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Edward Sucoff

EFFECT OF DEICING SALTS ON WOODY VEGETATION ALONG MINNESOTA ROADS

University of Minnesota, College of Forestry
in cooperation with
Minnesota Highway Department and Minnesota Local Road Research Board

Investigation Number 636

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College of Forestry

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Final Report – 1975

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COVER PHOTO TOP

Interstate Highway I-94 in St. Paul following a snow storm. Driving surfaces are dry. Snow-ice mixture is plowed to edge. White on highway and on shoulder is salt.

COVER PHOTO BOTTOM

Red pine browned by spray-salt. East side of TH 65.

ABSTRACT

Information was collected on amounts of deicing salts used and methods of application. Planting practices and investment were also surveyed. Techniques are presented for the recognition of soil-salt and spray-salt damage using visual symptoms and chemical analysis of leaves and soils. Proof was obtained that salt causes much of the twig dieback in hardwoods and needle browning in pines observed along certain Minnesota roadways. The locations are defined where salt-spray and soil-salt damage are likely to be high, moderate, or low. Species are rated for their sensitivity to soil-salts and winter spray-salts. A brief history of salt damage in Minnesota is presented, and the seriousness of current damage is evaluated in terms of mortality, reduced growth and disfigurement, and increased maintenance costs. Seven ways to reduce salt damage are presented including a planting guide to match species to site. Future prospects are estimated for salt damage in Minnesota. A permanent plot system is described that will monitor build up in plant and soil sodium and chloride as well as changes in the vegetation caused by salt damage.

CONTENTS

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TABLES

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MAJOR FINDINGS AND RECOMMENDATIONS

A. The Investigation Either Confirmed Or Newly Established That Salt Is Responsible For Damage To Woody Plants Growing Along Many Minnesota Roads.

1. Along salted highways:
   a. damage originates from both salt spray (salt deposited aerially on branches, buds, and evergreen leaves) and soil salts (salt deposited in the soil occupied by the roots);
   b. salt spray is the major cause (except for Dutch elm disease) of twig dieback in deciduous trees;
   c. salt spray is the major cause of the very visible spring-browning of red, white, Scotch, and Austrian pines;
   d. salt spray reduces the growth, worsens the appearance, and lowers the economic value of trees;
   e. salt spray sometimes kills sensitive species like white pine, but otherwise does not kill many established trees or shrubs;
   f. salt spray may contribute to mortality of new plantings; and
   g. soil salts appear to have raised the pH to undesirable levels within 45 feet of certain roads.
2. Along city streets:
   a. soil salt causes marginal leaf scorch, leads to branch dieback, and possibly results in plant death;
   b. the exchange sodium percentage is above 13 in many soils; and
   c. spray salt damage is relatively unimportant now partly because tree crowns are above spray.
3. Drought and cold interact with salt to cause damage. In times of drought, damage is worse. Resistance to damage from cold is less in salt-treated trees, and salt-related cold damage may sometimes be responsible for some midwinter dieback.
4. Salt is not the only factor causing damage. Low fertility, rodents, and water stress also cause twig and leaf damage or reduce growth.

B. Methods For Recognizing And Diagnosing Spray-Salt Damage and Soil-Salt Damage Were Expanded And Adapted To Minnesota Conditions.

C. Locations Where Probability Of Salt Damage Is High Were Specified With Some Exactness.

1. Salt-spray damage increased with Average Daily Traffic (ADT) of the road and nearness to road. An estimate of salt-spray damage is given for each distance from roads of different ADT's.
2. Salt-spray damage was heaviest on the south side of roads and was greater downslope and at intersections.
3. Soil-salt damage was high in cities where salted snow is plowed into a pile around the base of trees within 5 feet of the road.
4. Soil-salt damage is high in cities at locations such as intersections or hills that are given heavy salt applications.
5. Soil-salt damage is high in cities and near highways where trees are in undrained basins that collect runoff from the road or plowed snow. The basin may be small such as the depression around the trunk in new plantings or large such as some median strips.

D. Species Capable Of Growing In Minnesota Were Rated By Their Relative Tolerance To Soil Salts And Spray Salts. Data Are From This Investigation And The Literature.

E. Seven Methods Of Reducing Salt Damage Were Considered, And Six Are Recommended For Use As Appropriate. Some Are Described Below.

1. These recommendations are made for reducing salt damage in new plantings.
   a. Carefully match salt tolerant species to high salt sites. A classification of highway locations according to likelihood of salt damage and a determination of the salt tolerances of various species are provided. Devote more time, money, and skilled manpower to the complex job of matching species to site in landscape design.
   b. Continue current efforts in planting high quality trees and shrubs using good techniques. Increased attention could be given to rodent protection and soil drainage problems.
2. These recommendations are made for reducing salt damage in established plantings:
   a. Maintain the trees in good health by whatever techniques are appropriate and economically feasible, including rodent protection, watering, fertilization, and remulching. Minnesota might consider the specific allocation of money to maintain the several million dollar investment in trees and shrubs.
   b. In city locations where soil salts are accumulating, experiment with soil amendments and water to remove them.
   c. Correct drainage problems that cause needless accumulation of salt. Ditches drained by surface water are not a problem.
3. These recommendations could reduce salt damage by controlling the amount of salt applied:
   a. continue to use the correct amount of salt for the job;
   b. maintain better control over spot salting situations, such as intersections;
   c. when possible, avoid piling salted snow on plants, e.g. at overpass intersections.
4. The final recommendation is to accept and live with salt damage, lower expectations of growth, and recognize the costs of extra maintenance or initial planting to override salt damage. Avoid planting on sites where salt damage is too severe to be minimized or lived with. It may also be necessary on some sites to remove existing plants.

F. A Plot System Was Established To Monitor The Buildup Of Sodium And Chloride In The Soil And Plants And To Keep Track Of Damage. Sixty-One Plots With 1132 Individual Trees Or Shrubs And 139 Soil Samples Are Involved.

G. An Opinion About The Seriousness Of Salt Damage Is Given.

1. Salt damage is currently most serious in three situations:
   a. the browning of red pine, white pine, and cedar;
   b. keeping in check recent deciduous plantings, particularly those within 60 feet of the highway; and
   c. reducing growth and vigor in localized areas of high soil-salt along city streets and highway medians.
2. Salt damage has the potential to become more serious along salted city streets.
   a. As elms are removed, new young trees will be subject to more spray damage and possibly the accumulation of soil-salts in planting holes. Furthermore, species intolerant of soil-salt are being planted.
   b. As trees age, they lose the ability to tolerate the stresses induced by high soil-salt, and boulevard trees in many communities are becoming overmature.
   c. A prolonged drought might occur and interact with soil-salts to produce mortality.
3. Compared with other current problems of roadside vegetation, salt damage is often not the most serious. Dutch elm disease is worse in the city. Low soil moisture, low fertility, and rodent damage are more important in many locations along the highway. It is the potential for future mortality, particularly in cities, that deserves the most attention.

INTRODUCTION

Deicing salts are used to provide a dry pavement for safe, high-speed traffic movement during winter months. Drivers of motor vehicles have insisted on safe, high-speed driving conditions within hours of each snow storm and continuously during the freeze-thaw cycles of winter (cover photo, top). The public highway departments have assumed the responsibility of providing these conditions.

Sodium chloride (NaCl) used alone or with sand is the most common deicing salt. In this paper, unless otherwise specified, the term salt means NaCl. The more expensive calcium chloride is necessary only during infrequent, extremely low temperatures.

As with other chemicals, deicing salts have costs beyond purchase and application. The corrosive effects of NaCl on metals and road surfaces are well documented. Most recently, mild concern to alarm has been expressed about the role of deicing salts in the eutrophication of lakes, poisoning of water supplies, and stratification of surface waters.

This investigation is prompted by still another cost of salt. NaCl has been labeled a major cause of damage to roadside trees and shrubs. The major objectives of the investigation were to clarify the nature of this damage and learn ways of minimizing it. This report completes and organizes the research information generated under Investigation 636, "Effect of De-icing Salts on Woody Vegetation along Minnesota Roads," a cooperative study between the Minnesota Highway Department and the University of Minnesota.

The investigation began in the winter of 1971/72 and concluded in June 1974. It includes 20 studies, interviews with many knowledgeable public officials, years of observing roadside vegetation, and a literature search of over 275 articles, many of which are listed in the Selected Bibliography.

The research during the investigation attempted to determine how much damage deicing salts did to roadside vegetation, and how much of the damage was caused by soil salts and how much by salt spray. The term "soil salt" refers to the NaCl in the soil. It interacts directly or indirectly with plant roots and is taken up by roots. The term salt spray or spray-salt refers to NaCl deposited aerially on the twigs, buds, and evergreen leaves. The research attempted to learn how best to diagnose the damage. It examined where along roads, and along what kinds of roads, the damage occurred. The tolerance to salt damage of woody species grown in Minnesota was rated. Many methods to reduce salt damage were explored. Finally, the future impact of salt damage was estimated, and a long-term plot system was established to monitor it.

The report of these results is divided into four chapters, detailed in the Table of Contents. Chapter I provides background data; Chapter II presents information on the occurrence, diagnosis, and seriousness of salt damage; Chapter III gives methods of minimizing or living with it; and Chapter IV discusses the future of salt damage along Minnesota roads. Appendix A briefly describes the methods used in each study, and appropriate studies are referred to in the text.

CHAPTER I. BACKGROUND

The data in this chapter, unless otherwise stated, were provided by the appropriate state, county, or city agency.

SALT USAGE

Amount and Chemistry. Tables 1 and 2 show the use of salt in Minnesota by various highway departments. The use varies from year to year depending on weather, the increase in road miles and traffic, and the salt applier's goals and methods. The use of salt rose dramatically during the 1960's, peaking about 1968 to 1971. Since then, more careful control during application, increased use of abrasives, and more favorable weather have reduced the use of salt.

Most deicing salt used in Minnesota, according to one major supplier, Cargill Inc., is 98.5 percent sodium chloride, 1.2 percent calcium sulfate, 0.1 percent magnesium chloride, and 0.2 percent rock. Some suppliers add 0.02 percent sodium ferrocyanate as an anticaking agent.

Table 1. Salt use in tons by county and municipal highway departments (gross estimates)

Year	Hennepin County	Ramsey County	Washington County	Minneapolis	Roseville	St. Paul
1970-71	13,000	4,655	–	–	–	22,500
1971-72	–	3,450	–	–	–	–
1972-73	8,000	3,450	1,200	16,000	120	13,500
1973-74	8,000	–	–	–	120	–

– no data available

Table 2. Salt use by Minnesota State Highway Department, 1960-74

Date	Statewide	Area 9A	Area 5A	Area 5A
Calendar year	(tons)	(tons)	(tons)	(tons/lane mile)
1960	15,013			
1961	14,954			
1962	23,484			
1963	29,658			
1964	61,232			
1965	76,479			
1966	112,937			
Winter				
1966-67	143,700	19,414	44,447	–
1967-68	91,734	11,483	20,822	12.84
1968-69	–	–	47,804	29.47
1969*	204,205	48,090	59,395	–
1969-70	172,720	26,868	44,965	27.72
1970-71	148,712	25,487	37,845	23.35
1971-72	116,664	22,748	26,373	16.05
1972-73	92,343	23,483	22,417	13.58
1973-74	108,824	23,376	25,106	14.42
1974-75	–	22,127	31,200	17.35

*This is calendar year. No statewide data are available for winter of 1968-69.

Application Practices. The salting practices of the various agencies (state, county, and city) influence areas where salt damage occurs. Some of these practices, as related by agency personnel or agency literature, are described.

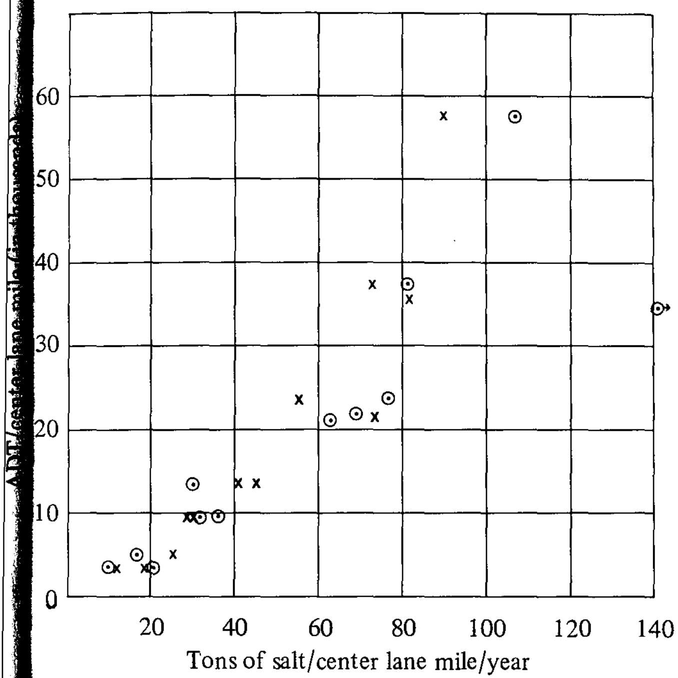
All agencies are governed by the 1971 Salt Usage Law which prohibits the use of salt on low average daily traffic (ADT) and low-speed roads, except in exceptionally hazardous circumstances.

Roads are maintained by the State of Minnesota Highway Department under a statewide system that calls for the use of plows, chemicals, and abrasives to provide specific levels of service according to the ADT of the road. The information below from Maintenance Area 5A defines the level of service for each road type.

Use of these guidelines in District 5A resulted in a close relationship between tons of salt per center-lane mile and ADT per center-lane mile (graph 1). Tonnage increased directly with ADT up to about 23,000 vehicles/day. Tonnage continued to increase with ADT above this point, but at a slower rate. The relationship found in graph 1 justifies the use of ADT in the investigation as an indirect measure of the amount of salt applied.

Like the state, Ramsey County bases salting decisions on ADT. Ramsey County used no pure salt during 1972/73 and 1973/74. An 11 percent mixture of salt in sand is used for most roads, and a 50 percent mixture is used on high ADT roads (such as Larpenteur Avenue, Silver Lake Road, and White Bear Avenue). This is a reduction from the practices before 1971/72 when a 25 percent mixture was used on most roads, a 50 percent mixture on high ADT roads, and pure salt on very high ADT roads. Salt is applied with the sand during the storm to prevent snow packing and to provide traction. At times, slag from NSP replaces the sand. After the storm, snow is plowed from the driving surface and winged off the shoulders. Maintenance is performed on 257 miles of county roads and 44 miles of village streets. Some snow removed from village streets is dumped into a gravel pit at Larpenteur Ave and Kent St.

Classification	ADT	Level of service	Coverage time (hrs.)
Urban commuter	Over 10,000	Bare pavement within 6 hours after termination of storm (12 hours for severe storms).	24
Rural commuter	2,000-10,000	Bare pavement within 24 hours after termination of storm. (On divided highways, left lanes should be half bare with sanded curves and hills before termination of snow removal effort.)	18
Primary	800-2,000	Intermittent bare pavement (compacted snow allowed in towns and sheltered areas).	18
Secondary	400-800	Two bare-wheel tracks and sanded hills and curves.	12
Secondary	250-400	Bare left wheel track and sanded hills and curves.	12
Secondary and frontage roads	Under 250 and gravel roads	Compacted snow is acceptable.	12



raph 1. Salt tonnage per center lane mile per year as related to average daily vehicular traffic (ADT) in Minnesota Highway Department Maintenance District 5A. Each point represents one subarea. X represents 1971/72; 0 represents 1972/73.

ennepin County also bases its salting on ADT. On all roads ith fewer than 7500 cars per day, sand is used with 5 percent lt mixed in to prevent freezing.

n roads with ADT more than 7500, such as County Road 62, ortland Avenue, and France Avenue, the road is cleared with underbody plow to get maximum snow removal. Plow eed is limited to keep snow as close to the roadway as posble. After plowing, pure salt is applied to the road with caliated spreaders at a rate not exceeding 250 pounds/lane mile. o salt is used around Lake Minnetonka, except on County oad 15.

or salting, Minneapolis is divided into three areas based on affic: The downtown loop and Lake Street, major arterial utes, and residential areas. In the downtown area, pure salt is pplied during the storm; the evening after the storm the reets are plowed and the snow is carted to snow dumps at 4th and Hiawatha or on Nicollet Island. Pure salt is also pplied during a storm on major arterial routes feeding into e downtown area (e.g., Portland Avenue or Nicollet Avue). These areas are later plowed with truck speed limited to ep the snow and salt on the boulevard. Residential streets e plowed and sanded at specific critical sites such as curves, lls, and intersections.

. Paul uses the same downtown loop, arterial route, and sidential street breakdown for salting procedures. Starting in e winter of 1973-74, the city seldom applies pure salt using instead a 50 percent salt, 50 percent sand mixture. This 50-50 mixture is applied during a storm in the loop area. Plowing then is completed the night after the storm. Snow is not removed unless there is a large accumulation and temperatures are so cold that the salt does not melt the snow. Main arterial streets, such as University Avenue, Snelling Avenue, Maryland Avenue and East 7th Street, also receive the same 50-50 mixture treatment. Other major streets receive a 25 to 30 percent salt mixture. Residential streets are plowed, and salt may be applied on hills, curves, and intersections. Plows are operated at reduced speeds.

The sampled smaller communities, Bloomington, Columbia Heights, Edina, and Roseville, do not apply pure salt. Streets are plowed after each storm, and sand with 5 to 10 percent salt is applied. Extra sanding occurs at intersections and on hills or curves.

All agencies take steps to keep stored salt from going into deep seepage or surface runoff.

PLANTINGS

Trees and shrubs are planted to enhance the aesthetics of the roadside corridor, stabilize slopes, reduce glare, and provide noise reduction and visual screening for nearby residents.

State Planting Practices. The state of Minnesota Highway Department has been the most active governmental unit in the roadside planting program. Table 3 shows the funds spent.

Before 1960, landscape plantings were installed by Department personnel. Starting in 1960, plantings were awarded to private contractors, with survival responsibility limited to a 60-day guarantee. Aesthetics were emphasized in landscape design and species selection, but limited attention was given species suitability to sites, quality of planting stock, planting method, or ease of roadside maintenance. The unfavorable survival results are well documented by Murphy *et al.* in *Landscape Planting Species Survival.*

Since 1966, improvements in contract specifications have led to increased survival. The guarantee period was extended to one growing season or 1 year. Current practices include appropriate watering, weeding, mulching, pruning, and guying by the contractor during the guarantee period. Detailed plans are drawn by the Landscape Design Section, Office of Environmental Services, in an effort to match species to site, and plantings are grouped on better sites to facilitate mowing and to improve growth. Most sapling trees are planted balled and burlaped (B&B) with increasing interest in large trees transplanted using tree spades. Shrubs are being planted more densely in large beds. Away from the high ADT roads, conifer seedlings are sometimes planted and larger wild stock is transplanted using tree spades.

Table 3. Cost of plantings by several agencies within the seven-county metropolitan area of the Twin Cities

Unit of government	Years	Amount (dollars)
Minneapolis, City of	1974	96,000*
St. Paul, City of	1974	120,000*
Minnesota State Highway Department	1961-1969	832,932
Minnesota State Highway Department	1970-1974	1,443,104

* Estimate for street trees

The species are selected by experience. Murphy lists the species used before 1968. A small number has been added or dropped since then. Research to screen ground covers is in progress (Investigation No. 634).

Federal matching funds pay most of the cost of planting along interstate highways. No matching funds are available for maintenance. Funds budgeted for planting along state highways do not include money for future maintenance.

County and Municipality Planting Practices. Neither Ramsey nor Hennepin County have done much roadside planting in the past; Hennepin County has planted some ash and basswood in scattered locations.

St. Paul currently is planting roadside trees to establish or maintain boulevard rows. Replacement of elms killed by Dutch elm disease is a major concern. Plans for 1974 included planting under an $80,000 capital improvement budget that contracted for planting of 2 1/2- to 3-inch B&B stock and a $40,000 elm replacement fund for 1 3/4- to 2-inch bare-root stock. The bare-root stock are grown and planted by the city. Care during the year after planting involves watering, staking, and pruning.

Minneapolis plants with objectives similar to St. Paul's. All trees are grown by the city and are planted bare-root in a mulched watering basin (Chap. II, Soil-Salt Damage). Estimated 1974 cost of growing and planting is $80 per tree; 1974 plans were to plant 1200 trees. During the 1st year, trees are watered; spot spraying is done in cases of heavy insect infestation. Species planted in St. Paul and Minneapolis include sugar maple, Norway maple, crimson king maple, Schwedler maple, red maple, pin oak, northern red oak, buckeye, Kentucky coffee tree, green ash, hackberry, imperial honey locust, little leaf linden, American basswood, radiant crab, and amur cork tree.

Post-Planting Maintenance. Post-planting maintenance of trees and shrubs along state highways is limited. This maintenance is not an identified item in Minnesota Highway Department District budgets. Pruning for safety is done. Little rodent control, guying, fertilizing, remulching, or insect or disease control is practiced. Chemical weeding is done on occasion, and shrub beds are sometimes damaged in the process. People knowledgeable in the maintenance of trees and shrubs are employed in some units of the department.

Post-planting maintenance by local units of government is also limited severely by lack of funds, but interest and good maintenance know-how are often very high. Tree pruning is done regularly in St. Paul and Minneapolis, and chemical control of disease and insects is used when funds and environmental consideration allow.

CHAPTER II. RECOGNITION, OCCURRENCE, AND SERIOUSNESS OF DAMAGE

HOW DEICING SALTS CAUSE DAMAGE

Deicing salts can cause damage as *salt spray*, salt deposited on the twigs, buds, or needles; they can also cause damage as *soil salt*, salt in the soil. The methods of salt reaching the plant are discussed later in this chapter.

The damaging chemicals in deicing salts are the Na and Cl ions. The physiologic basis for NaCl damage to plants has been studied in depth by others. To help readers understand the rest of this paper, a few points will be highlighted.

NaCl may cause damage without even entering the plant. By adding ions to the soil solution, sodium chloride decreases the availability of soil water or changes the plant's ability to take up water from the salty soil solution. These adjustments reduce growth. Sodium in the soil may decrease the availability to the roots of other ions such as calcium. This results in decreased root growth, which also leads to more water deficits in the tree. Too high a sodium level in the soil also breaks down soil aggregates or prevents their formation. This leads to the increase or maintenance of compaction in soils that along highways may already be too compact for optimum growth. Sodium also raises soil pH above the optimum desirable for ion uptake and root growth. Sodium can also accelerate leaching of organic matter.

Another mechanism of damage requires that Na or Cl enter the plant cells. Both Na and Cl are toxic to plant cells when present in sufficiently high concentrations. The ions adversely affect cell membrane stability and many other processes. The only symptom in milder cases of toxicity is reduced growth. In more severe cases leaf death is observed preceded by bleaching of the chlorophyll. The Cl may enter the plant easily through either roots or salt spray. Na tends to be excluded by the roots of most plants, but when sprayed on the tops it easily enters at least the extracellular space of twigs and leaves. The symptoms associated with NaCl entering through the roots are different from those entering as salt spray.

A new mechanism of damage was discovered during this investigation. NaCl was found to lower the cold resistance of hardwood twigs and to potentially interact with midwinter low temperatures to produce twig dieback (Appendix A, studies 5 and 6).

The resistance of trees to salt varies with type of damage and pathway into the plant; this is considered in suggestions for minimizing damage (Chapter III). It is also recognized that many modes of damage can operate simultaneously.

In need of formal investigation is whether damage can be caused by the anticaking agent, ferrocyanate, or the cyanide released on decomposition. Ferrocyanate was absent from the salt that produced the damage in controlled spraying experiments (Appendix A, studies 1, 6, and 7).

RECOGNITION AND DIAGNOSIS OF SALT DAMAGE

To aid in the recognition and diagnosis of salt damage, a description of symptoms has been synthesized from the literature and from personal experience. Symptoms differ somewhat depending on whether the damage is caused by soil salts or spray salts.

Soil-Salt Toxicity Symptoms in Deciduous Trees. Symptoms attributable to soil salt have been identified predominately in deciduous trees, usually large ones, planted along city streets. The symptoms are listed below in order of progressive development:

1. General reduction in growth without symptoms specific to NaCl. Reduced growth, the most common symptom is always present if other symptoms are. However, it is not specific to salt damage.
2. Marginal necrosis (browning) of leaves (figure 2). The browning begins as a yellowing of the leaf edge. A sharp boundary occurs between the brown tissue and the healthy green tissue with a yellow band between. Often only the side of the tree toward the road is affected (figure 1, right tree). This is the most specific symptom and the one most easily used for diagnosis.
3. Premature fall coloration, followed by premature leaf drop. This may occur before or after symptom 2.
4. Leaves small and yellowing, fewer in number. This results in a thin, sick-looking leaf and branch system (figure 4, figure 1, left tree).
5. Twig dieback followed by dieback of entire branch systems (figure 5). The crown becomes thinner and the main branch structure looks reduced especially if dead branches are pruned.
6. Tree death (figure 4).

Holmes and Baker (1966) classified and rated progressive leaf damage on sugar maples as follows:

"1. = a few leaves with dead tips 1 or 2mm long . . .;
2. = definite injury, many . . . leaves with dead tips and/or a few with marginal dieback up to 1 cm;
3. = many with marginal necrosis and/or a few extensive dead areas between the veins;
4. = many with interveinal necrosis involving up to the whole leaf . . . general brown appearance of the tree's crown and/or some defoliation;
5. = most leaves scorched and considerable defoliation."

Rich (1968) noted that premature autumn discoloration precedes marginal leaf scorch and is another symptom associated with salt damage, but early fall coloring has not been associated with salt damage in Minnesota (Appendix A, study 16).

Many symptoms may occur simultaneously on the tree (figure 1). In most cases the damage developed progressively over a number of years with continued winter salting. Cases exist, however, where almost all symptoms developed after a single winter of heavy salt application.

In addition to visual symptoms, analysis for leaf Na and Cl provides a reasonable diagnostic tool for soil-salt damage. Table 4 shows levels of Cl and Na found in leaves with and without marginal leaf necrosis for the permanent plots in this investigation (table 14). Tables 5 and 6 give values from the literature using many symptoms. The data are variable depending on whether Na or Cl caused the damage, the time of sampling, the position of the sample, and other factors. Experience and caution are required for interpretation of the data in tables 4, 5 and 6.

Analysis of soils, another diagnostic technique for analyzing the presence of salt damage, is particularly useful when visual symptoms are not specific or before leaf symptoms. Table 7 shows some typical analyses along Minnesota roads. Techniques developed by workers in soil salinity that may be used include conductivity of the saturation paste and Exchangeable Sodium Percentage (ESP). Conductivity of the saturation paste is an easily made measurement of the electrolyte content in the soil water. Soil-salt sensitive plants begin to suffer damage at 2 mmhos/cm, and tolerant plants withstand 16 mmhos. The test does not differentiate among ions, but within 30 feet of the highway in Minnesota ESP is well correlated with soluble Na and Cl; correlation coefficients are .82 and .70, respectively (Appendix A, study 20). ESP measures the percentage of the total cation exchange capacity occupied by Na. As ESP increases, growth rate decreases. In susceptible plants an ESP of 4 is associated with damage, while in soil-salt tolerant plants an ESP of 50 reduces growth only 1/3. The appropriate ESP is now known for Minnesota trees and shrubs; an ESP of 13 was arbitrarily set as the threshold for some damage and an ESP of 20 as the level of definite damage in most species.

Spray-Salt Toxicity Symptoms in Deciduous Trees. Symptoms attributable to salt spray are found primarily in trees and shrubs along highways. According to our experiments (Appendix A, studies 4, 6, 7, 8, 9, 15, 16, and 19), the major symptom is dieback of the previous year's growth beginning at the twig tip (figure 10). The dieback occurs during the winter. Death of the buds occurs with salt entering at leaf scars; the interbud portions of the stem also may show dead spots on the surface, and in cross section cambium and xylem show partial to total browning. Killing of buds and wood older than 1 year is uncommon. The killing is most obvious at leafing time in the spring (figure 10).

Because of the increase in kill of terminal buds, many lateral buds are released forming brooms instead of a single leader (figure 9). The dieback occurs year after year keeping the crowns narrow and the tree diameter and height small (figures 6-8). During surveys in this investigation, progressive dieback was rated 0 to 4 using characteristics shown in table 8.

Spray damage has a second symptom independent of dieback (figure 13). Full leafing out is delayed in the spring by as much as 3 weeks (Appendix A, studies 5, 7, and 10).

High sodium and chloride concentrations in winter twig samples can be used to help diagnose spray-salt damage. However, sodium or chloride levels in the leaves usually are not as high as in soil-salt toxicity, and we did not find them to be a useful diagnostic tool (Appendix A, studies 9 and 10).

Salt Toxicity Symptoms in Pine and Other Conifers. The symptoms described below are those which salt spray can produce in pines (Appendix A, studies 1, 2, and 3). Table 8 shows the scoring used in surveys.

1. As the weather warms, the tips of 1-year-old needles bleach and then turn bronze (figure 11); 25 to 75 percent bronzing is possible in severe damage. Just before browning, needles become flecked with bleached spots that often disappear later. These flecks help distinguish salt damage from other types of needle browning. Buds are not damaged.
2. The tips of 2- and 3-year-old needles, already brown from the previous winter's salt, will bronze still more. Needles that are 2- to 3-years old and more than 1/2 browned tend to fall off prematurely. The entire tree looks a bright rusty brown (cover photo).
3. Loss of needles and needle area reduces photosynthesis resulting in further thinning of the crown and reduced height and diameter growth (figure 12).
4. Soil-salt toxicity is to be suspected a) when needles exhibit browning the summer they emerge from the bud; b) when the needles in the upper crown show proportionally higher damage for the amount of salt received; and c) when needles sheltered from spray show as much damage as those exposed to it. Salt-spray symptoms tend to occur on the side of the tree facing the salted roadway.

To distinguish damage caused by salt from that caused by other agents, leaf sodium and leaf chloride analyses are very useful and reasonably reliable (tables 4, 5, and 6).

The needles of junipers (figure 15), arborvitaes, and spruce are also browned by deicing salt, but symptomology was not studied in detail.

Table 4. Chloride and sodium (percent oven dry weight) in leaves of trees and shrubs with and without leaf salt-toxicity symptoms. The samples were collected August 1973 on streets in metropolitan Twin Cities and Duluth*

	No symptoms				Symptoms			
	Chloride		Sodium		Chloride		Sodium	
Species	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range
Acer negundo	.55	.26-.84	0	–	.50	.18-1.28	.02	0-.04
A. saccharinum	.17	.11-.60	0	–	.31	.08-1.34	0	0-.04
A. saccharum	.26	.04-.95	0	0-.04	.33	.08-1.54	.01	0-.10
Aesculus glabra	.05	–	–	–	–	–	–	–
Celtis occidentalis	.59	.07-1.45	.004	0-.04	.63	.01-2.22	0	0-.03
Fraxinus pennsylvanica	.11	.04-.34	0	0-.03	.30	.04-2.55	.02	0-.07
Gleditsia triacanthos	–	–	–	–	.11	.08-.16	0	–
Malus sp.	–	–	–	–	.03	0-.08	0	–
Picea glauca	.08	.07-.08	–	–	.22	.19-.26	–	–
P. pungens	–	–	–	–	.26	.08-.56	.09	0-.33
Pinus nigra	.15	.10-.25	–	–	.24	.09-.59	–	–
P. resinosa	.19	.03-.49	–	–	.64	.10-1.29	–	–
P. sylvestris	–	–	–	–	.20	–	–	–
Pseudotsuga menziesii	.58	–	–	–	–	–	–	–
Rhamnus sp.	–	–	–	–	.90	.42-1.38	.01	0-.04
Rhus glabra	.68	.06-.88	.02	0-.03	.55	.10-2.04	.03	0-.04
Syringa vulgaris	.36	.28-.43	0	–	.83	.81-.85	.04	.03-.04
Tilia americana	.29	.09-.99	0	–	.74	.32-1.32	.01	0-.04
Ulmus americana	.56	0-.14	.005	0-.04	1.15	.38-2.21	.02	0-.07

*Trees of all species sampled in nurseries and gardens always had chloride levels below 0.05 percent.

Table 5. Literature report of chloride in leaves of 35 woody species with and without leaf salt-toxicity symptoms

Species	Leaf Cl (percent oven dry weight)				
	No symptoms	Symptoms in field observation	Symptoms in controlled applications	Month of measurement	Author number in bibliography
Acer platanoides	.01-1.0	–	1.8-3.7	–	89
A. saccharinum	.03-.19	.16-1.18	–	Apr/Jun/Sep	25
A. saccharum	.05-.61	.17-1.01	–	July	35
	.02-.14	.04-.93	.05-1.4	Aug	11
	.05-.29	–	3.64	Aug	34
	.02-.06	–	.13-.25	Aug	26
	.02-.09	.04-1.30	–	Aug	46
Betula alleghaniensis	.10-.78	–	–	Aug/Sep	66
B. lenta	.09-.84	–	–	Aug/Sep	66
B. papyrifera	.12	–	.42-.56	Aug	26
	.01-1.15	–	–	Aug/Sep	66
B. populifolia	.05-.27	–	–	Aug/Sep	66
Chamaedaphne calyculata	–	.11-.19	–	Jul/Aug	18
Forsythia intermedia var. spectabilis	.2-.8	–	–	Aug	27
Gleditsia triacanthos	.04-.18	–	–	Aug	26
Juniperus sp.	.03	.12	–	Feb	20
J. chinensis 'pfitzeriana'	.08-.15	.16-.18	–	Aug	28
J. horizontalis 'plumosa'	.05	–	.2	Aug	28
J. virginiana	.06-.09	–	–	Aug/Sep	66
Ligustrum vulgare	.1-.6	1.0-1.6	–	Aug	27
Lonicera tatarica	.1-.5	.8-.9	.7-.9	Aug	27
Picea sp.	.05-.07	.13-1.76	–	–	72
P. abies	.10-.16	.03-.32	–	Apr	38
	.46	–	.28	Aug	28
P. mariana	–	.03-1.17	–	Jul/Aug	18
Pinus mugo	.07	.58-1.12	–	May	33
P. m. var. mugus	.005-.15	–	.4-3.3	Jun	89
P. nigra	.10-.11	.68-.80	–	May	33
P. ponderosa	.17	–	1.68	–	64
	.06	–	2.3-3.3	–	70
P. resinosa	.09	.004-.41	–	Apr	38
P. strobus	.03-.07	1.0	–	May	33
	–	.33-.56	–	Jul/Aug	18
	.03-.50	–	.40-.50	Aug	28
P. sylvestris	.024	.021	–	Feb	20
	<.17	.17-2.06	–	May	33
Populus tremuloides	.12-.78	–	–	Aug/Sep	66
Quercus alba	.06-.14	–	–	Aug/Sep	66
Q. rubra	.02	–	–	Aug/Sep	66
Robinia pseudoacacia	.09-.32	–	–	Aug/Sep	66
Spiraea vanhouttei	.2	–	1.0-1.7	Aug	27
Thuja occidentalis	.33	.13	–	Apr	38
	<.29	.29-2.0	–	May	33
Tsuga canadensis	–	.01-.25	–	Apr	38
Ulmus americana	–	.60	–	Aug/Sep	29

Table 6. Literature reports of sodium in leaves of 19 woody species with and without salt toxicity symptoms

Species	Leaf Na (percent oven dry weight)			Month of measurement	Author number in bibliography
	No symptoms	Symptoms in field observation	Symptoms in controlled applications		
Acer saccharinum	.001-.018	.004-.148	–	Apr/Jun/Sep	25
A. saccharum	.0008-.0840	.0057-.0530	–	Jul	35
	.01-.03	.01-.73	–	Aug	46
	.03	–	.06-.13	Aug	26
	0	0-.22	0-.29	Aug	11
Betula papyrifera	.02	–	.15-.45	Aug	26
Forsythia intermedia var. spectabilis	.1-.6	–	.5-.9	Aug	27
Gleditsia triacanthos	.02-.12	–	–	Aug	26
Juniperus chinensis 'pfitzeriana'	.04	–	–	Aug	28
J. horizontalis 'plumosa'	.01	–	.07-.10	Aug	28
Ligustrum vulgare	0-.7	–	.04-1.5	Aug	27
Lonicera tatarica	–	–	.3-.8	Aug	27
Picea abies	.01-.02	.02-.06	–	Apr	38
	.20	–	0-.1	Aug	28
Pinus mugo	.06	.32-.78	–	May	33
P. nigra	.02-.08	.48-.65	–	May	33
P. ponderosa	.01	–	.01-1.4	–	70
	.02	–	.34	–	64
	.02-.08	–	.04-1.4	–	71
P. resinosa	.01	.02-.13	–	Apr	38
P. strobus	.02	.06-.16	–	May	33
	0-.05	–	.03-.05	Aug	28
P. sylvestris	<.26	.26-1.32	–	May	33
Spiraea vanhouttei	0	–	.2-.5	Aug	27
Thuja occidentalis	.04	.02	–	Apr	38
Tsuga canadensis	–	.03-.13	–	Apr	38

Figure 1. Soil-salt damage on trees next to heavily salted road. Brownish cast to leaves comes from marginal leaf scorch (figure 2). Tree on left has thin crown and small leaves, also characteristic of soil-salt damage.

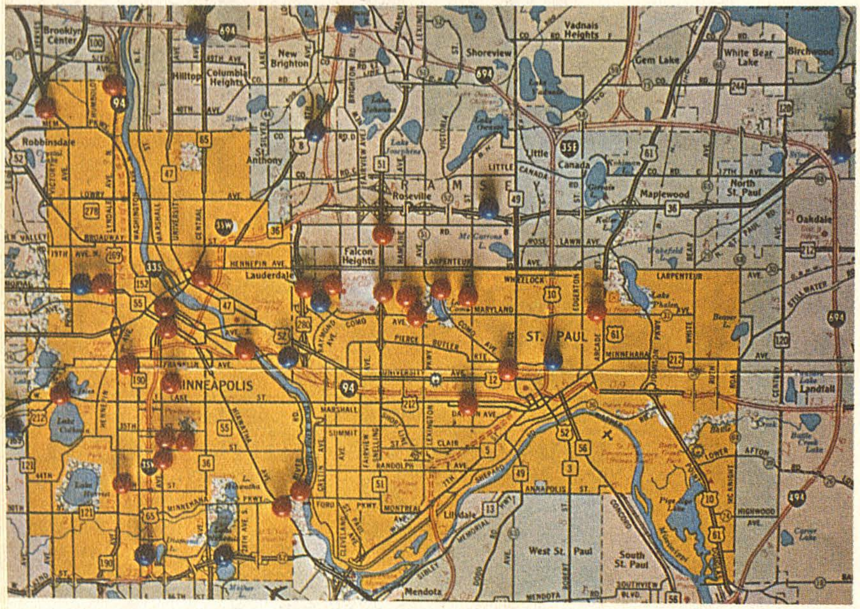
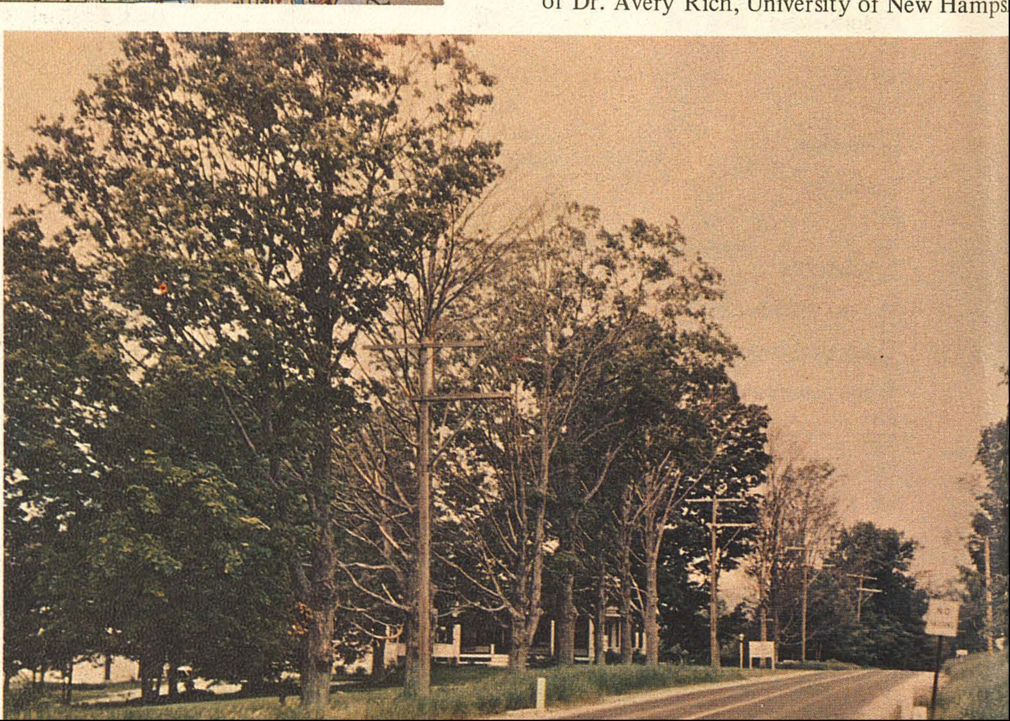


Figure 3. Some locations in Twin Cities area where soil-salt toxicity symptoms were found in leaves (red dots) or where exchangeable sodium percent in soil was greater than 13 (blue dot). Locations specified in table 9.

Figure 2. Soil-salt toxicity symptoms on American elm. The characteristic marginal scorch is separated from green interior by narrow yellow band.

Figure 4. New Hampshire sugar maples kille maple decline in which soil-salt is involved. other photos are from Minnesota. (Photo cou of Dr. Avery Rich, University of New Hamps



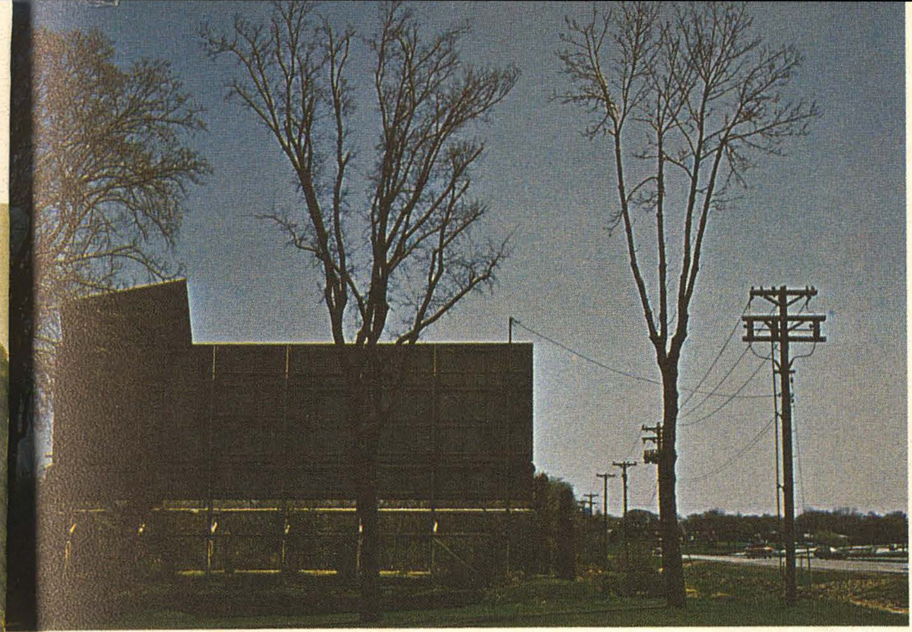
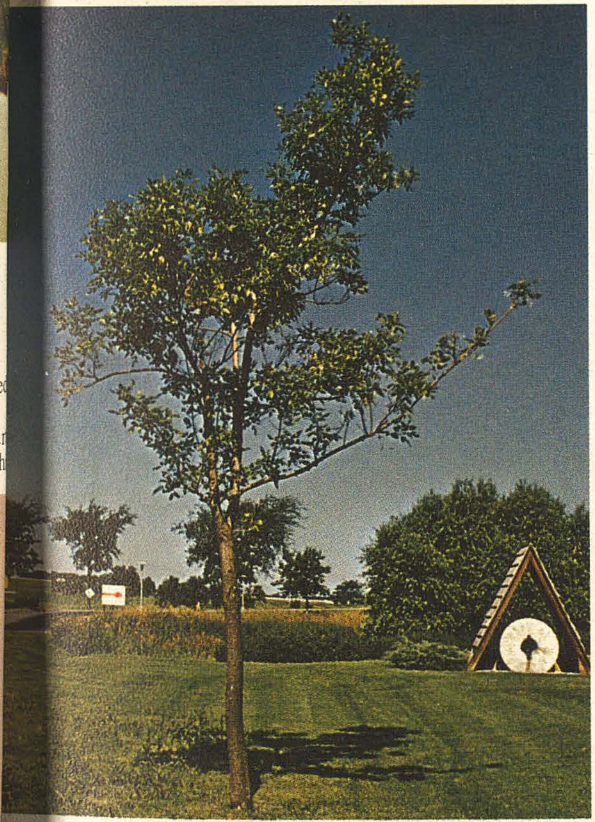


Figure 5. Size and fullness of crowns of American elm decrease with closeness to highway. Cause of decrease may be related to both soil-salt and spray-salt.

Figure 6. Healthy green ash, 5 years from planting; tree is without dieback.



igure 7. Moderately damaged green ash, at least 3 years lder than ash in figure 6. Class 3 damage (table 8).

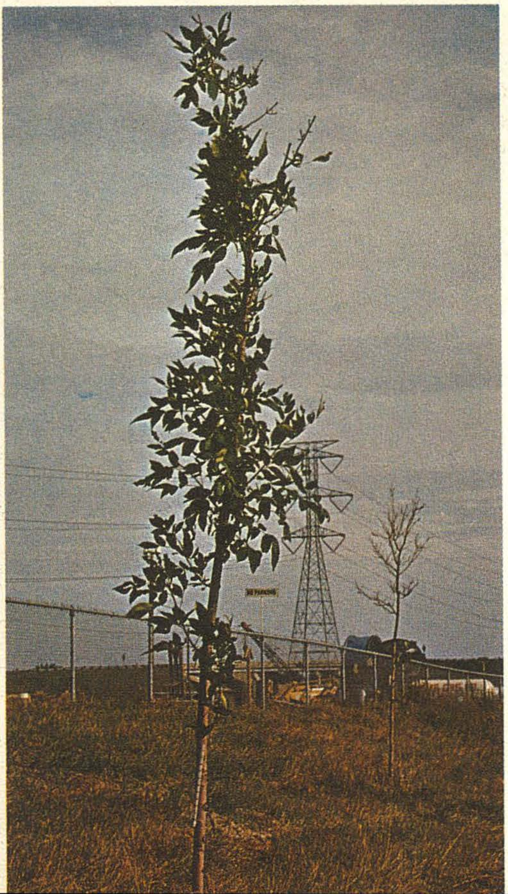


Figure 8. Severely damaged green ash, same age as in figure 6. Annual dieback keeps crown from expanding.

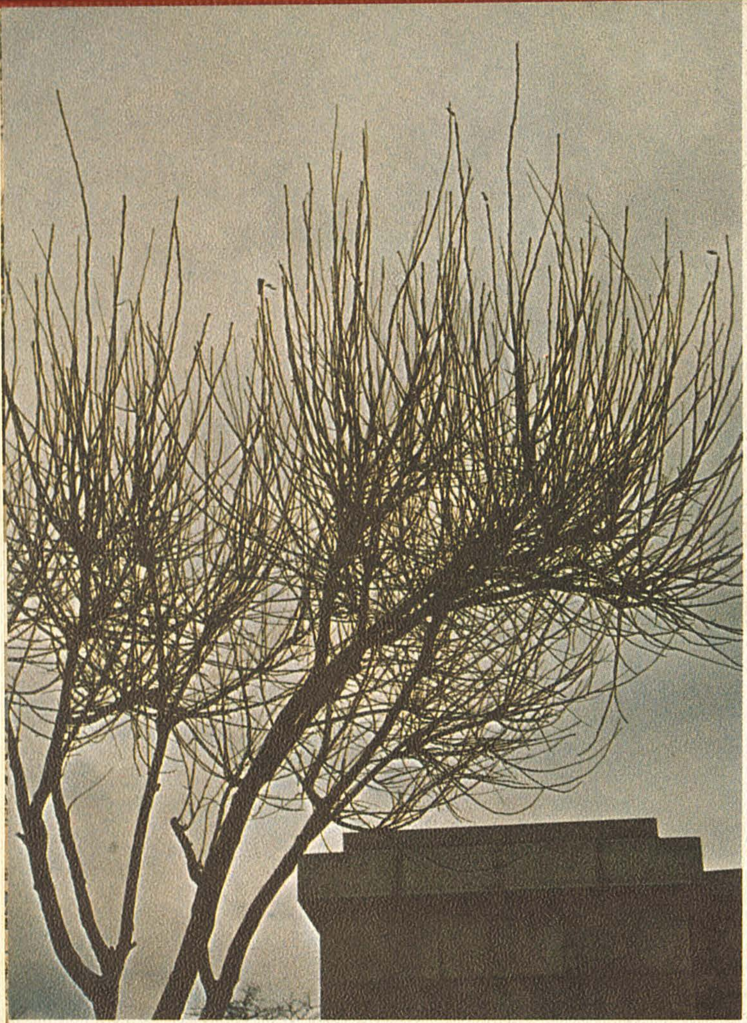


Figure 9. Brooming on flowering crab. Broom caused by release of lateral buds, after terminal buds are killed by salt spray.

Figure 11. Typical salt damage symptoms on red pine needles

Figure 10. Severe dieback on American linden caused by salt spray.

Figure 12. Fourteen-year old red pine showing thin crowns and reduced growth characteristic of trees with persistently browned needles.

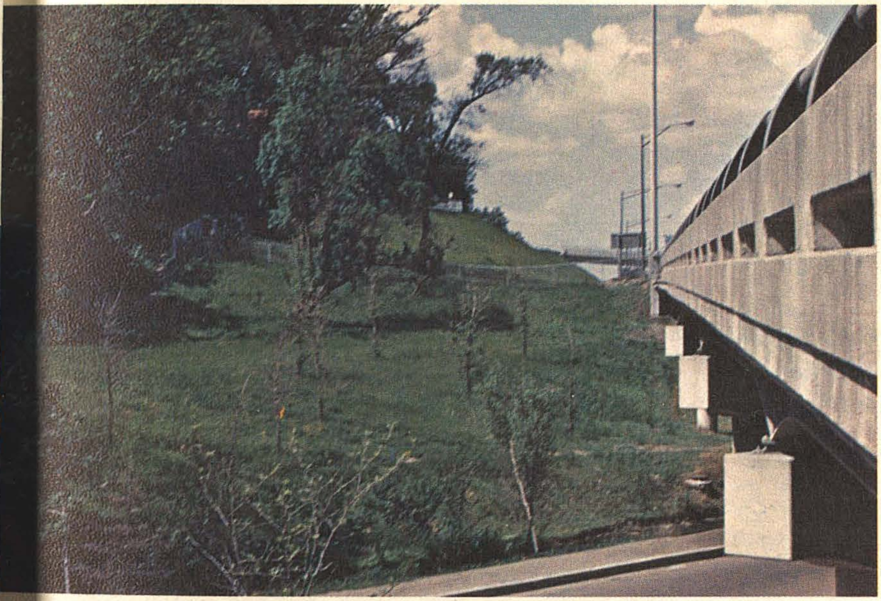


Figure 13. Spray damage beneath 35W at Minnehaha Creek. Trees near highway are coming into leaf late and have severe dieback. Notice arching elm with almost branchless limb facing the road.

Figure 14. Amur maple shrubs killed back each year. These shrubs cannot escape from weed competition or be seen by traveler.

Figure 15. Red cedar browned by salt spray.

Table 7. Representative soil data collected along Minnesota roads

Plot*	Feet to road	Sample depth (inches)	ESP	pH	Conductivity mmhos	Extractable Na (meq/100g)	Soluble Na (meq/100g)	Cl (meq/100g)
PP	4	0-10	2	7.6	.6	.5		.3
YY	3	0-10	9	7.6	1.7	2.2	.6	1.1
C	20	0-10	24	8.1	3.4	3.0	1.2	.6
	45	0-10	10	8.0	1.1	1.0	.2	.1
	60	0-10	4	7.2	.5	.4	.1	0
	20	10-20	30	8.2	1.9	3.7	.7	.7
X	20	0-10	2	7.0	.3	.1	0	0

*Location of plots PP, YY, and C in table 14; plot X is on T.H. 10, between Anoka and Elk River.

Table 8. Salt injury symptom classes used to evaluate damage to trees and shrubs

Injury symptom class	Hardwood trees	Spruce and cedar†	Pine†	Shrubs
0	Up to 20 percent of terminal buds dead (figure 6)	Little damage	No damage	Little damage
1	20 to 80 percent terminal buds dead	5 to 10 percent of leaves brown or lost	5 to 10 percent needle browning	5 to 10 percent dieback
2	Most terminal buds dead; 0 to 19 percent dieback*	11 to 20 percent of leaves brown or lost	11 to 30 percent needle browning	11 to 30 percent dieback
3	20 to 50 percent dieback (figure 7)	21 to 50 percent of leaves brown or lost (figure 15)	31 to 60 percent needle browning (figure 12)	31 to 60 percent dieback (figure 14)
4	Greater than 50 percent dieback (figures 8, 9, 10)	More than 50 percent of leaves brown or lost	More than 60 percent browning	More than 60 percent dieback

*Dieback percentages refer to previous year's twigs in summer observation.
†Browning measured on needles formed the most recent 2 growing seasons for spruce and pine, and on all leaves for cedar.

PROOF THAT SALT CAUSES DAMAGE

The roadside is a harsh environment for woody plants. High air and soil temperatures combine with high rates of air flow (from traffic and exposure) to produce high transpiration rates and low soil moisture levels. The trees and shrubs, therefore, suffer more severe water deficits than forest grown plants. Both soil and leaf analyses show that soils usually are infertile and devoid of organic matter (Appendix A, studies 9 and 20). Soil pH was often above 8.0. Compaction is common, particularly at intersections, allowing less moisture to enter the soil. Mechanical damage from mowers is widespread. Damage from rodents is high, as illustrated by the survey of rodent damage summarized below (Appendix A, study 12):

trees partially girdled by rodents	25 percent
trees totally girdled by rodents	5 percent
trees with root damage so that tree is loose	20 percent
trees with burrows within 2 feet of stem	48 percent

The same tree may be represented more than once in the percentages.

Under such substantially suboptimal conditions, some have questioned whether salt is involved at all in producing damage to roadside vegetation. This investigation spent considerable effort assessing what role, if any, salt has in producing the omnipresent damage observed in roadside woody plants. The lines of evidence briefly summarized below all indicate that salt is involved in causing the needle browning and twig dieback.

1. *Salt is present in the environment, and the more salt, the more is the damage.* Salt distribution studies, needle surface chloride analysis, and soil analysis all showed that salt is present in the immediate environment of roadside plants (Appendix A, studies 18, 19, and 20). Damage surveys showed that as salt use and traffic increased, damage increased, whether over time or from road to road (Appendix A, studies 2, 8, and 9). The surveys also showed that damage increased with proximity to the road.

2. *Damage increased as tissue Na and/or Cl increased.* With most species showing leaf damage symptoms, damaged trees and leaves had higher Cl and/or Na than undamaged ones (tables 4, 5, and 6). The more severe the damage, the higher were the concentrations. A similar relation was found with winter sampling of twigs on trees with twig dieback (Appendix A, studies 2 and 4).

3. *Applying salt to leaves and branches at highway concentrations produced damage symptoms in garden trees similar to those found along the highway.* Applications of salt on red pine, white pine, and 13 species of hardwoods produced damage symptoms similar to those found along the highway (Appendix A, studies 6 and 7). However, to produce equally severe symptoms, higher surface concentrations were required in the garden.

4. *Damage symptoms are unique to salt.* No other factor was found that produced the same patterns of browning on red pine; e.g. damage being heavier on the side facing the road. Many factors were found producing dieback in new transplants of trees and shrubs, but persistent dieback of 1-year-old wood seems unique to salt damage on trees. No unique pattern was found on many species of low shrubs. The general symptom of reduced growth can be caused by many factors.

For marginal scorch, any factors contributing to drought might be confused with salt, according to those who argue that the symptoms are similar; in fact, drought and salt damage probably interact.

5. *Evidence is lacking that damage is caused by other factors that are distributed from the road in the same way as salt.* The factors considered are:

- a) gaseous emission from vehicles,
- b) vehicle-generated wind,
- c) higher air temperatures,
- d) abrasion by moving particles or by rubbing in turbulent winds,
- e) poor soils from compaction and cut and fill during construction,
- f) particulate matter generated on the highway including lead, stack carbon from diesels, tire waste, and oils.

The factors that might be confused with salt damage would have to cause more damage in the winter than in the summer or indirectly result in winter kill. Only item "f" would seem to qualify for direct cause. Two factors deserving future attention are lead and the oil-soaked carbon that accumulates on twigs and needles during the winter months. Reasons were not found suggesting that factors "a" to "f" indirectly cause winter kill along highways.

The five lines of evidence put together indicate that the damage described as salt damage in the previous section is exactly that.

FACTORS AMPLIFYING SALT DAMAGE

The highway environment is already droughty, and salts aggravate this condition. Soil salts cause more injury when trees need water, as in droughty soils with low precipitation. As the soil dries, the salt solution around the roots becomes more concentrated causing the damage described earlier. As the roots grow less, the tree is less able to cope with the drought because roots must grow to the water.

Spray salts may cause more damage to trees and shrubs when the winter temperatures are very cold. This investigation showed that twigs high in Na and Cl are less resistant to low winter temperatures (Appendix A, studies 4, 5, and 6).

Spray-salt damage is also amplified by factors that facilitate entry of salt into trees. Lilac and ash along the highway had their cuticles loosened and thinned, presumably letting salts penetrate more easily.

The poor growing conditions of the highway make salt damage more serious by inhibiting the recovery of the plant.

WHERE SALT DAMAGE IS FOUND

This section characterizes which types of roads and which locations along the road are most likely to have salt damage. Salt-spray damage and soil-salt damage are considered separately. For both, however, the amount of damage occurring at any location varied with the salt tolerance of the species.

Ways Deicing Salts Leave the Road. Salt leaves the highway surface in several ways. Traffic sprays the solution from the road; winds including those created by the traffic often carry the drops many feet from the road. Trucks spray more than cars, and faster moving vehicles more than slower ones. Traffic and winds also move the white salt powder left on the roads after the surface dries (cover figure, top). Snow plows remove large amounts of snow-salt mixture when they clear the road or clear the shoulders. Finally, salt solution leaves the road in runoff. The percentage of applied salt that leaves the road varies greatly with each situation. In one study along two interstate highways, it was estimated that about 2 to 3 percent of the salt applied to the road during a 2- to 4-week period was deposited 30 or more feet from the road (Appendix A, study 18).

Spray Damage. These generalizations apply to damage caused by spray (Appendix A, studies 2,9,18, and 19).

1. Spray damage increases with the amount of salt applied and with traffic volume. As ADT increases, salt use increases (graph 1), and the two factors cannot be separated. The relation of ADT to damage, shown in table 11, refers largely to salt spray.

2. Spray damage decreases rapidly with distance from the road (table 12). At distances beyond 150 feet, only the most sensitive species sustain injury and then only at moderate levels. Deicing salts increased twig Cl as far as 400 feet from I-35W but no observable damage occurred at this distance.

3. The east and south sides of the highway (in the lee of prevailing winter winds) generally, but not always, receive more salt spray than do the north and west sides. This is particularly evident at distances greater than 60 feet.

4. Plants on higher speed roads receive more damage. In making this comparison, 30- and 40-mph city streets were compared with 55- to 70-mph highways of the same ADT. The effect of speed is particularly apparent in observing spray from large trucks. Whether the reduction of maximum speeds to 55 mph will reduce damage is not known. The author would guess that any reduction would be most visible beyond 50 feet.

5. Vegetation growing downslope from a road or beneath a bridge suffers more spray damage than that upslope from the road. 35W across Minnehaha Creek provides an example of drift down from the road (figure 13).

6. Roads with heavy truck traffic (e.g., TH 10) seem to have disproportionately high damage for their ADT, but other factors may be involved.

7. Intersections and frontage roads add to salt spray and salt-spray damage.

8. Tall trees and plants beneath the snow suffer less salt-spray damage because the spray does not reach their branches or leaves. This partly explains why older trees in the city have minimal spray damage.

Soil-Salt Damage. The occurrence of soil-salt damage was determined by marginal leaf scorch in hardwoods and by high ESP in the soil (Appendix A, studies 2 and 9). The leaf symptoms were found only near city roads, usually in association with ESP's below 7. The distribution of leaf symptoms or high ESP or both was irregular and it is more difficult to generalize a pattern of occurrence than with spray damage. However, an attempt follows.

1. Along highways, ESP decreased rapidly with distance from the road. It was usually heaviest within 15 feet of the road; this was the soil on which the brine was plowed. When the roadside was level or sloped upward, ESP dropped below 10 percent within 45 feet. When the roadside sloped downward, ESP continued high for longer distances; for example, along TH 36 near Dale Street, the ESP was 62 percent at 10 feet and 19 percent at 45 feet from the edge of the driving lane. Thirty-five-feet tall red pines have died at this site.

2. Along city streets, leaf symptoms and high ESP tend to occur when the salted snow from the streets is plowed directly around the bases of the trees within 8 feet of the road.

3. Situations of microrelief that put the tree roots in an undrained depression increase both leaf symptoms and high ESP. Three examples follow: 1) In new plantings along Olson Memorial Highway west of Lyndale, a depression existed around the base of the young trees where the planting soil had settled. While the ESP in the surrounding soil was 7 percent, the ESP of the soil in the depression was 17 percent. Similar differences in symptoms and ESP were also noted in places where trees were planted in holes on an otherwise paved boulevard, e.g., 46th St., Minneapolis. b) Undrained basins downslope from the road showed high soil Na. On Lake Street, across from Lake Calhoun, the roadside slopes drained into a basin so that ESP even increased moving away from the road and into the low area; the ESP was 3 at 5 feet and 6 at 30 feet from the road. This same situation occurred on Ford Parkway, near the Ford Bridge, where street runoff spreads over a low area adjacent to the road. c) Median areas that are lower than the road, such as on Olson Memorial Parkway near Lyndale and Snelling Avenue just north of Larpenteur, also showed

high ESP and leaf symptoms. At the Snelling site, where there is no curb to divert runoff, ESP's were 14 percent. At the Olson site, breaches in the curb allowed runoff to enter the low median. Mounds in the median had ESP of only 3 percent compared to 11 percent for the lower areas.

4. Locations spot-treated with unusually large amounts of salt have damage. An example is Midway Parkway near Pascal where snow melt runoff can accumulate and freeze; large amounts of salt have been used to keep the intersection safe.

BRIEF HISTORY OF THE OCCURRENCE OF SALT DAMAGE IN MINNESOTA

Salt damage has occurred in Minnesota since at least the early 1950's. In 1956, French surveyed 1914 trees and found 9.4 percent of them with discolored leaf margins typical of soil-salt damage. About 1/5 of these 9.4 percent were dead or dying. In subsequent years, still more have died. No information on salt use is available, but the years of observation (1954-56) did have unusually dry winters and springs. A 1973 survey of other trees showed damage was still occurring.

Salt damage to highway trees occurred long before widespread concern developed in the late 1960's. Murphy in 1968 observed signs of repeated twig dieback of planted hardwoods that he thought might be salt damage, and French observed damage to white pine and other species that he thought was salt related. Murphy thought that salt was involved in transplant mortality during the 1960's.

Local people have not agreed on the cause of the damage to the roadside trees. Explanations for damage to the pine include drought, winter burn, rhime, and air pollution. Twig dieback on hardwoods has been attributed to poor sites, transplant shock, drought, flooding, and the grimy surface deposits that accumulate in winter.

Following the winter of 1969/70, needle burn on red pine was apparent on major roads throughout the state. Twig dieback on deciduous trees was also heavy. The sudden increase in damage to pine (no record exists for hardwoods) may be associated with the large increase in salt usage and/or with the severe summer drought of 1969. Damage to both pine and hardwoods continued at a high level through 1972/73. Damage in 1973/74 was generally less in the metropolitan Twin City area, although pine browning was heavier on some roads elsewhere in the state.

SERIOUSNESS OF SALT DAMAGE IN MINNESOTA

Deicing salts can kill trees and shrubs, reduce their growth and disfigure them, and raise maintenance costs. The question that this investigation faced was how much death, growth loss, and disfigurement occurred along Minnesota roads.

Mortality. Observation indicated that salt was not a major cause of death in established plants along the highway. Individual cases where salt caused death involved white pine and red pine among the conifers and flowering crab among the deciduous. In city situations, French (1959) attributed the death of many elms in St. Paul to soil salt. Salt may be more important in causing mortality in new plantings. Although causes of mortality were not formally studied, L. Murphy, Office of Environmental Services, Minnesota Highway Department, thinks salt contributes to mortality, and at his request one such case was documented in 1973.

Reduced Growth and Disfigurement. It is a common observation that trees along the highway grow slowly compared to garden or park trees. The growth is sometimes so poor that the trees must be removed. Reasons for this poor performance are numerous and include deicing salts singly and interacting with other factors. Although isolating the effect of deicing salts alone is impossible, information generated in this investigation (Appendix A) showed dieback from salt to be omnipresent within 60 feet of the highway and often the chief cause of poor performance.

The probability and extent of salt damage to woody plants on many types of highways is shown in table 12 and discussed in Chapter III, page 27. In an analysis of green ash, the dieback was correlated with a 17 percent loss in growth, although it is often much higher. Reasonable methods do not exist for evaluating the dollar cost of salt damage. (Appendix A, study 8). An economic approach could allow for a more rational distribution of funds between planting and maintenance. For example, money spent planting a second tree that through lack of maintenance never becomes large enough to be seen by the passing driver or residential dweller might better be spent increasing growth on the first tree.

Table 9 and figure 3 show city locations where growth probably is being reduced by high soil salts. They were found in an extensive but not complete survey made in Minneapolis and St. Paul. The suburbs and other cities were not formally surveyed, and the extent of soil salt damage there is unknown.

The overall amount of dieback and leaf discoloration from soil salt found in Minneapolis and St. Paul is less than French found in the mid 1950's but this may not indicate the problem is less. Some of these trees are known to have been removed and in the 1973 survey, more than 50 percent of the trees were damaged on some stretches of boulevard.

Increased Maintenance Costs. The damage caused by deicing salts has secondary implications in the form of increased maintenance costs. For example, if a shrub is killed back by salt each year, it must be weeded to aid survival and to be seen (figure 14). As a second example, growth may have to be improved by expensive management techniques such as better initial soil or fertilization to compensate for salt damage.

Along city streets, salt dieback increases the need for pruning. With the Dutch elm beetle breeding on dead and dying wood, excellent maintenance is required to help prevent the build-up of the disease-carrying beetle.

Restrictions on Species Selection. Salt damage places restrictions on which species may be planted. For example, in city locations where the risk of soil-salt damage is great, salt intolerant species should not be planted. Unfortunately this eliminates some otherwise desirable species like sugar maple, American linden, and flowering crab. Limiting the number of species not only reduces aesthetic variety and lessens the opportunity to match species to soil, but increases the risk of a single pest destroying a large percentage of the trees.

Summary of Seriousness of Salt Damage in Minnesota. Deicing salts do cause widespread and serious damage to growth of trees; they also cause some mortality. The damage is severe enough to make certain locations unplantable and to eliminate certain species from most locations along the road.

The amount of salt used on some Minnesota highways and streets is large. Current damage is sufficiently widespread and severe to raise the question in the Twin Cities of whether salt could in the future destroy thousands of mature boulevard trees and greatly reduce growth of new plantings. Future prospects are considered in Chapter IV.

Table 9. Locations where marginal leaf necrosis was seen on trees (L) or ESP in soil exceeded 13 (S). Values in parentheses are ESP in upper 10 inches of soil followed by distance from road in feet.

Minneapolis
T. H. #55 at Humboldt (L,S) (ESP 20)
Lyndale and N. 49th Ave. (L)
Osseo Road and Upton Ave. (L)
4th St. S.E. and 3rd Ave. (L)
Lake Street – North of Lake Calhoun (L) (ESP 3, dist. 5)
Portland Ave. and 35th St. (L) (ESP 6, dist. 3)
E. 46th Street at 46th Ave. (L)
E. 26th Street at Portland Ave. (L)
Franklin Terrace at I-94 (Riverside Park Ave.) (L)
Minnehaha Parkway and Hiawatha Ave. (L)
West 46th Street near Lyndale (L) (ESP 3, dist. 5)
Portland Ave. and 26th Street (L)
Washington Ave. and 4th Ave. S. (L)
3rd Street and 2nd Ave. S. (L)
Plot PP: Blaisdell Ave. at 23rd St. (L) (ESP 2, dist. 4)
I-94 and Warwick (S) (ESP 18, dist. 20)
T.H. #62 E. of T.H. 36 (S) (ESP 25, dist. 10)
I-35W – N. of 60th St. So. (S) (ESP 45, dist. 20)

Fridley
I-694 and T.H. 65 Interchange (S) (ESP 20, dist. 43)

St. Louis Park
T.H. 100 and T.H. 7 Interchange (L,S) (ESP 21, dist. 20)

St. Paul
Plot YY: Midway Parkway and Snelling Ave. (L,S) (ESP 14, dist. 3
Dale St. and Parkview (L)
Dale St. and Marshall Ave. (L)
Como Ave. and Marion St. (L)
Como Blvd. and Lakeview (L)
Lexington Ave. and Estabrook Drive (L)
Maryland Ave. at Greenbrier (L) (ESP 10, dist. 3)
Midway Parkway at Buffalo St. (L) (ESP 8, dist. 3)
Eustis St. near Como Ave. (L)
Hendon Ave. and Grantham St. (L)
I-35E N. of Pennsylvania Ave. (S) (ESP 19, dist. 10)

Arden Hills
I-694 and I-35W Interchange (S) (ESP 24, dist. 25)

New Brighton
Plot C: T.H. 8 North of Co. Rd. D (S) (ESP 13, dist. 15)

Pine Springs
T.H. 36 East of I-694 (S)

Roseville
T.H. 51 (Snelling Ave.) at Ruggles (S) (ESP 14, dist. 20)
T.H. 36 West of Dale (S) (ESP 62, dist. 20)

CHAPTER III. METHODS FOR MINIMIZING SALT DAMAGE

This investigation explores how to reduce salt damage or the impact of salt damage on trees and shrubs. The following methods were considered: 1) using a planting guide to match salt-tolerant species to locations with high salt and to restrict salt-intolerant species to locations with low salt; 2) reducing salt use and modification of plowing practices; 3) flushing of sodium from the soil with soil amendments; 4) spraying films on plants to prevent spray salt entry; 5) improving planting procedures; 6) improving the growth of existing plantings to overcome salt damage; and 7) altering expectations from species.

PLANTING GUIDE FOR MINIMIZING SALT DAMAGE

Information gathered in the investigation shows that the severity of salt damage depends on both the tolerance of the woody plant and its location along the highway or street. Using this information, a guide was developed to aid the landscaper in matching species to location. Part I rates species for tolerance to salt and Parts II and III predict how species of different tolerance will perform along highways and streets.

Part I. Relative Tolerances to NaCl of Woody Species that Grow in Minnesota.

Table 10 lists relative tolerances to salt for woody species commonly planted along Minnesota highways. The ratings are abstracted from Appendix B which for 192 species lists relative tolerances as determined by various researchers. The typical study involved either application of soil salt, winter application of spray salt, or observations along highways. In rankings made in this investigation (Appendix A, studies 2,5,7,8,9; Appendix C), the standards were Blackhills spruce as the tolerant species, green ash as the moderately tolerant, and red pine as the susceptible species.

The reader should use the ratings cautiously particularly those without asterisks. Asterisks were used when the rating was considered somewhat reliable, i.e. it was based on one or more of the following: thorough observations, considerable quantitative data, agreement among investigators, agreement between studies using observation and experiment. In Table 10 more credance was given to spray than to soil experiments. Useful rankings are difficult to make because relative tolerance can change with climate, soil, and time of year; seedlings behave differently than saplings; tolerance to spray salt does not insure tolerance to soil salt, tolerance to NaCl and $CaCl_2$ vary. Relative ranking of a species also shifts depending on whether it is compared to more or to less tolerant species. Further, with only three tolerance groupings, there is much variation within a group.

Table 11 lists relative tolerances for species commonly planted along city boulevards. The ratings, abstracted from Appendix B, were determined primarily by observation along city streets or by sensitivity to soil salts under experimental conditions. When no observation or soil-salt data were available, highway or spray observations were used with the tolerance rating left the same, the rankings may shift when soil-salt data becomes available. Where results conflicted the more appropriate was followed. The ratings in Table 11 should be used with even more caution than those in Table 10 because very few are verified by local experience.

Tolerant species in Appendix B that are currently not planted may deserve testing in high salt highway environments.

Part II. Probable Salt Damage Occurring at Potential Planting Sites Along Highways.

Table 12 shows 30 locations along Minnesota highways: six types of highway (ADT) times 5 distance groupings from each highway. Table 12 shows 90 possible landscape situations: the 30 locations for each of the three tolerances of plants. For each landscape situation, an estimate is given as to the probable amount of salt damage that will occur. At any location the probable amount of damage increases with the susceptibility of the species. For example, a tolerant species planted 30 feet from a highway with an ADT of 39,000 is likely to suffer low salt-spray damage, but a susceptible species in the same situation is likely to be highly damaged. It is recommended that in selecting a species the landscaper regard probable high damage as unacceptable and probable medium-high damage as unacceptable in conifers, slow growing hardwoods and where tall shrubs are wanted. Probable medium and medium low damage ratings indicate situations where damage is obvious, but usually at an acceptable level. Low damage is of no practical concern.

The methods used to develop table 12 are presented in Appendix C. In constructing table 12, it was learned that although ADT and distance from road were the most important variables, other features of location sometimes influenced damage. Damage tended to be greater at intersections and to the leeward of the road, i.e., on the south and east sides.

Tables 10 and 12 may be used in combination to match species to location to minimize salt damage. To choose a species for a particular planting location, the landscaper should (a) find the location in table 12, (b) determine which tolerance groupings would have an acceptably low level of probable damage, then (c) consult table 10 for possible species.

To choose highway locations for specific species, first determine the species tolerance in table 10. Then find locations in table 12 with acceptable levels of damage.

Within 30 feet of the travel lane, damage increases dramatically because there is a large increase in salt spray and soil salt. It is recommended that along roads with ADT of 17,000 or more only very tolerant material be planted within 30 feet; along roads with very high ADT, success should not be anticipated. Along roads with ADT less than 17,000, tolerant and moderately tolerant species should be tried.

In matching species to location, future increases in ADT might be considered because trees and shrubs are long-lived. The tables may be expanded by the more experienced landscaper

Table 10. Relative tolerance to damage from deicing salts in *highway situations* for species commonly planted along Minnesota highways

TREES		
Tolerant	*Moderately tolerant*	*Intolerant*
*Austrian pine	American arborvitae	*American linden
*Black Hills spruce	*American elm	Cockspur hawthorne
*Colorado blue spruce	Box elder	*Dolgo crabapple
*Cottonwood	*Golden willow	European mountain ash
Imperial honeylocust	*Green ash	*Hackberry
*Norway maple	Laurel-leaf willow	*Hopa crabapple
*Russian olive	Paper birch	Pin oak
White ash	*Red cedar	*Radiant crabapple
White poplar	*Scot's pine	Red maple
	Silver maple	*Red pine
		*Sugar maple

SHRUBS AND VINES		
Tolerant	*Moderately tolerant*	*Intolerant*
Buffaloberry	*Amur maple	Corral berry
*Jackman's potentilla	*Common lilac	Dwarf ninebark
*Russian olive	*Froebel's spirea	Tatarian honeysuckle
*Siberian pea tree	Smooth sumac	Tatarian maple
*Vanhoutte spirea		Wayfaring tree
Virginia creeper		*Yellow twig dogwood
*Zabel's honeysuckle		*Red osier dogwood

*Reasonable confidence in tolerance rating (See Appendix B).

Table 11. Relative tolerance to damage from deicing salts in city situations for species commonly planted near city streets in metropolitan Twin Cities area

Tolerant	Moderately Tolerant	Intolerant
Austrian pine	American arborvitae	*American linden
Black Hills spruce	American elm	Cockspur hawthorne
Imperial honey locust	Amur maple	European mountain ash
*Russian olive	Box elder	Flowering crabapple
White ash	Colorado blue spruce	Pin oak
White poplar	Cottonwood	Red maple
	*Golden willow	Red pine
	Green ash	*Sugar maple
	Hackberry	
	Laurel-leaf willow	
	Norway maple†	
	Paper birch†	
	*Red cedar	
	Scot's pine	
	Silver maple	
	Small-leaved European linden‡	
	Smooth sumac	

*Reasonable confidence in tolerance rating
†May be tolerant
‡May be intolerant

Table 12. Probable amount of damage which will occur to species of various tolerances to salt as affected by average daily traffic (ADT) of road and distance from road. Amounts of damage classed as low (L), medium low (ML), medium (M), medium high (MH), and high (H).

Species tolerance to salt	ADT in thousands	Distance from travel lane (ft)				
		30-40	45-60	65-80	85-150	150
Tolerant	0 – 10	L	L	L	L	L
	10 – 19	L	L	L	L	L
	20 – 39	L	L	L	L	L
	40 – 59	ML*	L	L	L	L
	60 – 79	M	ML	L	L	L
	80+	H	M	ML	L	L
Moderately tolerant	0 – 10	M	L	L	L	L
	10 – 19	MH	L	L	L	L
	20 – 39	MH	ML	ML	L	L
	40 – 59	H	MH	MH	M	L
	60 – 79	H	H	MH	M	L
	80+	H	H	MH	M	L
Susceptible	0 – 10	M	ML	L	L	L
	10 – 19	H	MH	M	M	L
	20 – 39	H	H	MH	MH	ML
	40 – 59	H	H	MH	MH	ML
	60 – 79	H	H	H	H	M
	80+	H	H	H	H	M

*Solid lines and shadings separate low, medium, and high probabilities from each other.

to include other factors that either increase salt damage, such as highway islands, or decrease damage, such as productive organic soils. Both the tolerance ratings and probability damage estimates are only approximations of the real situation and need to be continually modified by experience. For example, the data were collected before the speed limit was reduced to 55 mph, and the lower speed limit may mean less salt-spray damage, particularly further from the road.

This section refers only to salt damage. In matching species to location, other site factors such as exposure, soil texture, and soil compaction are as important or more important than salt damage.

Part III. Probable Salt Damage Occurring Along City Boulevards.

Most existing trees on city streets were planted earlier and are much larger than trees along highways. Current city planting and salting practices also differ from those of the highway. Almost all trees are within 15 feet of the road. The speed limits are 20 to 40 mph. Snow not carted away is plowed at low speeds, reducing spray. Salt often is applied in special situations causing an irregular distribution of salt and salt damage. As a result of these differences, damage from soil salt in the city is more serious than on the highway, and damage from salt spray is limited to smaller trees and sensitive species.

The probability of soil-salt damage in the city is highest in these situations:

1. within 8 feet of the road on a salted street where snow is plowed against the base of trees,
2. in basins or depressions that collect runoff from salted streets (These may be very small depressions or large ones including the planting hole.), and
3. next to intersections that demand high salt applications.

The probability of spray damage currently is highest where spray from elevated roads wafts down onto the tree crowns. Spray damage will likely increase as smaller trees are planted to replace elms.

The following recommendations and table 11 may be used to minimize salt damage in city situations. It is recommended that no species intolerant to salt spray or soil salt be planted within 30 feet of the street. Only those species tolerant to both spray and soil salts should be planted within 10 feet of any street. Finally, moderately salt-tolerant, but drought sensitive, species should be treated as salt-intolerant species where soil salt is a risk.

REDUCTION IN SALT USE AND MODIFICATION OF PLOWING

If less salt were used, there would be less damage to trees and shrubs. Evidence for this is abundant. 1) Salt damage of white pine along TH 61 recovered after I-35W, a parallel alternate route, was completed. 2) The onset of heavy salt damage along highways in Minnesota coincided with the great increase in salt use. 3) Low ADT, and hence lower salt, produces much less damage (Chapter III). However, no exact mathematical function exists to relate amount of salt to amount of damage. For example, the amount of salt applied per lane mile in District 5A dropped from 28 tons in 1969/70 to 13 tons in 1972/73, but the spray damage did not decrease proportionately. Another example is in District 9 where much less damage occurred in 1973/74 than in 1972/73 although salt use was similar.

The author does not recommend that salt use be restricted to prevent damage to vegetation, although investigation makes clear that where salt use can be appreciably reduced plants will benefit. Techniques that are being employed increasingly to apply adequate but not excessive amounts of salt include salt-sand mixtures, calibrated dispensers on trucks, and closer supervision of actual applications.

Three snow plowing practices observed to harm vegetation are: 1) winging salt off salted frontage roads onto vegetation planted against the right-of-way fence; 2) pushing snow off overpasses or exit ramps onto vegetation or where it will all drain onto vegetation planted on the slopes next to the overpass; 3) plowing at high speeds in initial snow removal and in clearing shoulders. The first and second practices probably require the planting of tolerant species on such slopes and against fences, although they are far from the highway or along low ADT roads. The first two situations might sometimes be eliminated by small changes in procedures, which would not interfere with the plowing.

FLUSHING SODIUM FROM THE SOIL

A number of situations were found where the ESP, conductivity, and pH, singly or together, had reached levels probably too high for good growth, e.g., 43 feet from the intersection of I-694 and TH 65, the ESP was 20 and the pH 8.2. The author believes that by applying some combination of ammonium phosphate, ammoniom sulphate, and calcium sulphate ($CaSO_4$) amendments to the soil some of the sodium can be flushed from the exchange complexes and the pH lowered. In Maine, applied $CaSO_4$ reduced the level of soil sodium by one-third. Exact application rates and choice of amendment would have to be worked out in trials. The technique if proven beneficial could be combined with a monitoring system such as the Minnesota long-term plot system (p 33); when soils reach a critical level, the amendment could be applied.

SPRAYING FILMS TO PREVENT SALT ENTRY

The idea of coating plants with protective films to exclude spray NaCl has been tried with moderate success in Ohio and New Hampshire in glasshouses and in Germany and Minnesota in the field. In the field in Minnesota, sprays with two antidesiccants failed to prevent salt damage to two conifer and four deciduous species (Appendix A, study 11). The Germans also reported failure.

IMPROVING PLANTING PROCEDURES

The benefits to survival and early growth that are derived from good planting practices and planting stock have been discussed for Minnesota by Murphy *et al.* (1971) in the report on "Landscape Planting Species Survival." To reemphasize the need for good planting procedures, two examples follow illustrating the interaction between poor planting practices and salt.

Vanhoutte's spirea was spring planted in a compacted soil at a heavily salted intersection. The internal drainage was poor, and a salt solution accumulated in the planting hole. By October, leaf chloride was over 1 per cent and plants were dead or dying. The second example involved poor planting stock in sandy soils. The likelihood of success was probably marginal to begin with, but with salt spray killing off the top of the trees and soil salt adding stress to the soil, a slow recovery from transplanting was insured.

The watering basin left around new transplants has obvious advantages in keeping the tree well watered. However, if the basin collects salted runoff from roads or plowed snow, the soil might be leveled soon after the plant is well established.

IMPROVING GROWTH OF DAMAGED PLANTINGS

Improved maintenance gives improved growth. Along the highway, improved soil moisture, soil fertility, and rodent control would result in trees growing faster, having darker green leaves, and being more useful in their function. Spray damage would still occur, but it would be less important in keeping the tree stunted. There would be a fuller crown to expand after buds were killed, and extra food reserves would replace those lost in winter-killed branches. Post-planting maintenance techniques that would improve growth include: 1) rodent screens around young tree stems, 2) gopher control where needed, 3) slow release fertilizers where needed, 4) remulching on dry sites, and 5) release of overtopped shrubs from weeds the first few years after planting. These are well-known procedures that could be adapted to the highway situation by a skilled practitioner. The current lack of maintenance seems out of balance. Over $2.2 million has been spent since 1961 for planting along state highways in the Twin Cities metropolitan area; in comparison very little was spent to keep the plantings growing. This attitude differs from that held toward other investments along the highway.

Well maintained trees in the city grow faster. In our surveys, the trees on a block where the grass beneath them has been irrigated and fertilized were larger, greener, and showed less dieback and/or leaf scorch than trees left to grow under natural fertility and rainfall.

ALTERING EXPECTATIONS

If salt damage cannot be minimized, then it must be accepted and handled as a reality. Some implications of accepting the reality of salt damage follow. 1) Certain locations should not be planted, e. g., certain sections of road with high traffic and narrow rights-of-way. Even after planting, trees add to costs by making mowing more difficult and if a satisfactory tree cannot be grown, don't plant trees. 2) If certain locations are planted, rapid growth should not be expected. One way to live with slow growth is to plant larger trees, a practice being used increasingly. 3) If sensitive species like dogwood are used near a high ADT road, a 3-foot shrub resprouting each year, not a 6 to 8 foot screen of solid shrubs, should be expected. 4) Annual browning of pine needles and perpetual brown spots on cedar should be tolerated or the trees removed. 5) If the tree is dying or if shrub beds are killed back each year and taken over by weeds, consideration should be given to removal and possible replacement with more salt-tolerant plant material.

Each of these methods (except spray antidesiccants) has its place in a balanced program to minimize and to live with salt damage. At this time, the least expensive technique is the correct choice of species and sites. The technique that will most help existing plantings is improved maintenance.

CHAPTER IV. FUTURE PROSPECTS

The past and current extent and seriousness of salt damage in Minnesota was discussed in Chapter II. The future of salt damage in Minnesota is of equal concern. Will it worsen, ameliorate, or remain the same?

Salt damage far worse than in Minnesota occurs in Germany and New England. The history of deicing salt damage in these two locations will be summarized briefly to give perspective.

SALT DAMAGE IN GERMANY

Sodium chloride has been used for deicing purposes in Germany since 1940. However, no damage to vegetation was observed before the spring of 1959, when browning occurred in fir hedges along the Munich-Salzburg Autobahn. Subsequently, in numerous areas damage occurred to many species of roadside trees and shrubs while in other areas damage remained negligible. Applications of salt had been increasing during the late fifties and had reached 7 tons per center lane mile when damage first was noted.

In the spring of 1963, the damage to roadside vegetation suddenly became widespread and intense. However, concern was limited because the winter of 1962/63 had been the most severe in at least 20 years and perhaps since 1879/1880. During this severe winter, the use of deicing salt had increased dramatically. On the North Rhine-Westphalia Autobahn, for example, the salt use per center lane mile increased from 13 tons in 1961/62 to over 50 tons in 1962/63.

People thought that salt usage would decrease with normal winters and the roadside vegetation would recover, if indeed the damage was salt-related and not just a function of the severity of the winter. Salt usage decreased less than expected and by the relatively mild winter of 1965/66 it had climbed above that in 1962/63. The damage to highway vegetation continued to increase. Careful observation established that the damage was related to highways and to some material distributed from the highways as a spray. Salt was implicated more conclusively when twigs dipped in salt solutions produced highway damage symptoms. The German workers did not think soil salt was involved. Swiss researchers, in contrast, thought that soil salt caused much of the salt damage in their country.

Quantitative data were not given, but the German reports suggested widespread mortality of trees and of the branch systems within trees. The problem is continuing but has been altered by the decision to remove from near the road all trees that might be traffic hazards if hit by a vehicle. Planted in their place are fast-growing shrubs or small trees that can be cut periodically and that will sprout when cut. Salt tolerance has become a prime criterion in selecting these species.

Although the German Federal Highways (Autobahn) resemble the U.S. Interstate Highway system in being high-speed, high-ADT roads, they have considerably narrower rights-of-way. The median is generally no more than 13-feet wide and is planted with dense shrubs or trees for aesthetic value and for screening against the glare of oncoming headlights. Along other high-ADT roads in Germany, older trees frequently are located very close to the driving lane.

The German experience resembles what has happened along Minnesota highways in several ways. 1) Twig dieback and browning of conifers are among the first symptoms. 2) Spray damage seems more important than soil-salt damage. 3) As the use of salts increased so did the evidence of damage. In one important and related way, however, the experience is different. The damage seems to have been more severe in Germany. This could be attributed to the much closer location of trees to the roads in Germany than in Minnesota.

SALT DAMAGE IN NEW ENGLAND

In 1948, extensive tree injury, particularly marginal scorching of leaves, occurred in maples and horse chestnuts throughout Boston. This was the first evidence of possible deicing salt damage reported in New England.

In 1957, the New Hampshire Highway Department reported 13,997 dead trees along 3,700 miles of state roads. Most of these trees were mature sugar maples, and the cost of removal alone was estimated at $1,000,000. Subsequently, sugar maples declined along the roads throughout New England. The damage continues to the present.

The role of deicing salts in causing this enormous loss of sugar maples has been the subject of considerable controversy. When Marsdale first investigated the 1948 injury to Boston maples and horse chestnuts, he hypothesized that drought was the primary cause, but did not rule out the possiblity that salt was involved.

Banfield reported that salt-damage symptoms, as defined by New England workers, could not be distinguished from drought symptoms. He further noted that the decline of trees could be reversed by heavy midsummer watering. He is quoted as claiming that the higher evapotranspirational stress, soil temperature, and other factors of the roadside predominate and that salt is relatively minor. Unfortunately his environmental data are not published.

Most researchers, however, have thought that salt has played an important role in the decline of roadside sugar maples. They have correlated leaf chloride levels with injury symptoms and have induced similar damage by experimental salt application. Damage also has been related to distance from the road. Yet many researchers have wondered why not all trees on salted roads are affected and why salt toxicity symptoms are often but not always associated with high levels of internal chloride and/or sodium.

The chronicle of salt usage supports those who claim that salt injury is involved. Extensive salting started about 1940 and rose steadily. In 1954, Massachusetts used 4 tons per lane mile, in 1966 about 14 tons.

New England workers, for the most part, have considered only soil salts to be toxic to hardwoods. This may be appropriate to the rather narrow, often high-ADT New England State Highways where mature trees grow immediately adjacent to the highway. These results are not appropriate to most of Minnesota's highway plantings, but do apply to city streets and to specific sites along the major highways.

Other aspects or findings of New England experience with salt seem to apply to Minnesota: 1) Diagnosing soil-salt damage as distinct from other damage is difficult. 2) The practice of hauling away salted snow, rather than pushing it onto root zones of trees, is beneficial to the tree. 3) Decline can appear suddenly and erratically following many years of salting with only slight damage. If salting is moderate, years may pass before the build up causes damaging conditions. 4) The build up in leaf chloride can be a signal to the onset of the damage. 5) The damage often is most severe when stresses coexist in the trees, e.g., old age, water deficit, insects, pollution, and high soil temperatures. This means a dry period probably would bring about an increase in street salt damage in Minnesota. 6) Planting trees low in salt tolerance next to salted streets may lead to widespread death.

MINNESOTA ROADSIDES LONG-TERM PLOT SYSTEM

Looking at the German and New England experience, there is no reason to expect sudden widespread increases in salt damage in Minnesota if present levels of salting continue. The most apparent threat would seem to be a slow build up of soil salts and tissue Na and Cl in street trees. This build up especially if followed by a drought could possibly cause intense and widespread damage or death.

To monitor possible increases in soil and tissue NaCl and to keep track of damage in a number of situations, this investigation established the Minnesota Roadsides Long Term Plot System (Appendix A, study 9).

The plots were established during the summers of 1972 and 1973, and all the measurements taken are summarized in an unpublished report to the Minnesota Highway Department. There are 25 city plots with 482 plants representing 15 species, and 24 highway plots with 640 individuals representing 28 species. Table 13 lists the species in the system, and table 14 lists the plot locations. Soils data were collected on 46 plots, 32 where vegetation was sampled and 14 where vegetation was not included. For the trees and shrubs, information on location, size, appearance, damage symptoms, and internal nutrients was collected. For the soils, pH, exchangeable sodium percentage, soluble sodium, exchangeable sodium, chloride, and texture were measured.

The same trees, shrubs, and soil will be remeasured every 3 to 6 years to see what changes have occurred to the plants and soil concerning salt damage and salt build up. The system will also be used to keep quantitative records on other sources of damage to roadside trees.

Table 13. Number of individuals by species in permanent plots

Tree species	Highway	City street	Shrub species	Highway	City streets
American elm	17	156	Buffaloberry	9	
Austrian pine	54		Froebel's spirea	20	
American linden		30	Lilac	13	2
Black Hills spruce	75		Potentilla	15	
Colorado spruce	2	13	Sumac	10	7
Green ash	122	133	Vanhoutte spirea	11	
Hackberry	30	28	Zabel's honey-suckle	35	
Imperial honey locust	19	3	Buckthorn		3
Malus sp.	11	17	Amur maple	42	
Northern red cedar	6				
Populus sp.	23				
Red pine	61				
Russian olive	25				
Scots pine	27				
Silver maple	3	14			
Sugar maple	7	69			
White spruce	3	1			
Boxelder		4			
Prunus sp.		2			

Table 14. Summary of location and data collected on permanent plots

Plot	Location	County or city	Number of trees	Number of shrubs	Number of species	Soil data	Year planted
A	T.H. #36 & Cleveland Ave.	Ramsey	10	19	5	Yes	1966
B	W. side I-35W at Co. Rd. D	Ramsey	29	7	5	No	1966
C	E. side T.H. #8 N. of Co. Rd. D	Ramsey	14	0	2	Yes	–
D	E. side T.H. #51 Co. Rd. C-2 to Lydia	Ramsey	16	0	2	No	1964
E	E. side T.H. #280 at Como Ave.	Ramsey	36	9	5	Yes	1968
F	E. side T.H. #280 Larpenteur to Roselawn	Ramsey	28	15	5	No	1968
G	E. side T.H. #65 .65 mi. E. of mile 30	Anoka	10	0	1	No	–
H	S. side T.H. #36, .5 mi. E. of I-694	Washington	10	0	1	Yes	–
J	I-94 & Dartmouth Ave. interchange	Hennepin	52	14	9	Yes	1972
K	E. side I-94 at Warwick St.	Hennepin	26	0	5	Yes	1972
L	S. side I-94 at T.H. #280 exit	Ramsey	19	0	2	Yes	1972
M	N. side I-94 at Vandalia Ave.	Ramsey	20	7	6	Yes	1972
N	S. side I-94 E. of Fairview Ave.	Ramsey	17	0	4	No	1972
R	T.H. #36 & I-694 interchange	Washington	38	0	2	Yes	1972
S	I-35E & I-694 interchange	Ramsey	64	12	6	Yes	1972
T	I-694 at White Bear Ave.	Ramsey	16	20	4	No	1972
V	S.W. side T.H. #10, .5 mi. S. of mile 220	Anoka	10	0	1	No	–
W	S.W. side T.H. #10, .5 mi. S. of mile 217	Anoka	10	0	1	Yes	–
X	S.W. side T.H. #10, .1 mi. S. of mile 218	Anoka	10	0	1	Yes	–
Y	T.H. #100 & 27th St. in front of lot #2778	Hennepin	8	0	2	Yes	–
Z	I-694, .1 mi. S. of T.H. #120	Washington	21	10	3	Yes	1973
LL	I-94 & Franklin Terrace	Hennepin	32	0	4	No	1972
SS	T.H. #100 & T.H. #7 S.W. loop of inter.	Hennepin	16	0	2	Yes	–
NN	I-35, 1 mi. S. of T.H. #23	Pine	15	0	4	No	–
P	E. River Rd. in front of R. L. Stevenson	Fridley	8	2	4	Yes	–
Q	White Bear Ave. between 5th & 6th St.	St. Paul	13	0	1	Yes	–
AA	Lake St. near Lake Calhoun	Minneapolis	10	8	7	Yes	–
BB	Industrial Blvd. N. of Larpenteur	Minneapolis	10	0	2	Yes	–
CC	Olsen Memorial Hwy. W. of Lyndale	Hennepin	26	0	4	Yes	–
DD	Franklin Ave. near Grand	Minneapolis	20	0	1	Yes	–
EE	University Ave. Washington Ave. to Oak St.	Minneapolis	18	0	1	Yes	–
FF	Ford Parkway W. of Ford Bridge	Minneapolis	10	2	4	Yes	–
GG	W. 46th St. Lyndale to Blaisdell	Minneapolis	32	0	1	Yes	–
HH	Portland Ave. 38th to 40th St.	Minneapolis	22	0	2	No	–
I I	E. 36th St. 3rd Ave. to Portland	Minneapolis	25	0	1	No	–
J J	E. 26th St. Portland to Elliot	Minneapolis	27	0	2	Yes	–

Table 14 (continued).

Plot	Location	County or city	Number of trees	Number of shrubs	Number of species	Soil data	Year planted
KK	Washington Ave. 2nd Ave. to 5th Ave.	Minneapolis	28	0	2	No	–
MM	3rd St. 1st Ave. to 3rd Ave.	Minneapolis	26	0	2	No	–
NN	Portland Ave. 26th to 28th St.	Minneapolis	23	0	3	Yes	–
OO	Park Ave. 26th to 28th St.	Minneapolis	26	0	2	Yes	–
PP	Blaisdell Ave. 22nd to 24th St.	Minneapolis	22	0	2	Yes	–
QQ	Cedar Ave. 40th to 41st St.	Minneapolis	14	0	1	Yes	–
RR	Osseo Rd. at 47th St. N.	Hennepin	7	0	2	No	–
TT	Woodland Ave. from Hardy St. N.	Duluth	9	0	4	No	–
VV	E. 47th St. between 9th & 10th Ave.	Duluth	13	0	2	No	–
WW	London Rd. between 12th & 13th Ave.	Duluth	20	0	3	No	–
XX	Maryland Ave. Greenbrier to Weide	St. Paul	21	0	3	Yes	–
YY	Midway Pkw. Snelling to Buffalo	St. Paul	24	0	1	Yes	–
ZZ	Snelling Ave. at Ruggels	Falcon Heights	16	0	2	Yes	–
S-1	T.H. 36 0.2 miles W. of Dale St.	Roseville	–	–	–	Yes	–
S-2	Cty. Rd. 62 and T.H. 36 interchange	Minneapolis	–	–	–	Yes	–
S-3	I-35W S. of Cty Rd. C	Roseville	–	–	–	Yes	–
S-4	I-35E N. of Pennsylvania Ave.	St. Paul	–	–	–	Yes	–
S-5	I-35W S. of Washington Ave.	Minneapolis	–	–	–	Yes	–
S-6	I-35W near 58th St. S.	Minneapolis	–	–	–	Yes	–
S-7	I-35W near 40th St.	Minneapolis	–	–	–	Yes	–
S-8	I-94 at Hamline Ave.	St. Paul	–	–	–	Yes	–
S-9	I-94 at Snelling Ave.	St. Paul	–	–	–	Yes	–
S-10	I-94 at Dale St.	St. Paul	–	–	–	Yes	–
S-11	I-94 at Chatsworth St.	St. Paul	–	–	–	Yes	–
S-12	I-94 at Pascal St.	St. Paul	–	–	–	Yes	–

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*Informal English translations available.

Appendix A. A List and Brief Description of Methods Used in Major Studies of Investigation 636

1. *Effects of NaCl Sprays and Soil Applications on Red Pine and White Pine. (76)*[1,2,3]
During the winters of 1971/72 and 1972/73, NaCl was applied to 5- to 8-foot tall red pines in a forest plantation and during 1972/73 to trees along Highway 169. Salt was sprayed and maintained on the needle surfaces at levels equivalent to those observed along highways. Salt was also applied to the soil. Damage was observed and related to treatment and to needle Na and Cl. In a similar experiment, white pines in plantations were sprayed in 1971/72 and observed in 1972.
2. *Survey of Red Pine Damage Along Minnesota Roadsides. (76)*[1,2]
In 1972 and 1973, 109 red pine trees were surveyed for salt damage at 32 sites in the Twin Cities metropolitan area. Observed damage was related to vehicular traffic, distance from road, side of road, intersections, slope, and internal Na and Cl. Soil samples were collected at four sites. Similar supplementary observations were made on over 100 other red pines during other experiments.
3. *Determining Time When Red Pine Is Damaged. (76)*[1,3]
From October 1972 through October 1973, needles of red pine at six highway sites were sampled periodically for internal Na and Cl and for damage. A similar monitoring was done in the spring of 1974.
4. *Determining Time When Tip Dieback Occurs to Hardwoods Along Minnesota Roadsides.*[3,5]
From 1972 through 1973, five species were studied. Healthy branches on a number of trees on highway and garden sites were monitored periodically for twig surface Cl, internal Cl, and xylem, cambium or bud death. During the winter of 1973/74, the experiment was repeated on three species, and observations on cold hardiness were added to observations on damage and internal Cl.
5. *Effect of Highway Conditions on Cold-Hardiness of Hardwoods.*[5]
Factorial experiments were run separately on green ash and lilac in 1973/74. At each of four collection dates, highway and garden trees were compared for bud, xylem, and cambial kill at various freezing temperatures. The amount of damage was related to internal Cl and weather.
6. *Effect of Sprayed NaCl on Cold-Hardiness and Damage of Highway and Garden Grown Hardwoods.*[5]
NaCl was sprayed on highway and garden common lilac, radiant crab, and green ash and matching trees were unsprayed. At various collection dates, the cold-hardiness was compared for garden versus highway and salted versus unsalted. Results were related to internal Cl and weather.
7. *Damage Symptoms from Single Spraying of Hardwoods with Salt.*[2]
Seven species of hardwoods were sprayed midMarch 1972 with NaCl. Amount of salt on branches was monitored. Dates of bud opening and bud mortality were recorded.
8. *Survey of Damage to Green Ash Along Minnesota Roadways.*
A total of 303 green ash trees were evaluated at 24 sites. Each tree was described by salt-related damage, distance from road, ADT of road, nearness to intersections, side of road, elevation from road, size of trees, quality of soil, and other factors which might relate to damage. These factors were analyzed in various combinations to determine which were most related to damage. The data from several sites were used to estimate the loss in growth and value from deicing salts, based on a modified procedure of the International Shade Tree Conference (ISTC, 1970).
9. *The Minnesota Roadsides Longterm Plot System.*[4]
This experiment is described in Chapter IV. The data collected in establishing the plots were used to evaluate the tolerance of species to salt and to determine probability of salt damage by type of road. The data were also used to relate damage symptoms to internal Na and Cl.
10. *Seasonal Changes in Levels of Leaf Cl.*
The leaves of 21 green ash at seven sites were analyzed for Cl from May to November 1973 to determine stability of Cl in survey samples.
11. *Use of Antidesiccant Sprays to Reduce Damage. (16)*[1]
Six species growing near salted roads were sprayed with four formulations of Wiltproof NCF and Vapor Gard (no endorsement of these trade names intended). Damage and NaCl content were monitored in the spring.
12. *Survey of Rodent Damage Along Minnesota Roadsides.*
Girdling, root cutting, and animal burrows were observed along 5.2 miles of roadside. Sampled were 275 trees of green ash, honey locust, amur maple, flowering crab, Russian olive, Black Hills spruce, and Austrian pine.
13. *High Osmotic Potential as Cause of Needle Browning in Red Pine. (76)*[1,2]
14. *Chloroform-Soluble Deposits on Needles of Red Pines Near Roads.*[2]
15. *Damage to Roadside Vegetation from a Single Early Spring Application of Deicing Salts.*[3]
16. *Early Fall Coloration as a Symptom of Salt Damage.*[3]
17. *Aerial-Photo Detection of Highway-Associated Damage to Red Pines. (21)*[1]
18. *Amount of NaCl Deposited Near Roads.*[2,3]
Absolute amounts of NaCl deposited 15 to 300 feet from 11 highway sites were monitored with collection trays for a 2- to 4-week period. Dispersal also was studied in detail at three intersections along major highways. The influence of amount of traffic, road direction, and amount of salt applied was examined.

19. *Amount of Salt on Vegetation Near Roadway.*[2]
The amount of Cl intercepted by twigs and needles during the winter of 1971/72 was measured on 15 transects running perpendicular to 15 highway sites. The transects extended as far as 1000 feet from the highway. In addition, Cl was examined in 647 trees at various distances from three sections of highway.

20. *Amount of Salt in Soil Near Roads.*
Exchangeable sodium percentage, exchangeable sodium, chloride, conductivity, and pH were determined for soils at increasing distances from roads of different ADTS. Soils of various textures and cation exchange capacities were included.

[1] Number in parenthesis refers to publication cited in Selected Bibliography.

[2] Additional information available in 1971/72 Annual Report Project 636, submitted to Minnesota Highway Department (MHD).

[3] Additional information in 1972/73 Annual Report Project 636, submitted to MHD.

[4] Additional information in 1974 Final Report Project 636, submitted to MHD.

[5] More information available in manuscript in preparation.

Appendix B. Relative tolerances of woody species to NaCl under winter conditions. Compilation of results of this investigation and literature for species probably able to grow in Minnesota.

Key

A. First column – Scientific and common names of species, varieties, and cultivars. # indicates that the ability of the species to survive in Minnesota was not known.

B. Second, third, fourth columns – tolerant, moderately tolerant, susceptible.

1. The salt tolerance is indicated here by an entry in the appropriate column. The entries are letter coded to indicate to what conditions the species was found tolerant or susceptible, at what age the determination was made, and which study gave the information.

   a. Letter codes

Salt source	*Age of plant material tested* Juvenile	Mature
Soil salt (ground)	g	G
Spray salt (aerial)	a	A
Highway salt conditions	h	H
City street salt conditions	c	C

   b. Number codes. The number after the letter code indicates the author as listed below. The number, in parenthesis is the number in the Selected Bibliography.

Numbers	*Study*
1 (8)	Buschbom (1968)
2 (13)	Davidson (1970)
3 (14)	Dimitri (1972)
4 (25-28)	Hanes et al. (unpublished)
5 (33)	Hofstra & Hall (1971)
6 (53)	Monk & Peterson (1962)
7 (54)	Monk and Wiebe (1961)
8 (58)	Rich (1971)
9 (61-63)	Sauer (1967)
10 (66)	Shortle & Rich (1970)
11	Sucoff, experiments (Appendix A)
12	Sucoff, general observation
13 (89)	Zulauf (1965)
14 (91)	Zulauf (1966)

C. Example of how table may be used for *Acer ginnala.* Sucoff in studies and general observation along the highway found the species to be moderately tolerant. Buschbom in a controlled spray experiment found the species to be intolerant. For the highway situation in Minnesota, the species was evaluated and entered as moderately tolerant in table 10.

	Relative tolerance to salt		
Species	Tolerant	Moderately tolerant	Susceptible
Acer ginnala (Amur maple)		$Hh_{11,12}$	a_1
A. negundo (Box elder)		$a_1g_{14}H_{12}$	H_{12}
A. platanoides (Norway maple)	$Hh_9a_1g_{6,14}$	g_{13}	
A. rubrum (Red maple)			$H_{8,10}$
A. saccharinum (Silver maple)		a_1C_{12}	g_4
A. saccharum (Sugar maple)			$C_{12}H_{8,10,11}$
A. tataricum (Tatarian maple)			a_1
Aesculus hippocastanum (Horse chestnut)	$a_1g_{13,14}$		
Alnus glutinosa (Black alder)	a_1	Hh_9	g_{14}
A. hirsuta (Alder)		a_1	
A. incana (Speckled alder)		a_1	g_{14}
A. rugosa (Smooth alder)			H_{10}
Abies balsamea (Balsam fir)			H_8
Amelanchier X grandiflora			a_1
A. ovalis (Service-berry)	a_1		
Atriplex hastata #		g_{14}	
A. semibaccata #	g_{14}		
A. vesicaria #		g_{14}	
Berberis koreana (Korean barberry)		a_1	
B. thunbergii (Japanese barberry)			$g_{6,7}a_1$
B. vulgaris (Common barberry)			a_1
Betula alleghaniensis (Yellow birch)	$H_{8,10}$		
B. humilis			a_1

Appendix B (continued).

Species	Relative tolerance to salt		
	Tolerant	Moderately tolerant	Susceptible
B. kirghisorum	g_{14}		
Betula lenta (Cherry birch)	$H_{8,10}$		
B. papyrifera (Paper birch)	$H_{8,10}$	H_{12}	
B. pendula (European birch)		a_1	
B. populifolia (Gray birch)	$H_{8,10}$		
B. pubescens			a_1
Caragana arborescens (Siberian pea tree)	Hh_9a_1		
Carpinus caroliniana (American hornbean)			H_{10}
Carya ovata (Shagbark hickory)			H_{10}
Celtis occidentalis (Hackberry)		C_{12}	$Hh_{11,12}a_1$
Chamaecyparis pisifera (Sawara cypress)			a_1
Clematis vitalba (Traveler's joy)			a_1
Cornus alba			a_1
C. a. 'kesselringii'			a_1
C. a. 'sibirica' (Siberian dogwood)			a_1
C. a. 'spaethii'			a_1
C. amomum			a_1
C. mas (Cornelian cherry)			a_1
C. sanguinea (Red dogwood)			a_1
C. stolonifera (Red-osier dogwood)			Hh_{12}
C. s. 'flaviramea' (Yellow-twig dogwood)			$Hh_{12}a_1$
Corylus americana (American hazel)			a_1
C. cornuta (Beaked hazel)			a_1
Cotoneaster integerrimus (Cotoneaster)			a_1
Crataegus crus-galli (Cockspur hawthorn)			a_1
C. punctata			a_1
C. sanguinea			a_1
Elaeagnus angustifolia (Russian olive)	$g_{4,6,7}Hh_{9,11}a_1$	g_{14}	
E. X ebbingei #			a_1
E. umbellata			a_1
Euonymus alatus (Winged euonymus)			$g_{6,7}$
E. europaeus (European euonymus)			a_1
E. verrucosa			a_1

Species	Relative tolerance to salt		
	Tolerant	Moderately tolerant	Susceptible
Fraxinus americana (White ash)	$H_{8,10}$		
F. angustifolia		a_1	
F. pennsylvanica (Green ash)		Hh_{11}	
F. p. var. lanceolata (Green ash)		$g_{6,7}$	
F. p. 'Marshall's seedless' (Marshall seedless ash)		Hh_{12}	
F. p. var. subintegerina (Green ash)	g_{14}		
Gleditsia triacanthos (Honey locust)	$Hh_{11}g_6$		a_1
G. t. var. inermis (Thornless honey locust)	g_7		
G. t. 'imperial' (Imperial honey locust)	$Hh_{11}g_6$		
Halimodendron halodendron (Salt tree)	a_1		
Hippophae rhamnoides (Sea buckthorn)	Hh_9g_{14}	a_1	
Juglans nigra (Black walnut)			$g_{6,7}$
Juniperus chinensis 'pfitzeriana' (Pfitzer juniper)	g_4		
J. horizontalis 'plumosa' (Horizontal juniper)	g_4		
J. virginiana (Red cedar)	$H_{8,10}$	$Hh_{12}g_7$	
Larix decidua (European larch)	a_1		
L. leptolepis (Japanese larch)	a_1		
Ligustrum vulgare (Common privet)			Hh_9g_{14}
Lonicera amoena var. alba #			a_1
L. coerulea (Sweetberry honeysuckle)			a_1
L. maackii (Amur honeysuckle)			a_1
L. periclymenum	a_1		
L. tatarica (Tatarian honeysuckle)			a_1
L. t. 'zabelii' (Zabel's honeysuckle)	$Hh_{11,12}$		
L. xylosteum (European fly honeysuckle)	Hh_9	a_1	
Lycium chinense (Chinese matrimony vine)	a_1		
L. halimifolium (Common matrimony vine)	a_1g_{14}		
Malus 'dolgo' (Dolgo crabapple)			Hh_{12}
Malus 'hopa' (Hopa crabapple)			Hh_{12}

Appendix B (continued).

Species	Relative tolerance to salt		
	Tolerant	Moderately tolerant	Susceptible
Malus 'radiant' (Radiant crabapple)			a_{12}
M. sylvestris	a_1		
Morus alba (White mulberry)			a_1
Parthenocissus quinquefolia (Virginia creeper)	a_1		
Philadelphus coronarius (Sweet mock orange)	a_1		
Physocarpus opulifolius 'nanus' (Dwarf ninebark)		h_{12}	h_{12}
Picea abies (Norway spruce)			$a_1 g_{4,14}$
P. glauca (White spruce)			g_{14}
P. g. var. densata (Black Hills white spruce)	Hh_{11}		
P. pungens (Colorado blue spruce)	Hh_{11}	g_6	g_7
Pinus cembra (Swiss stone pine)			a_1
P. mugo (Mugo pine)	$g_{13,14}$		
P. nigra (Austrian pine)	Hh_{11}	H_5	
P. ponderosa (Ponderosa pine)	Hh_{12},	$H_{12} g_7$	
P. resinosa (red pine)			$H_{11,5,10} Ha_{11}$ $a_{12} H_{12,8,10,5}$
P. strobus (White pine)			$h_{12,2} g_4$
P. sylvestris (Scots pine)	Hh_{12}	$H_{11,12}$ $h_{2,11,12}$	$H_5 a_1$
Populus acuminata	g_{14}		
P. alba (White poplar)	$a_1 g_{14}$		
Populus angustifolia (Narrowleaved cottonwood)	g_{14}		
P. balsamifera (Balsam poplar)	g_{14}		g_{14}
P. X canadensis	$a_1 g_{14}$		
P. X canescens (Gray poplar)	$HA_3 a_1 g_{14}$		
P. deltoides (Cottonwood)	$g_{14} Hh_{12}$		g_{14}
P. grandidentata (Big tooth aspen)	H_{10}		
P. laurifolia			g_{14}
P. nigra (Black poplar)	$a_1 HA_3$	g_{14}	
Populus n. 'italica' (Lombardy poplar)	HA_3		g_{14}
P. n. 'plantierensis'	HA_3		
P. sargentii (Great Plains cotton-wood)	g_{14}		
P. trichocarpa (Western balsam poplar)	g_{14}		
P. tremuloides (Trembling aspen)	$H_{8,10,12} h_{12}$ g_{14}		
Potentilla fruticosa 'jackmanii' (Jackman's potentilla)	$Hh_{11,12}$		
Prunus padus (European bird cherry)	g_{14}	a_1	
P. serotina (Black cherry)	$H_{8,10}$		$a_1 Hh_9$
Pseudotsuga menziesii (Douglas fir)		$a_1 g_6$	$h_{12} a_1 g_7$
Quercus alba (White oak)	$H_{8,10,12} g_{14}$		$a_{5,8}$
Q. bicolor (Swamp white oak)			a_1
Q. macrocarpa (Bur oak)	$H_{12} g_{14}$	a_1	
Q. muhlenbergii (Yellow chestnut oak)			a_1
Q. palustris (Common pin oak)			a_1
Q. rubra (Red oak)	$H_{8,10} g_{14}$		a_1
Rhamnus catharticus		a_1	
R. crenatus		a_1	
R. davuricus	a_1		
R. frangula (Alder buckthorn)		a_1	
Rhus glabra (Smooth sumac)		Hh_{12}	
R. trilobata (Ill scented sumac)	$g_{6,7}$		
Ribes alpinum (Alpine currant)	$Hh_9 a_1$		
R. americanum (American black currant)		a_1	
R. aureum (Golden currant)	a_1		
R. divaricatum		a_1	
R. magdalenae #			a_1
R. nigrum (European black currant)	a_1		
Robinia pseudoacacia (Black locust)	$C_{12} H_{8,10}$ $g_{4,7} a_1$		
Rosa canina (Dog rose)			$Hh_9 a_1$
R. multiflora (Multiflora rose)			$g_{6,7}$
R. rugosa (Rugosa rose)	Hh_9		a_1
Rosa virginiana			$a_{5,8}$
Salix alba (White willow)	a_1	HA_3	

Appendix B (continued).

Species	Relative tolerance to salt: Tolerant	Moderately tolerant	Susceptible
S. a. 'vitellina' (Golden willow)		$HA_3g_{6,7}$	a_1
S. X alopecuroides #	HA_3		
S. amygdalina (Almond leaved willow)	a_1		
S. X basfordiana #			HA_3
S. caprea (Goat willow)		Hh_9a_1	
S. cordata		HA_3	
S. daphnoides #	a_1		
S. X dasyclados #	HA_3		
S. fragilis	$HA_3a_1g_{14}$		
S. X helix #		HA_3	
S. X hippophaefolia #		HA_3	
S. X meyeriana #	HA_3		
S. pentandra (Laurel-leaf willow)		$Hh_{12}a_1$	
S. purpurea 'lambertiana' # (Purple osier)	a_1		
S. p. 'nana' # (Dwarf purple osier)			$g_{6,7}$
S. X rubens #			HA_3
S. stipularis #		HA_3	
S. X tinctoria #	HA_3		
S. viminalis (Common osier)	HA_3g_{14}		
Sambucus canadensis (American elder)			a_1
S. nigra (European elder)			a_1
S. racemosa (European red elder)			Hh_9
Shepherdia argentea (Buffaloberry)	$Hh_{11}g_7$	g_6	
Sorbus aucuparia (European mountain ash)			a_1
S. decora (Showy mountain ash)	a_1		
S. X hybrida			a_1g_{14}
S. latifolia			a_1
Spiraea bumalda 'froebeli' (Froebel's spirea)		Hh_{11}	
S. X vanhouttei (Vanhoutte's spirea)	Hh_{12}		$g_{4,6,7}$
Symphoricarpos albus (snowberry)		a_1	
S. a. var. laevigatus (Garden snowberry)	Hh_9		
S. orbiculatus (Coralberry)			a_1
S. racemosus (Waxberry)	g_{14}		
Syringa vulgaris (Common lilac)		Hha_{11}	a_1
Tamarix petandra (Fivestamen tamarisk)	a_1g_{14}		
Thuja occidentalis (Eastern white cedar)	H_5	H_{12}	
Tilia americana (American linden)			$H_{8,10,12}C_{12}$
T. cordata (Small leaved European linden)	a_1g_{13}	g_{14}	$g_{6,7,14}$
T. platyphylla (Large leaved linden)	a_1		
Tsuga canadensis (Eastern hemlock)			$H_{8,10}g_4$
Ulmus americana (American elm)	g_{14}	$CHh_{11,12}$	$H_{8,10}$
U. glabra (Wych elm)	Hh_9a_1	g_{14}	
U. pumila (Siberian elm)	g_{14}		
U. p. var. arborea			a_1
Viburnum lantana (Wayfaring tree)			a_1
V. opulus (European highbush cranberry)			a_1
V. trilobum (American highbush cranberry)			Hh_{12}

Appendix C. Development of Tables Showing Probability that Salt Damage Will Occur at Specific Highway Locations

Tables that predict the likelihood of serious salt damage at specific locations could help the landscaper match salt tolerant species to high-risk locations. This appendix explains how such tables (e.g., table 12) were developed from our data. The strategy was to determine in detail where salt damage had occurred in the past and then to predict that it would occur in the same types of places in the future.

Three field surveys were conducted during 1972 and 1973 (Appendix A, studies 2, 8, and 9). In each survey, each plant was scored for salt injury symptoms on a scale of 0 to 4 using criteria explained in Chapter II and summarized in table 8. Only salt injury symptoms were rated. Data were also taken on each plant for Average Daily Traffic (ADT) of highway, distance from travel lane, side of road, intersections, slope to highway, and other features. The ADT was determined from traffic flow maps; these were usually 2 to 4 years old.

The first survey included 303 green ash from 24 different sections of highway. Using 2-, 3-, and 4-way stratifications, empirical relations between damage and location were sought. The best simple relation was achieved by dividing the 303 trees into 25 possible locations: five types of highway (by ADT) and five distance groupings from each highway; Table C-1 shows these. From zero to 33 trees were found in a particular location.

Initially the amount of damage at a particular location was determined from the field data by pooling all the trees in the survey found at a location, calculating the fraction of trees with each score (0 to 4), and calculating the mean injury score for the location. To make the mean scores useful to landscapers, they were divided into five damage classes of descriptive names. The names were applied to the average scores in such a way that for green ash high damage (H) meant an unacceptable landscape condition, medium high (MH) an undesirable condition, medium (M) or medium low (ML) an acceptable if not ideal condition, and low (L) an acceptable condition.

Table C-2 relates mean injury score to a descriptive code in the column labeled primary classification. To make them still more useful to the landscaper, the descriptive codes were modified according to extraordinary distributions of damage. For example, an average score of 2.2 indicated M damage but if 30 percent of the trees scored 4, the rating was raised to MH as this is an undesirable amount of damage. Typical distribution of symptom scores within each damage classification is presented in table C-3.

The amounts of damage in the 25 locations in table C-1 were coded using table C-2. In locations where trees were not found during the survey, codes were assigned by interpolation and extrapolation. Using appropriate data, the amounts of damage were also classified by side of road (table C-4) and by the presence or absence of intersections (table C-5).

In the second and third surveys, 109 red pines were examined along 32 sections of highway using techniques similar to those for green ash, except that needle Na and Cl were measured (Appendix A, studies 2 and 9). Using criteria like those in table C-2 for coding damage, table C-6 was constructed. The codes were interpreted the same except that MH damage on red pines is an unacceptable landscape condition. In the same situations, the damage to red pines is often higher, because red pines are susceptible to salt spray while green ash is moderately tolerant. Red pine, although no longer planted in the metropolitan Twin Cities, is an excellent example of a sensitive species and was helpful in preparing table C-7.

In the third survey, about 462 trees belonging to 17 species (and including 104 different individuals of green ash) were examined. These trees were divided into the three tolerance classes according to the similarity of their performance compared with green ash and red pines. These trees along with the red pines were pooled by tolerance class to form three tables similar in structure to table C-3. The three tables were combined to form table 12 of the text, repeated in this appendix as Table C-7. Table C-7 is a record of what happened in the past. Since this past record is to be used to predict future damage, the term "Probable" is added to the title of table C-7.

Tables C-1, C-6, and C-7 are only first approximations for several reasons. They are based on data where some rough assumptions had to be made, e.g., that salt damage was always distinguished from other damage. They are based on species grouped for tolerance, but tolerances vary within a group. The difference between the rating for midtolerant species in table C-7 and green ash (table C-1) is one measure of this difference. The accuracy in predicting damage decreases when going from single species tables (tables C-1 and C-6) to a pooled species table (table C-7). It diminishes further when species not used in developing the pooled table are rated with it. The tables are also approximate because factors in addition to ADT and distance influence damage. Intersections appeared to have only a slight effect (table C-5) but damage seemed much more severe beyond 60 feet on the south side of the road compared with other sides (table C-4). The sample size was too small to really study the influence of side of road. The tables do not consider soil salts or other forms of stress that interact with spray salt.

Whatever the uncertainty and inaccuracies, tables C-1, C-6, and C-7 present the best guides available to date. Their use should increase the chances that landscape plantings will not suffer salt damage.

Table C-1. Occurrence of high (H), medium (M), and low (L) damage classes on green ash growing at different distances from highways with various average daily traffics (ADT)

ADT (number of vehicles)	Distance from travel lane (ft)				
	30 – 40	45 – 60	65 – 80	85 – 150	> 150
9,500-19,999	H	L	L	L	L
20,000-39,999	H	H	ML	L	L
40,000-59,999	H	H	M	ML	L
60,000-79,999	H	H	MH	M	L
> 80,000	H	H	H	M	ML

Table C-2. Classification of salt damage as high (H), medium high (MH), medium (M), medium low (ML), and low (L) using symptom scores gathered in green ash survey

Mean symptom score	Primary classification	Modified classification when		
		At least 25 percent of trees rated 0 or 1	At least 50 percent of trees rated 3 or 4	At least 25 percent of trees rated 4
3.3 to 4.0	H	*	*	*
2.6 to 3.2	MH	M	*	H
1.9 to 2.5	M	ML	MH	MH
1.1 to 1.8	ML	L	M	M
0 to 1.0	L	*	*	*

* Indicates no modification needed or situation cannot occur. Primary estimate is used. In cases where one modification increases damage class and another lowers damage class, use primary estimate.

Table C-3. Typical distribution of trees among salt injury symptom scores (table 8) at the five damage classifications

Damage classification	Salt injury symptom class			
	0/1	2	3	4
H (High)	0	10	35	55
MH	15	35	35	20
M (Medium)	30	30	20	20
ML	30	50	15	5
L (Low)	80	15	5	5

Table C-4. Occurrence of high (H), medium high (MH), medium (M), medium low (ML), and low (L) damage classes on green ash growing on north and south sides of highway

Average daily traffic (number of vehicles)	Distance from travel lane (ft)				
	30 – 40	45 – 60	65 – 80	85 – 150	>150
			South Side of Highway		
20,000-39,999	H	H	H	MH	L
40,000-59,999	H	H	H	MH	M
60,000-79,999	H	H	H	MH	MH
> 80,000	H	H	H	H	MH
			North Side of Highway		
20,000-39,999	MH	M	ML	ML	L
40,000-59,999	H	H	ML	ML	L
60,000-79,999	H	H	MH	MH	L
> 80,000	H	H	H	MH	L

Table C-5. Effect of intersections near trees on damage rating classes in green ash

Average daily traffic (number of vehicles)	Distance from travel lane (ft)				
	30 – 40	45 – 60	65 – 80	85 – 150	>150
			With Intersections		
20,000-39,999	H*	MH	M	ML	L
40,000-59,999	H	H	M	ML	L
60,000-79,999	H	H	M	M	L
> 80,000	H	H	H	MH	M
			Without Intersections		
20,000-39,999	H	H	ML	ML	L
40,000-59,999	H	H	ML	ML	L
60,000-79,999	H	H	M	M	L
> 80,000	H	H	H	L	L

*See table C-2.

Table C-6. Occurrence of high (H), medium high (MH), medium (M), medium low (ML), and low (L) damage classes on red pines growing at different distances from highways of various average daily traffics (ADT)

ADT (number) of vehicles)	Distance from travel lane (ft)				
	30 – 40	45 – 60	65 – 80	85 – 150	150 or more
< 4,000	L	L	L	L	L
6,000-10,000	H	M	L	L	L
17,000-20,000	H	M	ML	L	L
25,000-40,000	H	MH	MH	MH	L

Table C-7. Probable amount of damage which will occur to species of various tolerances to salt as affected by average daily traffic (ADT) of road and distance from road. Amounts of damage classed as low (L), medium low (ML), medium (M), medium high (MH) or high (H).

Species tolerance to NaCl	ADT (in thousands)	Distance from travel lane (ft)				
		30-40	45-60	65-80	85-150	>150
Tolerant	0 – 10	L	L	L	L	L
	10 – 19	L	L	L	L	L
	20 – 39	L	L	L	L	L
	40 – 59	ML*	L	L	L	L
	60 – 79	M	ML	L	L	L
	80+	H	M	ML	L	L
Moderately tolerant	0 – 10	M	L	L	L	L
	10 – 19	MH	L	L	L	L
	20 – 39	MH	ML	ML	L	L
	40 – 59	H	MH	MH	M	L
	60 – 79	H	H	MH	M	L
	80+	H	H	MH	M	L
Susceptible	0 – 10	M	ML	L	L	L
	10 – 19	H	MH	M	M	L
	20 – 39	H	H	MH	MH	ML
	40 – 59	H	H	MH	MH	ML
	60 – 79	H	H	H	H	M
	80+	H	H	H	H	M

*Solid lines and shadings separate low, medium, and high probabilities from each other.