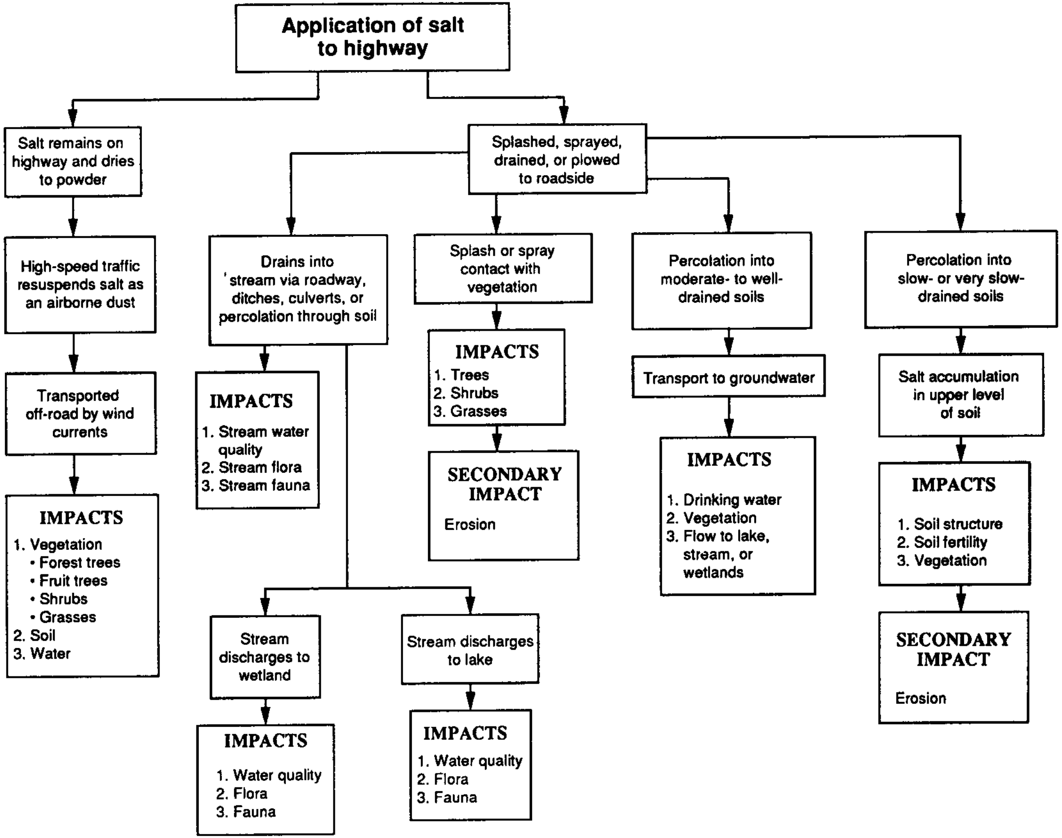

FIGURE 4-1 Flow diagram summarizing possible pathways of road salt movement through the environment.

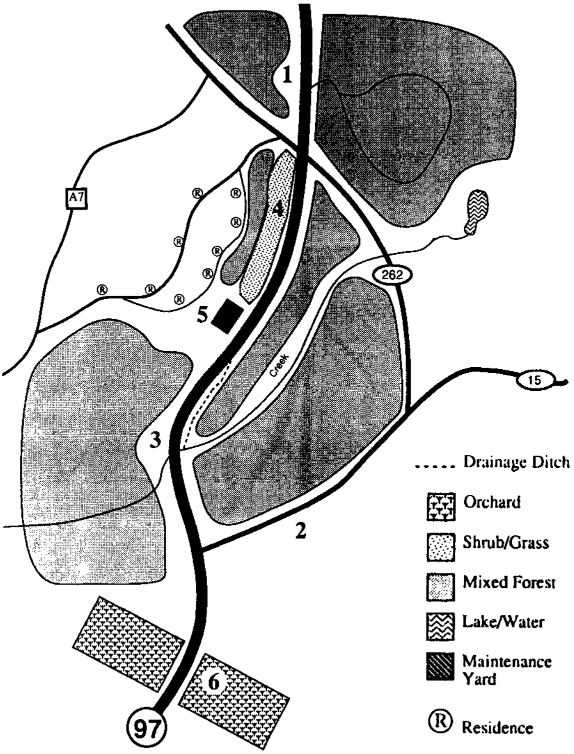

FIGURE 4-2 Map of six hypothetical sites.

local circumstances (e.g., tourist value and public concern) that cannot be depicted with this methodology.

Site 1

Site 1 consists of deciduous, coniferous, or mixed forest trees adjacent to a 1-mi section of a four-lane Interstate or other primary highway with open drainage (i.e., no special drainage system to divert runoff). Traffic speeds range from 50 to 65 mph, increasing the potential for airborne salt spray. A flat topography with no significant potential for roadside erosion is assumed. As a consequence, salt damage is confined primarily to forest trees and, to a lesser extent, soils. Annual salt loadings on the highway exceed 10 tons per lane-mi, as is common on many primary highways in New England, New York, and the Great Lakes region.

Forest Trees

Salt damage to roadside trees typically occurs as a result of (a) salt accumulation in soil, (b) traffic splash and direct contact with plowed snow containing salt, and (c) airborne salt spray or mist. The case study literature and information from discussions with state highway agencies indicate that damage from each of these causes is typically limited to within 40, 60, and 100 ft of the pavement edge, respectively. Within each zone, salt exposure declines rapidly with distance from the roadway. A standard corridor of forest, which is 1 mi long and 100 ft wide on both sides of the highway, can have from 1,250 to 3,500 trees per mile, according to estimates provided by highway agencies. The actual number of trees depends on the setback or tree-clear zone. In many states, especially in the New England and Middle Atlantic regions, all forest trees have been removed within 30 to 40 ft of Interstate highways, primarily for safety reasons. Because the major impact of salt is confined to within 60 ft of the highway, damage to forest trees is considerably less on highways with these large setbacks. Even under these circumstances, small trees or shrubs may be planted near the roadway for erosion or glare control.

Few measures are available to estimate tree condition along salt-treated highways. Connecticut and Michigan highway officials estimated that approximately 5 percent of forest trees along primary highways appear moderately to severely damaged (Connecticut and Michigan Departments of Transportation, personal communications). The Nevada Department of Transportation estimates that about 10 percent of coniferous trees in the Lake Tahoe basin are damaged by salt (Nevada Department of Transportation 1990). To estimate mortality rates, Nevada assumed that about 1 in 10 of moderately and severely damaged trees will not recover from salt injury and will die each year during a 10-year period.

Multiplication of the Nevada mortality index by the state estimates of tree damage suggests that between 0.5 percent and 1.0 percent—or about 0.75 percent on the average—of the forest trees in this hypothetical site might die each year during the next 10 years because of salt injury (0.10 × 5 to 10 percent). Multiplication of 0.75 percent by the estimated number of trees per mile (1,250 to 3,500) yields an annual loss of roughly 10 to 25 trees per mile per year for this hypothetical site (0.75/100 × 1,250 to 3,500 trees per mile). If these trees were removed and replaced, most highway agencies would plant small, younger, more salt-tolerant trees. According to estimates from several state highway agencies, the average cost of removing a dead or severely injured tree and planting and maintaining a young tree is approximately $500. Multiplication of $500 by the estimated 10 to 25 trees per year that might die on this site yields a cost of tree removal and replacement of $5,000 to $12,500.

Soil

High salt concentrations in soils may result in structureless and dense soil, which reduces water infiltration and lowers soil moisture content. High levels of sodium may cause the loss of essential plant growth nutrients such as potassium, calcium, and magnesium. If this occurs in excess, soil fertility will diminish, preventing the growth of desired vegetation or leading to soil erosion. Though salt concentrations can be elevated as far as 40 ft from the roadway, the literature suggests that it is unrealistic to assume an adverse effect on the entire band. Instead, damage is likely to be sporadic, and most damage is likely to be confined to 15 ft of the pavement edge.

In extreme cases, in which soil structure is severely altered and deficiencies in essential nutrients are discovered, soil reclamation is an option. The primary objective of soil reclamation is to improve soil infiltration and moisture retention. This can be accomplished by periodically treating the soil with gypsum if the soil is alkaline or with lime if the soil is acidic (Jacobs and Scofield 1980; Maryland Department of Transportation 1987; U.S. Soil Conservation service, personal communication). The calcium in these two products improves soil structure by removing the sodium and is also a nutrient for plant growth. Gypsum is normally applied at a rate of 10 tons per acre and costs about $40 per ton, resulting in an application cost of $400 per acre (Maryland Department of Transportation 1987; U.S. Soil Conservation Service, personal communication). In applying gypsum, tilling and other soil preparation is necessary, which costs approximately $250 per acre (Maryland Department of Transportation 1987). The total remediation cost is therefore about $650 per acre.

A 1-mi section of highway in which a 15-ft band of soil is affected on both sides of the roadway would require gypsum treatments on a total of about 4 acres of soil. At $650 per acre, the cost of one treatment would be $2,600 ($650 × 4 acres). Treatment once every 5 to 10 years yields an average annual cost of about $250 to $500 during the period ($2,600/5 to 10 years).

Site 2

Site 2 consists of deciduous, coniferous, or mixed forest trees adjacent to a 1-mi section of a two-lane rural (or secondary) highway with open drainage. A flat topography with no significant potential for roadside erosion is assumed. As a result, environmental damage is confined primarily to forest trees and, to a lesser degree, soils. Annual salt loadings on the highway are less than 10 tons/lane-mi, as is common on more lightly traveled roads.

Forest Trees

The tree-clear zone on the side of secondary roads is typically only 10 to 15 ft; however, because traffic volumes and speeds tend to be much lower on these roads than on primary highways, airborne salt spray and mist are less of a problem. Moreover, salt application amounts are usually lower on secondary roads, and plows rarely deposit salt-laden snow far from the roadway. As a result, tree damage is likely to be less severe on this secondary road than on the primary highway at Site 1. Almost all of the state highway agencies contacted for this study in the New England, Middle Atlantic, and Great Lakes regions indicated that tree damage on rural and secondary roads is low.

The only state that could roughly quantify this damage was Maine. About 80 percent of coniferous trees along primary highways in Maine experience some minor and temporary browning in late winter (for numerous reasons, including road salt), but fewer than 10 percent of trees on secondary roads exhibit similar effects (Maine Department of Transportation, personal communication). Multiplication of 0.125 (that is, 10/80) by the annual number of tree deaths along the primary highway at Site 1 (10 to 25 tree deaths per mile) yields a loss on the secondary road of 1 to 3 trees per year. At $500 per tree, the cost of tree removal and replacement for this site is $500 to $1,500 per mile ($500 × 1 to 3 trees).

Soil

The approach used for estimating the cost to mitigate road salt effects on soil is the same as for Site 1. The major difference is that lower vehicle speeds, traffic levels, and salt loadings result in even less salt being deposited on the roadside, reducing the frequency of gypsum treatments and other mitigation measures. Treatment once every 10 years yields an average annual cost of $250 (see discussion of Site 1).

Site 3

Site 3 consists of forested corridor adjacent to a 1-mi section of primary highway. A drainage ditch diverts highway runoff into a stream, which flows into a small lake several miles downstream. Unlike Sites 1 and 2, a downslope from the highway to the stream is assumed. Consequently, highway runoff flows freely downgradient, causing erosion of roadside soil.

Forest Trees

Approximately 10 to 25 trees per mile are lost due to salt injury, costing about $5,000 to $12,500 per year to remove and replace (see discussion of Site 1). However, this effect may be partially mitigated by the diversion of some highway runoff by the drainage ditch.

Stream Water Quality

The stream runs parallel to the highway at this site, resulting in a large portion of the water flow coming from areas in the watershed where road salt is used. Consequently, where the stream crosses the highway (Site 3 in Figure 4-2), sodium and chloride concentrations may be elevated during a thaw, as salt loadings from upstream and salty water from the drainage ditch combine. Reports in the literature indicate that chloride levels can be many times higher than usual in such circumstances, sometimes resulting in levels exceeding 500 mg/L. (In streams that receive a significant flow from unsalted areas, dilution will be greater, and chloride levels will be significantly lower.)

To protect aquatic life, Environmental Protection Agency standards (National Ambient Water Quality Criteria) for chloride concentrations in fresh water are 860 and 230 mg/L for exposure periods of 1 and 96 hr, respectively. The literature indicates that such high levels are rare. In extreme cases, as reported in the Irondequoit Bay basin in New York, chloride concentrations that reach these critical levels (which are several hundred times above normal) may harm aquatic life, and, therefore, reduction in salt use or changes in highway drainage may be necessary for stream recovery (Bubeck et al. 1971; Diment et al. 1973).

More commonly, however, chloride levels in the stream increase by a factor of 2 to 10 times above normal, and the stream experiences a nontoxic increase in salt that fluctuates during the year. In this case, the salt loading may result in slight changes in the species of biota present in the stream rather than widespread damage to the system. Unlike the obvious browning of leaves in roadside vegetation, changes in water biota are likely to be subtle and difficult to observe. For instance, they are unlikely to result in noticeable declines in game fish population.

Lake Water Quality

The impacts of road salt on lakes are not as well understood as those on roadside vegetation. Salt loadings large enough to reduce circulation and aeration in small lakes have been documented (e.g., Hawkins and Judd 1972), but this degree of damage is exceptional. In such cases, artificial circulation using compressed air is a mitigation option. More commonly, the lake shows increases in chloride concentrations close to the point source. Even if chloride concentrations rise 20 to 50 mg/L above background, significant ecological damage or organism mortality will probably not be observed (Lillie and Mason 1983).

Roadside Erosion

It is assumed that erosion of soil occurs along the sloped roadside at this site. Salt damage to vegetation is assumed to contribute to the process, both by allowing rain to fall directly on the soil (because of a loss of vegetation cover) and by damaging the root structure holding the soil in place. Erosion is caused by many interrelated factors, and, therefore, the cost of control is always site specific. Hence, it is not possible to project a cost for this impact.

Site 4

Site 4 consists of shrubs and grass adjacent to a 1-mi section of primary highway with forest trees in the background. Forest trees do not begin until a distance of 40 to 60 ft from the highway. A flat topography is assumed, resulting in no significant potential for erosion damage. Damage to soils, if any, is covered in the discussion of Site 1.

Shrubs and Grasses

The response of shrubs to road salt varies by species. However, many highway agencies contacted for this study report that, in general, most roadside shrubs are hardy and unaffected by salt. This is probably because salt-tolerant shrubs have been planted or natural salt-resistant species have become established over time (the time for maturity of a shrub is significantly less than that of a tree). Highway agencies report that shrubs are more often damaged by snowplows and snow accumulation due to plowing or blowing.

Few data are available to estimate the cost of shrub damage from road salt. If shrub mortality levels are one-quarter to one-half those of trees, which is plausible given their greater salt tolerance, 3 to 12 shrubs might need to be removed and replaced each year (0.25 to 0.50 × 10 to 25 trees). If an average removal and replacement cost of $75 dollars per shrub is assumed on the basis of various state highway agency estimates, the total annual cost is $225 to $900 ($75 × 3 to 12 shrubs).

Grasses also exhibit varying degrees of salt tolerance, although they tend to be more tolerant of salt than are shrubs. Some grass damage may occur within a few feet of the pavement, and reseeding with a salt-tolerant species may be required. The approximate cost of reseeding (and fertilizing) turf is $250 to $500 per acre (Goldman et al. 1986). If 4 acres (see Site 1 discussion on soils for acreage estimate) must be reseeded every 5 to 10 years, the average annual cost is $100 to $400 (4 acres × $250 to $500/5 to 10).

Forest Trees

Because the area of shrubs and grasses is assumed to be 40 to 60 ft deep, forest trees will be affected primarily by salt spray and mist. Findings in the literature suggest that the assumption that no more than 10 percent of tree damage (see Site 1 discussion) occurs that far from the roadway is reasonable. According to the cost estimates derived for Site 1, this damage might result in 1 to 3 tree deaths per year on both sides of the highway (0.10 × 10 to 25 trees), costing $500 to $1,500 to remove and replace (1 to 3 × $500).

Site 5

Site 5 consists of a maintenance yard adjacent to a highway bordered by a residential area and forest trees and shrubs. The maintenance yard is assumed to contain uncovered salt stockpiles.

It is generally agreed that on a per-unit-area basis, salt damage to the environment is more severe near salt storage and loading facilities. Many of the studies and complaints of salt damage to the environment have stemmed from improper salt storage and handling. These problems can usually be overcome by improving maintenance yard housekeeping and upgrading storage facilities, although the remediation of existing environmental damage may be necessary.

Improvement of salt storage can be accomplished in several ways. Outdoor stockpiles can be covered with a tarpaulin and placed on pads made of asphalt or other impermeable materials. Preferably, stockpiles can be stored indoors in specially built shelters, such as wooden sheds or concrete domes. Conveyer belts and special loading equipment can be used to reduce salt spillage during handling, and the loading area apron can be constructed of impermeable material that is swept clean of salt spillage on a frequent and timely basis after storms.

The cost of these improvements depends on the measures taken. The cost of installing impermeable flooring and controlling drainage may be a few thousand dollars for small outdoor stockpiles, whereas the cost of a concrete dome with specialized loading equipment for larger storage sites can exceed $250,000.

Site 6

Site 6 consists of an orchard adjacent to a 0.25-mi section of primary highway. A flat topography with no significant potential for erosion damage is assumed.

The impact of road salt on fruit trees varies by location. The effect is similar to that of forest trees. However, the literature indicates that fruit trees may be less tolerant of salt than are common forest trees. Table 4-3 presents costs of road salt damage to orchards in Ontario, Canada, as estimated by the Ontario Ministry of Transportation (Bacchus 1987). The data are based on claims of orchard owners. It is assumed that the effects extend to orchard trees within 100 ft of either side of the roadway and that damage results in 30 to 60 percent losses in crop yield from affected trees. The loss ranges from $475 to $1,400 per acre, depending on the type of fruit.

TABLE 4-3 ROAD SALT DAMAGE TO FRUIT CROPS FOR SITE 6 (Bacchus 1987)

Type of Crop	Full Value of Crop[a] ($/acre/year)	Percent of Crop Damaged	Value of Loss ($/acre/year)
Apple	1,590	30	475
Peach	2,300	60	1,380
Mixed (apple and peach)	1,645	45	740
Other (grapes, plums, and pears)	1,445	45	650

[a] Converted from 1985 Canadian dollars to 1990 U.S. dollars using an exchange rate of 0.86 and adjusted for inflation.

For this site, the affected 200-ft corridor contains 6 acres of orchard trees. The value of the loss in fruit is approximately $2,800 to $8,400.

SUMMARY

During the past 30 years, hundreds of articles and reports have been written documenting the impacts of road salt on the environment. The literature indicates that these impacts can be significant but depend on factors unique to each site, such as the timing and quantity of salt applied, local drainage features, weather conditions, soil type, topography, watershed size, vegetation cover and species composition, and distance from the roadway. In addition, salt impacts and other environmental perturbations, such as vehicle exhaust emissions, drought, and plant diseases and pests, are likely to interact. Hence, findings from each study must be reviewed in the light of the prevailing conditions at the particular site. The only generalization that can be made on the basis of the literature is that road salt impacts tend to diminish rapidly with distance from the roadway.

Findings from previous studies, as well as the general concerns expressed by the public and state highway agencies in various regions of the country, suggest that a plausible national ranking of these impacts, in order of overall severity, might be as follows:

Rank	*Impact*
1	Injury to roadside vegetation, especially trees
2	Damage to soil structure
3	Impact on surface water quality

Damage to roadside trees is a well-publicized concern in several regions of the country, especially in forests and parklands adjacent to highways. Trees and other roadside vegetation can be injured by salt through changes in soil chemistry and from salt splash and spray on foliage and branches. The symptoms of salt injury are similar to those of drought: inhibited growth, browning and falling leaves and needles, and sometimes dying limbs and premature plant death. Under extreme conditions, roadside vegetation can be exposed to salt as far as 500 ft from the roadway, although the impact is seldom significant beyond 100 ft. Tree damage is likely to be greatest along high-traffic highways with heavy salt use and steep, downsloping roadsides. Highway agencies in states where public concern about tree damage is greatest report that 5 to 10 percent of the roadside trees in forests located along heavily traveled highways exhibit signs of salt-related decline. Roadside shrubs, grasses, and wetland vegetation are generally more salt tolerant than trees; hence, most states report relatively minor damage.

Other side effects of road salt on soil and surface water are far more site specific. Salt's impact on soils is usually confined to 15 ft from the roadway, although greater distances have been reported. Long-term salt accumulation in soil increases soil density and diminishes permeability and fertility, which may adversely affect moisture retention and soil structure characteristics that are important for plant growth and erosion control. The accumulation of salt in soils depends on many factors, including soil type, precipitation, and topography. Whether salt has a cumulative effect depends on these site-specific conditions.

Road salt's effects on surface water are confined mainly to small streams running adjacent to salt-treated highways. Although small receiving lakes and ponds can be affected, few such incidents have been reported. Salt loadings in larger rivers and lakes are usually diluted because of the high water volume. In extreme cases, high and persistent concentrations of chloride (more than 500 mg/L) in small streams may harm fish and other aquatic life. Because of the complexity of stream environments and their site-specific nature, it is difficult to characterize and quantify these potential adverse effects in the aggregate.

Consolidation of the various site-specific environmental effects of road salt into a national estimate of environmental damage or cost is not possible. Such monetary evaluations have been attempted in previous studies (e.g., Murray and Ernst 1976) to shed light on the potential magnitude of environmental damage.[1] Whereas these previous estimates have led to further study of salt's environmental impact, they were not intended, nor can they be accurate enough, to compare the overall cost of salt with that of other deicing chemicals.

Meaningful estimates of the cost of environmental damage can be accomplished only for individual sites, whereby local circumstances can be evaluated in depth. Even when damage can be quantified for a specific site (e.g., number of trees injured), monetary values can be difficult to assign and highly subjective. Estimates of mitigation costs-such as the cost of removing and replacing an injured tree—provide some cost perspective, but they may be inaccurate or incomplete because they do not reflect the value to society of the injured tree or other indirect costs, such as diminished aesthetics and secondary effects on roadside ecosystems.

NOTE

1. For instance, Murray and Ernst (1976) estimated that the national cost of road salt damage to trees was about $50 million, or about an order of magnitude smaller than infrastructure costs.

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ABBREVIATIONS

FHWA	Federal Highway Administration
HRB	Highway Research Board
NCHRP	National Cooperative Highway Research Program
TRB	Transportation Research Board
USDA	U.S. Department of Agriculture

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