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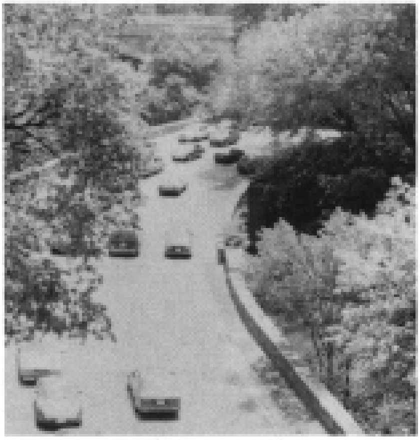
Road Salt Impacts on the Environment



Hundreds of reports have been written during the past three decades documenting the impact of road salt on the environment. The literature clearly indicates that the impacts can be significant but depend on a wide range of factors unique to each site.

The emphasis of this chapter is on summarizing what is known about road salt's environmental effects on the basis of these reports. The effects discussed are those most frequently cited in the literature—damage to roadside vegetation, water, and soil. Because the significance of each effect varies by location, in the absence of detailed information it is not possible to quantify costs on a national basis. Instead, to help illustrate the discussion and provide some perspective on cost, the chapter concludes with several hypothetical cases.

VEGETATION

The adverse effects of salt on roadside vegetation have been known for some time. Incidents of vegetation injury were first reported in Minnesota during the 1950s, when trees along city boulevards started to show signs of salt-related decline (French 1959). At about this time the New Hampshire Highway Department reported the death and removal of nearly 14,000 trees along 3,700 mi of salt-treated highways (Sucoff 1975).

Investigations of salt's impact on vegetation were conducted during the 1960s and 1970s in New Hampshire, Minnesota, Michigan, and several other snowbelt states, usually in response to concerns about damage to roadside trees (Lacasse and Rich 1964; Sucoff 1975; Bowers and Hesterberg 1976; Scharpf and Srago 1975). More recently, damage to trees and other roadside vegetation has been investigated in the Adirondack region in New York and the Lake Tahoe basin of California and Nevada (Gidley 1990; Fleck et al. 1988; Kliejunas et al. 1989; Nevada Department of Transportation 1990).

Whereas most of these investigations have been site specific, they have helped reveal the general mechanisms of salt injury to vegetation. Roadside trees and other vegetation are injured by salt primarily through two mechanisms: (a) increased salt concentrations in soil and soil water, which can result in salt absorption through roots, and (b) salt accumulation on foliage and branches due to splash and spray. Vegetation that has been injured by salt exhibits clear physiological symptoms, including leaf scorch, late summer coloration, early fall defoliation, reduced shoot growth, and dying twigs and branches in the crown. Injury due to salt is typified first by inhibition of general growth, followed by specific injuries to foliage and limbs, and, in some cases, plant death (Jones et al. 1986).

Concentrations of either sodium or chloride can be harmful to vegetation. Threshold levels for each vary by species and in relation to other environmental stresses and conditions. Factors such as temperature, light, humidity, wind, soil texture and drainage, precipitation, plant size, salt exposure, species tolerance, and especially water availability contribute to the degree of salt injury (Nevada Department of Transportation 1990). Other factors with an effect are vehicle exhaust emissions, wind exposure, and alterations in drainage patterns due to highway construction. In general, chloride is thought to be more harmful than sodium to vegetation. When absorbed through roots, chloride tends to accumulate in plant tissues over a long period of time, causing osmotic stress, which can lead to dehydration injury typical of drought (e.g., leaf scorch or tip burn) (Bowers and Hesterberg 1976; Walton 1969). Sodium's impact on vegetation is less direct, although high concentrations can alter soil structure and permeability, which can be detrimental to plant growth, as discussed later in this chapter.

Salt particles themselves can also adversely affect vegetation. High concentrations of salt particles in soil can damage root systems and inhibit root growth (Nevada Department of Transportation 1990; Eggens 1980). Salt particles may be deposited on foliage and twigs due to splash and spray from traffic and wind. Physical breakdown of the plant may result because of the added weight of the salt deposit, but tissue damage due to local dehydration is more common (Wilcox 1984; Bowers and Hesterberg 1976; Foster and Maun 1978). Broad trees and shrubs with high surface areas are especially susceptible to damage from salt splash and spray (Smith 1970). Damage increases with the amount of salt applied and with traffic volume and speed; it decreases rapidly with distance from the roadway (Lacasse and Rich 1964; Sucoff 1975). Splash and spray damage is evidenced by injury restricted to the windward side of the plant or portions not normally covered by snow and ice during the winter (Sauer 1967; Hofstra and Hall 1971).

The slope of the roadside is a key factor in determining where salt reaches vegetation, either from splash and spray or root absorption. For example, in a study of the Lake Tahoe basin, the percentages of salt-exposed trees were compared on steep, gentle, flat, uphill, and downhill slopes (Nevada Department of Transportation 1990). The mean percentage of salt-exposed trees on the steepest downhill slopes was significantly greater than on all other slope types; 50 percent of the trees on the steepest downhill slopes were affected by salt. The zone of salt exposure in that study ranged from 17 ft from the pavement edge for flat slopes to approximately 53 ft for steep downhill slopes. Overall, the mean zone of exposure was 36 ft from the pavement edge for downhill slopes and 22 ft for uphill slopes. Similarly, a study conducted in the Sierra Nevada by the California Department of Transportation indicated that vegetation was most likely to be exposed to road salt within 10 ft upslope and 40 ft downslope of Interstate highways (Gidley 1990).

The correlation between salt exposure and roadside slope is widely discussed in the literature (Lacasse and Rich 1964; Sucoff 1975). Exposure distances also vary according to other factors, such as drainage, traffic levels, wind and weather conditions, and the intensity and frequency of salt treatments. For example, the Connecticut Department of Transportation found that airborne salt traveled as far as 300 ft from the roadway under heavy traffic conditions on Interstate and other primary highways (Connecticut Department of Transportation, personal communication). Also, salt spray can be transported downwind for distances greater than 500 ft under high wind conditions (Chung 1981).

Even when exposed to high salt concentrations, the degree of vegetation damage depends on many other factors. The Nevada Department of Transportation has identified the following factors as especially important (Nevada Department of Transportation 1990):

- Temperature: The effects of salt are compounded by higher temperatures, which cause increased dehydration through foliage, faster movement of salt to the plant, and increased salt absorption through roots.
- Light: Exposure to direct light increases the rate of dehydration.
- Humidity: High humidity lowers the rate of dehydration and, therefore, helps alleviate water stress.
- Wind: Exposure to wind may increase the rate of dehydration. In general, more damage is found on the windward side of trees than elsewhere.
- Soil water: As salinity increases, the soil water available to plants decreases. High concentration of salt in soil can cause more injury when soil water is limited because of below-normal precipitation.
- Soil texture and drainage: The ability of soil to retain salt is partially determined by soil texture and drainage characteristics. For example, coarse-textured soils are quickly leached of salt, and steep slopes may not absorb salt because of rapid runoff.
- Precipitation: Rain and other precipitation are a transport mechanism for salt. Rainfall can flush salt deposits from foliage and dilute salt solutions in soil water. On the other hand, precipitation can transport salts, via surface runoff, to roadside soils.

The type and condition of roadside vegetation also affect the degree of salt damage. Different tree and shrub species have varying tolerances for salt, and within species, plant maturity and size affect salt tolerance. The sensitivity of various groups and species of vegetation is summarized in the following sections.

Deciduous and Coniferous Trees

Generally, the trees that are most sensitive to salt are broad-leaved species, such as linden, black walnut, and sugar and red maples (Murray and Ernst 1976). In roadside maples, levels of chloride greater than 0.5 percent dry weight of plant tissue have been highly correlated with moderate damage to leaves (e.g., discoloration) (Hall et al. 1972), and levels of 1 to 2 percent have been associated with severe leaf burn, defoliation, and even plant death (Allison 1964). Among conifers, chloride concentrations of 1 percent in the needles of red and white pine have been associated with extensive plant injury (Hofstra and Hall 1971).

Salt-resistant tree species include oak, birch, white ash, and Scotch and jack pine (Shortle and Rich 1970; Hofstra and Hall 1971). These trees tend to retain less chloride as a percentage of tissue weight. Table 4-1 gives 12 species of salt-tolerant trees and 10 species of intolerant trees (Shortle and Rich 1970). Other listings of the relative salt tolerances of trees and other woody species are provided in the literature (e.g., Sucoff 1975; Sauer 1967), and a near-complete listing—for more than 450 trees and shrubs—is contained in *Economic Impacts of Highway Snow and Ice Control* (FHWA 1977).

For salt-sensitive trees, distance from the roadway helps explain salt damage. A study in Ontario found that trees within 35 m (about 100 ft) of the pavement showed growth reduction trends, whereas trees more than 75 m (200 ft) away did not (Hall et al. 1972). A study of the effect of sodium chloride on ponderosa pine and greenleaf manzanita in the Sierra Nevada found few damaged trees beyond 40 ft of the roadway (Interstate highways) (Gidley 1990). Another study found that chloride concentrations in maple tissue from New Hampshire roadsides were above normal only within 30 ft of the pavement edge (Lacasse and Rich 1964).

In response to concerns about increasing tree mortality in the Sierra Nevada, state highway agencies in California and Nevada studied a 64-mi corridor of highway in the Lake Tahoe basin (Nevada Department of Transportation 1990). The corridor, which extended 100 ft on both sides of the roadway, had approximately 150,000 trees (2,400 trees per mile), of which an estimated 10 to 15 percent (20,000) were affected to some degree by salt. This estimate was based on 206 sample woodlots that contained 5,450 trees. Of the sampled trees, 55 percent did not exhibit any signs of salt injury, drought, disease, insects, or mechanical damage. Of the 10 to 15 percent of trees affected by salt, about one-third showed signs of other types of injury or disease as well.

Because similar estimates are not available for a wide range of circumstances and conditions, it is difficult to generalize about salt damage to roadside trees. However, the literature indicates certain conditions that are most likely to result in problems. Densely wooded areas located downhill and within 40 to 60 ft of heavily traveled, salt-treated highways are primary candidates for salt-related damage.

Orchard Trees

Some fruit trees are especially sensitive to aerial spray and soil concentrations of salt (Hofstra and Lumis 1975; Harper 1946). Hofstra and Lumis investigated injury to apple trees in orchards located along Ontario highways treated with salt. They found the suppression of

TABLE 4-1 SALT TOLERANCE IN COMMON ROADSIDE TREES (Shortle and Rich 1970)

Tree Species	No. of Trees Rated	Percent in Each Injury Class			Percent Chloride	
		Healthy	Slightly Injured	Moderate to Severe	Roadside Trees	Woodlot Trees
Salt Tolerant						
Red oak	108	100	0	0	0.02	0.02
White oak	70	100	0	0	0.14	0.06
Red cedar	29	100	0	0	0.06	0.09
Black locust	26	100	0	0	0.32	0.09
Quaking aspen	26	100	0	0	0.78	0.12
Black birch	19	100	0	0	0.84	0.09
Paper birch	3	100	0	0	1.15	0.01
Gray birch	78	96	4	0	0.27	0.05
Yellow birch	19	95	5	0	0.78	0.10
Black cherry	36	92	8	0	0.09	0.02
White ash	154	92	8	0	0.40	0.10
Large-toothed aspen	9	89	11	0	0.66	0.10
Salt Intolerant						
Basswood	54	57	41	2	0.90	0.18
Shagbark hickory	107	67	23	10	1.27	0.27
American elm	112	62	22	16	1.13	0.38
Red maple	282	63	11	26	1.01	0.36
White pine	155	43	29	28	0.58	0.24
Ironwood	26	43	27	30	0.94	0.34
Hemlock	80	1	62	37	0.68	0.50
Sugar maple	115	27	23	50	0.84	0.24
Speckled alder	117	31	8	61	0.91	0.54
Red pine	140	9	15	76	1.08	0.06

flowering and the dieback of shoots that are associated with increased levels of sodium and chloride in twigs. Chloride accumulation in tree tissues was found to increase from February to April, during the peak salting season. In follow-up spray tests, damage to these types of trees was associated with chloride values of 0.2 to 0.5 percent of dry leaf weight. Brown et al. found that foliage injury appeared when chloride concentrations reached 1 percent dry weight for apricot and peach, 0.6 percent for prune and plum, and 1.2 to 1.8 percent for almond (Brown et al. 1952).

Some orchard owners have sought compensation from highway agencies for salt-related damage to fruit trees and crops. In a case in Ontario, two fruit growers claimed substantially reduced crop quality and yields because of salt applied to highways adjacent to their fields. In response, the Ontario Ministry of Highways compiled data on 168 orchards in southern Ontario through a survey questionnaire (Ontario Ministry of Highways 1967). The survey results indicated a correlation between damage to trees and wind direction, presence of a downsloping roadside, and high traffic volumes. It was concluded that a number of different contaminants could have been responsible for the damage—including road dust and dirt, oil deposits, vehicle exhaust emissions, and road salt—which neither confirmed nor repudiated that road salt was a factor. However, the Ontario Supreme Court ruled that the plaintiffs were entitled to recover damages from the government for the losses that were ostensibly due to salting practices (Ontario Supreme Court 1981).

Shrubs, Ground Cover, and Grasses

Excessive sodium and chloride exposure can also cause droughtlike symptoms in some shrubs and ground cover because of osmotic stress and water imbalance. Certain shrubs and ground cover are less tolerant of salt than others. Hibiscus shrubs, for instance, have poor tolerance of salt. They exhibit leaf burn and defoliation at fairly low concentrations of chloride in tissue (Bernstein et al. 1972). Shrubs and ground cover generally demonstrating good to high tolerance of salt include rosemary, natal plums, and bougainvilleas (Bernstein et al. 1972).

Turf grasses, in general, can withstand and survive considerable salt exposure, especially from salt spray. Grasses tend to be more resilient than trees and shrubs. Some grasses are more tolerant than others; for instance, bent grasses are less tolerant than bluegrass, which is a preferred grass for midwestern and eastern roadside landscaping (Cordukes 1968). Dehydration injury has been observed in some grass sods when exposed to high salt concentrations in soil, though such concentrations are seldom generated by highway deicing (Eggens 1980; Holmes 1961).

Wetland Vegetation

Alterations in plant communities in roadside bogs were reported near an uncovered salt storage pile in Indiana (Wilcox 1986). High salt runoff from the pile caused the loss of many endemic plants, such as blueberry and huckleberry. After the storage problem was corrected, many of the endemic plants returned to the bog within 4 years.

Except for this incident, runoff of road salt into wetlands is rarely identified in the literature as a problem. Salt tolerance in many prominent wetlands species, such as cattails, is high (Anderson 1977). Currently, the state of Massachusetts is applying an alternative to salt (calcium magnesium acetate) on a new section of highway adjacent to a cranberry bog. The policy stems from a state agency ruling that prohibits the use of chloride deicers on this section of highway, although the impact of road salt runoff on cranberry bogs has not been established (Massachusetts Department of Public Works, personal communication).

Measures To Prevent Vegetation Damage

Concerns about salt injury to roadside vegetation have led to a number of recommendations for minimizing road salt's effects, including the following (Hanes et al. 1970):

- Use salt-tolerant grasses near pavements;
- Place sensitive woody plants as far from the roadways as possible;
- Use salt-tolerant woody plants in essential near-roadway plantings (e.g., for erosion, noise, and glare control);
- Use spray-tolerant plant species in areas subject to salt spray;
- Avoid planting sites near heavy runoff areas, such as low slopes; and
- Place shallow ditches along roadsides to divert salt runoff from sensitive trees.

For many situations, however, redesign of roadsides is not practical. As a result, most highway agencies are faced with three options: acceptance of some salt-related damage to roadside vegetation, discontinuance or restriction of salt treatments in especially sensitive areas, or use of a deicing substitute with fewer side effects than salt (Hanes et al. 1970).

SURFACE WATER

In most parts of the country, fresh water contains low salt concentrations. Average chloride concentrations in freshwater lakes and rivers are 0 to 100 mg/L, and most concentrations are lower than 20 mg/L (Goldman and Horne 1983). However, salt and its components, sodium and chloride, can access fresh water through numerous sources. Seawater, which contains chloride concentrations of about 20 000 mg/L (Table 4-2), is a potential source of salt in fresh waters in coastal areas. Other sources are natural salt deposits, brines from oil and gas fields, household sewage, agricultural chemicals, and industrial waste (Hanes et al. 1970). During the past 30 years, salt runoff from highways, especially from salt storage facilities, has been identified as a source of salt in surface water. In recent years greater attention to salt storage practices has reduced the incidence of storage-related contamination; hence, this section focuses on highway surface runoff as a source of surface water contamination.

TABLE 4-2 TYPICAL CHLORIDE CONCENTRATIONS IN SOURCES OF WATER (Hanes et al. 1970)

Type of Water	Chloride Concentration (mg/L)
Rainwater	0–2
Upland surface water	0–12
Unpolluted river water	0–15
Springwater	0–25
Deep well water	0–50
Sewage water	70–500
Seawater	20 000

During and after storms and during spring melts, highway runoff may contain high concentrations of sodium and chloride. For instance, chloride concentrations higher than 10 000 mg/L have been reported in Ontario and Wisconsin during early spring thaws near large roadside snowbanks (Kronis 1978; Schraufnagel 1965). Ordinarily, however, even high concentrations of salt are quickly diluted when they enter larger water systems. For example, Schraufnagel found chloride concentrations higher than 10 000 mg/L in spring runoff in Wisconsin, yet the maximum concentration in adjacent surface waters was only 45 mg/L (Schraufnagel 1965). As discussed in the following sections, this dilution effect varies by size and type of surface water.

Rivers and Streams

Correlations have been established linking road salt to elevated chloride concentrations in surface waters. The correlation is weakest for large rivers because of the large dilution factor associated with river volume (Scott 1976; Hawkins 1971; Walker and Wood 1973; Van de Voorde et al. 1973; Ralston and Hamilton 1978). Generally, smaller roadside streams and creeks are more likely to be affected. The magnitude of the impact depends on factors such as water flow, salting intensity, precipitation, type of highway drainage system, topography, and natural drainage patterns (Scott 1980; Champagne 1977; Wulkowicz and Saleem 1974).

A study of 28 streams in the Sierra Nevada found noticeably higher chloride concentrations at stream locations that crossed salt-treated highways than at upstream locations far from the highway (e.g., 50 to 70 mg/L versus 0 to 10 mg/L) (Hoffman et al. 1981). Studies of small creeks and drainage basins in Illinois and New York found maximum chloride concentrations that exceeded 500 mg/L during late winter and early spring thaws (Bubeck et al. 1971; Walker and Wood 1973; Diment et al. 1973; Hawkins and Judd 1972; Scott 1979). In contrast, Hutchinson found that the effect of road salt on sodium and chloride levels in seven Maine streams and rivers was compensated for by the increased flow associated with the spring snowmelt (Hutchinson 1970).

Like most studies of salt's impacts on the environment, investigations of stream and river impacts have been site specific, and findings have been largely circumstantial. Evidence, however, consistently points toward the general conclusion that salt concentrations diminish rapidly as water volume and distance from the roadway increase. Hence, small streams and creeks running adjacent to heavily traveled, salt-treated highways are more likely to be affected by salt runoff than larger streams and rivers, which are likely to experience comparatively minor impacts.

Lakes and Ponds

Some correlation has been found between salting activity and higher sodium and chloride concentrations in lakes and ponds. However, unlike small streams and creeks, ponds and lakes are often recharged by a large and varied watershed (including groundwater), which increases dilution and complicates efforts to identify specific sources of chloride and sodium. As an example, Hutchinson found that chloride concentrations in small roadside ponds in Maine varied from less than 5 to more than 100 mg/L, often for reasons only partially related to road salt usage (Hutchinson 1966).

Determination of sources of sodium and chloride concentrations in larger lakes is even more complicated because of the potential for many industrial and residential sources of sodium and chloride, particularly in urban areas. For example, chloride concentrations have been rising in the Great Lakes since the beginning of the century; however, it is not clear how these increases have been affected by road salt, because the upward trend began long before the widespread use of deicing chemicals (Bowden 1981; Kenaga 1978; Fromme 1971). Meanwhile, Lake George in New York and Lake Tahoe in California and Nevada, large rural lakes in regions with heavy salt use (e.g., to clear roads for ski resorts), have shown little change in sodium and chloride concentrations over time (Lipka and Aulenbach 1976; Goldman, unpublished data).

Aquatic Life

In general, the impacts of salt concentrations from highway deicing on water life are thought to be minor. Whereas high and sustained chloride concentrations in surface waters (more than 1000 mg/L) have been linked to growth changes in some plankton (Stewart 1974; Antonyan and Pinevich 1967), field studies indicate that such high concentrations are uncommon (Goldman and Hoffman 1975; Kersey 1981; Molles 1980). The extreme chloride concentrations that are harmful to fish (400 to 12 000 mg/L) are rarely generated by highway deicing (Schraufnagel 1973; Jones et al. 1986).

In theory, a salt load to a lake or pond will sink to the bottom because of its higher density. This effect can reduce water circulation and reaeration in lower depths, which can lead to loss of dissolved oxygen and mortality of organisms inhabiting this region (Hawkins and Judd 1972). Prolonged periods of reduced oxygen can result in increased nutrient loading at the stream or lake bottom, which could increase spring and summer algal growth, which, in turn, may further deplete dissolved oxygen. In the literature, however, few incidents of this extreme effect have been reported, the most notable being Irondequoit Bay near Rochester, New York (Bubeck et al. 1971).

Groundwater

Highway salt enters groundwater in several ways. Runoff from highways can flow from the pavement into unlined ditches and infiltrate surrounding soil. Road salt applied during snowstorms is generally plowed off the roadway and paved shoulder. When the resulting snowbanks melt, the meltwater, together with the dissolved salt, can migrate through soil and move to the water table. Groundwater supplies nearly half of the U.S. population with household water (Bouwer 1978). Hence, the potential for road salt to contaminate groundwater has become a concern in several parts of the country, especially in the Northeast, where salt use is heavy. Because this concern is related primarily to salt in drinking water and its impact on health, discussion of effects on groundwater is reserved for the following chapter.

SOIL

Road salt's impacts on vegetation and water are linked to its movement through soil, which is one reason to consider salt's impact on soil. Soil also merits separate attention because it affects other factors, such as roadside stability.

The infiltration of salt into soil depends on a variety of site-specific factors. Because most salt is plowed or splashed off the pavement, the highest salt concentrations are usually found near the shoulders of the roadway (Murray and Ernst 1976). When salt is transported by highway runoff, the transport distance usually depends on local features and conditions, such as the slope of the roadside, direction of drainage, type of highway drainage system, soil type, vegetative cover, presence of snow and ice, and precipitation (Colwill et al. 1982).

The downward transport of salt through soil is often slow and dependent on the drainage, or infiltration, characteristics of the soil.

Sand, gravel, and coarse-textured soil allow fast infiltration, whereas clay and fine-textured soil slow infiltration (Jones et al. 1986). Chloride moves through soil faster than sodium. Chloride ions are negatively charged and are repelled by similarly charged clay and other soil particles. Sodium ions, which are positive, undergo ion-exchange with other positive ions in soil particles, which results in the retention of higher percentages of sodium in the soil, especially if infiltration is slow (Jones et al. 1986; Murray and Ernst 1976; Maryland Department of Transportation 1987).

Studies of sodium and chloride levels in soil generally indicate that the greatest concentrations are found within 5 to 10 ft of the pavement edge (Berthouex and Prior 1968). However, depending on local conditions, impact areas can be more extensive. For instance, Hofstra and Smith reported higher-than-background concentrations of sodium and chloride as far as 30 ft from the roadway (Hofstra and Smith 1984). High concentrations of sodium and chloride are not usually found at depths below 1 to 3 ft (Prior and Berthouex 1967; Hutchinson and Olson 1967; Hanes et al. 1970). In some cases all concentrations of sodium and chloride are leached from the soil by late spring or summer (Berthouex and Prior 1968); in other cases leaching is slower and sodium may accumulate for several years (Hsu 1984; Hutchinson and Olson 1967).

The soil science literature has documented the impact of sodium chloride on soil structure. Sodium accumulation, in particular, can bring about undesirable properties in soil, including diminished permeability and higher alkalinity. A complete loss of permeability is unlikely, because highway runoff and precipitation often facilitate sodium leaching. Nevertheless, sodium can increase the compactness of clay soils and cause the dispersion of suspended particles in the soil that are important for improving percolation and aeration (Jones et al. 1986). Sodium can also increase soil alkalinity by reducing the exchange capacity of the soil, thereby reducing levels of calcium, magnesium, and other nutrients that are important for soil fertility and vegetation growth.

Chloride is generally considered less detrimental than sodium to soil. There is some evidence from laboratory experiments that chloride passing through soil contributes to mobilization (to groundwater) of some heavy metals, such as cadmium, zinc, and lead (Hahne and Kroontje 1973; Amrehein and Strong 1990), but field evidence of this effect is limited. A recent field study in southern Ontario found that concentrations of heavy metals in groundwater beneath roadside soils were similar to those in nonhighway locations (Pilon and Howard 1987).

HYPOTHETICAL SITES

Figure 4-1 shows a flow diagram of the major pathways of road salt in the environment identified in the literature. The diagram indicates that though it may be convenient to study the impacts of salt on one aspect of the environment in isolation (e.g., roadside trees or water quality), their ramifications on the entire roadside ecosystem must also be considered. Examples include the potential for increased soil erosion following the death of vegetation, the ability of soils to trap and flush salts, and the consequences for local vegetation and water.

To illustrate these impacts and their interactions under varying conditions and circumstances, several hypothetical sites are discussed in this section. Though they are generalized—derived from composites of many actual studies—they provide insight into how road salt interacts with the roadside environment. The sites are identified on the hypothetical road map in Figure 4-2. They include

1. Deciduous, coniferous, or mixed forest trees adjacent to a four- or six-lane Interstate or other primary highway;
2. Deciduous, coniferous, or mixed forest trees adjacent to a two-lane rural or secondary highway;
3. An Interstate or other primary highway through a forested corridor that drains into a stream and lake;
4. Shrub and grass vegetation adjacent to an Interstate or other primary highway with forest in the background;
5. A maintenance yard adjacent to a highway bordered by a residential area and forest trees and shrubs; and
6. An orchard adjacent to an Interstate or other primary highway.

For each hypothetical site, the type of impact and extent of potential damage is characterized, and the cost of mitigating the damage is approximated whenever possible. The characterizations are based in part on information provided by a survey of state highway agency officials and follow-up interviews. The cost estimates are intended to add perspective; however, they are not universally applicable and do not take into account costs that are more difficult to quantify, such as losses in roadside aesthetics. The latter costs are affected by