontinued. Chromium-containing ions may move readily through the soil and sometimes are involved in well pollution problems [20]. Hexavalent chromium in concentrations exceeding 0.05 mg/l constitutes grounds for rejection of a water supply [7].

For the past 15 years, Calgon, Inc., has been marketing a corrosion inhibitor, Banox, for mixing with salt. The additive is sodium hexametaphosphate and cost of the inhibitor adds from $3.00 to $4.50 per ton of salt. About 2 years ago, Cargill, Inc., came out with an additive, Carguard, said to contain agents providing an electrical and physical barrier to corrosion. The material is mixed at the mine and its cost adds an extra $4.00 to the salt's base price [31, 32]. Carguard contains sodium chromate, a hexavalent form of chromium. A concentration of 0.4 percent of sodium chromate in salt will result in a chromium to chloride ratio of 0.002; a hexavalent chromium concentration of 0.05 mg/l would be reached at a chloride content of 25 mg/l. A water supply influenced by runoff or seepage from chromate-treated salt would be

adversely affected by the chromium long before the chloride became a problem. Sodium hexametaphosphate, which is the effective agent used in Banox, can act as a nutrient. Use of this additive with salt at a rate of 1 percent will result in runoff containing about 1 part of phosphorus per 200 parts of chloride.

NITROGEN AND PHOSPHORUS DEICERS

Several nitrogen and phosphorus compounds have been and are being promoted as deicers. This is unfortunate from the standpoint of future surface water quality. Nitrogen and phosphorus are key nutrients and over-fertilization with these can result in excessive amounts of algae, rooted aquatic plants and other nuisance conditions. Sawyer and associates (33), after a study of southeastern Wisconsin lakes, indicated that frequent nuisance algae blooms would develop in lakes where the average annual concentrations of inorganic nitrogen and phosphorus exceeded 0.3 and 0.015 mg/l, respectively.

A noncorrosive mixture, CD-110(64), for the chemical removal of ice and snow at airports has been patented. Its patent indicates 22-29 percent urea, 71-78 percent ammonium nitrate and up to 2 percent of various sodium phosphates. Another formulation for runway deicing consists of 75 percent tripotassium phosphate and 25 percent formamide. The potential market for a runway deicer is estimated in tens of millions of pounds per year (34).

During the past few years an increasing number of stores have been noted handling chemical deicers. These are generally packaged in small plastic bags and are being promoted for use on sidewalks and driveways. Typically, the deicer formulation is not shown. The majority probably are calcium chloride but some of them are ammonium sulfate, some contain ammonium nitrate and one contains potassium pyrophosphate plus formamide. Warnings concerning damage to concrete surfaces by the aforementioned ammonium compounds have been issued by the Portland Cement Association and others (35, 36, 37). The extent of their use was not determined; however, with the increasing number of retail outlets marketing deicers this source of nutrients could become significant in a short time. Ammonium nitrate and ammonium sulfate contain 35 percent and 21 percent, respectively, of inorganic nitrogen.

OTHER DEICERS

Brief mention will be made of other deicers for more or less specialized uses. Their cost would probably prohibit extensive use. Some of the alcohols are used with gasoline to absorb water and melt ice. These and also ethylene glycol are sometimes used on small surfaces such as windows and windshields to clear ice. The quantities reaching surface waters now are probably insignificant. If substantial amounts were involved it is likely that the water's dissolved oxygen would be reduced and fish life jeopardized.

Ethylene glycol, methanol, ethanol and isopropyl alcohol have increasing biochemical oxygen demands (BOD's) increasing from 70 to 133 percent of the substances weight compared with 9 percent for urea (38). In sharp contrast, untreated sewage has a BOD of about 0.02 percent. Why might the BOD of a deicer be significant? A normal surface water has a dissolved oxygen content of up to 14 ppm or mg/l. One pound of a material with a BOD of 100 percent can utilize all the dissolved oxygen in about 70,000 lb of water. Fish and other forms of aquatic life require oxygen to live and propagate. Dissolved oxygen concentrations of less than 5 mg/l can interfere with fish propagation and with less than 3 mg/l fish may suffocate.

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Addendum

CORROSION

The Bell and Chicago Telephone Companies reported corrosive failures of underground cables and transformers near where deicing salts were used. The National Association of Corrosion Engineers studied the chloride content of manhole waters in Buffalo, New York. A series of 7 samplings over a $3\frac{1}{2}$-yr period were made at 25 locations. Of the 175 samples, 74 had chloride concentrations of more than 1000 mg/l. In 1965, the Milwaukee Water Engineering Division checked the chloride content of groundwaters near buried water mains. April and July chloride averages were 225 and 170 mg/l near streets that had been routinely deiced with salt compared with 10 mg/l in untreated areas. Concern was expressed about corrosive damage to water pipes and the substantial shortening of their useful life (38).

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Groundwater Contamination by Highway Salting

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ABRIDGMENT

•THIS is a brief discussion of the phenomena involved in groundwater contamination by highway salting as understood at this time.

Of the salt applied to the highways a part eventually lodges in or on nearby soil. Subsequent rainfall and snowmelt that enter the ground carry some salt down to the water table in waves or pulses and inject it into the continuous slow underflow of groundwater in the saturated zone below the water table. In the saturated zone, the salt moves laterally along with the groundwater, which in general ultimately discharges into surface streams.

In shallow unconfined aquifers in unconsolidated relatively permeable materials, the chloride concentrations in groundwater near salted highways fluctuate strongly, reflecting the interplay between surges of salty water carried down from the soil above and continuous flushing and dilution by laterally moving groundwater in the zone of saturation. At present it appears that under these conditions the fluctuations are cyclic annually, and that generally the chloride content increases only until a balance is reached between "salt recharge" and the continuous flushing and dilution by groundwater. The balance attained varies from place to place; generally it is such that the chloride concentration is much less than 250 ppm (hence undetectable by taste) during the entire year, but in some places it exceeds that figure at peak times or throughout the year. Where the chloride content continues to increase (say to 1000 or more ppm), fortuitous combinations of circumstances are responsible.

Effect of Sodium Chloride on Grasses for Roadside Use

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More than 24,000 lb of sodium chloride per mile of four-lane highway have been used per year for ice removal on some sections of Interstate 80 in Iowa. Salt applied at this rate during the winters of 1963-64 and 1964-65 affected median and foreslope soil structure and prevented satisfactory establishment of grass cover. Injury to grass seedlings and established turf has been greatest on heavy soils with little organic matter—i.e., glacial till. Soluble salt determinations made on soil samples taken along I-80 indicate concentrations of sodium chloride sufficiently high to restrict grass growth up to 10 ft from the pavement. Kentucky 31 fescue, slender wheatgrass, intermediate wheatgrass, western wheatgrass, Russian wild-rye and reed canarygrass have enough seedling vigor for rapid establishment and enough tolerance to clipping at a 3-in. height to be used effectively on roadsides. Of these grasses, Kentucky 31 fescue and western wheatgrass are the most salt tolerant. Up to about 600 ppm sodium chloride stimulated growth of all grasses tested, but injury became evident and increasingly more pronounced as salt levels increased from 1000 to 5000 ppm. Of the 10 grasses studied, Kentucky 31 fescue is best suited for use where roadside soils are contaminated by salt.

•SHOULDER and median areas and foreslopes receive nearly all the runoff water from adjacent pavements. Use of salts as deicers during winter months has increased in recent years, and sodium chloride used for this purpose has been correlated with problems in establishing and maintaining vegetation on roadsides in Iowa. The purpose of this investigation was to determine the extent of salt contamination of foreslopes and ditch areas along I-80 in Johnson County, Iowa, and to evaluate salt tolerance and suitability for roadside use of 10 coarse-textured grasses. Four tests were conducted:

1. Soil samples were analyzed to determine extent of salt contamination;
2. Salt tolerance of grasses was evaluated by treating turf with varying rates of sodium chloride;
3. Salt tolerance of grass seedlings and rate of turf establishment were determined under field conditions; and
4. Foliar and root development and tolerance of grasses to clipping were evaluated under controlled conditions.

<center>TEST 1</center>

Materials and Methods

Applications of sodium chloride totaled 12,400 lb per mile per 2 lanes during the 1963-64 winter and 12,485 lb during the 1964-65 winter on I-80 in Johnson County.

Figure 1. Salt accumulation in the soil of this median section of I-80 prevented the establishment of turf from seedings during fall 1964 and spring 1965.

Attempts to establish turf on roadsides in this area were unsuccessful during fall 1964 and spring 1965 (Fig. 1), and salt contamination of soil was considered a likely cause of poor seedling stands. To determine salt content of these soils, samples were taken from six areas with differing runoff patterns from the pavement. Eight samples were collected at each area representing soil conditions along foreslopes and ditch bottoms. Each sample consisted of 5 cores taken to a 3-in. depth. Samples were obtained in January and again in early April. Soluble salt readings were obtained from the samples by measuring the conductivity of a 1:2 soil extract on a Wheatstone bridge (2).

Results

There were high concentrations of salt where water ran from pavement onto fore-slopes. Conductivity readings varied from 150 to 225 mhos x 10^{-5} within areas up to 10 ft from the pavement. Soil conductivity readings in ditch bottoms varied from 48 to 57 mhos x 10^{-5}. These soils consisted of from 54 to 68 percent sand and gravel, 16 to 26 percent silt and 16 to 20 percent clay. Where physical properties of soils are more favorable for plant growth than these, a reading of 100 mhos x 10^{-5} is sufficient to reduce vegetative development. In general a reading of this order is equivalent to about 2000 lb sodium chloride per acre furrow slice (2) or about 1000 ppm sodium chloride. Thus, excessively high levels of sodium chloride existed along foreslopes and median areas tested. Data indicated that about 50 percent of the salt applied to the pavement may have been removed by traffic, about 25 percent was carried off in surface water, and about 12 percent leached through the soil. The remainder, distributed through the top 3 in. of soil, was equivalent to from 1500 to 2500 ppm sodium chloride.

TEST 2

Materials and Methods

Ten coarse-textured grasses (Table 1) were planted in $3\frac{1}{2}$-in. plastic pots filled with a soil consisting of 81 percent sand, 8 percent silt, and 11 percent clay. Grasses were seeded on March 1 at a calculated rate of 8 live seeds per square inch and clipped weekly at a 3-in. height for 3 months before sodium chloride treatments were made (Table 2). Salt was applied in 50 ml of water, and all pots were irrigated to field capacity. A randomized complete block design with four replications was employed to evaluate salt tolerance of established turf grown on this sandy soil under optimum moisture conditions.

TABLE 1

TEST GRASSES

Common Name	Scientific Name
Kentucky 31 fescue	Festuca arundinacea
Russian wild-rye	Elymus junceus
Reed canarygrass	Phalaris arundinacea
Buffalograss	Buchloe dactyloides
Sand lovegrass	Eragrostis trichodes
Side-oats grama	Bouteloua curtipendula
Blue grama	Bouteloua gracilis
Slender wheatgrass	Agropyron trachycaulum
Western wheatgrass	Agropyron smithii
Intermediate wheatgrass	Agropyron intermedium

TABLE 2

SALT TREATMENT—TEST 2

Level	ppm NaCl	Equivalent lb of NaCl per Mile of 2-Lane Highway
No Salt	0	0
A	210	4,000
B	631	12,000
C	1262	24,000
D	2525	48,000
E	5050	96,000

TABLE 3

PERCENTAGE DRY WEIGHT OF FOLIAGE FROM TEN GRASSES—TEST 2

Grasses	Mean Percentage Dry Weight in Grams*
Kentucky 31 fescue	40.8 a
Sand lovegrass	48.5 b
Western wheatgrass	49.8 c
Slender wheatgrass	51.2 d
Side-oats grama	51.6 e
Buffalograss	51.8 f
Russian wild-rye	53.7 g
Intermediate wheatgrass	54.2 h
Blue grama	57.9 i
Reed canarygrass	60.6 j

*Means not having letters in common are significantly different at the .01 level according to Duncan's multiple-range test. Low percentage dry weight indicates less salt injury.

TABLE 4

CONCENTRATION OF SALTS USED IN SOLUTION CULTURE—TEST 4

Salt	Molarity
$(NH_4)_2SO_4$	0.18×10^{-3}
$Ca(NO_3)_2 \cdot 4H_2O$	0.53×10^{-3}
$K_2HPO_4 \cdot 3H_2O$	0.80×10^{-3}
$CaSO_4 \cdot 2H_2O$	2.07×10^{-3}
$MgSO_4 \cdot 7H_2O$	0.79×10^{-4}
$Fe_2(SO_4)_3$	0.11×10^{-5}
H_3BO_3	0.90×10^{-6}
$MnSO_4 \cdot H_2O$	0.45×10^{-6}
$ZnSO_4 \cdot 7H_2O$	0.15×10^{-6}
$CuSO_4 \cdot 5H_2O$	0.16×10^{-7}
$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	0.16×10^{-7}

TABLE 5

DRY WEIGHT SOD AND ROOT YIELDS OF TEN TEST GRASSES GROWN IN SOLUTION CULTURE—TEST 4

Grasses	Mean Grams Dry Weight*			
	Sod		Roots	
Kentucky 31 fescue	8.0 a		5.5 a	
Intermediate wheatgrass	6.3	b	2.5	b
Reed canarygrass	5.3	bc	2.2	b
Russian wild-rye	4.4	cd	1.3	b
Sand lovegrass	2.3	ef	1.0	b
Side-oats grama	3.3	de	0.7	b
Slender wheatgrass	2.1	ef	0.6	b
Buffalograss	1.2	fg	0.4	b
Western wheatgrass	0.2	g	0.1	c
Blue grama	0.1	g	0.1	c

*Means not having letters in common are significantly different at the .05 level for roots and at the .01 level for sod according to Duncan's multiple-range test.

Results

In general, salt tolerance decreased in the order Kentucky 31 fescue > sand lovegrass > western wheatgrass > slender wheatgrass > side-oats grama > buffalograss > Russian wild-rye > intermediate wheatgrass > blue grama > reed canarygrass (Table 3). Tolerances differed among the grasses to increasing levels of sodium chloride (Fig. 2). All grasses had increased foliar growth at salt levels through 631 ppm (level B). Sodium chloride applications at 2525 ppm and 5050 ppm (levels D and E) caused varying amounts of injury depending on the grass. Kentucky 31 fescue was tolerant of 2525 ppm sodium chloride and only slightly injured at the 5050 ppm level. Reed canarygrass was completely killed at both 2525 and 5050 ppm levels. Intermediate wheatgrass and slender wheatgrass were severely injured from 1262 ppm through 5050 ppm sodium chloride.
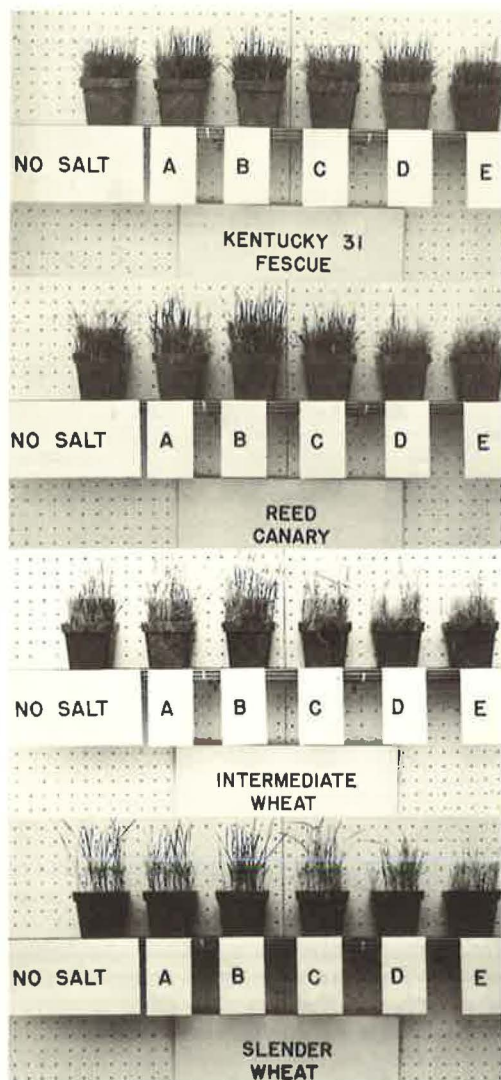
Figure 2. Foliar response of selected grasses to six levels of NaCl applied to a light-textured soil. Note increased growth of foliage at low salt levels (A = 210 ppm and B = 631 ppm) in all four grasses. Kentucky 31 fescue was most salt tolerant; reed canarygrass, intermediate wheatgrass, and slender wheatgrass were severely injured at high salt levels (D = 2525 ppm and E = 5050 ppm). Slender wheatgrass failed to develop a dense stand of turf.

TEST 3

Materials and Methods

Ten coarse-textured grasses (Table 1) were planted in field plots where the soil consisted of 37 percent sand, 37 percent silt and 26 percent clay. Grasses were seeded at a calculated rate of 17 live seeds per square inch. Sodium chloride treatments equivalent to the first 5 levels used in Test 2 (Table 2) were made at the time of seeding on May 13. The plot area was watered to create conditions favorable for seed germination. A randomized complete block design with 4 replications was employed to evaluate rate of seedling establishment and salt tolerance of seedlings on this high silt and clay soil.

Results

Kentucky 31 fescue, intermediate wheatgrass, slender wheatgrass and western wheatgrass established most rapidly (within 2 weeks). Reed canarygrass and Russian wild-rye were intermediate and sand lovegrass, side-oats grama, blue grama and buffalograss were slowest (Fig. 3).

Dispersal and deflocculation of the heavy-textured soil particles were noted at the 1262 and 2525 ppm sodium chloride levels. Effects of salt on turf establishment were evident only at the 2525 ppm level. Slower starting grasses were injured more than were the rapidly establishing wheatgrasses and Kentucky 31 fescue (Fig. 4).

TEST 4

Materials and Methods

Ten coarse-textured grasses (Table 1) were planted on specially constructed solution culture lids (1, 8, 10). Grasses were seeded on January 16 at a calculated rate of 100 live seeds per lid and established on a nutrient solution containing adequate but low amounts of all essential elements (Table 4). Solutions were changed weekly and all grasses clipped at a 3-inch height. A completely randomized design with three replications was used in this experiment to evaluate rate of seedling establishment, foliar and root growth characteristics and tolerance to defoliation.

Figure 3. Kentucky 31 fescue, slender wheatgrass, intermediate wheatgrass and western wheatgrass established most rapidly. Reed canarygrass and Russian wild-rye were intermediate and sand lovegrass, side-oats grama, blue grama and buffalograss were slowest. Note salt-treated plot (top) shows lighter color of deflocculated soil.

Figure 4. Slender wheatgrass (bottom) was more salt tolerant than Russian wild-rye (middle). Blue grama (top) was injured most by salt applications at 2525 ppm.

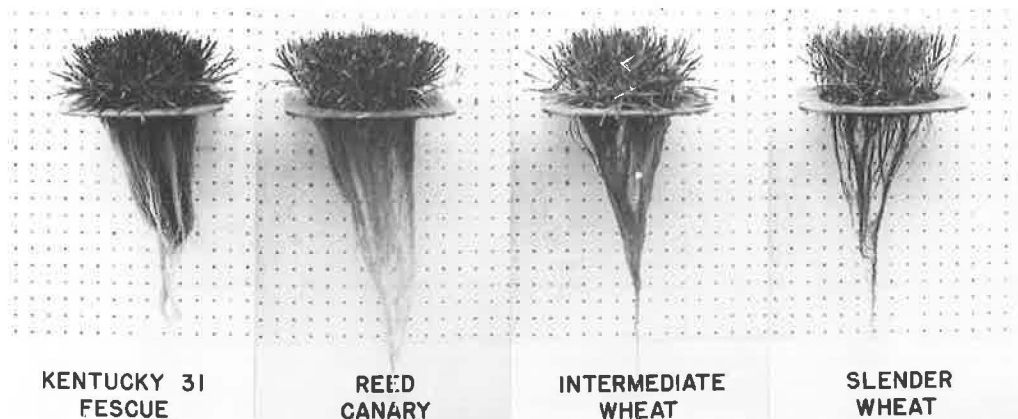| KENTUCKY 31 FESCUE | REED CANARY | INTERMEDIATE WHEAT | SLENDER WHEAT |

Figure 5. Sod and root development of Kentucky 31 fescue were superior to reed canarygrass and intermediate wheatgrass. Slender wheatgrass produced the least sod and roots.

Results

Kentucky 31 fescue produced more sod and roots than any of the other grasses (Table 5). Intermediate wheatgrass, reed canarygrass and Russian wild-rye developed good sod cover but had less roots. Slender wheatgrass produced a thin sod cover and a weak root system (Fig. 5). Buffalograss, western wheatgrass and blue grama failed to develop satisfactory stands. All grasses tolerated regular defoliation at a 3-in. height except intermediate wheatgrass, which declined in foliar production with continued clipping.

DISCUSSION AND CONCLUSION

The Johnson County I-80 area soils were classified according to pH and conductivity readings of soil extracts as nonsaline-alkali (containing sufficient exchangeable sodium to interfere with plant growth but not containing appreciable quantities of other soluble salts). Replacement of exchangeable sodium is required for correction of this soil condition. These soils had a dense, blocky, single-grain structure, which is hard to till when dry, and had a low hydraulic conductivity when wet. Soil aggregates were not stable and slaked down in water so that pores became filled with fine particles. Poor physical condition of these soils and toxic levels of sodium chloride were responsible for turf establishment failures. Salt contents of these soils accounted for only about one-eighth of the total sodium chloride applied to the pavement.

Of the 10 test grasses, western wheatgrass is listed by the U. S. Salinity Laboratory as among the most salt tolerant (14). Forsberg (4) has rated slender wheatgrass among the most tolerant in natural saline soils, particularly under dry conditions. McKenzie and Bolton (11) found that slender wheatgrass, tall fescue, and reed canarygrass were well adapted in saline areas of Saskatchewan. In Test 2, where soil was sandy and moisture conditions were favorable, reed canarygrass was injured more than might be expected. It is likely that sodium chloride alone, without a balancing effect from other salts, was responsible for this increased injury.

Harris (5) found the relative toxicity of soluble salts in the order of $NaCl > CaCl_2 > KCl > MgCl_2 > KNO_3 > Mg(NO_3)_2 > Na_2CO_3 > Na_2SO_4 > MgSO_4$. Harris and Pittman (6) compared the relative toxicity of sodium chloride at concentrations of 0 to 4000 ppm and Na_2CO_3 and Na_2SO_4 at concentrations up to 10,000 ppm at moisture levels ranging from 20 to 32 percent. Up to 1000 ppm, all salts were beneficial, but above 1500 ppm, all salts were increasingly toxic, chloride being the most toxic, sulfate the least and carbonate intermediate. The effect of increasing concentration of salt on vegetative development is usually recognized as a reduction in rate of growth, which may not be accompanied by visible symptoms of injury. Eaton (3) noted that, under marginal con-

ditions of salinity and in the absence of detectable symptoms of salt injury, it is difficult to recognize salt effects under field conditions. The first physiological reaction to increased salt concentration is reduced intake of water into the roots (7, 9, 12). Thus, if water is lacking in the root zone, injury is more pronounced than where adequate moisture exists. Initial injury usually starts with a tip burn and is followed by progressive involvement of additional tissue extending along the margins of the blade until the entire surface becomes brown and necrotic.

Although salt tolerance of a mature turf is important, seedling tolerance and rate of seedling development is critical in areas where new highways are being built. Climate places restrictions on duration of seeding operations which limit the amount of roadside establishment each year. Highways may be open for traffic and pavements salted before seeding roadsides. Thus, salt contamination of soils may be more important in establishing new turf than in maintaining older stands.

Although salt tolerance of sand lovegrass, side-oats grama and buffalograss is relatively high, slowness to establish restricts usefulness of these grasses except in mixtures with more rapidly developing types. Even so, slower developing grasses appear more sensitive to salt injury than grasses with higher seedling vigor.

Following establishment of roadsides, turf must withstand at least infrequent clipping at a 3- to 4-in. height. Since defoliation influences sod and root production (13), it is important that mowing practices do not unduly restrict sod and root development. Of the grasses found most salt tolerant, Kentucky 31 fescue produced better sod and roots.

Of the 10 grasses tested, Kentucky 31 fescue possesses the most desirable physiological and best overall growth characteristics for use on roadsides where soils are contaminated by salt.

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