

HIGHWAY SALT: SOCIAL AND ENVIRONMENTAL CONCERNS

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•AMERICANS use 6 million tons of salt every year to make winter driving safer, but nobody knows if it really does. Recent evidence suggests that the assumed positive relationship between highway salt and safety may be, to a significant degree, false (1). Yet, because of management decisions at local, state, and federal levels of government in part founded on this questionable assumption, America has become deeply committed to a "bare roads philosophy," a philosophy that will require an even greater reliance on the use of salt in the future if it is to be successfully implemented.

Upon completion of the federally financed Interstate Highway System and reconstruction of numerous primary and secondary roads already under way or planned, the use of salt in the United States could conceivably exceed 12 million tons by 1975. That is a lot of salt to be strewn about the environment relatively indiscriminately, perhaps a potentially dangerous amount considering that scientists know very little about the fate of salt in the environment. On the other hand, a great deal is known about the chemical, physical, and biological characteristics of salt that, if properly applied to what has already been learned about the technical applications of salt on highways, can provide extremely useful insights.

What I am suggesting is that, although much new information is needed, we already know enough to make viable interim decisions now. And what is even more important, a proper statement of what is already known will provide a firmer foundation for deciding the kind of scientific questions that need to be asked in the future.

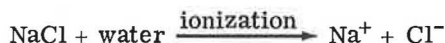
What follows is a first attempt to point the way. What must follow, if we are to avoid what in my judgment appears to be the very real potential for prematurely causing yet another ecological crisis, is at least a massive research effort, perhaps even a moratorium against the continued use of salt, but most certainly serious efforts to hold the line until certain absolutely essential questions can be answered. My arguments against persistent efforts to expand the use of highway salt as an assumed most efficient, safe, and cheap alternative method of snow removal proceed from a systematic analysis of the following fundamental questions:

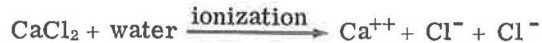
1. What is salt physically, chemically, and biologically?
2. Why does salt melt ice and snow?
3. What is the fate of salt in the environment?
4. What is the relationship between salt, safety, and economics?

Finally I will attempt to provide several specific recommendations that, if judiciously applied to current management practices, possess the potential for significant relief of existing environmental problems. Such recommendations should in no way be considered final answers. They are at best tentative and must remain constantly subject to continuing review and reevaluation.

PHYSICAL, CHEMICAL, AND BIOLOGICAL MAKEUP OF SALT

Salt used on highways is generally limited to either sodium chloride (NaCl), a mineral called halite, or calcium chloride (CaCl_2), designated hydrophylite. (Other chloride salts have been used but are generally too expensive or too inefficient to receive serious consideration.) Both substances dissolve freely in water and dissociate (i.e., they ionize, yielding charged ions) according to the following equations:





Because these chloride salts dissociate freely in water yielding charged ions and because the charge (electric potential) borne by the dissociated ions is essentially equivalent, NaCl and CaCl₂ are called neutral salts. Neutral salts are defined as substances that ionize in water to yield the equivalent of hydrogen (H⁺) and hydroxyl (OH⁻) ions or to react with neither (H⁺) or (OH⁻) ions. The charges between salt ions and water ions are essentially equivalent and are, for all practical considerations, nonreactive. This means that salt ions are free to react with water molecules rather than with water ions (HOH rather than H⁺ or OH⁻), which provides the key to salt's profound ability to lower freezing points and thereby assist in melting ice and snow. The mechanism of freezing point depression and melting will be discussed further along.

Biologically, pure water (water without salts or minerals—the equivalent of triple distilled or deionized water) is homogenous water. Homogenous water reacts only with itself. Pure water is then, in a biological sense, inactive. Water with small amounts of salt present becomes biologically active. That is to say, salt ions break up the tendency for water molecules to react only with themselves. Thus, water molecules become available to participate in biological reactions. A measure of water's potential for reacting biologically is osmotic pressure; the greater the reactive potential is, the lower the pressure will be. On the other hand, water with too much salt becomes biologically overactive. That is to say, very salty water interferes with normal biological reactions in a kind of "short-circuit."

From biological studies of salt metabolism, scientists have learned that moderate amounts of salt are absolutely essential to life. Primitive man, as his descendants are in the Sahara Desert today, was tied to a source of salt for his very existence. Recall the story of the recently discovered Japanese soldier who managed to survive in relative isolation on the island of Guam since World War II (2). He was in good health except for having become quite anemic, probably a condition known medically as hypovolaemia. Hypovolaemia is in part caused by too little salt, a condition characterized by a decrease in blood volume due to sodium deprivation. NaCl is also an essential constituent of blood plasma (the fluid part of blood) and erythrocytes (red blood cells). Although the soldier lived in a cave close to the sea where salt is perpetually available, fear of discovery forced him to subsist on snails, insects, plant foods, fruit, and leaves, with very low salt content.

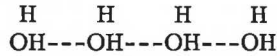
All plants and animals require salt to live; every hunter knows the value of a strategically placed salt lick. One possibly very serious problem resulting indirectly from the use of highway salt involves deer (3). Attracted to a wholly unnatural highway salt lick, deer can be killed tragically by fast-moving vehicles often at the risk of injury and death to the unsuspecting motorist as well.

Too much salt is a threat to all living creatures, even so to plants and animals living in the oceans where salt is present on the average of about 3.5 percent or 35 parts per thousand. Ocean organisms are not poisoned by salt simply because each species has evolved special structures, vacuoles or salt glands, that function to remove excess salt absorbed directly from the water or assimilated in its food supply. It is important to realize that most freshwater organisms have no special organs to protect them from excess salt. With the exception of certain organisms that have evolved the ability to tolerate both freshwater and saltwater environments, such as eels and salmon, all freshwater plants, invertebrates, fish, and aquatic mammals will die when placed in ocean water to the extent that acutely toxic amounts of salt are assimilated internally. Salt concentrations greater than 1 percent (1 gram/100 grams of water) endanger health, reproduction, and longevity in all species adapted to fresh water environments, including man.

Clearly, living organisms survive in a precarious balance between too little, just right, and too much salt, each in accordance with its genetic limitations and special adaptations. What we need to know most of all about the effects of highway salt in the environment is what is happening to this critical balance in organisms exposed to excess salt and, in a larger sense, what is happening to the continuing evolution of all species thus affected.

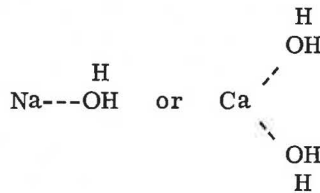
HOW SALT MELTS ICE AND SNOW

Recall that earlier we said that pure water reacts first of all with itself, molecule to molecule. The bonds formed between water molecules are called hydrogen bonds



indicated here by the dashed lines. Hydrogen bonds are relatively weak bonds that are easily influenced by the presence of competing substances. Even so, these weak bonds are sufficient to give water its characteristic density and specific gravity, either one of which provides a measure of hydrogen bonding. By convention, pure water is assumed to have a specific gravity of 1.00 at 4 C (maximum density) and standard pressure (sea level).

Remember also that salt dissociates easily in water; salt ions are thereby set free to react with water molecules:



Each interacting ion-water molecular bond formed disrupts prior existing hydrogen bonds. Salt ions interfere with hydrogen bonds because the bonding potential of salt ions exceeds the strength of the hydrogen bonds, and salt ions are favored preferentially. As the number of broken hydrogen bonds increases, the characteristics of density and specific gravity change proportionately and water becomes less dense. Changes in hydrogen bonding can also be caused by varying temperature or pressure.

For example, pure water at 100 C or 212 F and at standard pressure boils and evaporates rapidly. Evaporation occurs because at that temperature all hydrogen bonds are broken. At 40 C or 104 F, 50 percent of the hydrogen bonds are broken. At 0 C or 32 F (water), only 15 percent of the hydrogen bonds are broken. At 0 C or 32 F (ice) all hydrogen bonds are joined, and water has assumed a crystalline (solid) structure. It is important to note here that for each gram of water a change of 1 deg of temperature requires the loss or gain of 1 calorie of heat energy. To change water to ice (32 F water to 32 F ice) requires the loss of 80 calories of heat energy per gram. This is why ice, once formed, is difficult to remelt; a great deal of energy is required.

Salt plays a vital role in melting ice precisely because it changes the inherent structure of water, a process of interfering with hydrogen bonds, thereby lowering the freezing point. Yet, no matter how much salt is added, no melting of ice can occur without the addition of heat energy. The heat energy required for melting may be obtained from the atmosphere above the highway surface and the pavement or from subsurface materials in the form of latent heat or in the form of pressure and friction exerted by the tires of moving vehicles. At low environmental (ambient) temperatures (15 F and below) a phenomenal number of moving vehicles are required to maintain any significant amount of melting. What usually happens is that the partially melted snow and salt become mixed in a meal or grist-like consistency and the highway surface beneath becomes glazed, thereby creating unusually slippery conditions. What may also happen, if the amount of snow is excessive and ambient temperatures are low, is that the partially melted snow will bond to the highway surface, the remaining snow will pack, and its surface will become glazed with ice. A combination of alternating glazed and mealy driving surfaces is unusually hazardous; extremely dangerous driving conditions of this sort should be avoided if at all possible. Occasionally, public officials will actually close dangerous highways to the motoring public; it is ironic that most of the danger could have been avoided had salt not been used at all.

CaCl_2 , because one calcium ion (Ca^{++}) can interfere with two hydrogen bonds simultaneously, is approximately twice as efficient in lowering freezing points as NaCl , especially at low temperatures (below 15 F or -9 C). Conversely, sodium ions (Na^+) can associate with only one molecule at a time, but sodium is more efficient at lowering freezing points at relatively high temperatures (32 to 15 F) than calcium. Differences in the molecular structure of water at different temperatures also affect the way (Na^+) and (Ca^{++}) ions can react with water molecules, which accounts for some of the differences of efficiency in freezing point depression between CaCl_2 and NaCl . These concepts are rather complicated, and, because they do not bear directly on the question at hand, further discussion is deferred.

The practical question of how salt lowers freezing points and the importance of heat energy to melting can be best answered by analogy. What happens when salt is mixed with ice or snow is precisely what happens in an old fashioned ice-cream maker. Remember that an ice-cream maker consists of two chambers, a large outer chamber containing a mixture of salt and ice plus an inner canister, usually made of tin or aluminum (metals of high conductivity), containing the ice-cream mix. The salt lowers the freezing point, and the ice begins to melt. Because melting absolutely requires a source of heat energy to occur, the latent heat of the ice-cream mix is quickly conducted to the melting ice. In time, the temperature of the ice-cream mix falls below freezing and the mix partially solidifies, or at least it is supposed to solidify. On occasion an afternoon's work is rewarded only with iced soup.

Most of us are perhaps too young to remember, but Grandad knew best when he would admonish, "Not too much salt now!" Grandad knew what we either have forgotten or perhaps have never known, i.e., that too much salt poisons the ice-melting reaction. Because NaCl and CaCl_2 possess a finite ability to lower freezing points, the amount of salt required to lower the freezing point of water to the lowest possible temperature is called the eutectic concentration. Salt concentrations in excess of the eutectic concentration begin to raise the freezing point. Hydrogen bonds reform, the salt-laden icy water (brine) becomes slushy (with unmelted snow), and the demand for heat energy is short-circuited. Too much salt thereby impedes melting.

Under winter conditions at very low temperatures (-7 F and below for NaCl and -59 F for CaCl_2), too much salt inhibits melting and may, under certain conditions, aid the formation of ice. Fortunately, these conditions occur only rarely on highways in the United States. In regions of Canada and Alaska where such conditions can occur, the use of salt is limited to CaCl_2 , or salt is not used at all. At very low temperatures, heat energy required for melting is simply unavailable.

FATE OF SALT IN THE ENVIRONMENT

The question of what happens to salt in the environment has received only limited attention in professional biology and ecology journals. Most biological investigations have been limited to studies attempting to determine the effects of salt on roadside vegetation. However, the number of articles dealing with salt effects of a more general environmental nature appearing in technical journals, trade publications, and special symposium reports is on the increase. A comprehensive review of all literature references suggests that there are significant and perhaps critical unknowns that have not been fully investigated.

If we are to gain useful insights into the difference between what is known and what is yet unknown about the fate of salt in the environment, it is useful to construct a hypothetical model (Fig. 1). The model is based in part on information obtained from the general literature and in part on research conducted by the author. It appears probable that all possible alternative pathways for dispersal of salt in the environment have been identified, and, in that sense at least, the model may be considered relatively complete. Yet, it is in no final way possible to quantify the model in terms of how much salt will be found at a particular place in the environment at a particular moment in time. The kind of research necessary to enable such calculations has simply not yet been done. The model is valuable, despite obvious quantitative deficiencies, because it represents the first known attempt at a comprehensive synthesis of available infor-

mation. In addition, it is now possible to plan a coordinated research effort whereby quantitative unknowns may be systematically determined. What follows here is a first effort to identify research areas of greatest need based on an overall analysis of the model.

When salt or a salt-aggregate mixture is spread into the environment, it may be reasonably assumed that the salt will end up at some specific place in the environment. This assumption is based on the fundamental principle of physics that matter can neither be created nor destroyed. Salt is made up of elemental matter, sodium or calcium and chlorine, and thereby subject to all physical and biological laws governing the natural world. The elemental constituents of salt casually or quite deliberately cast into the environment must, at a later time and place, be accounted for.

Because salt is readily dissolved in water and snow or ice is the solid form of water, any salt-snow mixture will ultimately result, to a lesser or greater degree, in the disappearance of salt into solution. At the time of environmental distribution salt, snow, and salt in solution will enter into any one or combination of the following three possible alternative pathways:

1. Salt may dissolve in the melting snow and run off directly;
2. Moving traffic may splash salt or salt in solution onto the adjacent roadside environment where salt may percolate downward into the soil and become available to plant roots or the underlying water table or be deposited directly on roadside vegetation; or
3. Salt-laden ice and snow may be picked up, hauled away, and eventually discarded.

The ultimate fate of all salt liberated into the environment will be to enter the oceans or an equivalent reservoir such as fossil geologic water supplies (underground pools of water formed only during interglacial intervals called pluvials). At all other times, salt is free to become involved in all manner of living and nonliving environmental processes, many of which possess the potential for causing significant ecological alterations.

Direct Runoff of Dissolved Salt

Dissolved salt entering streams, rivers, ponds, and lakes acts as a weak electrolyte, thereby changing the electrical conductivity of the aquatic system. In concentrations greater than 1 percent, all freshwater species of bacteria, algae, invertebrates, fish, and higher plants are placed in immediate jeopardy. Science simply does not know what the long-term effects of small amounts of artificially induced salt are on species of freshwater organisms. We need to know which species are relatively resistant and which species are slightly or seriously affected, and most of all we need to know the effect of salt on fundamental evolutionary processes of selection and adaptation. It appears possible, if not entirely probable, that small concentrations of salt may act as an effective agent for natural selection much in the way that DDT and other chlorinated hydrocarbons were able to select and favor the survival of resistant varieties of mosquitoes and flies.

Salt in solution also affects the physical characteristics of small bodies of water such as ponds and lakes. In studies of Irondequoit Bay, New York (4), and First-Sister Lake, Michigan (5), the delay or failure of seasonal mixing due to salinity-induced stratification has been observed. Because the quantity of oxygen in the hypolimnion (lower depths) is directly affected by seasonal mixing, it is well within the realm of possibility that the addition of significant amounts of salt could contribute to the biological process of aging in lakes called eutrophication.

[G. Feick and his associates (12) presented evidence that the contamination of freshwater environments by the runoff of CaCl_2 and NaCl used for de-icing roads can accelerate contamination by mercury and undoubtedly by other toxic heavy metals as well. Highway salts act to increase the relative amount of mercury in equilibrium with the sediments by two to five or more orders of magnitude. Salts thus interfere with the ability of bottom sediments to bind mercury and other heavy metals *in vivo*. This evidence tends to confirm my suggestion that contaminating highway salts may contribute to the biological process of aging in lakes called eutrophication.]

The presence of salt in major river systems has apparently not yet reached critical proportions; the amount of dilution contributed by uncontaminated tributaries and precipitation is adequate to maintain extremely low levels of salt. However, there is no reason to conclude that, in the event of severe drought conditions or with significant increases in the use of salt, future problems will not emerge.

Salt entering potable water supplies, either directly as runoff contamination or indirectly via normal groundwater recharge aquifers and rapid percolation of Cl^- ions through the soil, can accumulate in sufficient quantities to render wells entirely useless (6). Numerous public and private wells in the northeast region of the United States have already been destroyed by salt at considerable expense to state and local governments.

Splash and Percolate

Dissolved salt and salt residues splashed onto roadside soils may percolate downward depending on the amount of runoff versus the amount of retention or adsorption onto roadside ice, snow, aggregates, exposed soils, or vegetation. Assuming percolation, the cations Na^+ and Ca^{++} will be captured by the anionic properties of clay particles in the soil. Only in very sandy soils will these cations migrate significant distances. It is important to note that in sodium- or calcium-deficient soils small amounts of salt will actually improve soil fertility. Yet, the small number of salt-deficient roadside soils in the United States can in no way justify massive applications of highway salt. The anion Cl^- percolates quite rapidly through the soil primarily because the clay particles in soil bear the same negative charge. Elemental chlorine thereby rapidly enters normal channels of groundwater migration.

The most obvious effect of salt on roadside vegetation is that susceptible species such as white pine, hemlock, sugar maple, red maple, and most ornamentals respond with symptoms of chronic toxicity, burned or browning foliage. Salt apparently interferes with normal photosynthetic and respiratory processes and, at acute levels of toxicity, will kill the leaves directly. Small amounts of salt absorbed through roots or exposed vegetation will lead to premature coloration of leaves and early leaf fall in the next year. With acutely toxic doses, the plant dies, and, unless the dead portions are removed, the salts contained therein will be recycled to the roadside environment.

A great deal is known about chronic and acute toxicity of salt in most sensitive plants (7). Very little is known about the subtle effects of low levels of salt contamination on so-called "resistant" species over long periods of time. It seems prudent to caution once again that in all probability salt has the potential for acting as a selection agent in the natural environment. The need for adequate research in this area is indeed critical.

Pickup and Discard

Problems associated with discarded salt-laden snow and ice scooped up from highways, sidewalks, and parking lots have been almost entirely ignored. Similar problems related to the storage of unused salt have been extensively treated. Why this disparity of understanding exists can be explained on the basis of ignorance and neglect: Discarded salt is essentially out of sight and out of mind; no problem is seen to exist.

Salt storage piles are large, conspicuous, hardly avoidable structures that are often sited adjacent to potable water supplies. Perhaps here lies an acceptable explanation. The enormous cost of developing new water supplies to compensate for salt contamination has forced local and state agencies to better protect the environment from salt contamination. All manners of covered or otherwise enclosed waterproof storage sheds have been invented and tried. In most instances the designs are quite functional and environmental contamination is entirely avoided. Yet, one cannot see dissolved salt in water, and, in the case of tarpaulin-covered storage piles, rainstorms followed by hot dry weather often tell a different story (Fig. 2).

Discarded piles of salt-laden snow, black and dirty, show little evidence of the salt within. Dumped wholesale into streams and rivers or piled in open fields, the salt within is instantly free to affect the environment. Figure 3 shows one such discard

Figure 1. Fate of salt in environment.

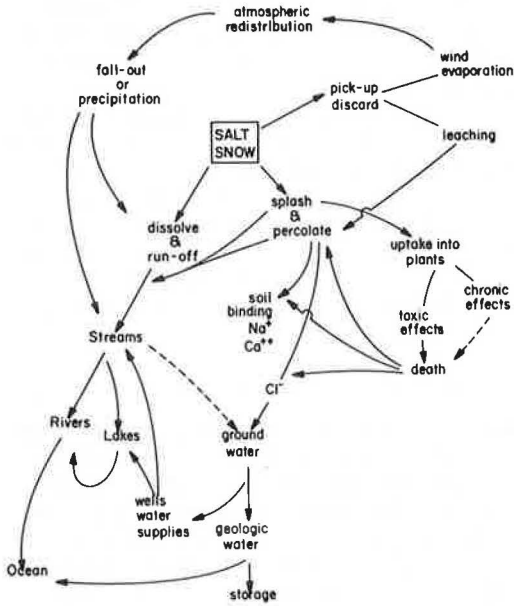


Figure 2. Pennsylvania Department of Transportation tarpaulin-covered salt storage area: (a) winter conditions, no apparent contamination; (b) fall conditions, evidence of salt contamination of roadside environment.

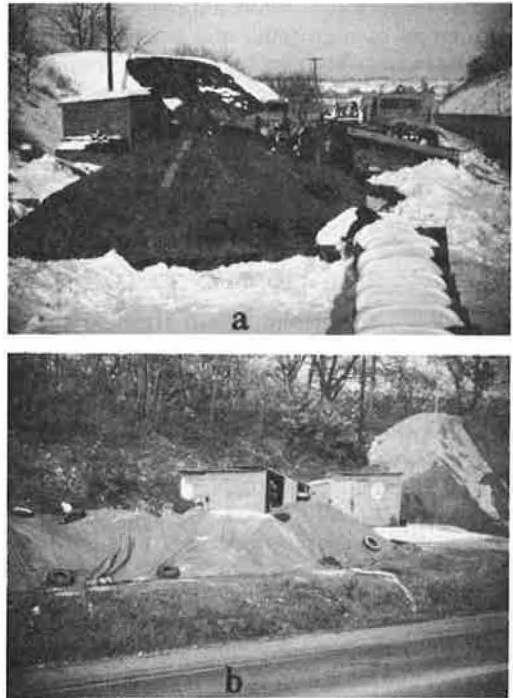


Figure 3. Discarded salt-laden snow and ice located on groundwater recharge aquifer.



area that is surprisingly located on a groundwater recharge aquifer. All of the salt leaching from these piles enters directly into underground water supplying unknown numbers of area wells. It is only a matter of time until the contaminating salt reaches chronic proportions and another source of water will have been destroyed. There is simply no excuse for such careless management of waste salt.

The question of what happens to salt that evaporates along with ice and snow under conditions of high wind and low relative humidity has not been examined experimentally. Preliminary observations and information extrapolated from related studies (8) involving atmospheric redistribution of ocean salts and sewage treatment effluents suggest that very large amounts of salt may be redistributed generally throughout the environment. Unfortunately, no quantitative estimates of amounts of salt involved or environmental effects are yet available. Clearly, there is a critical need for thorough research in all of the areas herein discussed if another potential environmental crisis is to be successfully avoided.

RELATIONSHIP BETWEEN SALT, SAFETY, AND ECONOMICS

Spokesmen for the Salt Institute make the rather bold claim that salt and safety are synonymous (9). Most arguments purporting to show a positive relationship between the use of salt and a decline in the frequency of highway accidents are based on statistics compiled by federal, state, and local government agencies. Depending on who interprets the statistics and for what purpose, many points of view may be developed. It is especially difficult to determine precise cause and effect relationships from non-specific statistical data. Yet, from precisely this kind of second-hand general statistical data, the Salt Institute concludes that salt means increased safety.

It is the author's divergent opinion that these so-called "convincing" statistics have not been properly corrected for the probable influence of alternative causal factors. In other words, the extent to which highway accidents have decreased in response to engineering improvements has not been properly accounted for as regards (a) improvements in the design of automobiles, (b) improvements in tire quality and efficiency, (c) improvements in driver performance resulting from expanded driver education programs, and (d) improvements in highway design, engineering, and construction.

Perhaps the most damaging argument against the Salt Institute's position is that insurance underwriters, using essentially the same basic data, have managed to convince federal and state insurance commissions that highway accidents are on the increase, not on the decrease. And, because accident rates are increasing, a corresponding increase in premium rates is justified. As a matter of fact, the average American motorist is paying higher insurance premiums today than at any prior time in history.

The question of salt and safety may also be examined experimentally. It is now known that under certain meteorological conditions the presence of salt may actually encourage the formation of ice or at least greater than normal slippery conditions (1, 10). Salt, especially CaCl_2 , is deliquescent; that is to say, salt can attract water. At low temperatures and high humidity, the presence of salt favors the deposition and retention of moisture on highway surfaces. The questions that need most of all to be answered experimentally are to what extent does salt-induced ice formation occur within the north temperate zone, and to what extent can winter accidents be directly attributed to the presence of salt?

Questionable Economics

The terms salt and snow are rapidly becoming synonymous in Europe, Canada, and the United States. In the 15 years from 1950 to the mid-1960s, the use of salt increased in England fivefold. In 1968, $1\frac{1}{2}$ million tons of salt were used in Canada; nearly 6 million tons were applied to roads in the United States. Two years later, consumption of salt in the United States increased to 9 million tons; approximately one-third of this increase can be accounted for as CaCl_2 . The salt industry has grown correspondingly, and the selling of salt has become quite literally a highly profitable business. As the marketplace expands (recall the projection of 12 million tons by 1975), competition will increase and the pressures to sell salt will become irresistible, especially if the

public, through effective advertising campaigns, becomes convinced that salt is the only practical answer to snow removal problems.

According to Adrian Clary (11), the pressures on public agencies to use salt have increased significantly in recent years. Even the courts have joined the controversy saying in effect that, once a road authority maintains a road in a certain condition, it must continue that condition or warn against a change. To violate this precedent means that public officials are immediately exposed to the risk of liability suits. Unfortunately, juries have been entirely generous in awarding substantial damage claims in suits involving liability or negligence.

The problem is made even more serious by convincing estimates of economic losses, associated with inefficient snow removal strategies, based on the use of highly questionable statistics. For example, in New York City, a commuter's time is valued at \$2.82 per hour. The loss of 1 hour's travel time per storm during an average winter is calculated to cost the city of New York \$30 million annually. In Detroit, savings to business resulting from the liberal use of salt were calculated to equal \$55 million saved against potential work losses, \$7 million saved against late delivery of goods, \$426 million saved against potential losses of consumer sales, and receipts of approximately \$67 thousand per day in public transportation.

These are strong economic arguments. After all, what public official in his right mind would intentionally assume responsibility for such staggering losses. The use of salt, if not environmentally justified, can at least be understood to have an irresistible economic justification. The pressure to buy salt has increased beyond rational control. The only way these irresistible economic arguments can be effectively countered is for the public to demand rational cost-benefit analyses. Any adequate cost-benefit analysis will include such externalities as the following:

1. The cost of salt's corrosive action on highway surfaces, especially to unseasoned concrete;
2. The cost of salt's corrosive action on structures, including bridge railings, bridge decks, and supportive framework; and
3. The cost of salt's corrosive action on metal and rubber automobile parts, including body parts, brakes, wheel cylinders, and steering mechanisms.

It will be interesting to see the contrast between assumed benefits and the true costs of salt use, costs that may be calculated finally only in response to significant new environmental research.

Despite the obvious need for viable research, the kinds of decisions needed to implement new research programs are simply not forthcoming. Why? The problem is essentially one of misplaced priorities. Despite the good intentions of many public officials, not one penny of federal research money was spent on salt research prior to 1963, and only a dribble of money has been invested officially in subsequent years. Conversely, the Salt Institute spends thousands of dollars annually on advertising, lobbying, and sponsored research, all of which is understandably pro-salt.

In addition, ecologists and conservationists who have dared to question the propriety of using salt in the environment have been summarily dismissed as "hysterical ecnuts." One can only ask, What is the real source of hysteria? The average citizen confronted with slick advertising and misleading statistical propaganda can hardly be expected to form anything less than a strong emotional attachment to highway salt, an attachment exemplified by the emotional words of a young mother who said, "As long as salt guarantees the safety of my children, I could care less what happens to the environment." The power of American advertising should never be underestimated, but advertising costs money, which is of course no real problem for those engaged in a disproportionately profitable business.

One way that the problem of environmental unknowns associated with new technologies, such as highway salt, could conceivably be solved is to finance the necessary research with an appropriate tax on the profits of the offending industry. At least in this way, a potential polluter would be forced to make a positive contribution to the discovery and implementation of viable alternative solutions.

Recommendations

Until a suitable physical or chemical alternative for salt is invented or until the true environmental costs of a salt-based technology are determined, there are several ways whereby public officials and highway maintenance personnel can make a positive contribution to the relief of existing environmental problems. One of the most serious problems involves relatively unrestricted spreading of excessive quantities of salt. The accidental or careless dumping of salt in piles on highway surfaces and the spreading of salt at maximum possible rates far in excess of actual need are not only economically wasteful but also environmentally destructive. Carefully controlled applications of salt according to calculated need by skilled operators will minimize environmental contamination. The additional problem of determining how much salt is required to melt a given amount of snow is skillfully explained in an article entitled *Understanding the Action of Salt* (13).

It makes little sense to spread salt where salt is not needed. A functional survey of local streets to determine the location of troublesome hills and intersections and the application of just the right amount of salt in the most advantageous location can simultaneously save money and protect the environment. As sound snow removal strategies are developed and implemented, public officials would be well advised to keep the public fully informed about goals and objectives.

Controlled applications of salt require that spreading equipment be maintained in excellent repair. Careful calibration of salt spreaders will ensure correct delivery rates. The employment of trained operators, especially those with a conscience, will more than compensate for higher pay rates in real savings; every pound of unnecessary salt saved is the equivalent of money in the bank.

Salt storage piles, properly contained and protected from wind and rain, will eliminate losses due to leaching. Remember, too much salt is a potential biological poison; handle salt accordingly.

The cautious discarding of salt-containing wastes is essential if environmental damage is to be minimized. If wasting is necessary, use only those methods that will maximize dilution. Waste dumps must be located outside known aquifer recharge areas. An alternative method of disposal would be to store waste salt in dry, non-leaching holding beds; the dry residue conceivably has the potential for reuse. Unfortunately, the concept of recycling salt has never been examined experimentally. Perhaps some enterprising public official will endeavor to develop a demonstration proposal involving recycled salt.

Most of all, public officials need to keep informed about recent scientific and technical developments. This will require a conscious commitment to read scientific and technical journals as well as trade magazines. Remember, whatever the official learns that is new and useful deserves to be shared with the public at large. A properly informed public is not only appreciative but, more importantly, quite willing to actively support positive programs.

CONCLUSIONS

There is little question that under many meteorological and environmental conditions chloride salts are effective agents for melting ice and snow. Yet problems of management, safety, and potential environmental damage are obviously more serious than simply melting snow. To calculate the true costs and real benefits of an expanding salt-based technology requires that a great deal of vital research be conducted. In the meanwhile, persistent efforts to expand the use of salt as an assumed most efficient, safe, and cheap alternative method of snow removal need to be strenuously questioned.

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