THE UNIVERSITY OF CALGARY

SOME EFFECTS OF HIGHWAY DE-ICING ON ADJACENT SOILS AND VEGETATION

by

Brenda Jean Squire

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "Some Effects of Highway De-icing on Adjacent Soils and Vegetation" submitted by Brenda Jean Squire in partial fufillment of the requirements for the degree of Master of Science.

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ABSTRACT

The necessity to de-ice highways is important for all motorized transportation and its significance to the Canadian economy. The presence of any snow or ice on the road surface constitutes a major hazard. Highway departments agree that the only truly safe pavement is bare pavement.

Sodium chloride is a common highway de-icier. Concern arises when one considers where excess salt goes after the storm event. Salt can enter the environment in three major ways: salt is redistributed atmospherically by the wind through fall-out or precipitation; percolation of salt into soils from roadsplash binds with the soil or is absorbed by plants; or salt dissolves into water. Once in the environment, salts can affect soils, vegetation and water.

In 1991, 1080 soil samples were collected from the TransCanada Highway and secondary roads through southern Alberta and were analyzed for concentrations of sodium ions. The results are interpreted and statistical tests performed to explain possible sodium concentration variation due to differences in location, type of highway, distance, depth and seasonality.

The results indicated an association between types of highways and distances from highways with the sodium concentrations of soil samples. Using this correlation, options for management techniques and alternative de-icing chemicals were examined.

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INTRODUCTION

1.1 RATIONALE

In response to demands for improved winter driving conditions the application of de-icing chemicals to highway surfaces has become common practice. This process in combination with snow ploughing is thought to improve road safety and minimize traffic delays to a considerable extent (Watkins, 1981). The impact of these chemicals (primarily sodium chloride) has produced some controversy as to the costs on vehicles, highway bridges, parking garages, other private property, groundwater, vegetation and soils. The effects of de-icing chemicals on the environment and the management of these chemicals will be the focus of this research thesis.

Improvements in technology, increases in income and the growth of the population have combined to create, enlarge and disperse settlements and resource areas. In order to develop new regions and maintain contacts between centres an extensive network (infrastructure) of roads was necessary. These highways were not developed without negative effects. Besides the disruption of land use and the natural drainage of both air and water, roads may also create a linear pattern of environmental alteration. Oils, grease, trace metals, exhaust, and other contaminants from construction and use of highways may pollute roadside soils and vegetation as well as lead to the contamination of fragile water sources (Webb, 1982). The development of the TransCanada Highway brought forth the ability for people to travel across the country on one major thoroughfare, therefore increasing the possible volume of traffic through Alberta. The TransCanada Highway may also increase the amounts of pollutants released along highways in Alberta. One area of concern may be in the application of salt to highway surfaces as a method of de-icing.

The start of the twentieth century showed a rapid change in snow removal practices. Horse-drawn wedge plows and carts accompanied by troops of men with shovels were the practical method well into the 1920s when mechanical trucks, tractors, graders and plows were first introduced (Minsk, 1970). These introductory snow removers have increased in weight but have remained relatively the same to this day. The plows then were used along with chloride-treated sand on compacted snow or ice-covered pavements and in the early 1940s sodium chloride made its debut as an ice preventative (Minsk, 1970).

Alberta Transportation and Utilities uses sodium chloride for de-icing highways in the province. In 1987, the Department used 109,000,000 kilograms of salt at a total cost of $7,500,000 (Mah, 1990). The salt applied on the TransCanada Highway today generally is acquired from Saskatchewan as a by-product of the potash industry. Essentially it is sodium chloride with 1-2% being potassium chloride and insolubles, thus giving it a pinkish tint (Mah, 1990). This compound is distributed to the regional Alberta Transportation maintenance yards throughout the province and it is stored in outdoor piles at a ratio of 93% sand to 7% salt in order to prevent the mound from freezing (Ullery, 1991). More salt can be, and often is added to make the mixture more effective during the various storm event conditions.

The aftermath of storm events causes great concern for public safety. Precipitation, whether in the form of rain, sleet or snow, can form ice creating dangerous conditions by lowering the skid resistance of the pavement. In the case of accumulation of moisture, water molecules are continually pulling away from the water surface and flying into the air immediately above (Transportation Research Board, 1974). The resulting equilibrium creates a fixed vapour pressure. Once water freezes the ice has a lower vapour pressure than the water and when the airborne molecules leave the water they attach themselves to the ice surface letting the thickness of the ice increase (Transportation Research Board, 1974). As salt is applied to the ice, crystals become enveloped in a film of solution involving the water vapour taken both hygroscopically from the air and from the moisture adhering to the ice (Schnieder, 1962). The salt and water solution becomes more concentrated and exhibits a lower vapour pressure than the ice (Transportation Research Board, 1974). The ice then begins to melt and will continue to do so until the salt concentration of the solution is reduced to a point which renders it ineffective. If ice remains, further salt applications are necessary.

The salt commonly used as a de-icer is sodium chloride as it is effective and inexpensive relative to other de-icers. Sodium chloride is labelled a neutral salt because when it is added to water it dissociates to form sodium cations and chloride anions. These sodium and chloride ions have equivalent charges to the hydrogen and hydroxyl ions found in water and therefore interfere with the hydrogen bonding in ice and snow (Russel, 1980). The salt ions have a bonding potential greater than the hydrogen bonds and are preferentially favoured to change the structure of $H_2O_{(s)}$. However, the addition of heat energy is necessary to actually melt the ice (Adams, 1973). The majority of this heat can be supplied by the atmosphere above the highway surface, supporting surface, or by the tires of moving vehicles creating pressure and friction (Schneider, 1962).

Salt has the lowest immediate costs at approximately $30 to $40 per 1000 kilograms (Bacchus, 1987). NaCl has been found to be a very effective method for melting packed snow and ice at temperatures near 0°C, however, the melting effects of salt diminish below -6.7°C, and cease at -21°C (Transportation Research Board, 1974). The relatively small range of effectiveness is made up by the inexpensive application costs.

The low immediate consumption costs must be differentiated from the costs that will develop in the future. The application of salt has been linked to the premature corrosion of vehicles as well as corrosive damage to highway structures like bridges. Sodium chloride is known to cause corrosion to reinforcing bars in concrete and other steel structures (Gurjar and Mah, 1992). The Calgary Herald (Alberts, 1992) reported that this deterioration is costing Calgary private parkade owners money as the weakened structures are in need of "band-aid" repairs totalling millions of dollars over as short a time as three years, or even more expensive rebuilding. August 1992 marked the first time a parkade in Calgary has been forced to close because of road salt damage as the 9th Avenue and Centre Street South Parkade was deemed dangerous to the public (Alberts, 1992). In an Ontario cost-benefit analysis of switching salt applications to an alternative non-corrosive agent, Bacchus (1987) found that the savings in corrosion damage to cars resulting from such a change would be about $650 million per year, which when spread over the car population of 4.8 million would be $135 per car per year. Other savings per year if the transportation companies would switch from salt would be approximately $900 million from bridge deterioration and $1795 million from parking garage deterioration (Bacchus, 1987). The cost of road salt has further reaches as well. Three ski resorts in Alberta are seeking compensation for the February 1992 power failure which cost the resorts approximately $200,000 in refunds (Lamb, 1992). The massive power failure reportedly was caused by a short in a salt-corroded power line conductor. However, even these cases and saving estimates would not offset the immediate costs of changing from salt to more expensive de-icing agents.

The costs of using salt as a highway de-icer has increased as more emphasis has been placed on the effects of highway salts on roadside soils, vegetation and water. Positive effects may be found by investigating the purity of the type of salts applied. A combination of other ions, such as magnesium, calcium or potassium may be found in combination with the NaCl in some rock salts and could improve the roadside environment by enhancing the nutrient content. However, adding salt to soils and ground water and the stress this contributes to plants and wildlife are major concerns. Recent concern over the browning of roadside vegetation and the increase of salt content in ground water wells has motivated individuals, public agencies and environmental groups to ask questions and get involved in de-icing matters. Why are de-icing compounds necessary and how is road salt applied?

North American economies are highly dependent on vehicular transportation. This dependence has forced highway departments to improve highway safety and in turn minimize the possible danger and detainment to both personal and business travel. One hazard to motorized transportation is winter driving. Snow and ice on highways may produce problems by causing injury to persons, damaging property or developing unforseen delays. Highway departments have concluded that the safest highway surface is bare pavement and have developed policies to strive for this condition even in the midst of winter (Field et al, 1974). These highway authorities also have agreed that applying salt (sodium chloride) to highway surfaces is the most efficient and economical method of ice removal (Salt Institute, date unknown).

Alberta Transportation has attempted to control the problem of snow and ice removal by using trucks which combine the process of plowing the snow off the highway and then dumping a sand and salt mixture from the truck hopper out of a spinner located under the truck onto the freshly plowed highway to remove the thin layer of snow and ice missed by the plow. However, the sand/salt mixture ratio is determined by the district foreman (Mah, 1991). The decision on the sand/salt spreading rate is made by the specific plow operator. Alberta Transportation has meters in their new trucks which can reduce the amount going through the spinner when the truck is moving slowly and increases the amount released when the truck is travelling fast. However, these meters commonly are not used. The truck operators set the speed and often do not change it as it is difficult to see how much of the mixture is coming out when they are trying to operate the vehicle. Using averages from 1983 to 1989, Alberta Transportation application rates range from 1500 to 11000 kilograms per kilometre of two lane highway (Mah, 1991). These figures are comparable to Saskatchewan but excessive as compared to British Columbia and Ontario (Mah, 1991). The rates applied in National Parks vary from 90 to 450 kilograms per two lane kilometre (Parks Canada, 1983). These rates are so diverse because they describe the practices in a variety of climates and through various topography all within the same province. Although operators may be experienced in applying de-icing mixtures for their region, the decision is still subjective as no set guidelines are used (Mah, 1991). Parks Canada (1983) defends this practice because "no two storms are alike, no one set of standards for spreading rates can be written to cover all such conditions or topographic regions". However, concerns arise after storm events when controllers are uncertain as to the minimum salt requirement necessary and may apply excessive amounts to be certain (Minsk, 1982). This excess salt is important to study to determine the impact caused not only to vehicles, bridges and pavement but also to the adjacent ecological systems. Therefore highway de-icing is an environmental as well as economical problem.

Sopher and Baird (1978) describe the soil as:

> "a purification system that is capable of holding many pollutants and tying them up so that they are either rendered inactive or biodegraded. However, the soil's olding capacity can quickly be saturated and the soil sterilized to a barren, polluted, unproductive area which can erode and become a further source of pollution."

Soil is one of society's greatest natural resources. As populations continue to grow more productive land must be acquired, soon even the marginal land must be utilized. Although roadsides constitute only a small fraction of available land in Alberta, these ribbons of soil are borders to the larger sections of land. Salt dissolves easily in water and can translocate. The effects of salt can spread. Problems arising from de-icing may lie in the excessive use of salt or in repeated salt applications. However, the question this thesis will concentrate on is whether de-icers are altering the soil significantly, and if so, what measures can be taken to reduce such problems. In Alberta Environment's 1991 Draft Regulations of Environmental Protection and Enhancement Legislation Document it states that the construction, operation and reclamation of upgraded highway projects are to be excluded from the environmental assessment process. This means that the highways in Alberta are subject to environmental screening only under exceptional conditions and that the Environmental Impact Assessment process still does not include the repercussions of highway de-icing on the adjacent soils and vegetation (animal migrations are considered) (Alberta Environment, 1991). However, as the province of Alberta, along with the federal government, develops more rigid environmental guidelines for proposed investments, highway roadsides should be added to improve the analysis. This thesis research is undertaken to better understand the effects of de-icing salt on roadside soils and to establish awareness of any environmental problems associated with de-icing salt use. The results of this study will attempt to show sodium concentrations and variations in soils along the TransCanada Highway and secondary roads in Alberta. This soil impact, combined with water and plant assessment, will be compared to current literature in order to suggest options of management techniques specific to road salt use in Alberta.

1.2 LITERATURE REVIEW

Sodium chloride (NaCl) is used most frequently as a de-icing compound due to its low cost, ready availability, and ease of application (Damas and Smith, 1987). Salt is applied to highways to prevent the formation of ice and build up of snowpack as well as melt ice which already has formed (Parks Canada, 1983). In North America alone, the application of sodium chloride in the early 1970s reached approximately ten million tons per year (Damas and Smith, 1987). In an average winter highways may expect to receive 11,000 kilograms to more than 56,000 kilograms of salt per kilometre (Field et al, 1974). With these values in mind, the question arises: what happens to this large quantity of road salt in the environment. Adams (1973) suggests three major pathways of salt into the environment: 1) salt mixes with the melting snow and will runoff directly; 2) traffic splash can spray the area adjacent to the road with salt solution ; or 3) salt can enter the environment during its removal and storage. See figure 1.1. Once de-icing chemicals have left the confines of the roadway they can result in significant alteration of the environment. Soils, plants, wildlife and water all are affected by road salts both independently as well as from biological links.

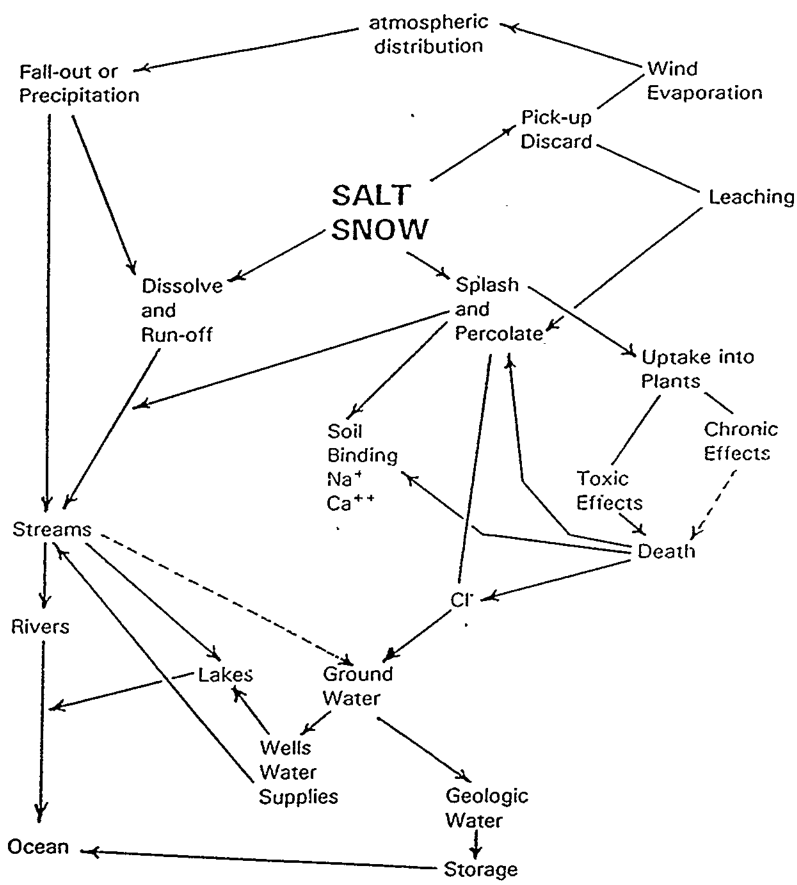

FIGURE 1.1. THE FATE OF ROAD SALT ON THE ENVIRONMENT (Adams,1973)

1.21 Environmental Effects on Soils

Research into the effect of salts on soil has been limited mostly to areas of agriculture. However, dissolved salts from highway runoff and splash also can percolate into adjacent soils and increase the salinity. Under natural conditions salt accumulates in soils primarily due to evaporation, whereas in the case of de-icing chemicals, ice and snow melt along with rain moves salts through the soil (Brandt, 1973). These de-icing compounds disassociate into their respective ions.

Sodium cations are absorbed by the negative charges on the soil surface whereas the majority of chloride anions pass through the soil carried by the ground water. The sodium cations replace the calcium cations on the soil colloids and the development of large pore space is restricted (Sposito, 1989). This restriction is caused when a calcium ion is replaced by two sodium ions which tend to occupy more space and reduce bonding surfaces for water molecules. This leads to a decrease in soil permeability thereby changing the soil's structure. Soil structure is important in maintaining a balanced relationship among the roots of plants, the air within the soil, and the soil waterholding capacity (Sopher and Baird, 1978). Excessive sodium destroys soil structure because the sodium ion has a natural affinity for clays and acts to disperse or deflocculate clays (Sopher and Baird, 1978). Since clays are a main contributor to soil structure, the addition of sodium to the environment can reduce the quality of the soil for agricultural crops and other vegetation.

The dispersal and eventual concentration of road salts in areas adjacent to highways should follow a catena model. High concentrations of salt ions are expected along the highway shoulder and also in the road ditches. The runoff from the highway introduces the salt ions to the disturbed soils closest to the road then subsurface lateral flow and surface runoff should carry the ions to a zone of accumulation at the lowest point in the ditch.

The concentration of road salt may also vary with the seasons. It is reasonable to assume that the percentage of de-icing compounds adjacent to the highways would be relatively higher just at the end of the winter season and relatively lower after the summer. We expect this because sampling during the spring melt suggests that the salts have not yet dispersed. Spring runoff and summer rains leach out the salts and along with the processes of time disperse the salts so that late autumn should produce the lowest salinity reading. The cyclical event repeats itself as the application process begins for another year.

1.22 Environmental Effects on Vegetation

The salt pollution of soils along the highway environment seems to lead to detrimental effects of the ability of soil to support desirable plant growth (Zelazny and Blaser, 1970).

Plants adjacent to highways can be affected by road salting by changed soil properties and the absorption of sodium from root uptake or vegetative exposure during splash events. In general, salts can cause both osmotic obstruction of water absorption and specific ion toxicity which combine to reduce plant growth and nutrient uptake (Shannon, 1982). Estimated as one of the most common soluble salts found in soils, sodium chloride can have serious negative effects on plants (Al-Rawahy, Stroehlein and Pessarakli, 1990).

The effect of sodium on plants varies due to the interaction of several factors including the physiological structure, stage of growth and rooting habits of the plant (Brady, 1990). Plants can be affected by salt through changing soil properties and the absorption of sodium from root uptake. Sodium tends to break down soil structure and disperse clays which can produce a dense surface crust and make the soil almost impermeable as well as saline (Bridges and Davidson, 1982). The soil's natural drainage is impeded which may create osmotic conditions similar to drought stress on the vegetation (Ricklefs, 1973). Another possibility would be poor drainage causing an accumulation of water which could produce waterlogging and a lowering of oxygen in the soil. This stress is emphasized when salts remain behind; as water is evaporated and transpired out of the soil changing the osmotic potential of soil water as well as specific ion concentration (Shainberg and Oster, 1978). The sodium denatures the enzymes within the plant and is not tolerated in the cytoplasm and therefore plants cannot salinize their cells, eliminating the chance of osmoregulation (Salisbury and Ross, 1978). Calcium is favourable to soil structure; however, it is replaced by sodium on the soil colloids. $CaSO_4$ fertilizer often is used to combat the sodium (Salisbury and Ross, 1978). This fertilizer leaches out the sodium ions and lowers the pH which benefits soil organisms and helps to form excellent soil structure (Sopher and Baird, 1978).

Soil pH also drastically affects the needs of plants. With the addition of Na^+, soil pH may rise to a value as high as ten (Hausenbuiller, 1978). The harmful effects of this new alkaline environment is the low solubility that the necessary plant nutrients experience within saline soils. Sodium cations may cause nutritional deficiency or toxic ion effects when they lower the availability of important nutrients, such as iron, manganese and potassium, to the plant and therefore may cause a decrease in growth as well as vigour. Organic matter also can be affected by high pH values as it can be carried upward by water's capillary rise to be deposited as a dark coloured surface film (Hausenbuiller, 1978). Common conditions developed from increased sodium ions are chlorosis (the lack of chlorophyll in leaves) and commonly necrosis (a localized death of tissues in leaf margins and tips) (Salisbury and Ross, 1978). Necrosis often is a protective method of isolating the toxic effect of the salts in dead cells (Mercado, 1973). In general when soils contain abundant sodium ions, soil fertility is reduced by both the increased alkalinity of the soil as well as sodium toxicity (Ricklefs, 1973).

Nonsaline sodic soils naturally contain less calcium and magnesium, so when these cations are replaced by sodium the resulting deficiencies damage the plant (Shainberg and Oster, 1978). A reduction in calcium deforms tissues and kills meristematic areas prematurely (along with the alteration of other aspects of plant metabolism). Magnesium deficiencies cause discoloration or yellowing of older leaves and reduced fundamental plant life activities (Salisbury and Ross, 1978).

Sodium ions also can interfere with the plant's absorption of potassium. Plants rely on the presence of calcium to create a high-affinity uptake system for the transport of potassium into the plant (Salisbury and Ross, 1978). When calcium is reduced due to an influx of sodium ions, the uptake system cannot be created and a potassium deficiency develops. Potassium deficient plants show signs of necrosis as well as a reduction in turgor pressure and enzyme activation for life sustaining syntheses (Salisbury and Ross, 1978).

Toxic effects also can be seen when the concentration of chloride ions in the soil water exceed normal conditions and are absorbed by the plant to accumulate in the leaves (Walker and Downton, 1982). This build-up can develop leaf burn, leaf drop, twig dieback and progressively kill the plant (Reeve and Fireman, 1967). Excess sodium and chloride ions also can impede the uptake of nitrogen (in two most important forms of ammonium and nitrate) contributing to a reduction in plant growth, leaf discoloration and dieback (Al-Rawahy, et al, 1990; Salisbury and Ross, 1978).

The effects of sodium chloride contamination combine to create an overall reduction in photosynthesis rates due to their interference with carbon dioxide assimilation (Brugnoli and Lauteri, 1990). The different solubilities of carbon dioxide and oxygen within plant cells are manipulated by increased salt concentrations to alter the normal levels of these cellular gases (Walker and Downton, 1982). Carboxylation, the key part of the Calvin cycle which forms carboxylic acid, is reduced because of the smaller amount of necessary carbon dioxide available due to restricted stomatal conductance (caused by osmotic drought which closes the stomata) (Brugnoli and Lauteri, 1990). This affects the growth and vitality of any salt influenced plant.

In general, the salinization of soils creates a medium which alters the water balance, depletes nutrients and increases toxicity which decreases plant growth (as large scale diversion of plant metabolism into chemicals for osmotic adjustment thus using its "food" normally used in growth) (Poljakoff-Mayber, 1982). Detrimental effects can begin with stunted growth then proceed to create brown spots on leaves, decreased cellular hydrostatic pressure, leaf drop and eventually end in the death of the plant (Brawley and Mathes, 1990). These toxicities are emphasized with rises in temperature, as heat and light tend to aggravate plant injury (Levitt, 1972). However not all plants react to saline conditions in the same manner.

Water stress on vegetation can result from drought, cold and salt. Plants can be divided into categories of salt tolerance with those sensitive to salt being the glycophytes and those tolerant to salt being the halophytes. Levitt (1972) defines five measurements by which plant tolerance to salt affected soils can be monitored. These measurements are: 1) the electrical conductivity of the soil corresponding to the standard percentage decrease in yield (this is the only measure which concentrates on plant resistance to salt; 2) the osmotic adjustment of a plant; 3) the rate of the sodium: potassium reaction in the plant and; 5) survival of sections of tissue in salt solutions (Levitt, 1972). The results from these measurements can indicate plants which do not display growth stress in a saline or sodic environment. These plants show a tolerance to salt affected soils and should not be confused with plants that avoid salinity effects by way of methods such as delayed germination or exclusion of salt at the root zone (Shannon, 1982).

Shannon (1982) uses the terms salt tolerance and salt resistance interchangeably as a description for mechanisms that allow plants to survive in saline environments. The importance of these tolerant species can be found in agricultural practices, where there is a need for increased productivity in the ever expanding saline regions (Rains et al, 1982). See figure 1.2.

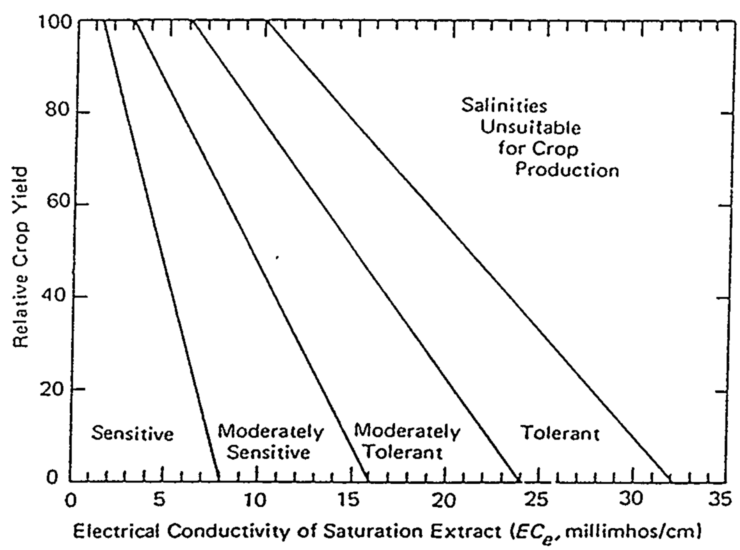

FIGURE 1.2. RELATIVE CROP YIELD AS A FUNCTION OF THE SALINITY OF SOIL SATURATION EXTRACT (Shainberg and Oster, 1978)

Salisbury and Ross (1978) identify two main types of terrestrial halophytes: 1) facultative halophytes; and 2) obligate halophytes. Many prokaryotes are facultative halophytes which thrive in soils with both high and low salt levels, whereas obligate halophytes have high concentrations of salt within their cells and therefore only grow in salty soil (Salisbury and Ross, 1978). Obligate halophytes are the most resistant to salt stress as they require high salinity for survival, as compared to facultative halophytes, which are capable of growing in high or nonsaline environments (Levitt, 1972). There has been much dispute if there can be obligate halophytes, as evidence shows all plants that grow in salty soils can also grow in non-salty soils. However, some prokaryotes seem to show the unique characteristics of obligate halophytes (Salisbury and Ross, 1978). Halophytes which absorb salts continually throughout the growing season and have an increasingly negative osmotic potential, are called salt accumulators; those halophytes which do not show this increase are called salt regulators (Salisbury and Ross, 1978).

Factors which can influence the tolerance of plants to salinity, vary with each species. Two major areas of plant sensitivity to salt are: duration of exposure to salt and the stage of plant growth (Shainberg and Oster, 1978). Plants generally follow a gradual adaptation to increases in soil salinity. The root is the first plant organ to be affected by the salinity of the surrounding soil medium and will adjust accordingly by altering hormonal levels, enzyme activities and permeability properties (Poljakoff-Mayber, 1982). Some plants are able to concentrate potentially damaging ions among tissues and cell organelles (Ziska et al, 1990). This root uptake selectivity, along with differential retranslocation and storage processes, are able to reduce the osmotic stress and ion toxicity present in salt affected soils (Blits and

Gallagher, 1990). Some plants are more efficient at this process than others. See Table 1.1.

TABLE 1.1. RELATIVE TOLERANCE OF CROP PLANTS TO SALTY SOILS

TOLERANT	MODERATELY TOLERANT	MODERATELY SENSITIVE	SENSITIVE
Barley,grain	Barley,forage	Alfalfa	Apple
Bermuda grass	Beet, garden	Broad bean	Apricot
Bougainvillea	Broccoli	Cauliflower	Bean
Cotton	Brome grass	Cabbage	Blackberry
Date	Fig	Clover, red, Ladino, strawberry, alsike.	Carrot
Natal plum	Clover,berseem	Corn	Celery
Rescue grass	Orchard grass	Cowpea	Grapefruit
Rosemary	Oats	Cucumber	Lemon
Sugar beet	Rye, hay	Lettuce	Onion
Salt grass	Sorghum	Pea	Orange
Wheat grass, crested	Sudan grass	Sweet clover	Peach
Wheat grass, fairway	Wheat	Timothy	Pear
Wheat grass, tall	Trefoil, birdsfoot	Rice,paddy	Potato
Wild rye, altai	Wheat grass, western	Soybean	Raspberry
Wild rye, Russian			Strawberry
			Tomato
			Pineapple; Guava

(Brady, p. 247, 1990)

The majority of research on the effects of highway de-icing chemicals has been focused on roadside trees. These trees are exposed to the ions of road salts both by root absorption and traffic spray. The vegetative injury resulting from de-icing salts develops as a general growth reduction followed by leaf scorch and curling, leaf drop, stem dieback and gradual decline in vigour ultimately leading to the death of the plant (Zelazny and Blaser, 1970).

Declining health of Sugar Maples (Acer saccharum) was studied on a road dividing island near Gates Mills, Ohio. Maples tend to be sensitive to salt (Jones, 1986). The study found an inverse relationship between tree health and de-icing salts in the soil as well as significant correlations between sap-sugar concentration and tree health (Herrick, 1988).

Another study focused on the health of white birch (Betula papyrifera) along a highway through Adirondack Park in New York. White birch has been observed to have a medium to high tolerance of de-icing salts (Shortle and Rich, 1970). This study detected that impact from road salt spray travelled as far as 150 m from the highway and changes to soil chemical properties as far as 30 m (Fleck et al, 1987). Fleck et al (1987) concluded that the stands of white birch would continue to decline if sodium chloride de-icing was not reduced considerably.

The impact of salts on roadside vegetation in California found a pattern of high sodium and chloride levels in all damaged pine (Pinus ponderosa) and Greenlead Manzanita (Arctostaphylos patula) with these values decreasing as the distance from the road increased (Gidley, 1989).

Such studies as these are becoming increasingly important as damage to vegetation is developing into a true cost to de-icing authorities. In 1981 two court cases altered the simplicity of de-icing practices. Schenck and Rokeby are two well established orchards, along the Queen Elizabeth Way and Highway 79 in Ontario, which held the government liable for the damage to their orchards from de-icing salts (Jones, 1986). In referring back to the relative tolerance of plants to salty soil in Table 1.1, fruit trees are classified as sensitive and therefore do not thrive in saline affected environments. After investigating the damages the Ontario government was found guilty of actionable nuisance and awarded compensation for damages and costs to the plaintiffs. Vegetation was found to be adversly affected by the use of de-icing salts.

1.23 Environmental Effects on Water Quality

The salt contamination of water is by far the longest reaching fate of de-icing compounds in the environment. After application, road salts dissolve in the snow and ice and can be transported with this water during run-off. Polluted water from runoff, splash, storage accumulation and precipitation can end up affecting the quality of streams, lakes and ground water. The sodium chloride dissolved in the run-off and percolated through the soil will lose most of the sodium ions to clay particles, leaving chloride ions to accumulate in wells of ground water (Adams, 1973). The rate of application of de-icing chemicals; the type of soils and geologic materials present; the type, intensity and quality of precipitation and the highway drainage design all influence where and to what extent chloride ions will accumulate.

The pollution from highway de-icing chemicals found in streams is most evident during the spring thaw and is caused primarily by the direct overland flow of salt concentrated water from the drainage basin into the water course (Walker and Wood, 1973). The salt contaminated stream then carries its pollutants on to larger streams, lakes and ultimately ends up in the ocean. Adams (1973) suggests that one of road salting's long-term effects could be the biological aging of lakes called "eutrophication". Lake Erie is an example of a lake heavily influenced by road salts. Road salts constitute 11% of the total input of waste chlorides entering the lake (Field et al, 1974). The introduction of road salt into Lake Erie has been linked to the stimulation of nuisance algal blooms by increasing one of the monovalent ions essential for optimum growth of blue-green algae (Field et al, 1974).

Another potential hazard of salts entering lakes occurs when there is a sodium and calcium exchange with the mercury tied up in bottom muds. This exchange releases the mercury and other toxic heavy metals into the overlying fresh waters (Field et al, 1974). Bottom sediments have a high capacity to bind mercury in the fresh water system and it is estimated that more than 90% of the total mercury in the system is absorbed and held by the sediments (Wang et al, 1991). Wang et al (1991) report that the slow release of the mercury from the sediment is regulated by environmental conditions including changes in the chloride concentrations. They go on to suggest that mercury levels increase in the spring due to higher concentrations of chloride ions from road salt and other imputs in the spring thaw and runoff. Increased sodium choride applications may lead to increased desorption of mercury from lake sediments. Once suspended in the water, mercury can be transported and absorbed by plants or ingested by animals in the drinking water or consumption of vegetation. Plants develop leaf abscissions, discolouration and collapse of shoots whereas animals concentrate the mercury mainly in the liver and kidneys creating lesions, weight loss and weakness (Lindqvist, 1990). Death results in both cases.

Many cities are realizing the problems caused by road salts from runoff, sewage and surface streams. In Chicago concentrations of 11,000 mg/l to 25,000 mg/l of chloride has been found in street runoff which enters sewage treatment plants and eventually returns to the streams (Field et al, 1974). City storm sewers also serve as transportation for salts to enter the receiving waters. Concentrations of 10,000 mg/l of salt, 100 mg/l of oils and 10 mg/l of lead can melt out and be transferred from accumulated snow deposits (Field et al, 1974). Hvitved-Jacobson and Yousef (1991) suggest that it is not only the salt that must be a concern but also the possibility that high concentrations of chloride may influence the environmental mobility and bioavailability of heavy metals.

Groundwater contamination can be another outlet for salts. The actual amount of salt that would reach the groundwater is a function of site specific features such as permeability, vegetation cover, gradients and roadside drainage (Field et al, 1974). Commonly noticed during a seasonal surge, salt can end up in aquifers and groundwater wells thereby entering the drinking supply and potentially influencing human health (Jones, 1986). The American Heart Association limits the intake of salt to 22 mg/l per day which is exceeded in cases such as wells in Hew Hampshire where salt concentrations were approximately 3500 mg/l (Field et al, 1974). Possible effects from this excess salt could be increased blood pressure and hypertension (Jones, 1986).

Water pollution is a widespread concern. Highway de-icing chemicals simply add to the numerous other contaminants, such as mercury, lead, and leaded gasoline, which are poisoning drainage basins on a world wide scale (ReVelle and ReVelle, 1984).

1.24 Effects on Wildlife

Often ignored when considering the potential hazards of highway de-icing is the effect that road salt has on the resident wildlife. Sodium is a major nutrient that is required as a solute in the extracelluar fluids of animals (Ricklefs, 1973). In nature this nutrient can be acquired (in excess) through water and food sources. The use of natural mineral licks by ungulates and other mammals is well documented and the majority of these studies have found sodium present in all licks examined (Damas and Smith, 1987). This attraction to sodium is further supported by the popularity of artificial licks containing sodium. The dangers of this natural affinity to sodium comes to light with the invasion of highways, through wild ungulate ranges, that require road salting to improve winter driving conditions. A few years after the road is established and salting practices have begun, the animals will have discovered it as a new source of salt and may adapt their movement patterns to include the salt's location (Damas and Smith, 1987). Damas and Smith (1987) also noted that ungulates displayed a seasonal attraction to sodium which peaked during the highest salt level period in spring or early summer (Moose were exceptions to this observation as they will lick salt from the road surfaces in winter). The popularity of salty roadsides is seen in the frequent use by animals. Moose tend to drink the puddles of salty water, hares enjoy licking the coated gravel and whitetail deer do not have a preference between the two techniques (Damas and Smith, 1987). The attraction to the sodium scattered on highways has created a dangerous driving hazard with animals crossing the highway, licking the surface or waiting next to the road. Wildlife mortalities and traffic fatalities are inevitable. Damas and Smith (1987) reveal that animals/vehicle collisions are indeed significant. In 1979, for Alberta alone, 2037 wild animals were struck by vehicles and out of these collisions 118 resulted in personal injuries to the vehicle occupants and one resulted in death (Damas and Smith, 1987). Some speculate these numbers are too low. Along with the list of numerous factors (such as feeding range, garbage attraction and seasonal migration) as reasons animals come into contact with highways, the attraction of wildlife to road salt increases the danger for both animals and humans (Damas and Smith, 1987).

Scanlon (1991) reports that although salt is an essential nutrient it has been documented to have possible toxic effects on both birds and mammals. The deterioration of the central nervous system and the eventual deaths of rabbits, pheasants, quail and pigeons have been linked to excessive sodium chloride (Scanlon, 1991).

In a study of five wetlands in Peter Lougheed Provincial Park in Kananaskis Country, Williams (1992) reports some of the less obvious dangers from salt on living organisms. Two of the wetlands studied displayed unusual qualities as compared to the other ponds and were located adjacent and downslope of highways. An analysis of these two ponds exhibited an increase in chloride concentration to almost ten times that of the other ponds and double the sodium concentration (Williams, 1992). A general decrease in water quality and a reduction in the diversity of fauna (larva, leeches, snails and blue-green algae) was found in the two ponds. One seriously affected wetland is located adjacent to highway #40. The long-toed salamander, once labelled as endangered but now referred to as uncommon, has been monitored at this pond since the 1970s.

In the 1970s the highway #40 pond recorded thousands of frogs, toads and salamander eggs. However, since 1980, the amount of eggs has dropped every year until it was reported in 1985 that the salamander eggs were no longer viable (Williams, 1992). Adult salamanders still went to the pond to mate and produce eggs, however, the eggs were witnessed to die and decompose before ever reaching the larva stage (Williams, 1992). Highway de-icing salt became suspect as the site is in a region of multiple saltings as it is located at the intersection into Peter Lougheed Provincial Park, by comparison, a productive pond is located south on the same highway at a point where the road is no longer de-iced (Highwood Pass is closed in the winter). Although many other factors may be related to this occurrance, road salt is a feasible explanation.

1.3 SUMMARY

Overall, the necessity for winter highway traffic has placed our environment under stress. There is strong evidence that the application of sodium chloride to highways as a de-icing compound alters our ecological balance. Changes to the physical and chemical properties of soils decrease fertility and can cause injury to resident vegetation. Salted highways endanger wildlife and occupants with the vehicles due to the increased possibilities of collisions. Sodium chloride can cause water pollution both at the stream level as well as the drainage basin scale and larger. More information on the path road salts follow through the environment must be investigated to assess their impact and suggest other methods to be developed or applied to reduce any detrimental effects currently experienced by our environment.

1.4 OBJECTIVES

The primary objectives of this thesis research are:

1. Examine soil samples for excess sodium concentrations and determine how these may affect the soils, vegetation and water.
2. Investigate variation in concentrations with distance from the highway, with increased depth, and with season of year.
3. Suggest management techniques and de-icing alternatives.

1.5 THESIS ORGANIZATION

Chapter One has introduced and provided rationale for this thesis topic. It included a literature review on the effects of highway de-icing on soils, vegetation, water and wildlife, summarized the problem and stated the objectives of the research. Chapter Two discusses the study area of Brooks, Calgary and Banff and includes a comparison summary. The selection of sampling locations as well as laboratory analysis is discussed in Chapter Three. Chapter Four examines the research results with a general comparison of the soil and vegetation observations, statistical analyses using correlation, two way analysis of variance and stepwise regression, and the results from these tests. A detailed inspection of the results is found in Chapter Five with a discussion of the some of the variables, an evaluation of the stepwise regression and some other factors to be considered.

Chapter Six reviews the possible effects of sodium chloride, future chemical alternatives for highway de-icing and other management techniques.

CHAPTER TWO

STUDY AREA

2.1 REGION

In Alberta the TransCanada Highway is a primary highway of high use. It is located in the southern portion of the province, extending from Medicine Hat to Lake Louise (See Figure 2.1). The Alberta section of the TransCanada Highway was completed to modern standards (two lane) in the 1950s, since then it has been twinned to a four lane highway through most of the province with the exception of a small portion at the border with Saskatchewan (Wilard, 1993). As previously mentioned, primary highways often alter the adjacent environments as they cut across the landscape. In an attempt to examine potential alteration from de-icing practices, an interest area was selected along a twinned section of the TransCanada Highway from Brooks to Banff, Alberta. The only exceptions were two sites (Lake Louise area) farther west from where the four lane highway ends.

The Banff region is maintained by the National Parks Service and the rest of the study area occupies Alberta Transportation's District 4. In Banff National Park the application of de-icing salts has increased dramatically in the past ten years. In the winter of 1979/80, 1,506,000 kilograms of salt was used on the highways with an application rate of 90 to 455 kilograms per two lane kilometre (Parks Canada, 1983). This is in contrast to 4,329,000 kilograms of

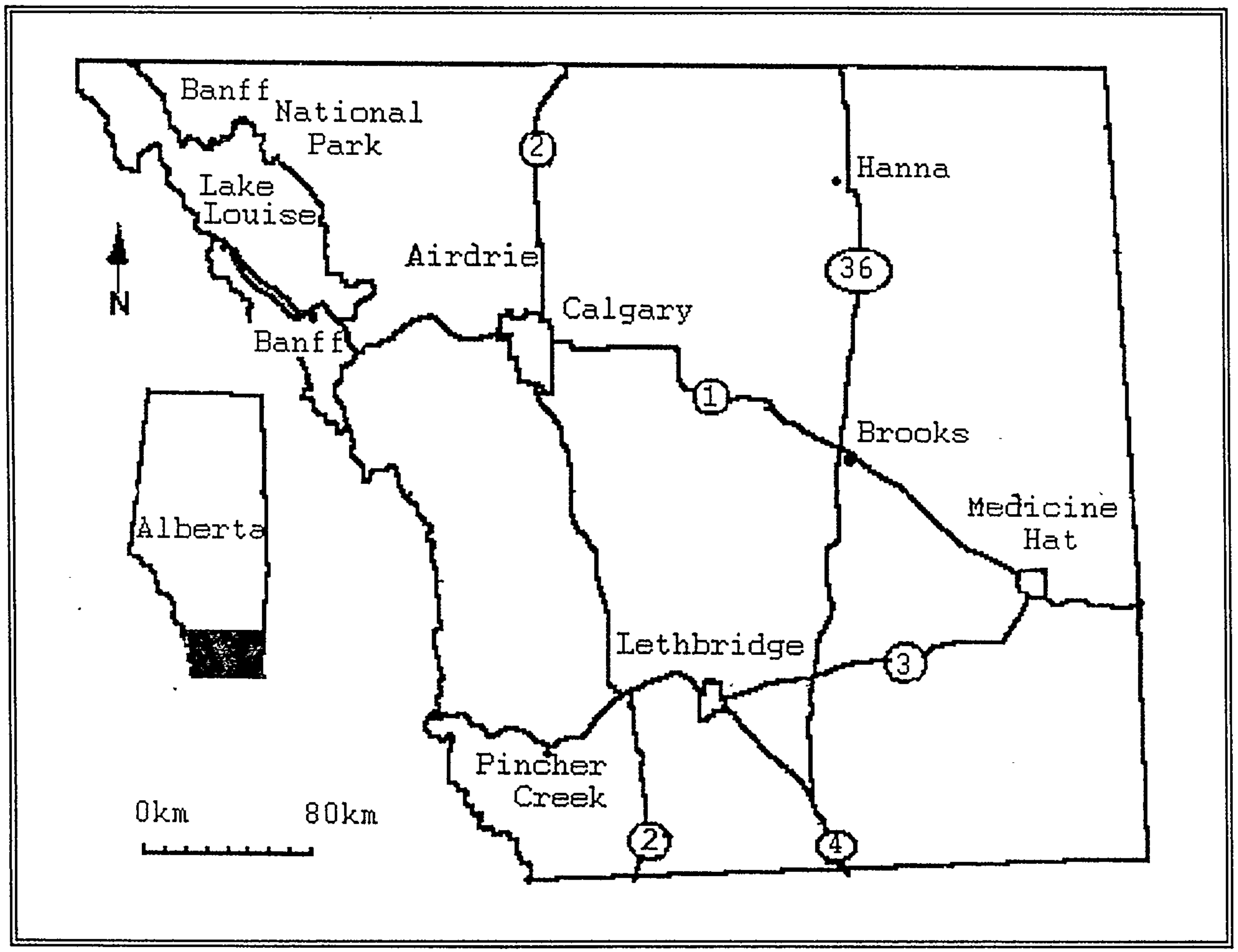

FIGURE 2.1. SOUTHERN ALBERTA STUDY AREA

salt applied in the winter of 1989/90 (Banff Warden Service, 1991). District 4, representing the Calgary and Brooks areas, reports 6,500 kilograms of salt was applied per two lane kilometre during the winter of 1990/91 (Ullery, 1993). These values include the amount of salt used to freeze-proof sand storage stockpiles.

The study region consists of three locations along the TransCanada Highway and neighbouring secondary roads; Brooks, Calgary and Banff. Alberta transportation (Seifert, 1993) reports average traffic flows on the TransCanada highway of: 4,700 vehicles daily east of the junction with highway 36 and 4,300 vehicles per day west of this junction in the Brooks region; 7,300 vehicles daily for east of Calgary by Chestermere Lake and 14,770 vehicles per day west of Calgary at the junction with the Banff Coach Road and 11,810 vehicles through Banff National Park per day.

2.11 Study Area One - Brooks

Brooks is a small city of approximately 10,000 people and is situated 185 km east-southeast of Calgary at 50° 34' north and 112° 54' west on the prairies (Alberta Tourism, 1988). The approximate elevation of the selected highway sites is 2475 feet (Surveys and Mapping Branch, 1975). This area is composed of gently warped limestones, shales, sandstones and evaporties which are mostly a result of marine deposition and both glacial and postglacial activity (McCann, 1987). Thick layers of sediment and rocks were deposited when southern

Alberta was covered by a shallow sea and then from the sediments resulting from the erosion of recently uplifted Rocky Mountains (Jackson and Wilson, 1987). These upper Cretaceous and Tertiary sediments have been smoothed by Laurentide continental ice advances through the area which altered the topography through both erosion and deposition and as a consequence have levelled out the landscape. The age of most of the sedimentary strata exposed on the Plains is Tertiary (Tippett, 1987). The lacustrine as well as morainal sediments that cover the land were deposited from inland seas, glacial lakes and from glaciers receding leaving till behind (Forest Service, 1974). The Brooks study area is situated in a well to moderately drained region with the water table greater than a three meter depth, and a gentle slope of 1 to 3% in Brooks (Agriculture Canada, 1990). The overall surface pattern surrounding Brooks is undulating (Agriculture Canada, 1989). Situated in a prairie setting, Brooks experiences high summer temperature along with strong winds and low precipitation which all combine to create a moisture deficit (Strong and Leggat, 1981). This condition follows through to the winter as Brooks receives the lowest mean October to April precipitation in the province resulting in shallow and discontinuous snow cover (Strong and Leggat, 1981). The strong winds may also lead to repeated de-icing applications as any salt applied may be blown off the highway.

The overall macroclimate of the study area is continental

(Holland and Coen, 1983). Cold winters are interrupted by the warm and dry chinook winds which moderate the temperature and can quickly melt snow (Forest Service, 1974). The chinook winds occur when strong westerly winds aloft flow over the Rocky Mountains and descend the eastern slopes warming as they approach the foothills (Ahrens, 1988). When precipitation occurs on the windward side of the mountain, the chinook is enhanced and the winds become very dry (Ahrens, 1988). In any case the key event is the melting of snow, often leaving some moisture behind. This moisture in the middle of winter may freeze overnight creating ice and the need for further deicing. These frequent warm spells may also lead to some surface thawing of the soil and could cause highway contaminants to infiltrate the soil even during the winter season. The physical characteristics of each location creates individual conditions to modify this southern Alberta macroclimate into their individual microclimate.

The climate of each study area adds to the individuality of the vegetation and can help generalize the ecoregion. Since the vegetation is both dependent on the soil characteristics and parent material on which it grows it may offer visual insights into the condition of the region (also can alter soil properties in further development). One other factor to consider in these studied regions is that the vegetation analyzed was in the roadside ditches. Most of the TransCanada ditches contain man-introduced grasses that are maintained by cutting or mowing. The secondary road ditches tend to display wild uncut grasses and can be an extension of the crop or other domestic vegetation in the adjacent field.

Brooks is located within the Short Grass Ecoregion which has lost most of its natural setting through agricultural practices. Cattle production on native pasture and crop production are important land uses in this area (Strong and Leggat, 1981). The land is both irrigated as well as fertilized. The dominant vegetation is grama grass (Bouteloua gracilis), spear grass (Stipa comata) and wheat grass (Agropyron spp.), however in the moister sections some willows (Salix spp.), poplars (Populus spp.) and birch (Betula spp.) can be found.

The soils of each of these regions have somewhat unique characteristics from the variations in climate and geology, topography and vegetation. It is important to remember that roadside soils have been disturbed and therefore do not have horizons. The lack of horizons limits the ability to classify soils, however, accepting the classifications of regional soils will allow comparisons and effects to be analyzed.

The soils surrounding Brooks vary from Brown Chernozemic to Brown Solonetzic and from clay loam to loam texture material from lacustrine/morainal parent material (Agriculture Canada, 1989). These soils tend to be strongly calcareous. Primarily agricultural land, these irrigated fields have depressions and sloughs with a surface salinity ranging from

1 - 49.9% of the region designated by Agriculture Canada (1990). This salinity reading is the percentage of area affected by salt with an electrical conductivity value of 8 dS/m or more (Agriculture Canada, 1990). This relatively high salinity rating may be explained by the presence of Solonetzic soils. These soils are believed to have been formed from uniformly salinized parent material, high in sodium, in semiarid to subhumid Interior Plains (Agriculture Canada, 1987). Brown Chernozemic soils are found to develop in arid regions for Chernozems and are associated with xerophytic and mesophytic grass and forb vegetation (Agriculture Canada, 1987). Black and Brown Chernozems have developed due to the relatively long frost-free period, the precipitation which leaches $CaCO_3$ and soluble salts combined with drying winds and high temperatures which cause evaporation and an upward movement of soil water that creates a balanced mature soil with minerals well-distributed throughout its horizons (Kananaskis Country, 1989). These soils are excellent for agriculture and are used mainly for cereal crops.

2.12 Study Area Two - Calgary

Calgary (51° 04' N and 114° 05' W) is one of the two largest cities in Alberta with a population of over 650,000 (Alberta Tourism, 1988). The average elevation of the selected highway sites around Calgary is approximately 3450 feet for the eastern sites and 3925 feet for the western sites (Survey and Mapping Branch, 1980 and 1990). As such a large centre, the Calgary study area would have higher traffic volumes from visitors, commuters and recreational travellers/day trips.

Calgary is a transition zone between two different ecological regions, where the prairies and agriculture on the east side meet the foothills and grazing land on the west side of the city (Forest Service, 1978). Much of Calgary's geological history is similar to that discussed in the development of the prairies in section 2.11. However, the foothills to the west of the city are definitely a change in the landscape. The alternating linear ridges and valleys depicting the topography of this area have resulted from the flat-lying sediments, like those on the prairies, altered through thrust faulting and folding in a manner similar to the formation of the front ranges of the Rocky Mountains (Tippett, 1987). The west Calgary sampling sites are located in the Bow Valley which cuts through these foothills. As the ice retreated from the valley after the last glaciation, the escaping waters cut spillways and developed into a glacial lake (Lake Calgary) covering much of the region to the west of Calgary. Clay, silt and fine sand sediments were deposited through these glacio-lacustrine processes (Wilson, 1987). The current topography acts as a transition from the undulating landscape in Brooks to the rolling surface in the Bow Valley through Banff National Park (Agriculture Canada, 1989). Calgary is located in a well to moderately drained region with the water table greater than three meters in depth and a moderate slope of 4 - 9% (Agriculture Canada, 1990).

The climatic transition from Brooks to Calgary finds a general decrease in temperature and an increase in moisture availability. This location tends to have increased snow depth and prolonged snow cover (Strong and Leggat, 1981). Both Calgary and Brooks experience chinooks. The warm and dry air descending from the mountains can create sudden thaws and, when finished, quick freezes. These chinooks may increase the soil's absorption of salt during the winter and the salt may become locked in a different location with the following freeze. The sodium and chloride ions may then be released from the upper soil in the spring and mobilized rapidly during spring and summer storm events (Peters, 1991).

Calgary is divided by two ecoregions. The eastern sites may be associated with the Fescue Grassland. The shrub communities become more dominant with the increased moisture with rough fescue (Festuca scabrella) and oat-grass (Danthonia spp.) remaining dominant; however, buckbrush (Symphoricarpos occidentalis), willow (Salix spp.), rose (Rosa spp.), saskatoon (Amelanchier alnifolia) and aspen (Populus tremuloides) become more common in the wetter and cooler regions (Strong and Leggat, 1981).

The western sites of Calgary are found in the Aspen Parkland where the grassland alternates with groves of trees. This ecoregion is the second largest in the province covering about 73,500 square kilometres (Strong and Leggat, 1981). The aspen parkland displays a wider variety of grasses, plus shrubs, aspen and balsam poplar. Numerous varieties of shrubs include gooseberry, dogwood, silverberry, buckbrush, wild rose, and willow (Kavanagh, 1991). The rich Black Chernozemic soil is very productive for barley, wheat, rapeseed, and oats as well as creating pasture land for cattle to graze in the foothills and on the rolling topography (Strong and Leggat, 1981).

Black Chernozemic soils dominate in the regions surrounding Calgary. Rich surface horizons resulting from the decomposition of grasses and forbs and the accumulation of organic matter characterize Chernozemic soils (Agriculture Canada, 1987). These grassland soils developed under native vegetation of short, intermediate and tall grasses (International Society of Soil Science, 1979). Commonly consisting of a clay loam subsurface texture and loam surface texture these soils originate from morainal parent material. They are strongly calcareous as influenced by the limestone and dolomite from the nearby Rocky Mountains. The undulating land has some depressions and a surface salinity of 0 to 4.9% of the region designated by Agriculture Canada (1990). Land still is used for agriculture but is changing towards grazing/pasture land the farther west travelled.

2.13 Study Area Three - Banff

Banff National Park (116° W 51° N) was the first national park in Canada. Selected primarily for its natural sulfur hot springs, Banff National Park is found on the southern portion of the Rocky Mountain Thrust Belt. The approximate area of Banff National Park is 6640 square kilometres and the average elevation of the highway is 4650 feet (Survey and Mapping Branch, 1981). This natural reserve combines beautiful scenery with accessibility as the TransCanada Highway cuts directly through the park.

The basic geology of all three study areas are generally similar, it is only the extent to which the areas have been rearranged and deformed during mountain building and in the level to which they have been eroded that their uniqueness develops (Tippett, 1987). Millions of years ago when most of Alberta was covered by a shallow sea massive amounts of sands and muds were deposited and through sedimentary processes transformed into sandstone, shales and limestones (Baird, 1974). These sediments were then folded and uplifted due to tectonic processes. This folding broke the sediments into imbricate sheets of rock that were thrust one over the other to create the Rocky Mountains (Jackson and Wilson, 1987). These rugged mountains were then subject to the erosion from wind, water and glaciation. Rivers and Glaciers carved out the current Bow Valley. Today the Banff valley (where the highway is built) is situated in a well to moderately drained region with a greater than three meter deep water table and a rolling slope ranging from 10 - 15% (Agriculture Canada, 1989).

Three main categories of bedrock are noncalcareous (medium and coarse grained clastic), noncalcareous (medium and fine grained clastic) and carbonate and calcareous clastic (Holland and Coen, 1983). The Bow Valley cuts through the mountain terrain which is composed mainly of limestones, dolomites and quartzizites (Forest Service, 1974). These sediments are associated with the palaeozoic and mesozoic eras (Beaty, 1984).

The mountain topography found in Banff National Park can vary the climate of the area over very short distances (Holland and Coen, 1983). Increased chinook activity and reduced influence of cold Arctic air can create warm winter temperatures through the major valleys of the park. Deep snow cover lasts longer in the park as the predominant west winds blow snow from the west valley floor to the east-facing slopes (Strong and Leggat, 1981). The higher elevation of the area plays a key role in the temperature ranges.

The majority of Banff National Park sites are located within the Montane Ecoregion with two sites located in the Subalpine Ecoregion. The major valley through Banff National Park is the Bow Valley and is classified primarily as Montane. The Montane ecosystem is characterised by relatively warmer climate found in the valleys than the surrounding mountains. These valleys channel warm Pacific air from British Columbia into Alberta and often avoid cold fronts that move into

Alberta from the north (Strong and Leggat, 1981). Common species of trees found in the region are aspen (Populus tremuloides), white spruce (Picea glauca), lodgepole pine (Pinus contorta) and Douglas fir (Pseudotsuga menziesii). Some of the drier sites are host to grassland vegetation. Common grass species found in the southern portion of the Montane Ecoregion are fescue (Festuca spp.) and oat grass (Danthonia spp.) (Strong and Leggat, 1981). These grassland sites prove to be excellent winter grazing habitat for large ungulates (Strong and Vriend, 1980).

The sites near Lake Louise and the Bow Valley Parkway are classified within the Subalpine Ecoregion. The Subalpine Ecoregion is an altitudinal zone between the Montane and Alpine Ecoregions. The array of vegetation is dependent of the altitude, slope and exposure of each individual area (Kavanagh, 1991). The criterion for characterizing Subalpine Ecoregions is the occurrence of Engelmann spruce (Picea engelmannii), and although there is some question as to why the altitudinal limits near the Bow Valley were raised to be included into this category, it is believed to be answered through the competition between Engelmann and white-black spruce (Strong and Leggat, 1981). Along with the Engelmann spruce the other common species are lodgepole pine and aspen on drier aspects, alpine fir (Abies lasiocarpa) in moister regions, willow and alder (Alnus spp.). As well as being important habitat for wildlife, these regions are used as watersheds, forest production and recreation (Strong and Leggat, 1981).

The Eutric Brunisols associated with the Banff National Park region are characterized by having a pH greater than 5.5 at a depth of 25cm below the top of the B horizon and very little to no Ah horizon (Agriculture Canada, 1987). They are also associated with calcareous geomorphic materials (Holland and Coen, 1983). Eutric Brunisols develop from high base status parent material under forest or shrub vegetation (Agriculture Canada, 1987). These soils have a loam surface texture, based on loam morainal parent material. The surface salinity is negligible. Climates which have cold winters and cool summers tend to develop Brunisolic soils. The cold weather restricts the soil forming process so these are young soils which show some B horizon development (common in river valleys) (Kananaskis Country, 1989).

2.2 COMPARISON - SUMMARY

The overall study area encompasses a range of comparison factors. Brooks is located in the prairies of Alberta on plains of horizontal bedrock. It is relatively an arid region that is already associated with high salinity in the presence of Solonetzic soils. Although it signifies the least amount of traffic volume of the three study sites, Brooks is already a saline environment and could show interesting results from any extra salt added. As the area with the least moisture and increased occurrence of capillary rise, Brooks is vulnerable due to its dependence on agriculture. Calgary offers a look at the prairie to foothills transition zone. The rich Black Chernozems may prove to be more susceptible to increases in salt concentrations that may accompany the de-icing practices at higher elevations and with the most amount of traffic out of the three study areas.

A natural setting such as Banff National Park gives the most extreme sampling with its rugged mountains, colder weather, and highest elevations. However, it is these same extreme conditions which may limit the effect of salt in the soil as they reduce the amount of activity occurring in the upper horizons of Eutric Brunisols.

CHAPTER THREE

METHODOLOGY

3.1 INTRODUCTION

This study focuses on selected sampling sites along the well travelled frequently de-iced stretches of the TransCanada Highway and compares the results with those of less travelled, infrequently salted roadways. Sampling sites are selected along the TransCanada Highway and neighbouring secondary roads which assume similar ecological characteristics. The soil samples are extracted using a screw/tear auger measuring approximately 6.5 cm at the mouth/head. Vegetation representatives are removed as well as quadrat counts and vigour assessments made. These soil and plant samples are necessary to discover roadside salt concentrations as well as indications of salt stress on vegetation. The seasonality of the data also is examined.

The research, including field work, for this thesis was based out of the University of Calgary. A Banff National Park Sampling Permit was obtained for permission to remove soil and vegetation samples from the National Park and Wardens provided related study reports. The Alberta Transportation Library also helped by loaning related internal papers and reports/studies. The techniques and procedures utilized within this study were selected to produce the most valuable results in both a cost and time efficient manner.

Research began with general background information on chemical and physical reactions of salts within soil, salt effects on vegetation, salt dispersal in water and the appeal of salt to wildlife. Then details on highway salt effects on the environment were examined. The de-icing practices, and possible alternatives were examined last.

3.2 SELECTION OF SAMPLING LOCATIONS

The research area concentrates along the TransCanada Highway which is a primary highway that cuts through many different land uses across the southern extent of Alberta. Three locations are selected for examination: Brooks, Calgary and Banff. Brooks is located in a prairie setting and has naturally more saline soils. Brooks is selected because although it may encounter less traffic than Calgary or Banff it is prone to excess salinity due to irrigation and fertilizer application from agricultural practices. The common use of fertilizer combined with sodic soils should give higher sodium readings. Perhaps when de-icing salt is added these roadside environments may reach toxic levels of sodium and spread to injure the surrounding agricultural fringes.

Calgary is selected for its high urban population which demands safe highways. The combination of salting from the City of Calgary and Alberta Transportation, along with urban contamination and heavy traffic, may lead to excessive levels of sodium outside of the city on the urban edges.

Banff National Park is selected due to the popularity of the region during the winter months. Banff not only receives the expected flow of travellers and commercial traffic heading east or west, but it also functions as a destination for winter recreationalists. Encompassing three ski resorts within it's boundaries and located on routes to others both on the Alberta and British Columbia sides of the park, Banff is forced to keep the highways in good driving condition on a year round basis. This area would reveal the impact of heavy traffic volume and frequent salting through the winter months. However, this area would also control for the influence of other contaminants through the Park's strict enforcement of pollution control.

The field research is divided into three seasons in order to take into account the possible seasonality of the data; May, July and October, 1991. Sampling in May is assumed to have the highest values as it would be during spring runoff. The mid-summer samples in July could provide a comparison point of salt dissemination and the October samples hope to catch the lowest concentrations just before the first snowfall and de-icing sessions. During each season every location is sampled during one day to maintain a consistency for conditions of extraction.

Ten sites are chosen at each location. Five sites bordering the TransCanada Highway investigate possible excess salt contamination and five sites line secondary roads parallel or in the near vicinity of each comparable

TransCanada site. These secondary road sites are used to compare the effects of a high traffic volume and frequently salted freeway with the less travelled and infrequently salted secondary highway in similar ecological areas (See Figures 3.1, 3.2, and 3.3).

The actual sampling of the soils takes place at three different distances from the highway. The exact distances vary slightly with each roadside, however, concentrate on: 1) the road shoulder; 2) the ditch; and 3) the fenceline. This tries to account for the effect of road splash and the horizontal run-off of the de-icing chemicals. The effect of infiltration and lateral movement of the salts in the soil is investigated by extracting samples at four different depths (0-5cm, 10-15cm, 20-25cm and 30-35cm depths). (See Figure 3.4). It is important to remember that the soil at the shoulder was disturbed during road construction and soil horizons were destroyed perhaps altering the natural salt flow. Ditch water (when available) was collected to examine if the standing water held excess salts. Obtaining snow samples in the winter season, during or shortly after deicing applications, is difficult. The few samples obtained may show insight into the amount of salt (especially chloride ions) that remain in the snow and are removed during snow melt.

3.3 LABORATORY ANALYSIS

The soil and water samples are taken to the laboratory at the University of Calgary to be examined and analyzed. The

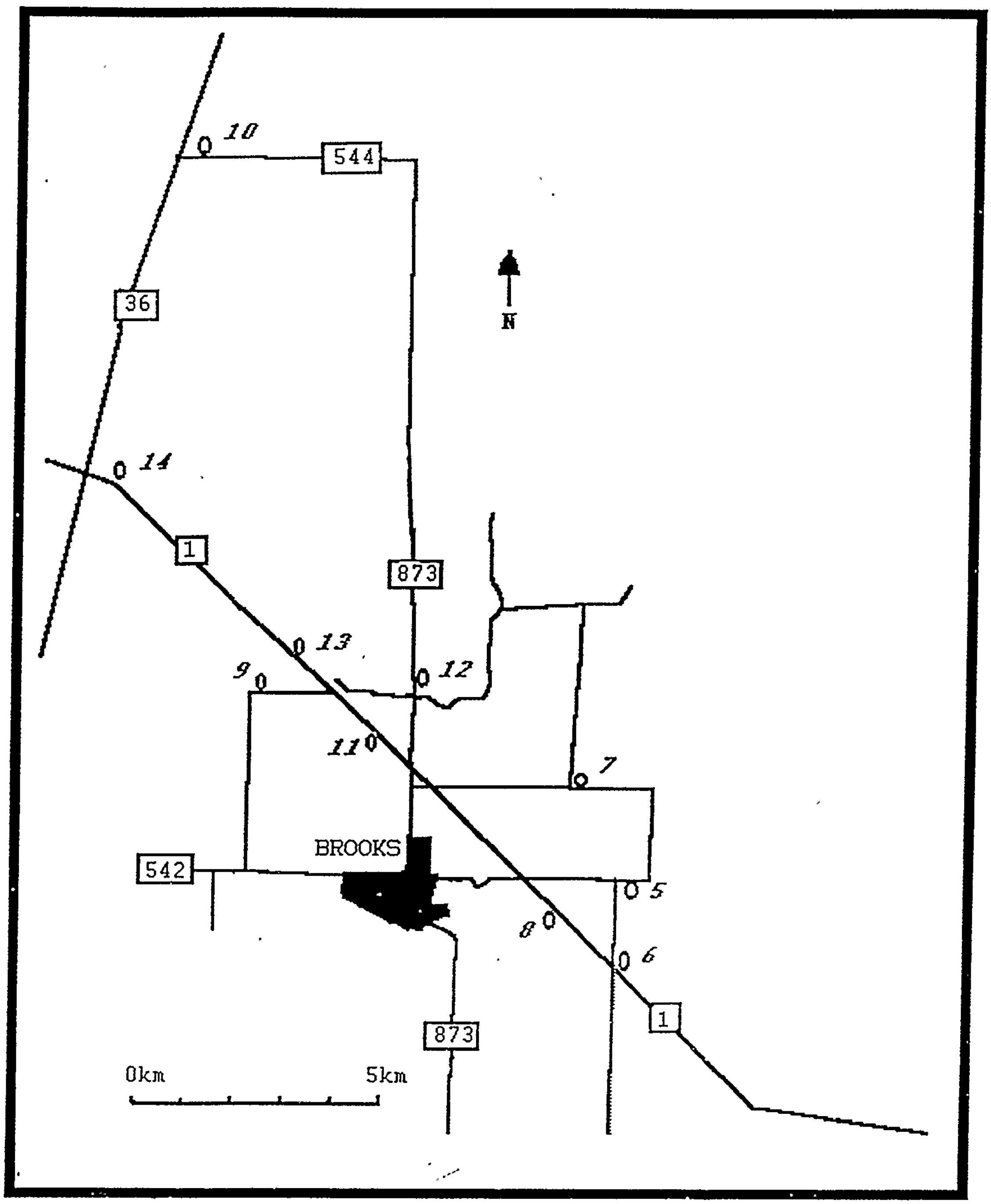

FIGURE 3.1. BROOKS STUDY AREA - SELECTED SITES

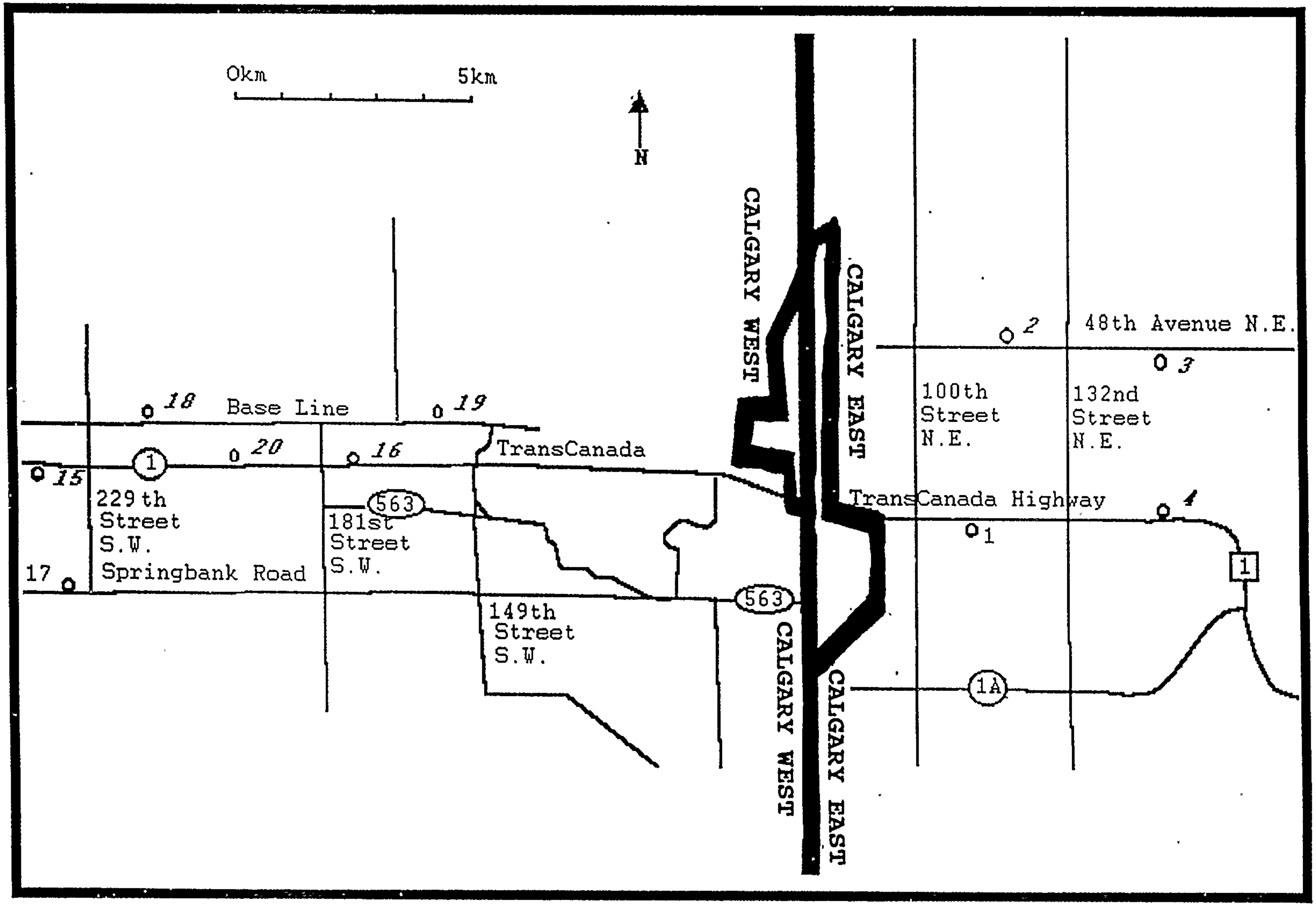

FIGURE 3.2. CALGARY STUDY AREA - SELECTED SITES

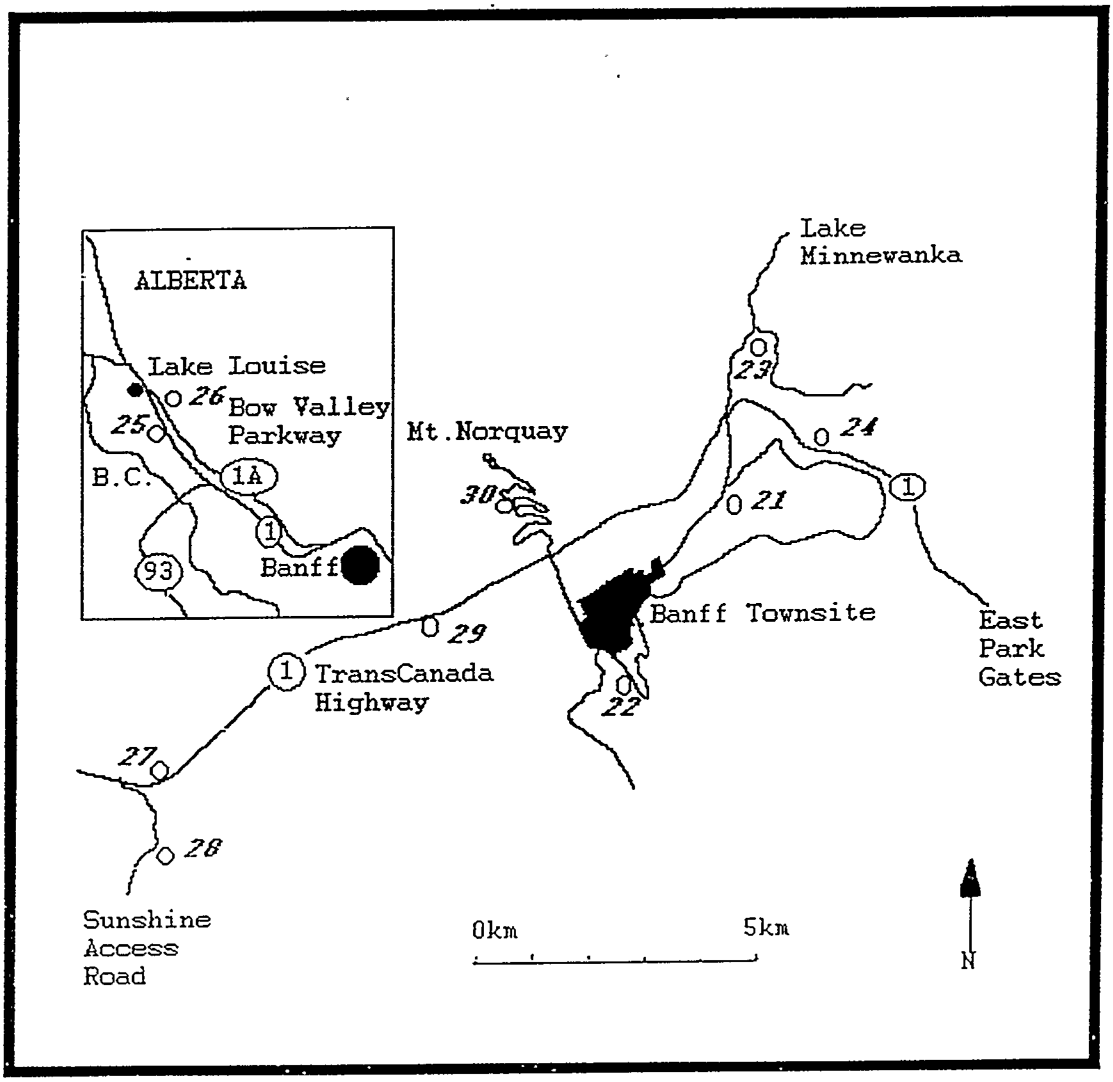

FIGURE 3.3. BANFF STUDY AREA - SELECTED SITES

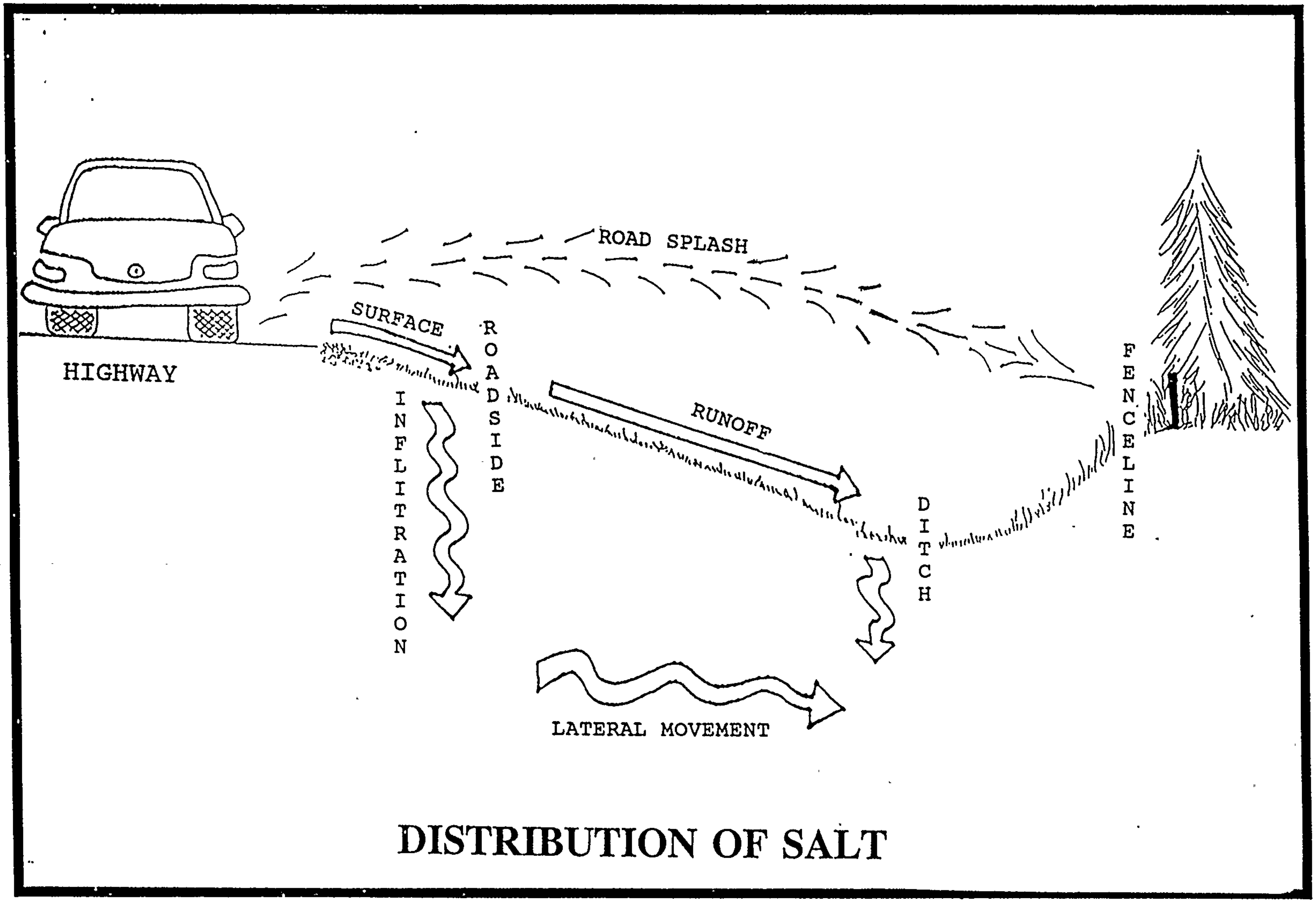

FIGURE 3.4. DESIGNATED SAMPLING POSITIONS

soil samples are air-dried, ground and sieved. The two millimetre and less diameter fraction are selected for analysis (McKeague, 1978). Three tests (sodium ion, pH/ electrical conductivity, and particle analysis) examine the salt concentrations as well as the characteristics of the soil. The first test produced the sodium concentration of each sample. Sodium concentrations are the focus of testing due to the assumption that the chloride component of salt does not interact significantly with the soil matrix and therefore is not considered a contaminant in the soil (De Haan and Van Riemsdijk, 1986).

The samples were prepared using a standard analytical procedure to extract the sodium cations out of solution (Perkin-Elmer, 1982). An extraction solution is mixed with the soil, shaken and filtered through Whatman ashless #42 filter paper, then the extract is analyzed (See appendix for complete details of the procedure). A sodium ion-selective electrode is used on the extract. This probe has a glass membrane which is sensitive to specific ions. The sodium cations are "transported across the membrane interfaces to extents that are proportional to the compositions of the solutions on either side of the membrane" and the concentration then can be measured (Talibudeen, 1991). The ion-selective electrode method is chosen for the reason that it is relatively inexpensive and quick (for 1080 samples) in comparison with spectrophotometric techniques. The main limitations to the use of ion-selective electrodes is the "imperfect selectivity for the measured ion, so that the presence of other ions causes errors" (Talibudeen, 1991). Interference from hydrogen ions was reduced by raising the pH of each extract to at least 8 or 9 and the interference from potassium ions has to be considered in the final analysis. However, as this is a comparison study between sites within the research area, any deviation in the reading should be carried uniformly throughout the data. Some researchers have found good correlations between the results from ion-selective electrodes and flame photometry (Talibudeen, 1991).

The problem of nutrient imbalances in alkaline soil samples is examined through the pH value. In general soils with a pH value of 7.5 or above show several micronutrient deficiencies and higher sodium and potassium concentrations (Brady, 1990). The ability of the salt within the soil samples to conduct electricity can estimate the salt concentration of the soil (Brady, 1990). This test is referred to as electrical conductivity. The Fisher Accumet 910 pH meter is utilized to examine the pH and electrical conductivity of each sample. Five grams of the prepared soil was mixed with twenty millilitres of deionized water and allowed to settle for thirty minutes (Mckeague, 1978). This 1:4 ratio was used to standardize all samples including those with high organic contents. The tests were then run using the one point standardization with manual temperature compensation for the pH values and the millivolt measurement for electrical conductivity.

Soil texture is another important test for the samples as it influences other physical properties of soil such as infiltration, percolation, water storing ability, aeration and erodibility. These properties may formulate paths which the salt follows in the environment. To assess the texture of the soil samples the hydrometer method was used. This method follows Stoke's Law which states that "the velocity at which a particle settles out of a suspension is related to the diameter of the particle as well as other factors" (Author Unknown). Forty grams of the soil is mixed in a calgon solution, left standing for at least twelve hours, then suspended in a cylinder for density measurements to be taken at time intervals after sedimentation is allowed to begin (See appendix for detailed laboratory procedures). These interval readings are then subject to the calibration factor and equations to reveal the percentage of sand, silt and clay. As texture is relatively constant (sites would not differ between seasons) and the hydrometer tests time consuming, a standardization of sampling sites between seasons was used creating one texture class for each site, distance and depth without the different readings for May, July, and October.

Plant samples were examined at each site during sampling sessions. When possible, plants were identified and their vigour was noted. Samples not able to be identified were collected and analyzed at the University of Calgary. Classification was completed using several plant identification books and visiting the Department of Geography's Herbarium.

Ditch water samples were collected when available during the sampling sessions. In testimony to the dryness of the area, very few samples were collected. Fresh snow samples were also difficult to obtain as the winter of 1991/92 had relatively few snow storm events. The samples that were gathered, were brought back to the University of Calgary Laboratory for analysis. The chloride contents of the snow and water samples was determined by a 0.0141N mercuric nitrate solution titrations of 100 ml size samples, and using dipluenylcarbarone as an indicator. Approximate salt concentrations were estimated by multiplying the chloride concentration by a constant and sodium concentrations were approximated through the use of the sodium ion electrode for the ditch water samples.

Special care was taken to insure the results were accurate, however, possible sources of error may occur during field sampling, sample mixing and measuring, hydrometer settling, and inaccurate readings due to both human error or equipment malfunctions. All tests were completed using the same techniques and if there are any discrepancies they will be carried equally throughout the samples and should equal out during comparisons.

CHAPTER FOUR

RESULTS

4.1 GENERAL COMPARISON

4.11 Soils

Preliminary results show that the average concentrations of sodium along the TransCanada Highway are higher than the average concentrations along secondary roads in the regions (with exception for the anomalously high values for three sites in Brooks that are discussed in the following paragraph). This supports research on the regular and sizable de-icing applications to meet the requirements of the "bare pavement policy" for the TransCanada Highway and the assumption that the control sites were salted infrequently due to their lower volume of traffic. Possible reasons for sodium concentrations to be high on secondary roads is due to traffic travelling from main highways to the secondary roads thereby depositing salt as it falls off the vehicle or perhaps the high salt concentrations on secondary roads (or any of the roadsides studied) may result in the data from naturally occurring salts within the soils. (See Tables 4.1 and 4.2).

The sampling sites in the Calgary Region along the TransCanada Highway showed the highest concentrations of sodium. The secondary roads in the Calgary location also were expected to show high concentrations, however, anomalously high values were recorded in the Brooks region. The three

TABLE 4.1. AVERAGE SODIUM CONCENTRATIONS (ppm) FOR THE TRANSCANADA HIGHWAY - 1991.

SITES	ROADSIDE	DITCH	FENCELINE
CALGARY	28.18 (1.93)	12.19 (0.92)	7.67 (1.08)
BROOKS	16.03 (1.70)	10.50 (2.19)	6.86 (2.45)
BANFF	14.62 (1.39)	7.78 (0.36)	2.87 (0.84)
AVERAGE	19.61 (3.51)	10.16 (1.05)	5.80 (1.21)

(Standard Error)

(See Appendix A for complete data set)

TABLE 4.2. AVERAGE SODIUM CONCENTRATIONS (ppm) FOR SECONDARY ROADS - 1991.

SITES	ROADSIDE	DITCH	FENCELINE
CALGARY	5.22 (0.67)	5.42 (0.77)	5.25 (1.06)
BROOKS	24.07 (5.91)	8.13 (1.43)	17.98 (3.22)
BANFF	5.19 (0.63)	3.39 (0.55)	1.78 (0.34)
AVERAGE	11.49 (5.13)	5.64 (1.12)	8.34 (4.02)

(Standard Error)

(See Appendix A for complete data set)

secondary road sites in the Brooks region which displayed peculiar results were sites 5, 9 and 10. Site 5 was located directly beside a livestock corral, leading to the assumption that the presence of cattle (urine) would result in high sodium concentrations for the adjacent soil. Site 9 was sampled off a secondary road in front of a fertilizer plant. The presence of fertilizer development could increase the expected sodium concentration as sodium may be a by-product of fertilizer manufacturing. This is especially true if sodium based compounds are converted to particular fertilizers. Therefore it is possible for sodium to be in abundance at fertilizer plants. Finally, the sampling for site 10 was completed near the intersection of the secondary road with a major highway (36). This intersection may display higher concentrations of sodium due to debris from vehicles turning onto the road and perhaps from de-icing trucks using the access to turn their unit. These three cases do not fit the hypothesis and generalizations made from the data will reflect this. Table 4.3 exhibits the sodium concentration averages when sites 5, 9 and 10 are omitted. The new averages clearly show that the soil samples collected along the secondary roads have sodium concentrations well below those of soil samples obtained along the TransCanada Highway.

TABLE 4.3. AVERAGE SODIUM CONCENTRATIONS (ppm) FOR SECONDARY ROADS - 1991 (OMITTING SITES 5, 9 AND 10).

SITES	ROADSIDE	DITCH	FENCELINE
CALGARY	5.22 (0.67)	5.42 (0.77)	5.25 (1.06)
BROOKS	2.81 (0.62)	2.71 (0.51)	5.29 (1.47)
BANFF	5.19 (0.63)	3.39 (0.55)	1.78 (0.34)
AVERAGE	4.41 (0.66)	3.84 (0.66)	4.11 (0.95)

(Standard Error)

(See Appendix A for complete data set)

The highest amount of sodium was found at the roadside and was expected as it would receive the highest concentration of de-icing salt from immediate application overflow, direct runoff and the splash from the speed of passing vehicles. However, the low concentration of sodium found in the ditches is unexpected. Following the soil catena model it is assumed that the ditch would act as a depression and therefore a zone of accumulation. The concentrations actually found in the ditches are significantly lower than amounts found along the roadsides and only slightly more concentrated than the fenceline samples. This may be explained by the distance the ditch and fenceline sites are from the roadway. Both sites would be over twelve meters away from the highway and therefore not as influenced by de-icing practices. Although the ditch is the lowest point between the roadside and the fenceline, it still would not have been enough of a depression to accumulate high concentrations of sodium. The fenceline had surprisingly high concentrations as compared to expected values. This may be explained by the influence of the adjacent farm fields and agricultural practices (See Figures 4.1 and 4.2).

The TransCanada Highway and secondary road individual site samples show a slight trend towards an increase of sodium concentration with depth. The overall averages of the TransCanada Highway sites displayed a strong trend of increased sodium concentration with an increase in the depth of sampling. The secondary road sites exhibited a weaker relationship between increased sodium with an increase in depth. The absorption of sodium also depends on the composition of the soil. Coarse soils do not retain large amount of sodium, while finer soils with a high percentage of clay may retain higher concentrations (Gidley, 1990). Further examination of the samples, including pH, electrical conductivity and texture analysis was necessary to formulate

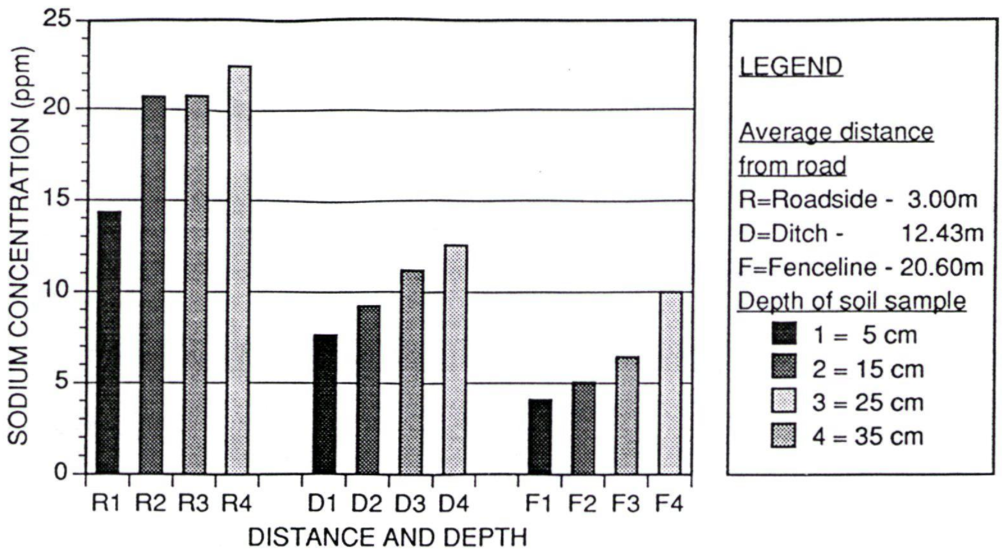

FIGURE 4.1. AVERAGE SODIUM CONCENTRATION IN SOIL SAMPLES - TRANSCANADA HIGHWAY - 1991

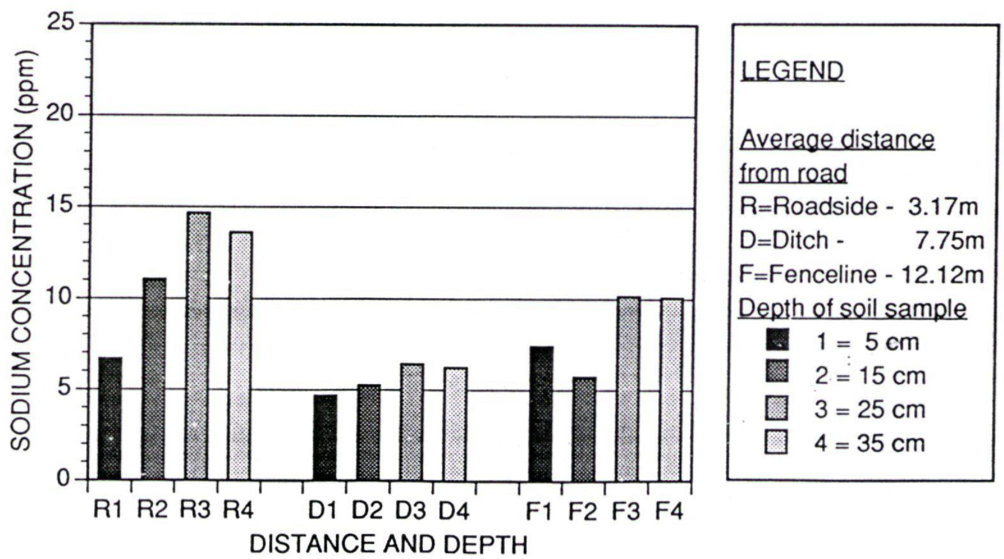

FIGURE 4.2. AVERAGE SODIUM CONCENTRATION IN SOIL SAMPLES - SECONDARY ROADS - 1991

possible reasons for the variations in concentrations.

Averages of soil sample properties were calculated and can be viewed in Table 4.4. In general all samples were neutral to slightly alkaline with electrical conductivity values focusing around -0.05 millivolts. The textures found for the soil samples ranged from: sandy clay loam to loam in the Brooks region; clay loam at the Calgary sites and; loam in the Banff area.

TABLE 4.4. AVERAGE SOIL PROPERTIES FOR SOIL SAMPLES TRANSCANADA HIGHWAY AND SECONDARY ROADS - 1991

	TRANSCANADA HIGHWAY			SECONDARY ROADS		
	CALGARY	BROOKS	BANFF	CALGARY	BROOKS	BANFF
pH MAY	8.00	7.46	8.19	7.81	7.92	7.71
pH JULY	8.08	8.38	8.14	7.98	8.11	7.83
pH OCTOBER	7.85	7.95	8.08	7.82	8.01	7.79
ELECT. CONDUCT. MAY (MV)	-0.06	-0.06	-0.07	-0.05	-0.05	-0.05
ELECT. CONDUCT. JULY (MV)	-0.06	-0.08	-0.07	-0.06	-0.07	-0.05
ELECT. CONDUCT. OCTOBER (MV)	-0.05	-0.06	-0.07	-0.05	-0.06	-0.05
SAND (percent)	20.81 (1.37)	51.79 (1.69)	44.77 (1.39)	23.75 (1.41)	44.00 (1.53)	47.42 (1.42)
CLAY (percent)	36.58 (1.03)	20.31 (0.80)	15.44 (0.54)	39.40 (1.07)	23.69 (0.93)	16.44 (0.55)
TEXTURE	CLAY LOAM	S.CLAY LOAM	LOAM	CLAY LOAM	LOAM	LOAM

(Standard Error)- not shown if less than 0.10.
(See Appendix for complete data set)

The seasonality of the data is very noticeable along the TransCanada Highway in Banff National Park as concentrations gradually decline through the summer months as the ions are leached away with rain and absorbed by plants (See Figure 4.3). An anomaly is discovered in the autumn samples. The autumn samples were collected in late October and unfortunately were extracted after the first snow storm events of the season. The surprisingly high concentrations which result from this October sample collection reveal that only a few de-icing sessions are required to increase the salt content of the soil.

The secondary roads do not show a seasonality trend (See Figure 4.4). In fact both July and October display ditch and fenceline concentrations that are higher than those found in May. This may be explained by the weaker influence of roadsalt on the infrequently de-iced roads and the stronger influence of the salts naturally occurring or added to the nearby agricultural fields, and perhaps the influence of evapotranspiration during the summer months which would bring salts toward the surface by capillary rise as the surface soil dries out.

4.12 Vegetation and Water

One of the visual effects from increased sodium concentrations in the soil is the adjustment necessary for the roadside vegetation. Although most of the roadsides investigated are covered dominantly with man-introduced vegetation, these plants can be looked at to examine their

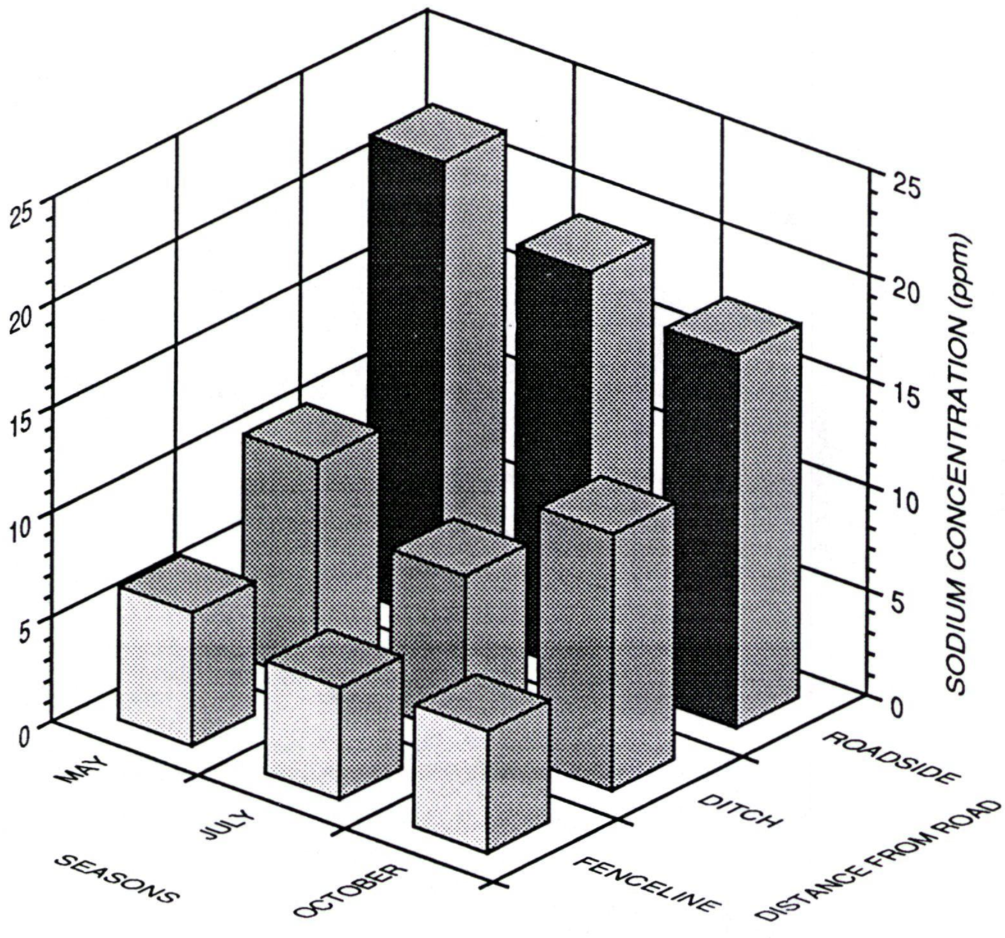

FIGURE 4.3. SEASONAL COMPARISON OF SODIUM CONCENTRATIONS IN SOIL SAMPLES - TRANSCANADA HIGHWAY 1991

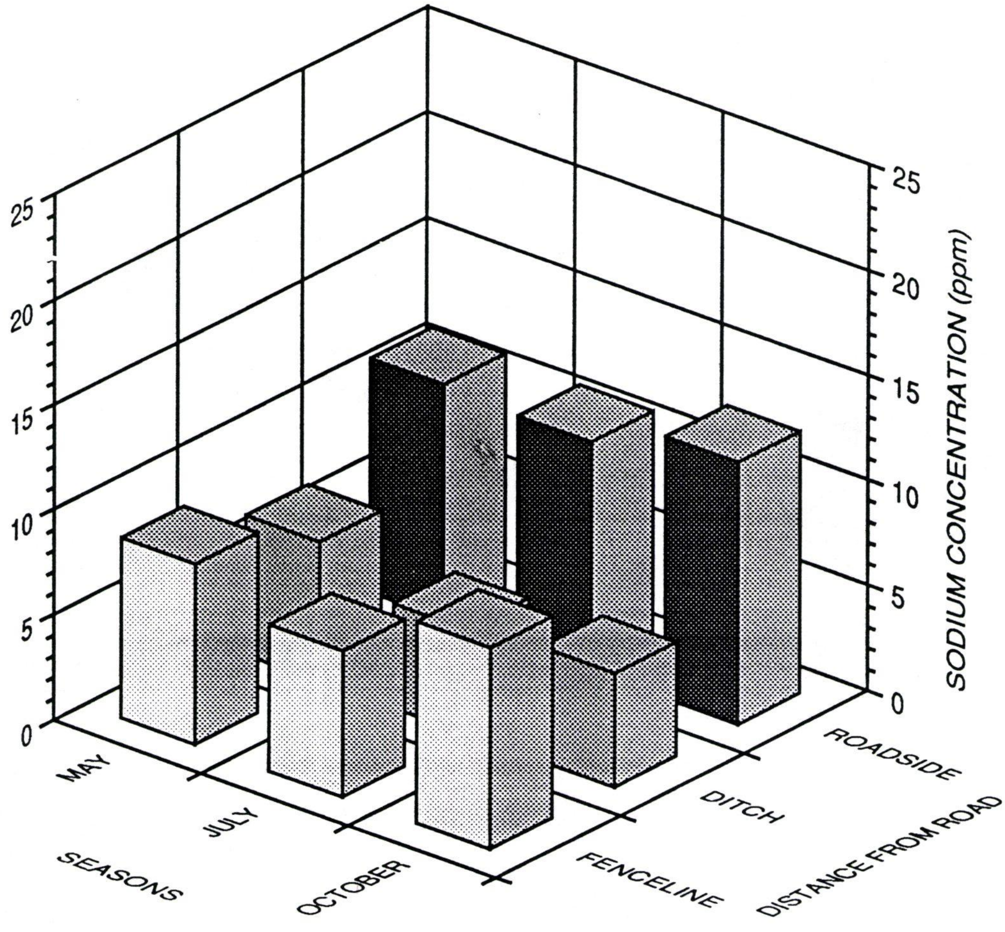

FIGURE 4.4. SEASONAL COMPARISON OF SODIUM CONCENTRATIONS IN SOIL SAMPLES - SECONDARY ROADS 1991

vigour and tolerance to salt as well as their frequency. Table 4.5 displays a grouping of vegetation samples that were collected from the various sites. These plants are a representation of the vegetation that occurred in the quadrat encompassing the soil sampling site. Grass dominated each site with the other plants, shrubs and trees occupying less than 10% of the quadrats. The Calgary and Brooks sites exhibited less variety of flora than the Banff sites. This may be explained by the domination of grasses in the prairie and aspen parkland ecoregions which limits the succession of other varieties of plants. This may also describe the encroachment of various native species from the surrounding environment in the protected regions within Banff National Park.

Some general trends can be developed from the information in Table 4.5. The Calgary and Brooks study areas tend to support vegetation that is tolerant to moderately tolerant of salt that thrive along roadsides. The exceptions would be species which have escaped cultivation, such as Alfalfa and Timothy, and invaded the roadside environment. However, the Banff study area does not have the wide buffers found along the roads in the prairies and native species can be found at the roadside. Some of these native species, such as Wild Strawberry and Lodgepole Pine, are sensitive to increased levels of sodium and were observed to show the signs of stress. Browning of leaves and needles as well as plant wilting was noted. After discussions with Banff National Park Wardens, these effects were isolated to the toxic levels of sodium detected in their foliage samples. The vegetation found along the secondary roads through the Banff study area generally required moist, rich soils. These plants could be severely damaged if the levels of salt increased in their region.

TABLE 4.5. COMMON VEGETATION FROM SAMPLING SITES - 1991

SITE	COMMON VEGETATION	COMMENTS
CALGARY	Thistle (Cirsium arvense)	Thrive at roadside
	Clover (Trifolium spp.)	Roadside - moderately sensitive to salt
	Dandelion (Taraxacum)	Waste places and roadsides
	Bluegrass (Poa spp.)	Drought resistant
TransCanada Highway	Oatgrass (Danthonia spp.)	Meadows
	Fescue (Festuca spp.)	Roadside - salt tolerant
Secondary Roads	Bromegrass (Bromus spp.)	Moderately salt tolerant
	Alfalfa (Medicago sativa L.)	Moderately salt sensitive
	Locoweed (Oxytropis spp.)	Grassland weed
	Aster (Aster)	Valley grasslands
BROOKS	Grammagrass (Bouteloua spp.)	Drought resistant
	Bluegrass (Poa)	
	Wheatgrass (Agropyron spp.)	Salt tolerant
	Dandelion (Taraxacum)	
TransCanada Highway	Prairie Sage (Artemisia ludoviciana)	Slough margins
	Thistle (Cirsium arvense)	
	Black Medick (Medicago lupulina L.)	Parkland species
Secondary Roads	Speargrass (Stipa comata)	Drought tolerant
	Locoweed (Oxytropis spp.)	
BANFF	Wheatgrass (Agronpyron spp.)	
	Buffaloberry (Shepherdia canadensis)	Well drained sites
	Dandelion (Taraxacum)	
	Bearberry (Arctostphylos uva-ursi)	Sandy hills and erodes slopes
	Feathermoss	Moist soils

TransCanada Highway	Fescue (Festuca spp.)	
	Oatgrass (Danthonia spp.)	
	Timothy (Phleum pratense L.)	Moderately salt sensitive
	Thistle (Cirsium arvense)	
	Locoweed (Oxytropis spp.)	
	Vetch (Vicia)	Escaped cultivation
	Clover (Trifolium spp.)	
	Rose (Rosa spp.)	Common along roadsides
	Wolfwillow (Elaeagnus cummutata)	Dry sites
	Wild Strawberry (Fragaria spp.)	Salt sensitive - damaged
	Shrubby Cinquefoil (Pontentilla fruticosa)	Poorly drained sites
	Beardtongue (Penstemon spp.)	Dry hills
	Yarrow (Achillea spp.)	Common along roadsides
	Bunchberry (Cornus canadensis L.)	Shady areas
	Tansy (Tanacetum vulgare L.)	Common along roadsides
	Lodgepole pine (Pinus contorta)	Salt sensitive - damaged
Secondary Roads	Juniper (Juniperus spp.)	Rocky soils
	Goldenrod (Solidago spp.)	Moist, rich soils
	Horsetail (Equisetum spp.)	Wet regions
	Wintergreen (Pyrola spp.)	Moist woodlands
	Gooseberry (Ribes spp.)	Moist, rich soils
	Bedstraw (Galium spp.)	Moist forest
	Willow (Salix spp.)	Moist regions
	Balsam poplar (Populus balsamifera)	Rich soils
	Hairy Galinsoga (Galinsoga cilliata)	Close to man-made structures

The ditch water and snow samples have a relatively small role in this thesis. Complications in the acquisition and analysis of the samples have limited the value of the data as low numbers of samples reduce any significance. However, these samples can offer suggestions to the water quality at the sampled locations for each specific period and some general observations can be stated (See Tables 4.6 and 4.7).

In both data sets the chloride concentrations range from negligible into the hundreds (mg/l). Although the highest values are not comparable to the extreme values found outside some American cities, they are still well above the acceptable levels. The ditch water samples displayed a general decrease in concentrations through the sampling seasons, with May exhibiting the highest concentrations well above the concentrations analyzed for July and October. The ditch water samples were most common in May as the roadsides began to melt and dry out from the winter. These May samples, primarily found in Brooks and Banff, exhibit the highest concentrations of chlorides and salt. Surprisingly, the strongest concentrations are found along the secondary roads in Banff National Park. Curiously, these two sites are both located near ski resorts. Site 26 is along the Bow Valley Parkway near the access to Lake Louise Ski Resort and site 28 is along the access road to Sunshine Mountain Ski Area. These high values may represent the demand for de-iced access There is a general decrease in the concentrations as the sample periods progress through the year.

The snow samples help to demonstrate the differences found between the TransCanada Highway and secondary roads. The average values of 86.94 mg/l for chloride and 143.45 mg/l for salt concentrations along the TransCanada Highway were well above those for secondary roads, 0.72 mg/l of chloride and 1.19 mg/l of salt. The highest concentrations were found west of Calgary which coincides with the area of highest traffic volume.

TABLE 4.6. SALT CONCENTRATIONS IN DITCH WATER SAMPLES TRANSCANADA HIGHWAY AND SECONDARY ROADS - 1991

LOCATION	SITE	Cl^- (mg/l)	Na+ (mg/l)	SALT (mg/l)
MAY				
BROOKS	8-TRANSCANADA	5.00	30.43	8.25
	5-SECONDARY	14.00	173.03	23.10
	9-SECONDARY	42.00	27.90	69.30
BANFF	26-SECONDARY	162.50	101.32	268.13
	28-SECONDARY	190.00	155.94	313.50
JULY				
BANFF	25-TRANSCANADA	23.00	33.97	37.95
OCTOBER				
BANFF	23-SECONDARY	8.00	12.23	13.20
	26-SECONDARY	8.00	2.15	13.20

TABLE 4.7. SALT CONCENTRATIONS IN SNOW SAMPLES CALGARY TRANSCANADA AND SECODARY ROADS (APRIL 1992)

LOCATION	SITE	Cl^- (mg/l)	SALT (mg/l)
TRANSCANADA	1	0.50	0.83
	4	0.30	0.50
	15	134.70	222.23
	16	264.80	436.92
	20	34.40	56.76
SECONDARY ROADS	2	0.10	0.17
	3	0.30	0.50
	17	2.10	3.47
	18	.60	0.99
	19	.50	0.83

4.2 CORRELATION

Correlation analysis is a method of determining and expressing the strength and direction of an association (the extent of covariance) (Weinbach and Grinnell, 1987). The data were separated into groups and correlations run on the selected sites. See Table 4.8.

Correlations run on the groups using all cases, all TransCanada cases and all secondary road cases show a negative correlation (ranging from -0.17 to -0.50) between the concentration of sodium and the distance away from the highway. This supports the idea that sodium concentrations decrease with increasing distance from the highway. This negative correlation is strongest (-.5) in the TransCanada cases where higher concentrations near the highway and and longer distances to the ditch and fenceline are found. The above mentioned correlations seem to be the highest associations found in the correlation matrix. Weak positive correlations are discovered for sodium concentrations and depth, pH, and clay inferring that the sodium concentrations tend to increase with an increase in depth, pH values (alkaline) and clay content. Electrical conductivity and sand show a weak negative correlation with sodium. This seems logical when compared to the weak positive relationships as sand has an inverse relationship with clay. However, pH and electrical conductivity do not necessarily have an inverse relationship. Some salts can be neutral or even acidic in

TABLE 4.8. CORRELATION SUMMARY

Correlation Variables with SODIUM		All Cases (360)			Trans Canada Highway (180)			Secondary Roads (180)	
	MAY	JULY	OCT	MAY	JULY	OCT	MAY	JULY	OCT
Distance	-.2732	-.2618	-.1981	**-.4845**	**-.5016**	**-.3704**	-.1959	-.1736	-.1657
Depth	.1341	.1158	.0974	.1486	.1408	.2226	.1268	.1047	.0267
pH	.2282	.1071	.1265	**.3492**	.2232	.2198	.0961	-.0223	.0551
Elec.Cond.	-.2030	-.1019	**-.9032**	**-.3250**	-.2101	-.1596	-.0768	.0214	-.0444
Sand	-.1087	-.0595	-.0586	-.1368	-.0478	-.0228	-.0941	-.0785	-.0954
Clay	.1359	.1474	.1197	.1378	.1537	.0716	.1626	.1676	.1724

Correlation Variables With Sodium	Calgary TransCanada Highway (60)	Calgary Secondary Roads (60)	Brooks TransCanada Highway (60)	Brooks Secondary Roads (60)	Banff TransCanada Highway (60)	Banff Secondary Roads (60)
MAY -Distance	**-.6654**	-.2445	-.1924	-.0788	**-.6371**	**-.4640**
Depth	.0920	-.1159	.2795	.2381	.0947	.1165
pH	**.6428**	.0414	.0147	.0227	**.3120**	**.3093**
Elec.Cond.	**-.6046**	-.0634	-.0118	-.0226	**-.3215**	-.2695
Sand	**.4687**	.2137	**-.4707**	**-.3820**	-.0122	-.1222
Clay	-.2725	-.1783	**.4042**	**.5725**	-.0199	-.0116
JULY -Distance	**-.5305**	.1866	**-.4876**	-.2418	**-.5484**	-.2422
Depth	.0989	.0020	.2598	.1628	.0665	.1974
pH	**.4415**	.0384	.0716	-.2460	.2070	.2450
Elec.Cond.	**-.4418**	-.0405	-.0449	.2633	-.1913	-.2276
Sand	**.4982**	.2038	-.0523	-.2833	.0161	-.2366
Clay	-.2883	-.1091	.1850	**.5033**	-.0186	**.3030**
OCT. -Distance	**-.5649**	.0388	-.0731	-.1111	**-.6068**	**-.3149**
Depth	.0457	.0434	**.4306**	.0411	.1047	-.0167
pH	.2918	.2535	.0777	-.0959	**.4988**	.1679
Elec. Cond.	**-.3145**	-.2748	-.0907	.1154	-.2569	**-.3330**
Sand	**.5148**	.2248	-.1880	**-.3351**	.0680	-.1055
Clay	**-.3871**	-.1291	.2681	**.5171**	-.0814	-.0597

reaction and still produce a high electrical conductivity. In the case of sodium and other salts found in these particular soil samples, the high pH values should result in high electrical conductivity values creating a strong positive relationship. The correlation values have been discussed through a comparison process. The one statistically significant correlation is between the sodium concentrations for all cases in October and the electrical conductivity for those samples. The strong negative correlation (-0.90) indicates a decrease in electrical conductivity with an increase in sodium concentration.

4.3 TWO WAY ANALYSIS OF VARIANCE

After examination of the correlations within the data, a definite association between the type of highway, such as the TransCanada Highway and secondary roads, and distance from the highway was established. To determine if the distance a sample is

from the highway has an effect on the sodium concentration of the sample, if the type of highway has an effect on the sodium concentration of the sample, or if there is a significant interaction effect between both distance and type of highway a two way analysis of variance was performed on the data. As with the other statistical tests in this thesis, certain assumptions were made on the data. It is assumed that the data represents a random sample with normal distribution of parent population and that the parent populations have equal variances. An acceptable significance level of 0.05 was used. Table 4.9 shows the analysis of variance (ANOVA) results.

TABLE 4.9. TWO WAY ANALYSIS OF VARIANCE - DISTANCE AND TYPE OF HIGHWAY

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F VALUE	SIG OF F
MAIN EFFECTS	6172.16	3	2057.39	9.71	0.000
TYPE OF HIGHWAY	1143.33	1	1143.33	5.39	0.021
DISTANCE	5028.83	2	2514.41	11.86	0.000
INTERACTION	1554.73	2	777.36	3.67	0.027
EXPLAINED	7726.86	5	1545.38	7.29	0.000
RESIDUAL	75040.19	354	211.98		
TOTAL	82767.08	359	230.55		

The analysis suggests that distance does have a significant effect on the sodium concentrations, the type of highway has a significant effect on the sodium concentrations as well as a significant effect from the interaction of the two factors on the sodium concentrations found in the soil samples. In all three cases the calculated value for each factor was greater than their respective critical value. Both variables and their interaction were found to have a statistically significant effect on concentrations of sodium. This seems logical as the splash and runoff of highway de-icing chemicals would definitely alter the soils at the roadside and likely would be influenced by gravity to accumulate in the ditches. However, very minute amounts of the salt mixture could be splashed from the highway to the fenceline nor would the salt run vertically out of the ditch to the fenceline. The type of highway dictates the amount of de-icing salts used as there is an emphasis on bare-pavement for primary highways. The interaction between the two is explained with the presence of excessive salt on primary highways and the occurrence of increased traffic at higher speeds which combine to increase the concentrations of sodium in the adjacent soils as well as increase the distance these salts may travel.

4.4 MULTIPLE REGRESSION

During investigations into the interaction of different variables, the necessity for generalizations will develop. Regression analysis can be used to highlight these trends in data and discover coefficients for the relationships observed. Linear regression can display the trend between an independent variable, of time or space, and a corresponding dependent variable. The resulting linear relationship is a straight-line which best fits the scattered array of data. However, in phenomena relating to humans or nature, there is often more than one independent variable acting upon the dependent variable. There are three main methods which use regression on more than one variable. Discriminant analysis uses regression for classification studies, canonical correlation uses regression analysis on a weighted set of predictor (x) variables to discover their relationship with a weighted set of criterion (y) variables (Hope, 1968).

Multiple regression makes it possible to develop mathematically a best fit surface or plane, rather than a two-dimensional line, to a set of independent variables associated with a dependent variable (Yeates, 1974). Multiple regression is a very powerful tool when dealing with the multivariate data commonly found in actual life situations (Tabachnick and Fidell, 1989).

4.41 Stepwise Regression

Multiple regression is an expansion on the influence assessment of one variable on another, used in the linear regression method (Clark and Hosking, 1986). In general, this regression analysis concentrates on the presence or absence of correlations. Stepwise regression takes a multivariate relationship and investigates the amount of explanation each variable adds to the relationship. This regression adds in one independent variable at a time, in a stepwise fashion, to see: 1) the amount of explanation given by the independent variables in whole; 2) the sign and value of each regression coefficient which yields an explanatory and predictive model; 3) the importance of each independent variable in explaining total variation and ; 4) the ability to predict the value to the dependent variable once the values of the independent variables are known (Waters, 1991). The order of variable entry is based on statistical rather than theoretical criteria (Tabachnick and Fidell, 1989). Therefore, stepwise regression does not necessarily give the best selection of variables, but more likely the best statistical selection of variables under specified constraints, such as maximizing the goodness of fit while minimizing the amount of variables (Clark and Hosking, 1986). Stepwise regression simply enters the variable which adds the most to the predictive equation (the most significant increase in R^2) at each step (Tabachnick and Fidell, 1989). The predictive model for the variables and partial regression coefficients would be:

$$y = b0 + b_1x_1 + b_2x_2 \ldots +b_nx_n$$

In this study, stepwise regression is used to look at the amount of explanation variables such as the: distance, depth, pH, electrical conductivity, sand and clay have on the concentration of sodium. The data were divided into three TransCanada and three secondary road locations as well as all TransCanada, all secondary roads and all cases combined then twenty seven stepwise regressions were performed. These divisions helped to look at the overall influences to all cases as well as the differences in explanation due to seasonality and TransCanada Highway or Secondary Road locations. Regressions were performed on all the cases for each of the seasons, then selected runs analyzed separate information on primary and secondary road influences. See Table 4.10.

The overall regression using all of the 360 cases selected distance as the first step of the equation. This

TABLE 4.10. STEPWISE MULTIPLE REGRESSION OF SODIUM CONCENTRATION IN SOIL SAMPLES - 1991. All significant values.

LOCATION	SAMPLE SIZE	MAY	R2	JULY	R2	OCTOBER	R2
CALGARY							
TRANSCANADA	60	DIST	.44	DIST	.28	DIST	.32
		SAND	.59	SAND	.47	SAND	.52
		pH	.65	DEPTH	.52	DEPTH	.56
		DEPTH	.68				
SECONDARY	60					ELEC CONDUCT	.07
BROOKS							
TRANSCANADA	60	SAND	.22	DIST	.24	DEPTH	.19
		DIST	.35	CLAY	.36		
		DEPTH	.44				
SECONDARY	60	CLAY	.33	CLAY	.25	CLAY	.27
						ELEC CONDUCT	.34
BANFF							
TRANSCANADA	60	DIST	.41	DIST	.30	DIST	.37
						pH	.43
SECONDARY	60	DIST	.21	CLAY	.09	ELEC CONDUCT	.11
ALL TRANSCANADA	180	DIST	.23	DIST	.25	DIST	.14
		SAND	.27	CLAY	.27	DEPTH	.19
		pH	.31				
		ELEC CONDUCT	.32				
ALL SECONDARY	180	DIST	.04	DIST	.03	CLAY	.03
ALL CASES	360	DIST	.07	DIST	.07	DIST	.04
		pH	.10	DEPTH	.08		

fits with the assumption that the sodium concentration will vary with the distance the site is from the highway. Theoretically, the concentration of sodium would decrease as the distance from the highway increases. It is assumed that the highest concentrations would develop at the roadside, some salt would accumulate in the ditch and the lowest concentrations would be found along the fenceline.

The TransCanada Highway site regressions selected distance as the first step for all of the three seasons. Relatively strong explanations resulted from the May and July seasons with a weaker explanation from distance in the October season. This may infer the reduced amount of roadsalt present late in the season after precipitation has washed much of the salts away. Both May and July TransCanada regressions made texture the second step with equal explanation from both. October samples selected depth as the second step. The May TransCanada sites proceeded to further steps selecting pH and electrical conductivity respectively.

Secondary roads for May and July only went through one step in the regression. Both groups chose distance as the best explanation for the sodium concentrations. The October sites showed a very weak explanation using the percentage of clay for its first and only step. These weak explanations lead to the assumption that the selected variables do not significantly influence sodium concentrations along secondary roads.

Difference between the Calgary, Brooks and Banff sites were numerous even with the acceptance of distance as the most common explanation variable. The Calgary TransCanada Highway sites showed a very strong explanation from distance, sand and depth with some influence from pH in the May sampling season. These variables
provided approximately 68% of the explanation behind these concentrations of sodium in May then 52% for July and 56% for October. The secondary roads around Calgary did not select any of the variables to explain sodium concentrations.

In the Brooks region, the TransCanada sites oddly selected texture as the best explanation for the sodium concentrations found in the May samples with the distance factor playing a secondary role. The average texture for the Brooks TransCanada area is sandy clay loam. This texture is different from all the other sites. The high percentage of sand was also negatively correlated with the sodium concentration for May along the TransCanada Highway in the Brooks study area. This leads to the conclusion that increased percentage of sand improves drainage and therefore the sodium is not trapped within the soils adjacent to roads.

Distance was selected for the July season and depth for the October season. Clay was included in the July regression steps, however, clay is vital in explaining the variation in sodium concentrations for the secondary roads surrounding Brooks. As discussed earlier, there are three secondary sites in Brooks which showed abnormally high sodium concentrations. Perhaps these sites have high sodium concentrations due to the high percentage of clay found at these sites. The high percentage of clay may impede drainage and therefore influence the accumulation of sodium.

In the May sampling season for both the TransCanada and secondary road sites in Banff National Park, distance was selected as an explanation for the sodium concentrations found at the sites. This selection of distance as the first step in the regression formula was repeated for the July and October seasons along the TransCanada Highway with pH offering some influence in the October season. Weak explanations from distance are found for the July and October sampling seasons along secondary roads in the area. The most highly correlated variables in these samples are clay and electrical conductivity respectively and perhaps infer a lack of strong relationships rather than the importance of these two variables.

In an attempt to view the relationships in whole and separated into different study regions, highways and seasons, the multiple stepwise regressions were performed individually on each particular interest group. Therefore it is inaccurate to use the generated R^2 values (even if the z scores are used) to relate the values across seasons, highways, and locations. General comparisons between the selection of variables with the strongest explanations for each step was acceptable only when viewing the data in each individual data arrangement.

4.5 DISCUSSION OF RESULTS

There are many questions on how the sodium concentrations affect the soil. Some of the answers to these questions developed from the lab work. The variations of sodium concentration between: TransCanada Highway and secondary road locations; Calgary, Brooks and Banff study areas as well as between the different seasons leads to the supposition that something other than natural causes have altered the sodium content of the soils.

The sodium concentration of soil samples decreased from the TransCanada Highway levels to lower levels found along secondary roads. This was assumed as the TransCanada is a primary highway requiring quick and effective de-icing applications for the safety of larger traffic volumes. This reasoning follows through for the Calgary area and its relatively high concentrations of sodium. The regions around the city of Calgary experience a large number of travellers whether they be visitors, commuters or residents going on day trips. There also may be an overlap of de-icing applications at the boundary between provincial and civic responsibility, thus the city limits may receive twice as much roadsalt as the surrounding highways. Other high sodium values may be explained through detailed location description, such as the sites in Brooks which are near a livestock corral, beside a fertilizer plant and at an intersection.

The concentration of sodium also varied with the distance each sample was extracted. As assumed, the highest sodium concentrations were discovered at the roadside sites. The absorption of roadsalt along the roadsides from direct application, drainage from the road surface and from road splash was almost double the concentrations found in ditches and along fencelines. Both the lack of significant accumulation of sodium in the ditches as well as the higher than expected averages for sodium along the fencelines were surprising. Perhaps the overall topography drained the ditches to even lower elevations adjacent to the highway thereby reducing the ditch concentrations. The high fenceline concentrations may be a result of agricultural practices in the adjacent farming fields.

Individual soil sampling sites showed a slight trend for increased sodium concentration with an increase in the depth of sampling. There was strong relationship between increased sodium concentration with an increase in depth along the TransCanada Highway, however, this inclination weakened along the secondary roads. This association between concentration and depth may be analyzed by examining the soil texture. Higher clay contents tends to be connected with higher sodium concentration, whereas less clay and higher sand percentages tend to lower the sodium concentration. Clay impedes the drainage and therefore reduces the dispersal of sodium and sand improves the drainage to aid in the removal of sodium.

Some seasonality of the data was observed. There seemed to be a decrease in sodium concentration from May to July, however, October showed a slight increase in sodium concentration. This may be explained through collecting the October data after the first snow storm events, or perhaps by the evapotranspiration during the summer and into the autumn months.

In other relationships the concentration of sodium decreased with increased distance, pH, sand content,and with decreased depth, electrical conductivity and perhaps with decreased clay percentage. These relationships did not seem to change in direction between the TransCanada and secondary road sites but did tend to be stronger at TransCanada locations.

The vegetation along the highways in the Brooks and Calgary study areas were well suited for the environment. Drought resistant and salt tolerant species dominated the roadsides. This suggests that these species have naturally moved to and thrived along the roadsides to out-compete other species or have been introduced through seeding programs (to stabilize roadsides and reduce the amount of dust blown from these areas) by man. However, along highways through Banff National Park the native species do not have a buffer against the highways. Strawberry and pine trees are sensitive to excessive amounts of salt and exhibit stress associated with sodium.

The water and snow samples show a decrease in water quality along the ditches. High concentrations of salt are found in ditch water sampled during the May season when runoff is still prevalent. These concentrations decline through the seasons with the lowest concentrations occurring in October. The snow samples display extremely high concentrations of salt along the TransCanada Highway as compared to minimal salt values along the secondary roads.

Overall, there is an increase of sodium concentration in soils along highways. This increase in sodium is potentially hazardous to any vegetation sensitive to effects of salt. These concentrations of sodium can vary with the distance from the highway, the depth of the sample and the season of the year.

CHAPTER FIVE

DISCUSSION

5.1 DISCUSSION OF RESULTS

5.11 TransCanada Highway vs. Secondary Roads

The amount of road salt discovered along the roadsides can vary considerably. Some of the influential factors on concentration levels can be attributed to characteristics of the highway, such as the length and type of the road. The TransCanada Highway is a primary highway demanding safe driving conditions for thousands of daily travellers. By shear numbers the amount of road salt applied and the interval of applications is much greater on the TransCanada Highway than on secondary roads. This observation is reinforced by the data which depicts the TransCanada Highway sodium concentrations as higher than the secondary roads in virtually every location from the roadside to the ditch to the fenceline. Previous studies on the effects of de-icing chemicals on roadside environments focus on highways of primary use instead of secondary roads with the assumption that reducing the serious problem on major highways will in turn lessen contamination along secondary routes. The topography of the roadways may also alter the distribution of road salts. The TransCanada Highway has strict codes as to acceptable gradients whereas secondary road construction does not have to be as stringent. Therefore, the accumulation of road salt may be relatively evenly spread and remains behind along the TransCanada Highway but along possible steeper inclines on secondary roads the road salt may be swept away with the spring runoff before the ground has a chance to thaw.

The velocity of vehicles on the roadways also plays a role in the dispersal of road salts. In general, the larger the highway the higher the acceptable speed for vehicles. With higher velocities, it is assumed there will be a greater displacement of the de-icing salts. This would lead to the belief that since the TransCanada Highway is the largest study road, with the highest velocities it would also have the strongest dispersal of road salt. The sodium concentrations along the ditches and fencelines of the TransCanada Highway therefore should be higher than the concentrations of ditches and fencelines along secondary roads. This would agree with the problems in Ontario from road salts affecting the orchards through splash events (Jones, 1986).

However, this theory of increased dispersal with increased velocity does not always hold true. If the increased velocity increases the dispersal of the road salt, would it not also lower the concentration or intensity of the road salts. McBean and Al-Nassri (1986) tested this hypothesis and discovered that at speeds up to 70 km/h the intensity of road salts is lowered gradually with increased velocity, however the hypothesis was not accepted at speeds above this limit. These highways with velocities exceeding 70 km/h may receive more thorough plowing once the snow pack and ice begins to melt and therefore there could be less substance splashed great distances from the highways and more concentrated road salt slowly draining into the adjacent area.

5.12 Distance and Depth

The previous section introduced the idea of variations in the concentration of sodium with different distances of sampling from the highway. Topography also plays a role in the accumulation of road salts at different distances from the change in slope between the roadside to the ditch and the ditch to the fenceline. As previously mentioned it was expected that the ditch would accumulate the highest concentrations of sodium as it would act as an accumulation pool during any melting event. However, no significantly high concentrations of sodium were found in the ditch location. The general lack of excess sodium ponding in the ditches may indicate that there is strong regional drainage for the roadsides in which salts may be drained to completely different sites along the highway.

The TransCanada Highway exhibited a trend for increased sodium concentration with increased depth. One hypothesis for this discovery may be the physical composition of the soils adjacent to the TransCanada Highway. The TransCanada roadsides (3 m to 20 m) are much wider in average than the secondary roads (3 m to 12 m). The demand for safe, wide, and smooth primary highways created the need for Alberta

Transportation to truck in gravels and sands to reduce the amount of maintenance necessary for the upkeep of the TransCanada Highway. The gravels and sands improve the drainage under and near the highway and therefore reduce the possible damage from the elements, such as frost heave. The presence of the sands and gravels would also increase the penetration of sodium into the soil. Therefore higher concentrations of sodium may be found at increasing depths.

5.13 Seasonality

The concept of seasonality was to test to see if there would be any significant reduction in sodium concentration through the summer months. This hoped to reveal a pattern of soil recovery from the effects of de-icing salts over several months. Perhaps this recovery period would be long enough for vegetation to recuperate. If the salts could be disseminated quickly enough, the concern would not be with the adjacent roadside but could be concentrated on the wider problem of water contamination. In general there was a decrease in sodium concentration from the May sampling season to the July season. However, this decrease was not witnessed for the October sampling season. The October samples were extracted after the first snow storm events of the 1991/92 winter. Although there was only a few de-icing applications, a noticeable increase in sodium concentration was observed. This may offer insight into how only small amounts of salt can penetrate the soil relatively quickly. These few "pre-season" de-icing applications could cause even more concern as the soils are not yet frozen and the sodium can be absorbed immediately.

5.14 Location

Scott (1980) suggests that an important factor influencing the variation of salt concentrations found along highways may lie in the degree of urbanization for the area. The Calgary study region displayed the highest concentrations of sodium. It would be expected that the Calgary area would reveal the strongest levels of a great variety of pollutants. This could be explained by the greater area of impervious surfaces associated with urban areas and their tendency to increase the quickness and completeness of salt removal to accumulate in adjacent environments (Scott, 1980).

The prominence of agriculture in the Brooks area has an effect on the sodium concentration found there. The influence of livestock, fertilizer, agricultural practices as well as natural evapotranspiration could increase the sodium content in the ribbons of soil which separate farm fields from highways. The irregularities found in three Brooks locations suggest that other influences rather than de-icing salts increased the concentration of sodium.

The soil sampling sites in Banff National Park exhibited the lowest concentration of sodium out of the three sampled regions. The roadsides through the Brooks and Calgary regions seem to consist of dry environments in a relatively confined space. Therefore salts are restricted in their movements. Banff National Park does not contain well defined roadsides. The freedom of salt movement coupled with an increased moisture regime allows the sodium to disseminate and therefore roadside concentrations are lower than found in Brooks or Calgary.

5.15 Effects on Soils, Vegetation and Water

In general the sampling sites along the roadsides were compacted and extraction of cores were often difficult. In many of the sites the concentrations of sodium found in the samples were high if not toxic. However, compared to a 1990 study of de-icing salts on roadsides in California the average values for sodium concentration along the TransCanada Highway, through southern Alberta, were far below those along Interstate 5 in California (Gidley, 1990). Furthermore, average sodium concentrations along secondary roads through southern Alberta were far lower than the average concentrations for sodium along Highway 89 in California. California may exhibit higher sodium concentration in the soil due to the reduced period in which soil remains frozen. More de-icing applications may occur when the soil is not frozen, allowing for increased sodium absorption.

The de-icing problems in Southern Alberta can be put in perspective with similar problems in other areas of the continent. As previously mentioned, roadside sodium concentrations in California exceed those found in the study areas. Ohio also has found difficulties when dealing with de-icing salts. In a study near Gate Mills, Ohio average sodium concentrations along a primary boulevard were 228 ppm and 51 ppm at reference sites. These values are well above those found at the southern Alberta study sites. Two main factors may account for these substantial values. The first is the climate of the study area. Southern Ontario is very humid and, in the winter, this leads to the increased development of ice. The second is strictly a matter of population and traffic volume. Increased traffic leads to increased demands for safe driving conditions. It is the second reason which is a concern to southern Alberta. The current sodium concentrations of roadside soils through southern Alberta may not be at dangerous levels yet, however, as the population increases, so will the need for alternatives.

A study at Cascade Lakes in New York reinforces the possible seasonality of the data. The study concluded that sodium concentrations were highest in April, just after snow from the preceding winter had melted. In addition, chloride levels were higher in April than in soils collected in October (Fleck, Lacki and Sutherland, 1988). Jones (1986) suggests that the maximum salt concentrations occur during the winter and gradually decrease throughout the spring, summer and fall. In a study by Berthouex and Prior (1968) it was observed that most of the salt in roadside soils was leached from the top 0.9m of the soil by the first of March and by the first of

April the salt would be leached from the top 1.5 m. Jones (1986) also suggests that the seasons may also alter the concentrations of sodium potentially found at different distances. With an increase in the temperature, there will be more infiltration and less horizontal runoff, therefore the roadside soils would absorb the most highway runoff, whereas less runoff would reach the ditch or fenceline.

The vegetation along the TransCanada Highway focused on salt tolerant plants, such as wheat grass, fescue, clover, dandelion and thistle. Secondary highways supported these species as well as many cultivated species which have encroached the highways from farm fields. The most notable damage on vegetation from de-icing salt was witnessed in Banff National Park. Along the TransCanada Highway strawberry, pine and Douglas fir trees were spotted, brown and wilting. Foliage from these trees were sampled and tested with chloride from highway de-icing named as the dominant cause of grievance. The Banff Warden Service (1991) concluded that the salt concentrations in the soil far exceeded tolerable limits for plant survival. This is especially true for vegetation sensitive to salt, such as Red osier dogwood, Beech, Manitoba Maple, White pine and White spruce (Jones, 1986). If sodium chloride continues to be used as a de-icing agent, perhaps salt tolerant trees, such as Blue spruce, Jack pine or Cottonwood, could be introduced to the roadside environment and provide a buffer to the less tolerant species (Jones, 1986).

5.2 ADVANTAGES AND DISADVANTAGES OF STEPWISE REGRESSION

The use of stepwise regression has encountered some criticism for applications in geographical research. Hauser (1974) states that stepwise regression often produces inadequate models due to the presence of multicollinearity. Multicollinearity occurs when there is a high correlation between several of the independent variables in the data set. Hauser (1974) describes two major ways in which multicollinearity detrimentally changes the stepwise regression equation. First, multicollinearity tends to be seen when the number of independent variables increases and interdependence escalates causing the instability of coefficients to increase (Hauser, 1974). Secondly, these high intercorrelations give high standard errors for the coefficients and alter the accuracy of the regression equation, ultimately resulting in poor model selections (Hauser, 1974). The severity of the model error is emphasized when the domain of the model is used for making predictions on the data behaviour (Brooks, Carroll and Verdini, 1988). Careful selection of variables as well as the close monitoring of interdependence is essential when using stepwise regression. Stepwise regression is a controversial procedure because it adds in the variables based on their statistical nature rather than being based on theoretical criteria (Tabachnick and Fidell, 1989). The stepwise process is helpful in interpreting the data, especially with the management of larger data sets.

In general, multiple regression and all its related techniques provide an excellent method for quantifying data. Multiple regression allows researchers to examine the relationships of many different independent variables on a dependent variable, and be able to predict the changes in the dependent variable from alterations in the independent variables. The variation in sampling and organization in research has created various adaptations to multiple regression. The use of variable transformation, trend surface analysis and stepwise regression has increased the capability of multiple regression and opened new areas of research for investigation. The problems discovered when using multiple regression can be minimized simply through an increased user-awareness to the limitations of the technique. Overall, multiple regression is a powerful statistical method, which allows the relationship of one dependent variable with a set of independent variables to be examined and predictive models to be developed. Other techniques simply enhance this process by showing the significance of the relationship and the importance of each of the independent variables, as well as the ability for multiple regression to be utilized with relatively nonapplicable data.

5.3 OTHER FACTORS TO DE-ICING SALT CONCENTRATIONS

5.31 Climatic Conditions

The climate of an area plays an essential role in the way salt enters the environment and its path through the system. The winter of 1990/91 had temperatures slightly below normal with the early winter experiencing higher than average snowfalls which decreased as the winter progressed. See Table 5.1. Before the freeze up at the beginning of the winter there were deficiencies in soil moisture across most of the province (Environment Canada, 1991). Environment Canada (1991) reported very little snow cover in the east-central areas of the province but snow packs above average along the Rockies. These drier than normal conditions would exaggerate any surficial salinity and reduce the lateral movement of salts in the soils. Dryness also would increase the amount of salt lost to the atmosphere by winds.

Precipitation plays a key role in the accumulation and dissemination of de-icing salt. Rainfall may accelerate the melting of salt-laden snow pack thereby quickening the spread of salts into the water system but could also dilute the concentration of salt in a greater discharge (Scott, 1980). This could have affected the salt accumulation at the sampling locations by washing the road salt from the site and therefore reducing the amount of salt absorbed by the soil and vegetation. This process would have been most evident in November 1990 as precipitation was higher than normal.

TABLE 5.1. TEMPERATURE DATA FROM OCTOBER 1990 - OCTOBER 1991

STATION	BANFF	CALGARY	BROOKS		BANFF	CALGARY	BROOKS
OCTOBER'90				MAY'91			
MEAN	2.6	4.1	6.2	MEAN	8.0	9.4	11.3
DIFF NORM	-1.8	-1.4	-1.3	DIFF NORM	0.3	0.0	-0.4
SNOWFALLcm	57.8	11.0	8.1	SNOWFALLcm	15.0	0.6	3.7
% NORM	325.0	81.0	82.0	% NORM	105.0	7.0	150.0
PRECIP mm	80.8	12.9	14.0	PRECIP mm	74.4	96.1	32.2
% NORM	258.0	73.0	83.0	% NORM	144.0	197.0	108.5
NOVEMBER'90				JUNE'91			
MEAN	-3.2	-4.0	-1.2	MEAN	11.2	13.0	15.4
DIFF NORM	0.7	-1.3	0.0	DIFF NORM	-0.4	-0.5	-0.7
SNOWFALLcm	88.4	30.9	48.3	SNOWFALLcm	0.0	0.0	0.0
% NORM	275.0	190.0	315.5	% NORM	0.0	0.0	*
PRECIP mm	84.6	20.7	36.3	PRECIP mm	103.2	113.2	109.9
% NORM	272.0	163.0	235.5	% NORM	168.0	127.0	155.5
DECEMBER'90				JULY'91			
MEAN	-13.0	-10.7	-10.8	MEAN	14.9	16.4	17.2
DIFF NORM	-4.1	-2.9	-4.1	DIFF NORM	0.1	0.0	-2.1
SNOWFALLcm	51.2	17.2	27.3	SNOWFALLcm	0.0	0.0	0.0
% NORM	114.0	83.0	122.0	% NORM	*	*	*
PRECIP mm	33.4	11.7	23.4	PRECIP mm	41.4	29.6	22.5
% NORM	88.0	73.0	124.0	% NORM	98.0	45.0	54.0
JANUARY'91				AUGUST'91			
MEAN	-10.3	-8.8	-9.5	MEAN	16.8	18.1	20.5
DIFF NORM	1.2	3.0	2.0	DIFF NORM	3.0	2.9	2.3
SNOWFALLcm	10.4	11.1	15.1	SNOWFALLcm	0.2	0.0	0.0
% NORM	24.0	53.0	55.0	% NORM	200.0	*	*
PRECIP mm	6.8	7.4	13.1	PRECIP mm	53.2	64.2	52.9
% NORM	18.0	46.0	56.5	% NORM	109.0	116.0	128.0
FEBRUARY'91				SEPTEMBER'91			
MEAN	1.5	0.9	1.8	MEAN	10.5	11.5	13.6
DIFF NORM	7.8	8.2	8.3	DIFF NORM	1.2	0.9	0.6
SNOWFALLcm	14.4	16.1	13.8	SNOWFALLcm	0.0	0.0	0.0
% NORM	44.0	84.0	70.5	% NORM	0.0	0.0	0.0
PRECIP mm	11.2	14.9	19.4	PRECIP mm	41.6	25.9	17.6
% NORM	40.0	96.0	109.5	% NORM	100.0	68.0	49.5
MARCH'91				OCTOBER'91			
MEAN	-3.3	-3.5	-1.8	MEAN	2.3	2.2	4.0
DIFF NORM	0.1	0.5	1.0	DIFF NORM	-2.1	-3.3	-3.5
SNOWFALLcm	43.0	24.0	17.5	SNOWFALLcm	27.4	24.0	18.5
% NORM	173.0	121.0	85.0	% NORM	154.0	178.0	189.0
PRECIP mm	26.0	21.0	21.2	PRECIP mm	25.1	15.8	20.4
% NORM	124.0	130.0	102.0	% NORM	80.0	90.0	119.0
APRIL'91							
MEAN	3.9	5.4	7.2				
DIFF NORM	1.5	2.1	2.0				
SNOWFALLcm	17.0	3.2	4.0				
% NORM	54.0	12.0	21.0				
PRECIP mm	24.0	7.1	34.7				
% NORM	64.0	22.0	105.0				

* = DATA NOT AVAILABLE

Precipitation also could alter the amount of salts analyzed for the May, July and October sampling seasons. There was virtually no snowfall between the May and October, 1991. This allows the emphasis on salt movement to be placed on precipitation. Rain increased the amount of leaching in soils. June and August, 1991 were months of higher than normal precipitation. With the help of the rainfall, sodium concentrations were able to decrease from the values discovered in May to the lower concentrations found in July. The early snow storms and de-icing applications in October eliminated any trend for decreasing concentrations. The unexpected high concentrations of sodium in October testify to the increase of sodium due to de-icing practices.

5.32 Time of Application

The point in time that the salt is applied to the road also plays an important role in its dispersal in the environment. If applied during the night when traffic is at its lowest the action of heat from vehicles would be missing from the formula. If applied during windy conditions the salt would not stay on the road, have zero effect on improving conditions and enter the environment without ever providing benefits.

5.33 Traffic Density

In areas of high traffic volumes the salt may be dispersed faster and to greater distances. High traffic volumes melt the snow/ice/salt mixture and displace it off the road much faster than on a less travelled highway. The splash/spray and runoff enters the environment more quickly and coupled with the idea that due to the wide highway there is more salt used on the road to begin with... more salt is introduced faster. The same amount of salt on a secondary road may stay on longer and stand less of a chance of being sprayed on to the adjacent vegetation, however it would still end up in the ditches.

5.34 Topography

The overall topography and highway drainage of the area can change the accumulation points of salt in the environment. If a sampling site has a significantly deep ditch but is elevated higher than the surrounding area, there is a good chance that the salt, which would normally be expected to accumulate in the immediate ditch, would travel downslope to the lowest point in the region and accumulate. This would disperse the salt farther when the soil is still frozen (during sudden melts and early spring thaw). However, it may also allow the soils to retain the salts during overland flow to the ditches and by the drainage channel itself (Scott, 1980). Gradual slopes may decrease the speed at which the salts would be dispersed from the immediate location and increase the absorption of salts by the soil whereas steep gradients may increase the rate at which the salts would move to watercourses thereby reducing the absorption of salts by the soils but quickening the contamination of watercourses.

Possible infection of salts to the water supply may increase from these steep gradients as road salt can be carried by drainage waters as well as from the stronger applications often associated with highway characteristics such as steep slopes (Scott, 1980).

5.35 The Actual Accumulation of Snow

The amount of road salt that could be absorbed by the underlying soils is closely related to the amount of salt that accumulates prior to a thaw period. This accumulation and dispersal of road salts can be altered by the behaviour of the snow pack. Scott (1980) states that the rate of rise in temperature at the start of the thaw, the maximum temperature attained during the thaw and the duration of temperature above freezing also influence the behaviour of the snow pack and, therefore the behaviour of the de-icing salts. In general, near the melting point of snow, some of the snow converts to water. This water is retained in the intercrystalline spaces within the snow and may refreeze if the temperature is lowered (Scott, 1980). It is possible for de-icing salt to be trapped in this situation (if the temperature is low enough) and the snow will become salt-laden. Since the snowpack now has a lower melting point, when the temperature increases the snow will begin an early melt. This melt water will have high concentrations of salt until it can be diluted with more water as the temperature increases further.

CHAPTER SIX

CONCLUSION

6.1 SODIUM CHLORIDE AS A DE-ICING AGENT

Common salt is not often referred to as a contaminant. However, Sheppard et al (1992) define a contaminant as:

> "a material not naturally found in soil, usually one that has potentially undesirable effects. It may be extended to naturally-occurring materials that are toxic, such as arsenic and radon."

Using this definition along with data collected from previous studies as well as this thesis, sodium chloride can be classified as a contaminant. Details were given as to the effects of sodium on soil characteristics. Sodium ions are explicated to bond to soil colloids and restrict the development of large pore space (Sposito, 1989). This influences the soil structure which is destroyed due to the natural affinity for clays and acts to deflocculate clays (Sopher and Baird, 1978). This action results in a dense surface crust which makes the soil impermeable (Bridges and Davidson, 1982). Once the soil's natural drainage is impeded the osmotic pressure is altered which can create stress on the overlying vegetation (Ricklefs, 1973). The soil samples along the TransCanada roadsides showed sodium concentrations high enough to influence the structure and fertility of the soil.

The detrimental effects of sodium chloride on soils limits the ability of that soil to support plant growth

(Zelazny and Blaser, 1970). Increasing the amount of salt within the soil medium can alter the water balance, deplete nutrients and increase toxicity creating hazardous conditions for most plant life (Poljakoff-Mayber, 1982). Other effects of highway de-icing on adjacent vegetation may occur from actual absorption of sodium by the roots of the plants or surficial contact from traffic spray. Injury resulting from this encounter is a general growth reduction followed by leaf scorch and curling, leaf drop, stem dieback and gradual decline in vigour ultimately leading to the death of the plant (Zelazny and Blaser, 1970). The majority of plant species along the roadsides in the Calgary and Brooks study area were moderately salt tolerant to salt tolerant and were well suited to the environment. The vegetation in Banff National Park was less tolerant to de-icing salts. Strawberry, pine and Douglas fir trees showed visible damage from the stress associated from salt with the browning of leaves and needles.

Far reaching contamination of water systems is a concern for the continued use of sodium chloride as a deicing agent. Polluted water from runoff, splash, storage accumulation and precipitation can end up affecting the quality of streams, lakes and ground water. Concerns as to the effects of salt away from the roadside locations may include eutrophication of lakes, release of mercury from lake bottom sediments, increased growth of nuisance algal blooms and contamination of drinking water potentially influencing human health. The concentrations of chlorides naturally present in ground water are usually low, at less than 10 mg/l (Jones, 1986). The concentration of chlorides found in ditch water samples along highways in Banff National Park for the month of May were over ten times greater than this normal concentration (162 and 190 mg/l). Although a percentage of this concentration will be filtered out before it reaches the ground water, the water will still contain a significant amount of chlorides.

Many new highway development projects have considered wildlife and their attraction to highways and the road salt. Fences, such as those used along the TransCanada Highway through Banff National Park, have been erected to limit the likelihood of vehicle and wildlife collisions. Other concerns are for the availability of sodium chloride on the highways to wildlife and the possibility of toxic effects leading to potential deaths or the contamination of roadside ponds which may negatively impact the reproduction of some aquatic species.

These environmental concerns are multiplied when the economic costs are added to the problem. Premature corrosion of vehicles and corrosive damage to highways and related structures, such as bridges, parkades, and power conductors, cost the public millions of dollars annually (Bacchus, 1987). However, alternatives must be developed and tested before sodium chloride may see discontinued use. New deicing agents should maintain the efficiency of sodium chloride, without

NaCl's negative effects nor add adverse consequences of their own.

6.2 ALTERNATIVE CHEMICAL DE-ICERS

One of the most recent and popular products for de-icing is calcium magnesium acetate (CMA). CMA is a generic term applied to the reaction product of acetic acid and limestone or dolomite (Ostermann and Economides, 1985). Studies comparing the environmental impacts of CMA to sodium chloride have shown that CMA is biodegradable in soil and does not disturb the structure, compaction or strength of the soil and actually increases the permeability (Author unknown, 1990). The acetate component of CMA may stimulate roadside growth of vegetation as it is the most abundant organic acid metabolite found in nature (Author unknown, 1990). CMA is less toxic to aquatic life than sodium chloride (Author unknown, 1990). Unlike sodium chloride, CMA may increase the pH of soil and decrease the solubility of trace metals coprecipitated with oxides, hydroxide, and carbonate (Amrhein and Strong, 1989). Only mildly irritant to human skin and eyes and can reduce the amount of sand necessary for de-icing and therefore reduce air pollution from the resulting particulate emissions (Author unknown, 1990). The problems with CMA is in its poor mobility in the soil as it is unlikely to reach the ground water (Author unknown, 1990). Calcium and magnesium tend to increase water hardness. The most prevalent adverse effect is in its potential to deplete oxygen in standing surface water.

The most attractive quality of CMA is that it is both safe for the environment as well as non-corrosive to man-made structures (Ostermann and Economides, 1985).

Damas and Smith (1987) created a detailed list of alternative deicing compounds with their advantages and disadvantages being discussed. They are as follows. Calcium chloride is used frequently in addition to NaCl due to its effectiveness at lower temperatures (effective down to -34 C). However calcium chloride tends to keep the pavement wet longer than sodium chloride and its melting action is often only at the ice surface. Although one of the most practical and promising alternatives, calcium chloride's substantial cost cannot justify the benefits resulting from its use. Urea is recommended as an alternative to sodium chloride due to its non-corrosive action. It is non-toxic and can promote growth of roadside vegetation (high concentrations can cause "fertilizer burn"). Urea would experience more frequent use as a road deicer if not for its high cost and ineffectiveness at temperatures below -9 C. Ethylene glycols and other glycols create numerous different liquid deicers. Mixtures of these glycols with water produce a solution with a very low freezing point. Reported cases of excessive slipperiness produced by glycols and their disappearance before deicing action was complete has limited their use on highways. Formamide is an unlikely alternative due to its biodegradation into toxic products and its high cost. Tetrapotassium

Pyrophosphate is a popular alternative in regions of mild winter, however, it is ineffective at temperatures below -4 C. Methanol also cannot be considered a good replacement for sodium chloride as its effects are short-lived and has potentially toxic effects. Most of these have even worse consequences for the environment.

6.3 OTHER ALTERNATIVES

6.31 Highway Construction

Fromm (1982) suggests an alternate method of controlling ice build up on highways by using chemicals incorporated into the asphalt concrete to keep the road surface from icing and the snow from sticking to the road. "Verglimit" is an example of this new approach to winter driving safety. This agent is a combination of calcium chloride and NaOH, coated with a water-resistant layer, mixed with asphalt and applied as permanent pavement (Damas and Smith, 1987). Five thousand vehicles per day are necessary for the gradual release of these chemicals. The disadvantages are the initial high cost, reduction of surface life and an increase in the slipperiness during rain events (Damas and Smith, 1987).

Road construction is also under criticism in the case of road splash from damaging roadside vegetation and specifically adjacent orchards. It has been suggested that the road surface could be altered in order to reduce the spray. The problem has been identified as the small ridges and depressions in highway surfaces holding the salt after the melting and creating splash ponds. The orchard owners would like these small collection points eliminated. This causes problems as a flat surface may let the salt run off into the ditch rather than splashing but it also can create slippery conditions if weather causes icing. Evaluate methods to reduce the spray, raised by passing vehicles, from blowing onto roadside orchards (Fromm, 1982).

In an attempt to reduce the amount of sanding and de-icing necessary on highways, Sweden came up with the idea of using rubber particles in asphalt construction. A system of using three to four percent of coarse rubber particles incorporated into hot mixed asphalt pavements was first developed in Sweden under the trade name "Rubit" and now is patented under the name "PlusRide" in the United States (Esch, 1984). Under traffic action the protruding rubber particles flex and cause a breakdown of surface ice deposits (Esch, 1984). Esch (1984) describes the benefits of this modified pavement which include: 1) the ability to shed an ice cover more quickly than conventional pavements; 2) the reduction of stopping distances on icy non-salted roadways (25% less than on normal pavements; 3) the development of a more flexible and fatigue-resistant pavement; 4) a reduction in tire noise, and; 5)the beneficial use of what is normally a troublesome waste product, used tires.

6.32 Management Techniques

While deicing alternatives to sodium chloride are being developed, ideally an improvement in the current management techniques for using common road salt should be implemented. Some of these techniques are practised but not all are consistent. A standard set of guidelines and training seminars should be created and adhered to strictly for progress to be made. The difficulty with the creation of these guidelines is the necessity to include different systems for each unique area and situation. A predictive equation could be developed that may help in the determination of salt application for a variety of circumstances (Fromm, 1982).

Management should start from the beginning and therefore with the storage of sodium chloride. Fromm (1982) suggests that the salt should be stored in a sealed shed with proper flooring to decrease the amount of salt leaking out, a reduction in the amount of salt added to storage piles of sand to 5% from the current 7% and, once the salt is added to the sand to form the deicing mixture, the mixture should be covered in a salt dome to reduce the amount of salt lost to the environment through leaching, wind and precipitation (Fromm, 1982).

Some basic regulations for the actual use of the de-icers would be to use salt only for deicing purposes, sand only for skidproofing highways when the temperature is not suitable for the use of salt, and never salt before the arrival of a storm or during the course of a storm but only just after the beginning with a greater emphasis on the use of snow plows and after storm clean-ups (Fromm, 1982).

Along with the recommendation to reduce the amount of salt used by initiating guidelines for suggested deicing application amounts and rates, Fromm (1982) advises the evaluation of different percentages for the salt in sand mixture to see if these mixtures might lead to the use of less salt. A more complicated suggestion is to prewet the salt before application as a liquid mixture is estimated to work faster and use a predicted 25% less salt than used in normal applications (Fromm, 1982).

Esch (1984) suggests the use of sand only with the plow. This could provide temporary skid resistance and may be effective if reapplied often. The accumulation of sand from the winter months would have to be removed from the drainage network during the spring thaw to prevent any blockage. This clean-up would be necessary to limit the use of dust control agents, such as calcium chloride, in the summer to reduce further contamination in the region from a different season. "The less sand that is used as a winter traction aid and the sooner it is cleaned up in the springtime, the smaller the dust emissions from this source will be" (Reckard, 1988).

The difficulty with using straight sand on winter highways is that the sand works only for traction or to skid proof the road. When the temperature of the sand and ice are close to the melting point, the sand adheres to the ice and skid resistance is developed. However, when the temperature is much lower than the melting point the sand cannot penetrate the ice surface and simply blows off from the motion of vehicles or the wind. Hayhoe (1984) suggested the application of preheated sand on the highway which would allow the sand to penetrate the ice and thereby to develop a skid resistant surface. The main problem with this technique would be the cost of preheating the sand, maintaining the heat until the application and perhaps the development of excess ice after application during marginal temperatures.

In 1984, the strangest of suggested management techniques was offered and tested by Aspinwall and Wilson at The Ontario Ministry of Transportation and Communications. It was labelled "The Preferred Salt Option Study" and investigated the use of straight salt for highway deicing. The study focused on portions of freeway in and around Metropolitan Toronto. The conclusions were that the amount of salt used did not increase with a change in maintenance procedure to straight salt and that the factor of highway safety was improved and there was a reduction in spreader trips and cleanup operations. Mah and Pasquan (1988) investigated this policy and possible implementation in Alberta. They concluded that due to the Alberta's colder climate, the "straight salt" policy would not be as beneficial here as it was stated for Ontario. As well, potential safety hazards could occur during the colder months and at nighttime temperatures (Mah and Pasquan, 1988). The use of straight salt, whether it maintains the current usage or not, still does not reduce the amount of danger to the environment.

6.4 CONCLUSIONS AND SUGGESTIONS

Using sodium chloride as a highway de-icing agent has been found to be detrimental to the environment. It alters basic soil properties, limits plant growth, contaminates the water system and may harm wildlife. However, it is not economically feasible to change de-icing practices haphazardly. Stopping the de-icing process completely would be controversial as this would jeopardize human safety. Abruptly switching to a de-icing alternative without the proper testing would also prove detrimental as there would be no certainty as to the possible side-effects of these options. Initial attempts to reduce the adverse effects of de-icing salt use would be guidelines for the storage and application of the deicing mixture. The process to improved de-icing management techniques will be slow. Areas significantly sensitive to salt would be good locations to begin trial studies on alternatives.

Mount Norquay in Banff National Park is home to a ski resort and must contend with the winter road circumstances to create route conditions that will encourage the public to visit the ski hill through all types of weather. The difficulty arises from the native vegetation along the access route. For hundreds of years this slope has been home to a population of Douglas fir trees. Highly sensitive to sodium chloride, these trees are showing the decreased vigour and browning associated with salt toxicity. Banff National Park Wardens obtained samples of the foliage and performed a detailed analysis. Excessive chloride concentrations were named as the cause. Sensitive regions such as Mount Norquay would be excellent areas to begin studies into the alternatives to sodium chloride for de-icing. Urea has been suggested for de-icing, however, more research is needed as to the dilution, handling and application of this substance. In the proper concentration this compound could de-ice the access road as well as act as a fertilizer for the roadside vegetation. The road is relatively confined and not very long. This would provide an superb trial area.

Overall, soil is an essential natural resource. As society stretches the environment to its limits, more marginal land must be utilized. The detrimental effects associated with road salt and the mobility of sodium chloride must be further studied to gain a better understanding and awareness of the environmental consequences from highway de-icing.

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APPENDICES

APPENDIX A

COMPLETE DATA SET

LEGEND FOR DATA SET

LOCAT = Location of sampling
1 - Calgary TransCanada Highway
2 - Calgary Secondary Roads
3 - Brooks TransCanada Highway
4 - Brooks Secondary Roads
5 - Banff TransCanada Highway
6 - Banff Secondary Roads

SITE = Sampling sites at each location
-See figures 3.1, 3.2 and 3.3.

DISTMAY = Distance of samples from highway for May (m)

DISTJULY = Distance of samples from highway for July (m)

DISTOCT = Distance of samples from highway for October (m)

DEPTH = Depth of samples extracted (cm)

NAMAY = Sodium concentration for May (ppm)

NAJULY = Sodium concentration for July (ppm)

NAOCT = Sodium concentration for October (ppm)

pHMAY = pH value for May

pHJULY = pH value for July

pHOCT = pH value for October

ECMAY = Electrical conductivity for May (MV)

ECJULY = Electrical conductivity for July (MV)

ECOCT = Electrical conductivity for October (MV)

SAND = Sand content (percentage)

SILT = Silt content (percentage)

CLAY = Clay content (percentage)

LOCAT	SITE	DISTMAY	DISTJULY	DISTOCT	DEPTH	NAMAY	NAJULY	NAOCT	pHMAY	pHJUL	pHOCT	ECMAY	ECJULY	ECOCT	SAND	SILT	CLAY
1	1	1.5	1.5	1.5	0.05	35.65	50.34	25.54	9.11	9.12	8.97	-0.124	-0.124	-0.115	53.75	23.75	22.50
1	1	1.5	1.5	1.5	0.15	61.25	46.20	38.99	9.93	9.46	9.20	-0.136	-0.144	-0.129	43.75	28.75	27.50
1	1	1.5	1.5	1.5	0.25	73.53	57.51	39.06	9.29	9.32	9.06	-0.134	-0.135	-0.121	48.75	27.50	23.75
1	1	1.5	1.5	1.5	0.35	72.89	57.69	44.79	9.09	8.95	8.64	-0.122	-0.115	-0.098	36.25	32.50	31.25
1	1	8.0	8.0	8.0	0.05	10.39	28.34	10.50	7.48	8.53	7.91	-0.028	-0.089	-0.053	40.00	33.75	26.25
1	1	8.0	8.0	8.0	0.15	11.99	6.86	10.51	8.27	8.60	8.35	-0.073	-0.094	-0.079	33.75	37.50	28.75
1	1	8.0	8.0	8.0	0.25	15.34	8.70	13.09	8.41	8.40	8.58	-0.079	-0.081	-0.092	28.75	43.75	27.50
1	1	8.0	8.0	8.0	0.35	11.61	5.49	10.21	7.99	8.43	8.43	-0.058	-0.084	-0.084	27.50	41.25	31.25
1	1	23.0	22.5	23.5	0.05	3.47	0.69	1.06	7.94	8.44	7.15	-0.056	-0.084	-0.012	33.75	37.50	28.75
1	1	23.0	22.5	23.5	0.15	2.77	2.49	1.51	8.32	7.80	8.11	-0.078	-0.048	-0.066	31.25	40.00	28.75
1	1	23.0	22.5	23.5	0.25	5.82	13.21	3.63	8.40	7.82	8.17	-0.081	-0.048	-0.069	21.25	47.50	31.25
1	1	23.0	22.5	23.5	0.35	9.71	40.01	6.36	8.36	7.72	8.15	-0.078	-0.042	-0.068	28.75	40.00	31.25
1	4	2.5	2.0	2.0	0.05	30.39	23.57	14.97	7.77	8.26	7.76	-0.044	-0.072	-0.045	45.00	38.75	16.25
1	4	2.5	2.0	2.0	0.15	30.10	23.39	22.35	8.65	8.39	8.37	-0.095	-0.080	-0.082	36.25	36.25	27.50
1	4	2.5	2.0	2.0	0.25	26.64	32.07	19.47	8.70	8.56	8.54	-0.099	-0.094	-0.090	33.75	37.50	28.75
1	4	2.5	2.0	2.0	0.35	24.95	21.53	20.75	8.83	7.50	8.31	-0.106	-0.037	-0.076	31.25	40.00	28.75
1	4	13.5	13.5	13.5	0.05	26.42	18.20	21.34	7.38	6.73	6.31	-0.022	0.017	-0.044	41.25	37.50	21.25
1	4	13.5	13.5	13.5	0.15	10.87	17.75	27.32	6.86	7.38	7.17	0.007	-0.024	-0.009	33.75	42.50	23.75
1	4	13.5	13.5	13.5	0.25	16.61	27.86	27.81	7.52	7.19	7.22	-0.029	-0.009	-0.012	31.25	48.75	20.00
1	4	13.5	13.5	13.5	0.35	18.53	20.25	23.68	7.08	7.24	6.84	-0.003	-0.011	0.006	33.75	40.00	26.25
1	4	16.0	16.0	16.0	0.05	13.70	9.11	24.39	5.92	5.23	5.54	0.068	0.108	0.093	26.25	50.00	23.75
1	4	16.0	16.0	16.0	0.15	20.32	1.05	25.93	7.48	7.59	6.65	0.025	-0.025	0.031	31.25	45.00	23.75
1	4	16.0	16.0	16.0	0.25	3.06	12.37	27.35	7.86	7.38	6.72	-0.049	-0.021	0.019	33.75	43.75	22.50
1	4	16.0	16.0	16.0	0.35	17.00	26.60	29.25	7.44	7.39	6.57	-0.024	-0.020	0.019	31.25	46.25	22.50
1	15	2.0	2.0	2.0	0.05	30.12	17.91	28.92	9.27	8.46	8.99	-0.132	-0.084	-0.116	51.25	30.00	18.75
1	15	2.0	2.0	2.0	0.15	47.87	28.48	30.49	9.02	9.28	9.08	-0.117	-0.133	-0.122	23.75	42.50	33.75
1	15	2.0	2.0	2.0	0.25	45.88	27.42	26.17	8.95	9.07	9.14	-0.113	-0.119	-0.126	21.25	42.50	36.25
1	15	2.0	2.0	2.0	0.35	47.80	14.59	28.33	8.65	8.89	8.90	-0.100	-0.111	-0.110	26.25	45.00	28.75
1	15	17.5	17.5	17.0	0.05	2.98	1.73	7.96	7.67	7.94	7.28	-0.038	-0.053	-0.017	18.75	52.50	28.75
1	15	17.5	17.5	17.0	0.15	10.48	9.03	7.21	7.82	7.85	7.09	-0.047	-0.046	-0.007	26.25	50.00	23.75
1	15	17.5	17.5	17.0	0.25	10.18	13.64	9.41	7.98	7.82	7.85	-0.056	-0.050	-0.048	11.25	40.00	48.75
1	15	17.5	17.5	17.0	0.35	10.34	12.72	8.01	8.05	7.97	7.96	-0.062	-0.055	-0.055	10.00	43.75	46.25
1	15	24.0	23.0	23.0	0.05	1.78	4.47	3.56	7.29	7.28	7.28	-0.017	-0.014	-0.014	25.00	51.25	23.75
1	15	24.0	23.0	23.0	0.15	5.90	6.89	6.61	7.85	7.79	7.36	-0.049	-0.050	-0.020	21.25	47.50	31.25
1	15	24.0	23.0	23.0	0.25	12.05	9.94	8.69	7.89	8.00	7.55	-0.050	-0.056	-0.033	11.25	55.00	33.75
1	15	24.0	23.0	23.0	0.35	8.57	12.76	9.03	7.92	7.59	7.33	-0.055	-0.032	-0.019	10.00	37.50	52.50
1	16	3.5	3.0	3.0	0.05	9.94	15.18	15.45	8.33	8.13	8.55	-0.077	-0.067	-0.090	18.75	38.75	42.50
1	16	3.5	3.0	3.0	0.15	18.43	20.88	20.72	8.54	8.46	8.53	-0.090	-0.084	-0.090	5.00	41.25	53.75
1	16	3.5	3.0	3.0	0.25	15.90	17.63	17.82	8.37	8.57	8.66	-0.079	-0.092	-0.097	0.00	45.00	56.25
1	16	3.5	3.0	3.0	0.35	10.01	14.00	12.93	8.70	8.81	8.72	-0.098	-0.106	-0.100	0.00	48.75	51.25
1	16	10.0	10.0	9.5	0.05	12.09	14.99	24.32	7.92	7.84	7.75	-0.052	-0.053	-0.043	6.25	50.00	43.75
1	16	10.0	10.0	9.5	0.15	13.74	9.91	16.30	8.25	8.35	8.19	-0.072	-0.078	-0.070	1.25	42.50	56.25
1	16	10.0	10.0	9.5	0.25	15.38	13.85	13.62	8.04	8.41	8.09	-0.063	-0.082	-0.064	0.00	45.00	55.00
1	16	10.0	10.0	9.5	0.35	13.68	12.61	16.84	8.37	7.96	8.23	-0.081	-0.062	-0.071	3.75	38.75	57.50
1	16	16.0	15.5	15.5	0.05	1.43	1.37	2.89	7.92	7.78	7.84	-0.052	-0.044	-0.047	13.75	45.00	41.25
1	16	16.0	15.5	15.5	0.15	2.49	2.52	5.60	8.09	8.35	7.38	-0.064	-0.079	-0.024	8.75	48.75	42.50
1	16	16.0	15.5	15.5	0.25	4.29	2.45	0.65	6.89	8.27	6.81	0.007	-0.073	0.010	6.25	48.75	45.00
1	16	16.0	15.5	15.5	0.35	2.09	2.41	1.96	7.17	7.61	8.14	-0.014	-0.051	-0.067	3.75	43.75	52.50
1	20	3.0	3.0	3.5	0.05	22.20	20.00	13.78	8.13	8.66	7.96	-0.065	-0.099	-0.056	27.50	37.50	35.00
1	20	3.0	3.0	3.5	0.15	23.19	31.13	10.61	7.88	8.62	8.41	-0.061	-0.093	-0.083	0.00	48.75	51.25
1	20	3.0	3.0	3.5	0.25	21.42	24.34	13.59	8.13	9.00	8.39	-0.065	-0.117	-0.081	0.00	47.50	52.50
1	20	3.0	3.0	3.5	0.35	25.08	15.29	13.51	7.98	7.97	8.35	-0.057	-0.055	-0.080	0.00	36.25	63.75
1	20	9.5	9.5	9.5	0.05	10.90	2.35	8.67	7.86	8.40	7.88	-0.049	-0.082	-0.050	3.75	50.00	46.25
1	20	9.5	9.5	9.5	0.15	2.12	1.43	5.89	7.89	7.71	7.78	-0.054	-0.034	-0.045	1.25	47.50	51.25
1	20	9.5	9.5	9.5	0.25	3.35	1.88	2.52	7.69	8.17	7.98	-0.039	-0.067	-0.058	0.00	46.25	53.75
1	20	9.5	9.5	9.5	0.35	6.69	2.60	2.35	7.79	8.37	8.22	-0.046	-0.079	-0.071	0.00	43.75	56.25
1	20	16.0	15.0	16.0	0.05	5.29	8.38	3.16	6.67	7.33	6.40	0.021	-0.018	0.034	26.25	45.00	28.75
1	20	16.0	15.0	16.0	0.15	2.70	2.72	2.59	6.74	7.60	6.83	0.020	-0.032	0.014	7.50	53.75	38.75
1	20	16.0	15.0	16.0	0.25	2.33	2.75	3.17	6.75	7.21	6.94	0.018	-0.010	0.006	18.75	45.00	36.25

1	20	16.0	15.0	16.0	0.35	3.00	0.57	2.65	7.23	7.55	6.44	-0.011	-0.032	0.036	3.75	42.50	53.75
2	2	2.0	2.0	2.0	0.05	3.33	3.87	0.96	8.83	8.61	8.22	-0.106	-0.093	-0.072	66.25	16.25	17.50
2	2	2.0	2.0	2.0	0.15	4.57	5.79	2.03	8.34	8.53	7.93	-0.078	-0.088	-0.056	41.25	27.50	31.25
2	2	2.0	2.0	2.0	0.25	4.09	4.86	4.48	8.14	8.31	8.19	-0.066	-0.080	-0.070	41.25	31.25	27.50
2	2	2.0	2.0	2.0	0.35	3.75	2.27	6.07	7.78	8.29	8.25	-0.049	-0.075	-0.072	46.25	28.75	25.00
2	2	5.5	6.0	5.5	0.05	8.15	21.89	13.87	7.54	8.18	8.11	-0.035	-0.069	-0.064	36.25	31.25	32.50
2	2	5.5	6.0	5.5	0.15	8.34	27.18	13.18	7.79	7.81	8.16	-0.045	-0.047	-0.068	31.25	37.50	31.25
2	2	5.5	6.0	5.5	0.25	4.90	19.22	29.37	7.86	8.13	8.51	-0.049	-0.064	-0.088	21.25	30.00	48.75
2	2	5.5	6.0	5.5	0.35	6.82	13.53	11.62	8.07	8.40	8.18	-0.061	-0.081	-0.069	51.25	26.25	22.50
2	2	6.5	7.0	7.0	0.05	3.05	17.18	33.19	7.53	7.53	7.95	-0.032	-0.031	-0.055	41.25	26.25	32.50
2	2	6.5	7.0	7.0	0.15	10.67	21.74	34.04	7.87	7.72	7.45	-0.050	-0.041	-0.032	26.25	30.00	43.75
2	2	6.5	7.0	7.0	0.25	9.17	19.04	28.82	7.72	7.60	7.93	-0.041	-0.037	-0.055	33.75	36.25	30.00
2	2	6.5	7.0	7.0	0.35	6.19	14.81	21.24	7.82	8.19	8.57	-0.047	-0.069	-0.091	31.25	33.75	35.00
2	3	2.0	2.0	2.0	0.05	14.18	1.15	0.89	8.36	7.35	8.17	-0.080	-0.025	-0.068	56.25	18.75	25.00
2	3	2.0	2.0	2.0	0.15	5.45	2.00	3.99	7.98	8.34	7.84	-0.055	-0.081	-0.051	32.50	36.25	31.25
2	3	2.0	2.0	2.0	0.25	5.15	2.99	35.06	8.12	7.83	8.21	-0.063	-0.050	-0.072	32.50	31.25	36.25
2	3	2.0	2.0	2.0	0.35	5.79	5.07	8.53	8.50	7.42	7.50	-0.087	-0.023	-0.029	31.25	31.25	37.50
2	3	4.5	4.0	4.0	0.05	1.29	0.50	1.10	7.53	8.02	7.91	-0.030	-0.059	-0.053	38.75	22.50	38.75
2	3	4.5	4.0	4.0	0.15	1.86	1.38	0.75	7.93	7.26	8.10	-0.052	-0.017	-0.064	23.75	28.75	47.50
2	3	4.5	4.0	4.0	0.25	5.95	0.53	2.17	7.80	7.85	7.69	-0.045	-0.048	-0.039	40.00	18.75	41.25
2	3	4.5	4.0	4.0	0.35	2.55	0.27	0.50	7.88	8 47	7.82	-0.050	-0.086	-0.046	33.75	22.50	43.75
2	3	5.0	5.5	5.5	0.05	1.00	0.69	0.37	7.18	8.10	7.95	-0.011	-0.063	-0.054	36.25	23.75	40.00
2	3	5.0	5.5	5.5	0.15	2.54	0.99	1.14	7.66	8.11	7.70	-0.037	-0.063	-0.040	28.75	25.00	46.25
2	3	5.0	5.5	5.5	0.25	1.81	1.11	1.14	7.84	7.34	7.29	-0.049	-0.023	-0.019	22.50	30.00	47.50
2	3	5.0	5.5	5.5	0.35	2.14	1.09	1.21	7.82	8.10	7.31	-0.047	-0.066	-0.023	23.75	31.25	45.00
2	17	1.5	1.5	1.5	0.05	14.66	2.22	9.56	7.31	7.78	7.94	-0.016	-0.047	-0.058	31.25	37.50	31.25
2	17	1.5	1.5	1.5	0.15	14.34	9.17	13.93	8.24	7.91	7.12	-0.074	-0.055	-0.011	28.75	41.25	30.00
2	17	1.5	1.5	1.5	0.25	8.92	7.66	8.81	8.13	8.29	7.99	-0.066	-0.076	-0.058	26.25	36.25	37.50
2	17	1.5	1.5	1.5	0.35	7.30	1.73	7.64	6.62	8.28	8.25	-0.015	-0.076	-0.072	20.00	38.75	41.25
2	17	3.5	3.5	3.5	0.05	5.47	5.23	5.21	7.74	7.05	8.20	-0.045	-0.002	-0.069	16.25	46.25	37.50
2	17	3.5	3.5	3.5	0.15	5.15	4.20	5.08	7.70	8.44	8.29	-0.047	-0.089	-0.076	23.75	38.75	37.50
2	17	3.5	3.5	3.5	0.25	3.67	4.18	5.09	8.16	8.59	8.34	-0.068	-0.092	-0.079	33.75	33.75	32.50
2	17	3.5	3.5	3.5	0.35	5.32	5.12	4.82	8.19	8.78	8.28	-0.069	-0.103	-0.076	15.00	45.00	40.00
2	17	6.5	6.5	7.0	0.05	0.92	0.29	0.74	7.50	7.72	7.64	-0.027	-0.041	-0.036	25.00	48.75	26.25
2	17	6.5	6.5	7.0	0.15	0.90	0.61	1.29	7.48	7.54	7.66	-0.027	-0.030	-0.037	16.25	56.25	27.50
2	17	6.5	6.5	7.0	0.25	1.53	0.68	0.96	7.37	7.69	7.16	-0.020	-0.038	-0.009	16.25	50.00	33.75
2	17	6.5	6.5	7.0	0.35	1.77	0.70	0.63	7.41	8.08	7.52	-0.052	-0.062	-0.030	13.75	47.50	38.75
2	18	2.0	3.0	3.0	0.05	2.58	1.41	0.66	7.92	7.94	7.80	-0.052	-0.054	-0.046	18.75	41.25	40.00
2	18	2.0	3.0	3.0	0.15	2.17	0.64	1.20	8.15	7.87	7.46	-0.065	-0.055	-0.032	18.75	37.50	43.75
2	18	2.0	3.0	3.0	0.25	3.07	1.11	1.08	7.79	8.25	8.12	-0.045	-0.060	-0.065	21.25	40.00	38.75
2	18	2.0	3.0	3.0	0.35	6.75	1.12	0.68	7.86	7.78	6.38	-0.049	-0.044	0.033	12.50	43.75	43.75
2	18	4.5	4.0	4.0	0.05	2.20	0.71	0.69	7.49	7.78	7.70	-0.027	-0.044	-0.041	8.75	46.25	45.00
2	18	4.5	4.0	4.0	0.15	2.22	0.70	1.03	7.66	7.68	7.58	-0.036	-0.038	-0.034	18.75	41.25	40.00
2	18	4.5	4.0	4.0	0.25	3.14	0.98	1.32	7.31	8.04	7.21	-0.016	-0.063	-0.010	16.25	50.00	33.75
2	18	4.5	4.0	4.0	0.35	2.70	0.57	0.76	7.27	7.83	7.17	-0.016	-0.048	-0.009	33.75	32.50	33.75
2	18	6.5	6.5	6.5	0.05	13.62	0.29	0.48	6.15	6.96	7.22	0.048	0.002	-0.010	16.25	50.00	33.75
2	18	6.5	6.5	6.5	0.15	1.91	0.49	0.53	7.65	7.78	6.95	-0.036	-0.042	0.002	18.75	50.00	31.25
2	18	6.5	6.5	6.5	0.25	1.15	0.74	10.84	7.32	7.88	7.62	-0.015	-0.051	-0.034	13.75	47.50	38.75
2	18	6.5	6.5	6.5	0.35	1.69	0.37	0.51	6.99	7.85	7.63	0.003	-0.048	-0.035	6.25	45.00	48.75
2	19	2.5	2.0	2.0	0.05	5.89	3.43	3.62	8.20	8.28	8.01	-0.071	-0.074	-0.059	11.25	43.75	45.00
2	19	2.5	2.0	2.0	0.15	5.33	4.51	1.75	8.21	8.28	8.20	-0.069	-0.073	-0.069	6.25	45.00	48.75
2	19	2.5	2.0	2.0	0.25	5.26	3.67	3.67	8.22	8.25	8.18	-0.073	-0.072	-0.069	0.00	38.75	61.25
2	19	2.5	2.0	2.0	0.35	3.29	4.78	3.61	8.32	8.44	8.15	-0.078	-0.087	-0.067	0.00	41.25	58.75
2	19	7.5	7.0	7.0	0.05	4.12	4.53	4.63	8.11	7.98	8.08	-0.064	-0.062	-0.064	6.25	48.75	45.00
2	19	7.5	7.0	7.0	0.15	5.48	2.51	4.60	7.93	8.61	7.83	-0.055	-0.097	-0.051	1.25	47.50	51.25
2	19	7.5	7.0	7.0	0.25	6.28	4.20	4.53	8.23	8.38	8.32	-0.071	-0.079	-0.078	40.00	2.50	57.50
2	19	7.5	7.0	7.0	0.35	5.16	3.16	3.56	8.55	8.31	8.49	-0.090	-0.076	-0.087	0.00	40.00	60.00
2	19	11.5	11.0	11.0	0.05	2.04	0.30	0.47	7.66	7.63	7.18	-0.038	-0.042	-0.011	8.75	52.50	38.75
2	19	11.5	11.0	11.0	0.15	2.24	0.43	0.82	7.74	7.81	7.88	-0.042	-0.049	-0.056	13.75	45.00	41.25
2	19	11.5	11.0	11.0	0.25	3.62	2.90	1.48	7.77	7.87	8.00	-0.043	-0.050	-0.057	0.00	43.75	56.25

2	19	11.5	11.0	11.0	0.35	5.67	12.48	4.48	8.07	7.91	6.58	-0.061	-0.056	0.005	0.00	42.50	57.50
3	6	2.0	2.0	2.0	0.05	8.12	17.45	3.77	7.89	9.01	7.65	-0.051	-0.116	-0.043	51.25	30.00	18.75
3	6	2.0	2.0	2.0	0.15	8.75	23.84	9.59	8.54	9.10	7.72	-0.090	-0.121	-0.044	46.25	30.00	23.75
3	6	2.0	2.0	2.0	0.25	12.29	15.49	9.21	8.14	8.78	8.37	-0.071	-0.103	-0.080	43.75	31.25	25.00
3	6	2.0	2.0	2.0	0.35	12.98	10.90	5.54	8.48	8.48	7.69	-0.085	-0.086	-0.041	43.75	32.50	23.75
3	6	13.0	13.5	13.5	0.05	10.78	1.24	2.36	7.12	8.68	7.91	-0.009	-0.097	-0.053	23.75	45.00	31.25
3	6	13.0	13.5	13.5	0.15	39.43	1.73	14.75	8.11	8.55	8.25	-0.063	-0.090	-0.072	11.25	57.50	31.25
3	6	13.0	13.5	13.5	0.25	33.35	4.66	65.36	7.68	8.35	8.05	-0.039	-0.080	-0.061	8.75	57.50	33.75
3	6	13.0	13.5	13.5	0.35	83.70	7.47	72.66	7.88	7.91	8.11	-0.051	-0.062	-0.065	11.25	55.00	33.75
3	6	22.5	22.0	22.5	0.05	1.78	1.36	3.58	7.06	7.89	7.71	-0.001	-0.053	-0.041	13.75	55.00	31.25
3	6	22.5	22.0	22.5	0.15	1.65	2.03	29.81	7.15	8.18	7.63	-0.007	-0.067	-0.045	17.50	51.25	31.25
3	6	22.5	22.0	22.5	0.25	17.01	2.81	1.74	6.79	7.88	7.81	0.013	-0.060	-0.047	13.75	55.00	31.25
3	6	22.5	22.0	22.5	0.35	33.79	5.90	1.97	7.66	8.04	8.19	-0.039	-0.067	-0.069	16.25	53.75	30.00
3	8	1.5	1.5	1.5	0.05	7.36	0.99	1.14	7.98	8.32	7.31	-0.057	-0.078	-0.028	58.75	26.25	15.00
3	8	1.5	1.5	1.5	0.15	10.98	2.25	5.59	8.87	8.68	8.58	-0.109	-0.101	-0.091	55.00	26.25	18.75
3	8	1.5	1.5	1.5	0.25	14.06	5.39	6.55	9.01	8.58	8.27	-0.117	-0.095	-0.078	51.25	32.50	16.25
3	8	1.5	1.5	1.5	0.35	19.89	8.29	14.00	8.29	8.23	8.89	-0.075	-0.071	-0.110	51.25	30.00	18.75
3	8	12.5	12.5	12.0	0.05	4.36	1.00	1.34	7.99	8.03	6.72	-0.059	-0.059	0.004	51.25	27.50	21.25
3	8	12.5	12.5	12.0	0.15	9.90	2.61	6.90	8.47	8.23	7.43	-0.095	-0.071	-0.021	70.00	11.25	18.75
3	8	12.5	12.5	12.0	0.25	1.67	2.58	1.55	8.10	8.33	7.64	-0.065	-0.076	-0.037	71.25	12.50	16.25
3	8	12.5	12.5	12.0	0.35	5.55	4.61	18.25	8.67	8.64	7.94	-0.096	-0.095	-0.056	76.25	10.00	13.75
3	8	16.5	16.0	16.5	0.05	17.68	13.42	1.03	7.23	7.45	6.01	-0.013	-0.033	0.054	58.75	25.00	16.25
3	8	16.5	16.0	16.5	0.15	9.83	11.43	9.86	7.99	8.21	7.97	-0.057	-0.070	-0.056	56.25	23.75	20.00
3	8	16.5	16.0	16.5	0.25	17.23	12.14	33.20	8.28	8.23	7.70	-0.074	-0.069	-0.042	63.75	17.50	18.75
3	8	16.5	16.0	16.5	0.35	23.00	32.51	79.71	7.60	7.81	7.61	-0.035	-0.044	-0.042	58.75	17.50	23.75
3	11	1.5	2.0	2.0	0.05	14.46	13.15	9.87	7.84	9.32	7.61	-0.047	-0.136	-0.041	70.00	18.75	11.25
3	11	1.5	2.0	2.0	0.15	23.62	24.64	24.45	9.04	9.03	8.65	-0.117	-0.119	-0.124	67.50	18.75	13.75
3	11	1.5	2.0	2.0	0.25	11.35	21.57	18.21	9.01	9.72	9.23	-0.118	-0.158	-0.131	71.25	13.75	15.00
3	11	1.5	2.0	2.0	0.35	9.19	34.01	15.25	8.74	9.60	9.02	-0.103	-0.150	-0.118	62.50	18.75	18.75
3	11	14.5	14.0	14.0	0.05	2.66	0.44	0.56	7.93	7.68	8.55	-0.055	-0.040	-0.090	57.50	27.50	15.00
3	11	14.5	14.0	14.0	0.15	1.34	1.09	1.13	8.42	8.65	8.67	-0.085	-0.095	-0.097	68.75	20.00	11.25
3	11	14.5	14.0	14.0	0.25	2.28	3.49	1.42	8.35	8.20	8.51	-0.081	-0.070	-0.088	63.75	22.50	13.75
3	11	14.5	14.0	14.0	0.35	3.69	2.25	9.89	8.09	8.72	8.02	-0.063	-0.101	-0.061	67.50	18.75	13.75
3	11	16.5	17.0	17.0	0.05	1.07	0.87	2.21	8.42	8.61	7.48	-0.082	-0.093	-0.029	63.75	22.50	13.75
3	11	16.5	17.0	17.0	0.15	2.06	1.22	2.49	7.86	8.71	6.21	-0.049	-0.099	0.039	68.75	20.00	11.25
3	11	16.5	17.0	17.0	0.25	5.62	0.62	4.36	7.08	8.71	7.67	-0.009	-0.101	-0.038	63.75	25.00	11.25
3	11	16.5	17.0	17.0	0.35	6.31	1.62	12.73	8.28	7.89	7.24	-0.072	-0.053	-0.016	61.25	23.75	15.00
3	13	2.0	2.0	2.0	0.05	10.00	11.38	6.47	7.33	8.36	8.40	-0.020	-0.081	-0.079	73.75	15.00	11.25
3	13	2.0	2.0	2.0	0.15	9.75	11.32	0.61	7.84	9.39	8.87	-0.047	-0.140	-0.108	73.75	13.75	12.50
3	13	2.0	2.0	2.0	0.25	8.30	9.22	12.85	8.87	8.22	9.16	-0.107	-0.072	-0.126	73.75	13.75	12.50
3	13	2.0	2.0	2.0	0.35	10.71	10.35	16.63	9.00	8.15	9.07	-0.117	-0.069	-0.123	72.50	15.00	12.50
3	13	11.0	10.5	10.5	0.05	2.74	2.06	1.55	7.79	8.23	8.38	-0.048	-0.078	-0.080	68.75	18.75	12.50
3	13	11.0	10.5	10.5	0.15	2.91	5.52	27.09	8.27	8.49	7.66	-0.070	-0.086	-0.038	68.75	17.50	13.75
3	13	11.0	10.5	10.5	0.25	6.99	1.23	27.62	7.93	7.57	7.74	-0.056	-0.048	-0.044	77.50	7.50	15.00
3	13	11.0	10.5	10.5	0.35	2.55	0.86	28.56	8.59	8.92	8.25	-0.091	-0.113	-0.073	78.75	6.25	15.00
3	13	17.5	17.0	17.0	0.05	2.26	0.60	4.74	7.49	8.71	8.43	-0.033	-0.102	-0.084	68.75	17.50	13.75
3	13	17.5	17.0	17.0	0.15	3.75	0.78	4.71	7.70	8.57	8.39	-0.041	-0.091	-0.081	66.25	15.00	18.75
3	13	17.5	17.0	17.0	0.25	4.02	3.84	4.13	7.95	8.50	8.52	-0.054	-0.089	-0.089	71.25	16.25	12.50
3	13	17.5	17.0	17.0	0.35	3.16	13.17	11.40	8.36	8.33	7.67	-0.083	-0.077	-0.043	78.75	10.00	11.25
3	14	2.0	2.0	2.0	0.05	19.07	17.92	9.67	8.16	8.84	8.05	-0.069	-0.106	-0.064	46.25	32.50	21.25
3	14	2.0	2.0	2.0	0.15	19.74	34.25	19.41	8.00	8.93	8.76	-0.058	-0.112	-0.103	38.75	35.00	26.25
3	14	2.0	2.0	2.0	0.25	26.26	44.80	20.29	7.55	8.39	7.97	-0.032	-0.082	-0.055	37.50	36.25	26.25
3	14	2.0	2.0	2.0	0.35	44.77	71.20	62.42	8.11	7.58	7.98	-0.063	-0.029	-0.056	37.50	35.00	27.50
3	14	17.0	17.0	17.0	0.05	4.42	0.67	1.71	7.54	8.32	8.17	-0.030	-0.078	-0.068	35.00	46.25	18.75
3	14	17.0	17.0	17.0	0.15	6.51	4.19	6.14	7.33	7.59	7.38	-0.017	-0.033	-0.019	38.75	42.50	18.75
3	14	17.0	17.0	17.0	0.25	9.25	8.34	8.92	7.25	7.47	7.19	-0.012	-0.026	-0.009	28.75	42.50	28.75
3	14	17.0	17.0	17.0	0.35	7.87	25.45	8.56	6.97	7.17	7.63	0.003	-0.011	-0.035	23.75	27.50	48.75
3	14	23.5	24.0	23.5	0.05	5.31	2.09	4.09	6.73	7.67	7.04	0.020	-0.037	0.001	32.50	48.75	18.75
3	14	23.5	24.0	23.5	0.15	5.89	0.77	7.75	7.38	7.91	7.32	-0.020	-0.049	-0.016	21.25	40.00	38.75
3	14	23.5	24.0	23.5	0.25	5.45	1.32	6.95	7.65	8.32	7.65	-0.029	-0.077	-0.039	33.75	32.50	33.75

3	14	23.5	24.0	23.5	0.35	5.17	1.47	10.81	8.06	8.58	7.33	-0.060	-0.091	-0.019	51.25	25.00	23.75
4	5	1.0	1.0	1.0	0.05	34.67	35.83	23.79	7.46	8.18	8.02	-0.026	-0.069	-0.058	41.25	22.50	36.25
4	5	1.0	1.0	1.0	0.15	88.55	120.56	107.77	7.63	7.35	8.02	-0.036	-0.028	-0.059	23.75	30.00	46.25
4	5	1.0	1.0	1.0	0.25	137.71	165.36	165.32	7.73	8.01	7.41	-0.043	-0.059	-0.023	26.25	32.50	41.25
4	5	1.0	1.0	1.0	0.35	106.87	115.55	148.51	8.04	7.98	8.07	-0.062	-0.056	-0.062	31.25	31.25	37.50
4	5	5.0	4.5	4.5	0.05	32.81	11.86	9.08	8.10	7.95	8.26	-0.063	-0.058	-0.073	33.75	27.50	38.75
4	5	5.0	4.5	4.5	0.15	37.13	13.51	11.52	8.40	8.49	8.44	-0.080	-0.086	-0.084	33.75	27.50	38.75
4	5	5.0	4.5	4.5	0.25	53.81	17.20	18.48	7.19	8.75	8.04	-0.012	-0.104	-0.062	31.25	35.00	33.75
4	5	5.0	4.5	4.5	0.35	37.61	14.44	29.25	8.62	7.80	8.28	-0.092	-0.045	-0.075	31.25	38.75	30.00
4	5	6.0	5.5	5.5	0.05	29.72	23.82	28.82	8.29	7.71	7.52	-0.074	-0.039	-0.034	32.50	38.75	28.75
4	5	6.0	5.5	5.5	0.15	25.85	28.78	18.15	8.01	8.23	7.93	-0.058	-0.073	-0.053	28.75	45.00	26.25
4	5	6.0	5.5	5.5	0.25	36.16	30.09	26.36	8.44	8.21	8.11	-0.085	-0.069	-0.063	31.25	43.75	25.00
4	5	6.0	5.5	5.5	0.35	32.00	30.94	26.63	8.16	8.70	8.15	-0.067	-0.097	-0.067	33.75	37.50	28.75
4	7	1.0	1.5	1.5	0.05	0.96	0.43	0.76	7.14	7.89	7.76	-0.007	-0.051	-0.044	68.75	17.50	13.75
4	7	1.0	1.5	1.5	0.15	1.81	0.36	12.81	7.85	7.97	6.70	-0.049	-0.055	-0.004	78.75	20.00	1.25
4	7	1.0	1.5	1.5	0.25	0.77	0.28	0.75	7.94	8.37	7.85	-0.056	-0.080	-0.051	51.25	27.50	21.25
4	7	1.0	1.5	1.5	0.35	4.37	0.24	1.36	8.03	8.38	7.68	-0.061	-0.081	-0.043	43.75	33.75	22.50
4	7	5.5	5.0	5.0	0.05	1.46	0.51	1.05	7.48	7.69	7.98	-0.027	-0.035	-0.054	41.25	35.00	23.75
4	7	5.5	5.0	5.0	0.15	0.69	0.59	0.56	7.60	7.77	8.09	-0.035	-0.050	-0.062	26.25	52.50	21.25
4	7	5.5	5.0	5.0	0.25	0.85	0.24	0.84	7.91	8.34	8.08	-0.052	-0.078	-0.061	28.75	45.00	26.25
4	7	5.5	5.0	5.0	0.35	1.17	0.45	0.93	8.28	7.36	8.18	-0.074	-0.081	-0.071	30.00	46.25	23.75
4	7	7.5	7.0	7.0	0.05	1.97	0.74	0.63	7.18	8.20	7.79	-0.010	-0.067	-0.044	53.75	32.50	13.75
4	7	7.5	7.0	7.0	0.15	1.24	0.59	1.07	7.65	8.12	7.18	-0.037	-0.064	-0.012	51.25	30.00	18.75
4	7	7.5	7.0	7.0	0.25	0.75	0.38	1.28	7.58	7.84	8.21	-0.033	-0.048	-0.070	48.75	33.75	17.50
4	7	7.5	7.0	7.0	0.35	1.48	0.68	1.25	7.77	7.48	8.03	-0.044	-0.026	-0.060	43.75	35.00	21.25
4	9	2.0	2.0	2.0	0.05	1.76	4.19	47.26	7.95	8.38	7.84	-0.054	-0.079	-0.050	61.25	20.00	18.75
4	9	2.0	2.0	2.0	0.15	3.25	1.08	0.68	8.04	8.24	8.31	-0.059	-0.070	-0.079	55.00	21.25	23.75
4	9	2.0	2.0	2.0	0.25	1.56	2.66	1.97	8.30	8.15	6.97	-0.074	-0.067	-0.011	61.25	22.50	16.25
4	9	2.0	2.0	2.0	0.35	10.37	5.61	5.76	8.16	7.93	8.55	-0.068	-0.056	-0.090	73.75	12.50	13.75
4	9	6.5	6.5	6.0	0.05	14.42	1.35	0.95	8.35	7.65	8.01	-0.077	-0.037	-0.059	61.25	20.00	18.75
4	9	6.5	6.5	6.0	0.15	2.11	1.22	1.36	8.37	8.53	8.59	-0.079	-0.092	-0.093	60.00	21.25	18.75
4	9	6.5	6.5	6.0	0.25	2.21	2.12	0.86	8.38	8.75	8.36	-0.081	-0.103	-0.081	58.75	22.50	18.75
4	9	6.5	6.5	6.0	0.35	3.18	5.00	0.54	8.20	7.89	8.25	-0.071	-0.051	-0.073	56.25	25.00	18.75
4	9	8.5	9.0	8.0	0.05	2.51	1.56	2.63	8.06	8.39	7.93	-0.062	-0.082	-0.053	63.75	23.75	12.50
4	9	8.5	9.0	8.0	0.15	3.03	3.85	3.26	7.81	8.45	7.86	-0.051	-0.085	-0.049	62.50	20.00	17.50
4	9	8.5	9.0	8.0	0.25	35.20	38.85	6.53	8.42	7.67	7.10	-0.083	-0.038	-0.006	65.00	20.00	15.00
4	9	8.5	9.0	8.0	0.35	18.63	68.79	19.54	8.51	7.40	8.03	-0.088	-0.023	-0.059	56.25	23.75	20.00
4	10	1.5	2.0	1.5	0.05	0.76	3.05	0.79	8.07	8.70	7.42	-0.066	-0.102	-0.029	50.00	27.50	22.50
4	10	1.5	2.0	1.5	0.15	1.91	5.37	0.93	8.51	8.12	7.96	-0.086	-0.071	-0.059	38.75	32.50	28.75
4	10	1.5	2.0	1.5	0.25	2.03	5.96	1.53	8.43	8.35	8.11	-0.086	-0.083	-0.066	31.25	36.25	32.50
4	10	1.5	2.0	1.5	0.35	6.66	8.01	2.73	8.19	7.76	8.30	-0.072	-0.044	-0.077	25.00	37.50	37.50
4	10	7.0	7.0	7.0	0.05	1.03	1.21	1.30	8.33	8.25	7.66	-0.078	-0.073	-0.039	33.75	40.00	26.25
4	10	7.0	7.0	7.0	0.15	3.90	2.97	9.16	8.52	8.25	8.35	-0.088	-0.073	-0.078	26.25	43.75	30.00
4	10	7.0	7.0	7.0	0.25	12.10	2.92	12.36	8.67	7.39	8.70	-0.098	-0.026	-0.101	28.75	35.00	36.25
4	10	7.0	7.0	7.0	0.35	23.47	2.49	27.79	8.85	7.66	8.91	-0.108	-0.038	-0.113	27.50	37.50	35.00
4	10	10.0	10.5	10.0	0.05	3.44	1.17	143.89	6.61	8.54	7.92	0.026	-0.088	-0.054	35.00	37.50	27.50
4	10	10.0	10.5	10.0	0.15	24.98	1.41	18.30	7.63	8.23	7.59	-0.035	-0.073	-0.029	36.25	37.50	26.25
4	10	10.0	10.5	10.0	0.25	44.55	2.55	71.87	7.74	8.32	7.95	-0.040	-0.078	-0.054	31.25	35.00	33.75
4	10	10.0	10.5	10.0	0.35	86.66	9.42	1.78	7.79	7.77	7.50	-0.044	-0.045	-0.028	41.25	41.25	17.50
4	12	2.0	2.0	2.0	0.05	7.44	0.47	1.49	6.39	8.24	7.88	0.052	-0.072	-0.050	63.75	25.00	11.25
4	12	2.0	2.0	2.0	0.15	5.70	0.91	2.25	7.15	8.42	7.84	-0.007	-0.083	-0.049	61.25	23.75	15.00
4	12	2.0	2.0	2.0	0.25	3.14	2.75	1.81	8.02	8.43	8.49	-0.063	-0.084	-0.085	68.75	17.50	13.75
4	12	2.0	2.0	2.0	0.35	3.78	5.37	7.34	8.03	8.41	8.86	-0.062	-0.081	-0.108	38.75	40.00	21.25
4	12	6.0	6.0	6.0	0.05	2.36	5.97	2.04	7.30	8.44	7.90	-0.015	-0.083	-0.051	47.50	35.00	17.50
4	12	6.0	6.0	6.0	0.15	1.97	4.63	3.35	8.02	8.09	8.41	-0.059	-0.069	-0.082	50.00	31.25	18.75
4	12	6.0	6.0	6.0	0.25	3.33	6.60	3.34	7.85	8.17	8.27	-0.048	-0.068	-0.076	26.25	53.75	20.00
4	12	6.0	6.0	6.0	0.35	9.43	6.90	5.71	7.94	8.30	7.94	-0.054	-0.076	-0.057	26.25	52.50	21.25
4	12	11.0	12.0	11.0	0.05	1.18	2.29	3.20	6.68	8.05	8.09	0.019	-0.062	-0.063	51.25	35.00	13.75
4	12	11.0	12.0	11.0	0.15	3.48	7.19	5.66	7.75	8.35	8.27	-0.042	-0.078	-0.076	41.25	42.50	16.25
4	12	11.0	12.0	11.0	0.25	22.32	8.97	1.27	8.13	8.11	8.36	-0.065	-0.065	-0.079	38.75	36.25	25.00

4	12	11.0	12.0	11.0	0.35	33.60	10.43	15.10	7.81	8.20	8.24	-0.046	-0.071	-0.075	41.25	33.75	25.00
5	21	4.5	4.5	5.0	0.05	8.48	1.67	0.77	7.42	7.25	8.15	-0.025	-0.011	-0.080	33.75	48.75	17.50
5	21	4.5	4.5	5.0	0.15	13.28	3.36	4.71	8.25	8.48	8.61	-0.071	-0.088	-0.095	31.25	55.00	13.75
5	21	4.5	4.5	5.0	0.25	9.73	7.84	12.73	8.75	8.30	8.21	-0.102	-0.084	-0.076	48.75	35.00	16.25
5	21	4.5	4.5	5.0	0.35	9.44	6.61	10.83	8.47	8.72	8.60	-0.086	-0.101	-0.095	46.25	37.50	16.25
5	21	10.0	10.0	10.0	0.05	15.58	9.82	8.84	7.62	7.27	8.01	-0.034	-0.017	-0.064	26.25	58.75	15.00
5	21	10.0	10.0	10.0	0.15	21.84	14.12	15.48	8.23	8.11	7.84	-0.073	-0.063	-0.050	28.75	53.75	17.50
5	21	10.0	10.0	10.0	0.25	20.46	19.03	14.39	8.56	8.20	7.56	-0.094	-0.070	-0.041	11.25	61.25	27.50
5	21	10.0	10.0	10.0	0.35	19.18	9.14	17.29	8.30	8.37	8.32	-0.077	-0.080	-0.078	3.75	70.00	26.25
5	21	21.5	20.0	20.0	0.05	4.83	0.51	2.89	7.50	8.32	7.92	-0.030	-0.077	-0.055	43.75	45.00	11.25
5	21	21.5	20.0	20.0	0.15	2.06	0.52	2.39	7.80	7.94	7.01	-0.047	-0.058	-0.002	31.25	45.00	23.75
5	21	21.5	20.0	20.0	0.25	5.52	17.54	1.77	8.24	8.14	7.41	-0.072	-0.065	-0.032	10.00	56.25	33.75
5	21	21.5	20.0	20.0	0.35	2.24	1.26	0.98	8.26	7.65	8.16	-0.065	-0.041	-0.067	11.25	58.75	30.00
5	24	6.5	6.5	7.0	0.05	13.92	6.72	1.22	8.43	8.65	7.24	-0.086	-0.100	-0.027	53.75	31.25	15.00
5	24	6.5	6.5	7.0	0.15	13.42	9.62	2.49	8.58	8.92	8.18	-0.100	-0.113	-0.074	82.50	13.75	3.75
5	24	6.5	6.5	7.0	0.25	17.53	13.24	6.21	8.58	8.66	8.56	-0.094	-0.099	-0.093	56.25	28.75	15.00
5	24	6.5	6.5	7.0	0.35	24.11	9.46	5.52	8.54	8.73	8.54	-0.091	-0.101	-0.090	61.25	30.00	8.75
5	24	15.0	15.0	15.0	0.05	1.81	0.46	0.78	7.35	8.39	8.16	-0.033	-0.080	-0.071	46.25	37.50	16.25
5	24	15.0	15.0	15.0	0.15	2.16	0.66	0.76	7.95	7.88	8.62	-0.053	-0.052	-0.097	56.25	30.00	13.75
5	24	15.0	15.0	15.0	0.25	2.23	0.43	1.93	7.96	8.35	8.26	-0.057	-0.083	-0.073	68.75	17.50	13.75
5	24	15.0	15.0	15.0	0.35	1.74	0.34	1.49	7.52	8.24	8.72	-0.037	-0.074	-0.104	68.75	18.75	12.50
5	24	24.5	25.0	25.0	0.05	0.83	0.11	0.45	8.04	7.76	7.12	-0.062	-0.043	-0.009	60.00	30.00	10.00
5	24	24.5	25.0	25.0	0.15	0.82	0.42	0.37	7.88	8.14	7.56	-0.053	-0.065	-0.036	58.75	31.25	10.00
5	24	24.5	25.0	25.0	0.25	1.84	0.77	0.32	7.77	7.43	7.58	-0.048	-0.035	-0.041	63.75	28.75	7.50
5	24	24.5	25.0	25.0	0.35	0.73	0.23	0.83	7.52	8.32	8.48	-0.029	-0.079	-0.088	53.75	33.75	12.50
5	25	4.0	4.0	4.0	0.05	11.26	21.28	9.04	8.61	8.67	8.41	-0.094	-0.097	-0.083	71.25	22.50	6.25
5	25	4.0	4.0	4.0	0.15	30.81	25.42	49.21	8.87	9.29	9.22	-0.109	-0.134	-0.131	43.75	37.50	18.75
5	25	4.0	4.0	4.0	0.25	20.56	18.09	31.98	9.17	8.50	8.96	-0.129	-0.088	-0.118	91.25	10.00	-1.25
5	25	4.0	4.0	4.0	0.35	39.79	18.73	29.78	8.95	9.16	9.10	-0.115	-0.126	-0.124	58.75	27.50	13.75
5	25	11.5	10.0	11.0	0.05	3.09	14.84	5.18	6.62	7.92	7.02	0.021	-0.051	-0.002	33.75	52.50	13.75
5	25	11.5	10.0	11.0	0.15	2.51	21.92	8.35	7.29	7.52	7.78	-0.017	-0.031	-0.048	58.75	32.50	8.75
5	25	11.5	10.0	11.0	0.25	5.58	23.45	7.96	7.66	7.66	8.12	-0.035	-0.039	-0.066	41.25	43.75	15.00
5	25	11.5	10.0	11.0	0.35	9.11	13.80	5.27	7.06	8.01	8.28	-0.006	-0.057	-0.078	37.50	43.75	18.75
5	25	21.0	20.0	20.0	0.05	14.06	3.74	5.31	6.55	6.71	5.75	0.024	0.018	0.075	41.25	41.25	17.50
5	25	21.0	20.0	20.0	0.15	16.37	5.25	7.99	7.23	7.00	6.47	-0.009	0.004	0.038	38.75	40.00	21.25
5	25	21.0	20.0	20.0	0.25	11.27	6.21	6.77	7.02	7.70	6.88	-0.005	-0.036	0.012	56.25	30.00	13.75
5	25	21.0	20.0	20.0	0.35	12.05	4.32	7.95	6.97	7.83	7.52	0.001	-0.045	-0.023	21.25	56.25	22.50
5	27	2.5	2.5	2.5	0.05	14.53	5.48	31.17	8.28	8.38	9.20	-0.079	-0.080	-0.128	48.75	40.00	11.25
5	27	2.5	2.5	2.5	0.15	27.91	9.18	36.46	8.53	8.59	9.28	-0.092	-0.093	-0.133	48.75	36.25	15.00
5	27	2.5	2.5	2.5	0.25	17.26	12.60	36.15	8.58	8.17	9.13	-0.093	-0.073	-0.013	51.25	32.50	16.25
5	27	2.5	2.5	2.5	0.35	14.82	7.41	34.74	8.80	8.63	8.75	-0.105	-0.097	-0.113	55.00	31.25	13.75
5	27	13.0	11.0	12.5	0.05	17.21	3.70	19.07	7.38	8.48	7.81	-0.026	-0.086	-0.050	41.25	47.50	11.25
5	27	13.0	11.0	12.5	0.15	13.53	3.67	13.86	7.79	8.40	8.18	-0.050	-0.084	-0.068	31.25	51.25	17.50
5	27	13.0	11.0	12.5	0.25	9.38	7.60	12.24	8.37	7.97	8.22	-0.081	-0.059	-0.076	32.50	56.25	11.25
5	27	13.0	11.0	12.5	0.35	11.81	2.52	12.21	8.50	8.67	7.44	-0.088	-0.098	-0.500	35.00	51.25	13.75
5	27	22.0	20.5	20.5	0.05	1.65	0.63	0.82	7.87	8.06	7.54	-0.051	-0.064	-0.035	43.75	42.50	13.75
5	27	22.0	20.5	20.5	0.15	0.91	0.58	1.33	8.11	8.16	7.43	-0.065	-0.068	-0.023	33.75	46.25	20.00
5	27	22.0	20.5	20.5	0.25	0.88	0.42	1.72	8.25	8.19	8.03	-0.073	-0.071	-0.063	43.75	40.00	16.25
5	27	22.0	20.5	20.5	0.35	0.26	0.67	1.99	8.28	8.21	7.84	-0.076	-0.071	-0.050	46.25	38.75	15.00
5	29	6.0	7.0	6.5	0.05	9.21	4.71	1.22	8.43	8.24	8.04	-0.083	-0.073	-0.062	43.75	40.00	16.25
5	29	6.0	7.0	6.5	0.15	11.55	5.30	8.33	8.59	6.95	8.56	-0.092	0.002	-0.090	36.25	45.00	18.75
5	29	6.0	7.0	6.5	0.25	16.30	9.29	13.83	8.78	7.65	8.78	-0.105	-0.040	-0.105	33.75	47.50	18.75
5	29	6.0	7.0	6.5	0.35	14.74	6.90	9.05	8.80	8.18	8.81	-0.105	-0.075	-0.109	48.75	37.50	13.75
5	29	12.5	13.0	13.0	0.05	1.20	0.75	2.55	8.18	8.41	7.14	-0.067	-0.084	-0.016	41.25	42.50	16.25
5	29	12.5	13.0	13.0	0.15	0.77	0.69	2.39	8.53	8.17	8.12	-0.091	-0.069	-0.071	41.25	41.25	17.50
5	29	12.5	13.0	13.0	0.25	0.84	0.68	5.15	8.76	8.48	8.51	-0.103	-0.086	-0.089	53.75	28.75	17.50
5	29	12.5	13.0	13.0	0.35	0.63	0.81	2.90	8.77	7.78	8.37	-0.103	-0.051	-0.081	48.75	36.25	15.00
5	29	34.0	32.5	32.0	0.05	0.83	0.44	0.27	8.15	8.24	8.05	-0.068	-0.073	-0.061	48.75	36.25	15.00
5	29	34.0	32.5	32.0	0.15	0.73	0.95	0.77	8.33	8.34	8.29	-0.078	-0.079	-0.075	48.75	35.00	16.25
5	29	34.0	32.5	32.0	0.25	1.30	1.12	0.29	8.43	8.18	8.45	-0.084	-0.071	-0.086	43.75	42.50	13.75

5	29	34.0	32.5	32.0	0.35	0.79	0.97	0.70	8.20	7.84	8.47	-0.070	-0.048	-0.086	36.25	47.50	16.25
6	22	7.0	6.5	7.0	0.05	1.07	0.34	0.40	7.71	7.96	8.01	-0.039	-0.055	-0.059	53.75	33.75	12.50
6	22	7.0	6.5	7.0	0.15	1.83	0.87	0.57	7.65	8.12	8.04	-0.033	-0.066	-0.059	61.25	20.00	18.75
6	22	7.0	6.5	7.0	0.25	3.80	2.48	0.80	8.10	7.32	8.15	-0.070	-0.030	-0.068	61.25	26.25	12.50
6	22	7.0	6.5	7.0	0.35	3.53	2.32	1.48	8.38	8.11	8.15	-0.083	-0.066	-0.070	58.75	27.50	13.75
6	22	13.5	13.5	13.0	0.05	0.49	0.31	0.62	7.45	8.16	7.98	-0.029	-0.067	-0.056	56.25	28.75	15.00
6	22	13.5	13.5	13.0	0.15	0.99	0.27	0.63	7.75	7.96	8.12	-0.045	-0.055	-0.066	43.75	35.00	21.25
6	22	13.5	13.5	13.0	0.25	1.37	0.32	0.89	7.45	7.91	8.43	-0.031	-0.053	-0.083	53.75	28.75	17.50
6	22	13.5	13.5	13.0	0.35	1.14	0.31	0.76	8.05	7.77	7.98	-0.064	-0.044	-0.060	58.75	27.50	13.75
6	22	20.5	21.0	21.0	0.05	0.39	0.65	1.11	6.70	7.75	7.72	0.019	-0.042	-0.041	41.25	47.50	11.25
6	22	20.5	21.0	21.0	0.15	0.77	0.49	1.90	7.45	7.46	7.80	-0.030	-0.025	-0.044	46.25	40.00	13.75
6	22	20.5	21.0	21.0	0.25	1.39	12.77	2.33	7.83	7.56	7.42	-0.051	-0.034	-0.023	66.25	16.25	17.50
6	22	20.5	21.0	21.0	0.35	0.91	0.48	1.44	7.20	8.27	7.17	-0.015	-0.075	-0.007	53.75	35.00	11.25
6	23	5.0	5.0	5.0	0.05	8.38	0.46	0.66	7.49	8.33	8.24	-0.031	-0.077	-0.073	33.75	47.50	18.75
6	23	5.0	5.0	5.0	0.15	1.13	0.58	1.73	7.81	8.24	8.06	-0.046	-0.074	-0.067	26.25	52.50	21.25
6	23	5.0	5.0	5.0	0.25	1.22	0.67	0.89	7.96	8.09	7.92	-0.054	-0.073	-0.064	51.25	30.00	18.75
6	23	5.0	5.0	5.0	0.35	22.19	0.83	0.80	7.80	8.21	8.25	-0.045	-0.070	-0.074	41.25	42.50	16.25
6	23	12.5	12.5	13.0	0.05	0.79	0.76	0.65	7.86	7.73	7.39	-0.049	-0.041	-0.021	28.75	55.00	16.25
6	23	12.5	12.5	13.0	0.15	1.02	0.83	1.15	8.20	7.12	7.79	-0.071	-0.009	-0.048	53.75	30.00	16.25
6	23	12.5	12.5	13.0	0.25	0.70	0.33	0.36	8.07	8.08	8.08	-0.066	-0.070	-0.062	51.25	37.50	11.25
6	23	12.5	12.5	13.0	0.35	0.72	1.30	0.31	7.55	7.50	8.27	-0.034	-0.032	-0.076	28.75	50.00	21.25
6	23	19.5	19.5	20.0	0.05	0.57	0.38	0.16	7.27	6.30	6.75	-0.017	0.040	0.016	51.25	42.50	6.25
6	23	19.5	19.5	20.0	0.15	0.59	0.32	0.36	7.60	7.75	7.33	-0.037	-0.043	-0.016	41.25	48.75	10.00
6	23	19.5	19.5	20.0	0.25	0.70	0.68	0.82	7.46	7.18	7.74	-0.015	-0.013	-0.045	33.75	55.00	11.25
6	23	19.5	19.5	20.0	0.35	0.71	0.53	0.41	7.48	7.43	7.86	-0.031	-0.027	-0.051	61.25	23.75	15.00
6	26	3.5	3.5	3.5	0.05	4.24	5.05	4.18	7.46	7.54	7.75	-0.026	-0.027	-0.040	41.25	46.25	12.50
6	26	3.5	3.5	3.5	0.15	3.80	3.34	6.24	7.48	7.72	7.80	-0.027	-0.034	-0.039	48.75	31.25	20.00
6	26	3.5	3.5	3.5	0.25	2.97	4.34	2.62	7.35	7.30	7.90	-0.200	-0.015	-0.043	33.75	33.75	32.50
6	26	3.5	3.5	3.5	0.35	4.86	22.09	6.36	7.76	7.85	7.36	-0.051	-0.048	-0.020	33.75	30.00	36.25
6	26	10.0	10.0	10.0	0.05	1.48	0.45	0.60	5.55	7.43	7.58	0.085	-0.020	-0.028	46.25	45.00	8.75
6	26	10.0	10.0	10.0	0.15	6.30	0.68	2.85	6.40	7.63	7.85	0.030	-0.033	-0.048	33.75	50.00	16.25
6	26	10.0	10.0	10.0	0.25	3.21	0.08	1.18	7.12	7.95	7.69	-0.013	-0.053	-0.036	46.25	38.75	15.00
6	26	10.0	10.0	10.0	0.35	3.60	1.02	0.90	7.21	7.46	6.23	-0.012	-0.024	0.042	46.25	32.50	21.25
6	26	19.0	19.0	19.0	0.05	0.41	0.68	0.65	4.67	7.15	6.25	0.134	-0.002	0.048	46.25	37.50	16.25
6	26	19.0	19.0	19.0	0.15	0.81	1.26	1.33	6.34	7.10	7.25	0.041	-0.001	-0.001	41.25	40.00	18.75
6	26	19.0	19.0	19.0	0.25	0.82	0.42	0.29	7.06	7.91	7.15	-0.002	-0.053	0.000	33.75	40.00	26.25
6	26	19.0	19.0	19.0	0.35	0.56	0.27	0.85	7.27	8.13	7.18	-0.015	-0.064	-0.002	35.00	31.25	33.75
6	28	8.0	6.5	6.0	0.05	8.38	10.55	4.63	8.15	7.87	7.05	-0.066	-0.049	-0.003	35.00	48.75	16.25
6	28	8.0	6.5	6.0	0.15	5.47	10.96	10.53	8.29	8.39	8.13	-0.076	-0.079	-0.065	48.75	32.50	18.75
6	28	8.0	6.5	6.0	0.25	3.58	6.47	6.04	8.40	8.53	8.67	-0.083	-0.090	-0.097	68.75	18.75	12.50
6	28	8.0	6.5	6.0	0.35	2.89	9.70	6.47	8.64	8.63	8.84	-0.096	-0.095	-0.109	66.25	22.50	11.25
6	28	11.5	11.5	11.5	0.05	10.78	9.89	10.11	8.00	8.24	7.81	-0.057	-0.064	-0.047	36.25	47.50	16.25
6	28	11.5	11.5	11.5	0.15	7.77	11.76	15.98	8.18	7.46	7.32	-0.069	-0.029	-0.019	26.25	60.00	13.75
6	28	11.5	11.5	11.5	0.25	5.99	15.99	14.45	8.24	8.05	8.00	-0.072	-0.059	-0.056	21.25	62.50	16.25
6	28	11.5	11.5	11.5	0.35	6.78	8.61	13.05	8.02	8.37	7.50	-0.062	-0.084	-0.030	48.75	36.25	15.00
6	28	21.5	20.0	20.5	0.05	1.03	0.74	0.83	7.20	6.76	6.74	-0.011	0.015	0.019	92.50	6.25	1.25
6	28	21.5	20.0	20.5	0.15	1.50	5.23	1.18	7.63	7.86	6.82	-0.037	-0.049	0.019	31.25	51.25	17.50
6	28	21.5	20.0	20.5	0.25	6.67	9.22	1.85	8.20	8.08	7.82	-0.068	-0.064	-0.046	37.50	41.25	21.25
6	28	21.5	20.0	20.5	0.35	3.89	7.04	1.50	8.24	7.08	7.32	-0.071	-0.005	-0.020	43.75	30.00	26.25
6	30	5.5	6.0	6.0	0.05	6.36	1.04	12.09	8.44	8.01	7.70	-0.083	-0.060	-0.500	73.75	20.00	6.25
6	30	5.5	6.0	6.0	0.15	8.07	1.36	9.78	8.60	7.84	8.79	-0.094	-0.055	-0.109	53.75	32.50	13.75
6	30	5.5	6.0	6.0	0.25	17.94	4.66	8.18	8.58	8.61	8.54	-0.094	-0.092	-0.092	58.75	28.75	12.50
6	30	5.5	6.0	6.0	0.35	8.02	12.34	7.02	8.61	8.56	8.59	-0.094	-0.091	-0.087	33.75	45.00	21.25
6	30	15.5	15.0	15.0	0.05	1.77	3.84	1.46	7.92	8.05	8.08	-0.052	-0.061	-0.063	75.00	13.75	11.25
6	30	15.5	15.0	15.0	0.15	1.59	5.94	0.69	8.16	8.17	7.98	-0.069	-0.067	-0.058	38.75	36.25	25.00
6	30	15.5	15.0	15.0	0.25	1.99	7.78	1.06	8.20	8.28	8.26	-0.069	-0.076	-0.073	45.00	43.75	11.25
6	30	15.5	15.0	15.0	0.35	2.08	3.28	1.00	8.24	7.93	8.37	-0.073	-0.056	-0.079	33.75	50.00	16.25
6	30	22.5	22.5	22.0	0.05	0.77	1.07	0.77	7.86	7.27	7.94	-0.051	-0.022	-0.056	73.75	10.00	16.25
6	30	22.5	22.5	22.0	0.15	0.56	1.52	12.17	8.16	8.02	8.07	-0.068	-0.060	-0.064	46.25	38.75	15.00
6	30	22.5	22.5	22.0	0.25	5.72	0.92	0.70	8.24	8.03	8.25	-0.075	-0.062	-0.075	58.75	25.00	16.25
6	30	22.5	22.5	22.0	0.35	0.90	0.38	1.73	8.38	8.20	8.23	-0.082	-0.071	-0.074	53.75	30.00	16.25

APPENDIX B

LABORATORY PROCEDURES

Perkin-Elmer

ANALYSIS OF SOILS

Extractable Cations

Introduction

There are several different extracting solutions used to determine extractable cations in soils. A 0.05N HCl in 0.025N H_2SO_4 solution (Double Acid) or a 0.1N HCl solution is common. These are suitable for several elements, including calcium, copper, iron, magnesium, manganese, potassium, sodium and zinc, and may be applicable to other elements.

There are also solvent extraction methods available to concentrate elements present in low concentrations, such as cobalt and cadmium.

High concentrations of elements can be extracted using a 3% v/v HNO_3 solution.

Using these methods, air-dried ground soil is weighed out and placed in a flask, and extracting solution is added. Soil/solution ratios and shaking times vary with each method. The samples are then filtered and the extract is analyzed directly or concentrated by means of solvent extraction and then analyzed.

TYPICAL ANALYTICAL PROCEDURE

Sample Preparation
Place 5.0 g of an air-dried, ground and sieved sample in an Erlenmeyer flask. Add 20 ml of extracting solution (0.05N HCl + 0.025N H_2SO_4). Place in a mechanical shaker for 15 minutes. Filter through Whatman #42 filter paper into a 50 ml volumetric flask and dilute to 50 ml with extracting solution.

Analysis
Determine the concentration of the interest using conditions listed in the "Standard Conditions" pages. All working standards should be prepared using the extracting solution.

REFERENCE: Perkin-Elmer, January 1992

pH AND ELECTRICAL CONDUCTIVITY

Soil Preparation

Weigh 5 g of prepared soil into a 50 ml beaker: add 20 ml of deionized water and stir well. Allow the solution to settle for 30 minutes. A 1:4 soil:water mix was used for all samples to account for sites with high organic matter but retain consistency.

One Point Standardization: Fischer pH Meter

Set FUNCTION selector to STANDBY position. Set SLOPE control at 100%. Select a buffer that has a pH value with 1 or 2 pH units of the solution to be measured.

Calibrate the pH meter using the 7.0 pH standard solution. Carefully immerse the electrode, make sure it does not touch the bottom of the beaker. Switch the meter from STANDBY to pH and allow the display a few minutes to stabilize - then adjust the reading with the calibration knob. Once standardized, return to STANDBY and carefully raise the electrode and wash it off well with deionized water. When not in use, immerse the electrode in a beaker of clean, deionized water.

Immerse the electrode in the sample fluid, not the settled out solid fraction in the bottom of the beaker. Switch the FUNCTION selector to pH and allow the display a minute to stabilize. Record the value. Proceed with electrical conductivity reading.

Electrical Conductivity: Millivolt Measurement

There is no need to standardize the instrument with a buffer solution. Readings can be taken as soon as the millivolt zero reference is established.

With electrode immersed in sample fluid set FUNCTION selector to MV. Allow a minute for millivolt reading to stabilize and record the value. Set FUNCTION selector to STANDBY and rinse the electrode thoroughly with deionized water. Follow procedure for next samples.

REFERENCE: McKeague, 1978, pp. 67, Geography 413/Fall'88 and Fischer.

PARTICLE ANALYSIS

HYDROMETER METHOD FOR PARTICLES OF LESS THAN 2 mm
(After Bouyoucos 1962; McKeague 1978)

Preparation of CALGON Solution
Weigh 50 g of CALGON crystals into container with 950 ml of deionized water. Close container and shake vigorously until all no crystals settle out and the CALGON is in solution.

Preparation of Soil
Equally combine all seasonal samples from each particular site (ie: the May, July and October samples at site #1-Calgary TransCanada/roadside-distance/25cm-depth are combined to create one sample). From this combined sample, weigh 40 g of soil into a 600 ml beaker and 100 ml of the 50 g/l CALGON solution. Stir solution well and allow to sit overnight (for at least 12 hours).

Hydrometer Calibration
Record serial number of hydrometer and use the same one for all samples. Add 100 ml of the 50 g/l CALGON solution to a 1 litre cylinder. Fill the cylinder to the 1 litre mark with deionized water. Place a rubber stopper securely in the mouth of the cylinder and carefully invert it a few times to mix the solution. Allow solution to settle for about a minute then place hydrometer in and allow it to stabilize. Take the reading from the scale on the hydrometer and record it as the correction factor to be used later in calculating the sand, silt and clay fraction.

Soil Dispersion
Stir soil sample well and pour into a mixing cup. Wash out the beaker well with the squeeze bottle to make sure that all particles are in the cup. Mix using the machine for 5 minutes. Pour dispersed sample into a 1 litre cylinder, wash mixing cup thoroughly and add deionized water to cylinder to bring fluid level to just under the 1 litre mark.

Measurement
Wet down a rubber stopper and place it firmly in the mouth of the cylinder. Carefully invert the cylinder 5 times. Carefully set the cylinder down where it won't be disturbed, remove the stopper and wash both the stopper and sides of the cylinder. Add a few drops of amyl alcohol to disperse any foam on the solution surface.
Carefully place the hydrometer into the solution and allow it to stabilize. Take a reading at 40 seconds and record the value. Remove the hydrometer. Repeat the steps above for a 4 hour reading, record the value and dispose of sample.

<u>Calculations</u>
Once all readings are completed, use the calibration factor and this information to calculate the percentage of sand, silt and clay in the samples as follows:

weight of soil = W calibration factor = C
40 second reading = S 4 hour reading = H

Equation #1 - Percentage SAND
W + C = T (T = If 0 second reading was possible)
T - S = SAND SAND x 2.5 = PERCENTAGE OF SAND

Equation #2 - Percentage CLAY
H - C = CLAY CLAY x 2.5 = PERCENTAGE OF CLAY

Equation #3 - Percentage SILT
S - (SAND + CLAY) = SILT
SILT x 2.5 = PERCENTAGE OF SILT

Equation #4 - Verification of SILT
100 - (PERCENTAGE OF SAND + PERCENTAGE OF CLAY) = PERCENTAGE OF SILT

Repeat calculations for each sample.

REFERENCE: McKeague 1978, pp. 15 - 16, Geography 413/Fall'88.