Proceedings
and Conclusions
of

The Flow of Road Salt Through the Environment

A One Day Workshop
Thursday
March 25 1993

DRAFT

Soilcon Laboratories Ltd.
April 1993

Canadian Cataloguing in Publication Data
Main entry under title:
Proceedings and conclusions of the flow of road salt through the environment

"A one day workshop, Thursday, March 25, 1993".
ISBN 0-7726-1844-5

1. Roads - British Columbia - Snow and ice control. 2. Salt - Environmental aspects - British Columbia. I. Soilcan Laboratories Ltd. II. British Columbia. Ministry of Environment, Lands and Parks. III. Title: Flow of road salt through the environment.

TD870.P76 1993 625.7'63 C93-092256-5

Soilcon
LABORATORIES LTD.

April 26 1993

Mr. Jim van Barnevelt
Ministry of Environment
Integrated Management Branch
780 Blanchard St.
Victoria B.C. V8V 1X5
p: 387-9945 f: 387-9750

Dear Mr. van Barnevelt;

Re: The Flow of Road Salt Through The Environment - A One Day Workshop

Soilcon is pleased to present the proceedings and conclusions of the one day workshop held on March 25 1993.

We found the workshop was successful in transferring knowledge and concerns between the environmental scientists, government regulators and road maintenance personnel who attended. This report firstly outlines the morning speakers and then presents the conclusions of the afternoon discussions. The workshop provided new ideas and highlighted special concerns. We feel it was especially beneficial in focusing and establishing priorities for the proposed research.

Soilcon enjoyed organizing the workshop and working on this important and inter-related topic.

Sincerely,

Michael J. Goldstein P. Ag. M.Sc. C.Arb.
President

DRAFT

DISCLAIMER:

The Information, opinions and recommendations contained in this report are those of the consultant and do not reflect policy or position of the Province of British Columbia. The use of trade names or names of commercial products in this report does not constitute endorsement or recommendation for use.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

On March 25 1993 a workshop entitled *The Flow of Road Salt Through the Environment* was held at the Richmond Inn. The workshop was sponsored by The Roadside Tree Injury Committee to develop recommendations for future research on the effects of road salt on the environment.

The workshop was organized by Soilcon Laboratories Ltd. who had previously prepared the report entitled; Phase II: A Reconnaissance Study of Roadside Tree Injury and Decline at 17 sites in Interior British Columbia (Davis et al 1992). This report was authored by Gerry Davis, Shân Krannitz and Michael J. Goldstein. The report found the road salt was the major inciting factor at 16 of 17 sites throughout south-central B.C., where decline of roadside trees had taken place. A workshop of the effects of road salt was on of the recommendations of the report.

2.0 Workshop Participants

Three groups of people were invited to the workshop: environmental scientists, government regulators (who have responsibility of protecting the environment) and Ministry of Transportation and Highways personnel (who are concerned with road maintenance, specifically the application of road deicing and dust control chemicals). Many of the participants wore two of these hats. Table 1 is a list of the 25 participants. 6 of these participants presented brief talks during the morning information session. The following section gives summaries of these talks.

Table 1 List of Participants

Name	Position	Branch &/or Address
Archer, Barbara	MOTH Environ Coordinator	3A-940 Blanshard St. Victoria V8M 3E6
Bilkel, Dennis	MOTH Maintenance	940 Blanshard St. Victoria V8M 3E6
Bodnarchuck, Tony	MOTH Roadside Development	310 Ward St. Nelson V1L 5S4 354-6418
Coates, Bill	MOTH Area Manager	254 Haynes St. Penticton
Davis, Gerry	Pedologist, Min of Forests	518 Lake Street Nelson
Goldstein, Michael	President Soilcon Labs Ltd.	275-11780 River Rd. Richmond V6X 1Z7
Hecker, Doug	MOTH Maintence Stds Tech	940 Blanshard St. Victoria V8M 3E6
Hughes-Games, Geoff	BCMAFF Reg Soil Specialist	101-33832 S Fraser Way Abbotsford V2S 2C5
Husband, Steve	District Tech; Okanagan & Shuswap District	4402-27th Street Vernon
Jacobs, David	MOTH Area Manager	209-540 Borland St. Williams Lake
Jarvis, Lynn	Proj Coord. Soilcon Labs Ltd	275-11780 River Rd. Richmond V6X 1Z7
Knapp, Wayne	Fisheries and Oceans	555 West Hastings Vancouver
Kruzynski, George	DFO West Van Lab	4106 Marine Dr. West Van V7V 1N6
Lachmuth, Grant	Dist Hwys Manager; Lakes District	Box 288 Burns Lake VOJ 1E0
Macfarlane, Mike	BC Environment	777 Brougton St. Victoria V8V 1X5
Nolan, Daryl	MOTH	213-11011 Fourth Ave. Prince George V2L 3H9
Novack, Mike	Assistant Professor	Department of Soil Science UBC
Planiden, Al	Mgr. Roadside Development	MOTH 940 Blanshard St. Victoria V8M 3E6
Raine, Russ	MOTH Jr. Chem Lab Scientist	Geotech 324 Kingston St. Victoria V8V 1V7
Redman, Errol	DHM Fort George District	4055-15th Ave. Prince George
van Barnevelt, Jim	Ecos Mon Coor/ RSTIC	Min of Environ, Lands & Parks, IMB 387-9945
van Vliet, Laurens	A / Head BC Land Resource Unit	Agr. Canada 6660 NW Marine Dr. Van V6T 1X2
Waters, Jane	MOTH Coord Roadside Dev.	940 Blanshard St. Victoria V8M 3E6
Whitfield, Paul H.	Head Environmental Network, Environment Canada	224 West Esplanade North Vancouver V7M 3A7
Zapf-Gilje, Reidar	Golder Associates	500-4260 Still Creek Dr. Burnaby V5C 6C6

3.0 Workshop Proceedings

The first half of the workshop was a series of informal talks designed to bring the heterogeneous group to an even level for further discussion. The workshop began with an Introductory talk by Mr. Jim van Barnevelt who gave the history of the Roadside Tree Injury Committee prior to the workshop. Next Mr. Anthony Bodnarchuk, of the Ministry of Highways described the current road maintenance standard and the of role road salt as the primary deicing agent. Mr. Bodnarchuck also presented the road classes in maintenance regarding deicing application levels.

The role the hydrologic cycle plays in acting as the circulatory system which moves salt from the road through snow storage areas to possible receptors such as soil plants, animals, fish and to groundwater was presented by Michael Goldstein. Mr. Goldstein also described how the soil acts as a 'magic sieve' by sorbing the smaller sodium cations and allowing the larger chloride anions to pass through. Dr. Reider Zapf-Gilje traced the history of the investigation of freeze concentration of contaminants in acid snow from Norway, to effluent disposal in Kamloops. The findings of saline snow-pack melt were also mentioned.

3.1 A Welcome and Introduction from The Roadside Tree Injury Committee

Presented by Mr. Jim van Barnevelt, Ministry of Environment

Since 1985, a number of public inquires have been submitted to the BC Ministry of Environment Lands and Parks (MOELP), Forests (MOF), and Ministry of Transportation and Highways (MOTH) regarding tree injury and decline adjacent to interior highways. The queries have questioned the possible role of deicing salts in this injury. In April of 1989 the Minister of Environment formed the Roadside Tree Injury Committee (RSTIC) which included the MOTH, MOF and the MOELP. The main purpose at that time was to investigate the extent and nature of the reported injury. Specifically, the MOTH was concerned with its responsibility/liability for the damage, the cost of rehabilitation and evaluation of current winter road maintenance practices and standards. The MOF was interested in forest resource damage and the infection hazard for adjacent forests. Some of the issues the MOELP wished to be investigated by the RSTIC were damage to wildlife habitat, environmental degradation and groundwater quality.

The first task undertaken by the RSTIC was, what is now known as, 'The Great Salt Trip'. Members of the RSTIC toured British Columbia and found the observable injury to be relatively widespread in the drier regions and that 24 contributing factors and causes were involved. The RSTIC also found that the situation in Boitanio Park was urgent. Figure 1 shows the chronology of events of the RSTIC since its inception. This chart shows how the committee has addressed the specific Boitanio Park problem as well as the more complex and on-going Provincial deicing problem.

Mr. Jim van Barnevelt stated that the RSTIC has come to the following conclusions and recommendations following the study completed by Soilcon:

The RSTIC concludes that road deicing materials have contributed to highly localized and largely reversible damage to soil and vegetation of traffic spray areas and of drainage collecting areas adjacent to highways throughout the dry interior of British Columbia. No evidence of surface water or ground water contamination was collected, leaving the ultimate fate of deicing salt and its constituent compounds undetermined.

It has been reported that, at present, deicing salt injury does not represent a significant risk as an 'infection center' for the health of the forests of BC. Nor have significant salinization effects of fresh water bodies been found that would present a risk for the integrity of fish and health and aquatic biota. However, some observed ephemeral rise in cyanide levels in some streams (from YPS) has been reported elsewhere. These effects and the long term fate of deicing salts on groundwater and closed or slowly drained surface water bodies requires further investigation to determine if an environmental risk exists.

The Roadside Tree Injury Committee recommends:

1 That Phase III, a detailed study of 5 selected sites, be replaced by:

a) a workshop to be organized and reported by Soilcon to determine the parameters affecting the fate of deicing salt in the environment.

b) an integrated study to be developed and formulated by Soilcon to determine functional and quantitative relationships between deicing salt and its constituents and environmental factors including (but not limited to) climate, soil, topography and hydrology.

c) conduct an inter-agency integrated study of a typical interior basin in order to develop guidelines by which the use of deicing salt can be managed to minimize adverse environmental impacts.

2 The MOTH should continue its search for viable alternatives to road deicing salts and may consider more costly alternatives in specific (often sensitive) sections of highways and review its current objectives and policies of highway winter maintenance. RSTIC emphasizes that, although immediate ecosystem damage may result from the use of road salt it does not bio-accumulate to levels that cause long-term risk to human health and wildlife, and effects are often easily reversed once the rate of influx is reduced to below levels of natural transport away from a site. Among the environmentally toxic compounds, road salt is less insidious and more manageable. In the long term, effects from its minor constituents (YPS contaminants) may prove to be a greater environmental concern than the salt itself. Before they are used alternative materials should be thoroughly tested for environmental effects.

Figure 1 Chronology of RSTIC Events

April 89
Minister of Environment initiates RSTIC

↓

May 89
The Great Salt Trip

↓

October 89
<u>Provincial approach:</u>
1-overview of likely causes
2-site specific investigations
3-management options
4-monitoring

↓

September 90
MOELP Administer Contract Study

↓

February 91
Contract with Soilcon

↓

May 92
Soilcon Reports:
Literature Review and 17 Detailed Sites

↓

December 92
RSTIC Recommendations to Ministry Executives; Awaiting response

↓

March 93
Integrated 'Flow of Salt Through The Environment' Workshop

↓

April 93
Recommendations for Integrated Study by Interested Participants

↓

Onward
MOTH Action Plan Implementation
Joint Study?

(From May 89) ↘

July 89
Boitanio Workshop

↓

October 89
Preliminary Study Report;
MOTH Press Release

↓

April 90
Boitanio Options Workshop

↓

July 90
Recommendations to Williams Lake
MOTH, MOF, and MOELP;
Boitanio Park Report Release

↓

September 90
Boitanio Drainage re-constructed

3 Intensive management of road deicing salt use will require more detailed record keeping and appropriate training of operational personnel to minimize avoidable effects on the environment.

4 Safety hazards, damage and health concerns (for example dead trees, and ground water quality effects) arising from the use of road salt should be addressed and appropriate action taken. The MOTH needs to specify a policy for field staff to respond to such concerns.

In summary, concerns for forest land and soil degradation have been addressed in the Soilcon study, however; concerns about the amounts and long-term effects of salt loadings on streams and groundwater remain unanswered.

The workshop is designed to bring together experts from a variety of disciplines involved in the fate of deicing salt in the environment. The purposes of the workshop are:

1. Develop a conceptual model of the fate of salt.
2. Describe and prepare Terms of Reference for a 'small basin study' to obtain a qualitative understanding of the fate of salt in the environment.
3. To aid in the development of guidelines for the management of deicing salt-use in an environmentally sustainable manner.

3.2 Why and When does the Ministry of Highways Prescribe Road Salt

Presented by Mr. Anthony Bodnarchuck, Ministry of Transportation and Highways, Roadside Development Supervisor, Nelson.

Throughout the interior of British Columbia in the past 30-40 years, the highways have been receiving a heavy dose of de-icing chemicals. This dosage has been doubling approximately every 10 years. Currently, the Ministry Personnel do not apply de-icing chemicals, the contractors are required to comply with a 6 page maintenance standard "Winter Abrasive and De-icing Chemical Applications". Both abrasive materials (sand) and de-icing chemicals are applied in accordance with climatic conditions.

In terms of concerns the MOTH receives a great deal of public complaints about roadside kills, and both flora and fauna. The quality of well water has also be queried. It is a fact that the loading to the environment is increasing. However in regards to this workshop, Mr. Bodnarchuck stated that there is a large amount of information available on alternate de-icing chemicals. Perhaps it is not necessary to re-invent the wheel in our search for a compromise between environmental degradation and human safety. Other agencies have reduced salt inputs by as much as 40%. It would be highly beneficial if B.C could adapt these technologies. For example the Kootenays have experimented with pre-wetting de-icing agents. Liquid magnesium chloride or calcium chloride are added to sand or salt at 30 liters per tonne. It is pumped onto the spinner. The hydroscopic characteristic of the calcium chloride and magnesium chloride melts the particles into the ice preventing blow-off. The effectiveness of these pre-wetted de-icing agents is much greater than sodium chloride since they melt to -20°C while NaCl only melts to -5°C.

Light application rates (maximum of 60 kg/lane-km) are targeted for pre-storm periods to prevent snow and ice build-up. Medium rates are applied if the pre-storm period has been missed and the conditions require higher amounts of deicing material. High rates (maximum of 130 kg/lane-km) are typically applied to melt compact snow and ice. The rates are maximums and are determined by calibrating the trucks at the beginning of each season.

The MOTH feels that contractors must be environmentally more aware, of the consequences of continual salt loadings. Discrepancies may arise with individual interpretations of the maintenance standards. However, there is an economic incentive for the contractors to minimize the application of abrasive & chemical de-icing agents each season. Contractors obtain pay for highway maintenance and the remuneration is not calculated on amount applied per season.

Currently, only total application rates and averages are recorded, thus site specific rates cannot be calculated. This creates problems in obtaining information about the distribution of locations which receive heavier applications. As well, correlation of application rates to environmental effects is difficult if not impossible, on site specific scales. Calibration of trucks could be more tightly regulated.

Currently information requested by the MOTH from contractors does not include climatic conditions or the reasoning behind the time or rates of application. (This was mentioned in response to Mr. Whitfield's findings that deicing agents had been applied when temperatures were above freezing).

3.3 The Water Balance and the Salt Balance

Presented by Mr. Michael Goldstein, P.Ag., Soilcon Laboratories Ltd.

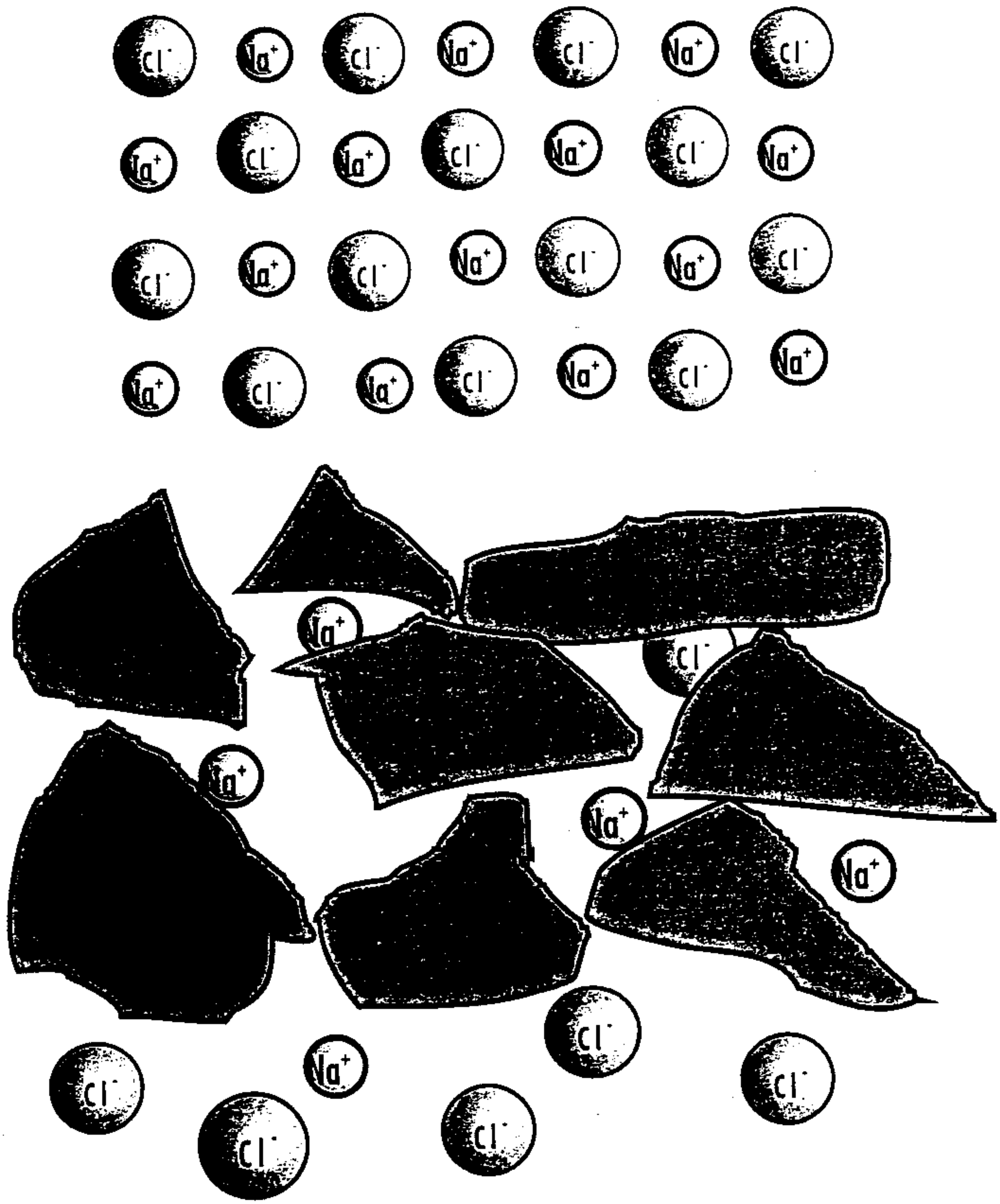
Water serves as the circulatory system of the environment. Eventually most of the salt applied to roads will enter either streams or groundwater systems or both. This presentation will focus upon the water and salt balance at two sites; Cache Creek and Williams Lake.

Most salt in spray or melt water leaving the roadside environment does not directly enter the aquatic or groundwater systems, but first travels through soil. The soil can be thought of as a magic sieve. Chlorine and sodium ions become dissociated in solution and it is these anions and cations which are sieved through the soil. Chlorine is a much larger anion compared to the smaller sodium cation. Against the typical principles of a standard sieve, soil particles with their inherently negative charged surfaces attract the smaller sodium cation. The majority of chlorine anions travel through the soil, even though physically these ions are larger. Figure 2 illustrates this magic soil sieve. This strength of this simplified 'sieve' scenario to hold sodium cations depends to a large extent upon the cation exchange capacity or the abundance of negative 'sites' within the soil. Generally sites with increased amounts of organic matter and clay have a larger cation exchange capacity than, for example, a pure sand.

To balance the electrical charge of the Cl^- ions in solution H^+ ions are released from the soil. This release of H^+ may be great enough to lower the pH of streams and groundwater, thereby directly affecting aquatic organisms.

In the soil, Cl^- and Na^+ are available to plant roots for uptake when they are either adsorbed to soil particles or in the soil solution. As well both ions can be absorbed through plant foliage. Cl^- is considered an essential nutrient for plant growth, while Na^+ has been shown to be essential only for certain salt tolerant plants and is generally considered toxic to most plants (phytotoxic). However; at elevated concentrations Cl^- ions are also phytotoxic. Part of the Na^+ toxicity to plants is the increased salinity (excess of plant required soluble salts; Ca^{2+}, Mg^{2+}, Na^+, and K^+) of the soil water which decreases the available water for plants.

Figure 2 The Magic Soil Sieve

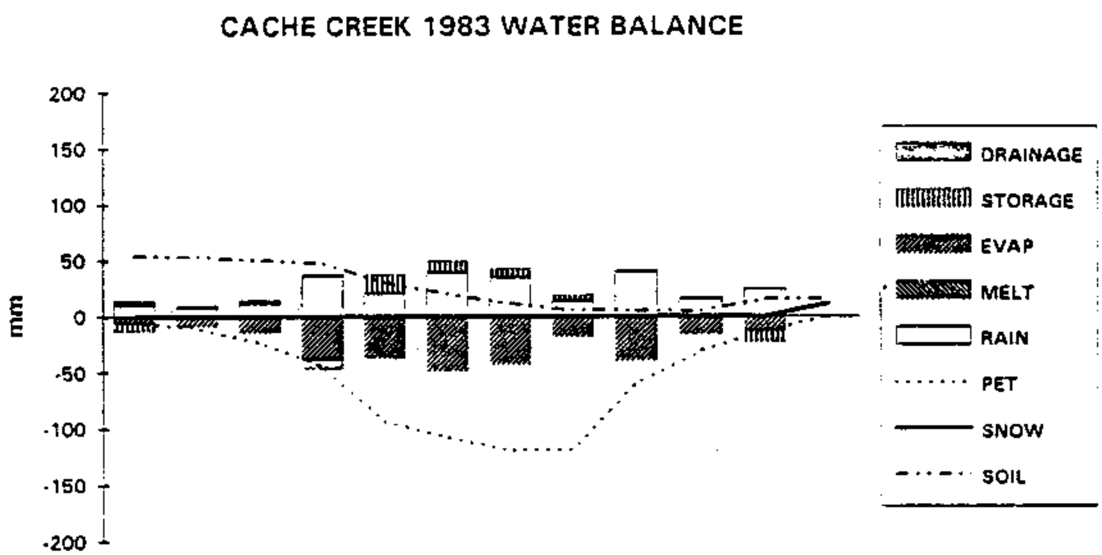


Another deleterious effect of high concentrations of Na^+ in the soil solution is altered soil structure. When Na^+ is the predominant cation on the exchange complex of soil (normally Ca^{2+} and Mg^{2+} are dominant), the resulting soil structure is more massive and unstable with reduced air porosity to plant roots.

The following section briefly shows the hydrology at Cache Creek and Williams Lake as altered by the roadside environment.

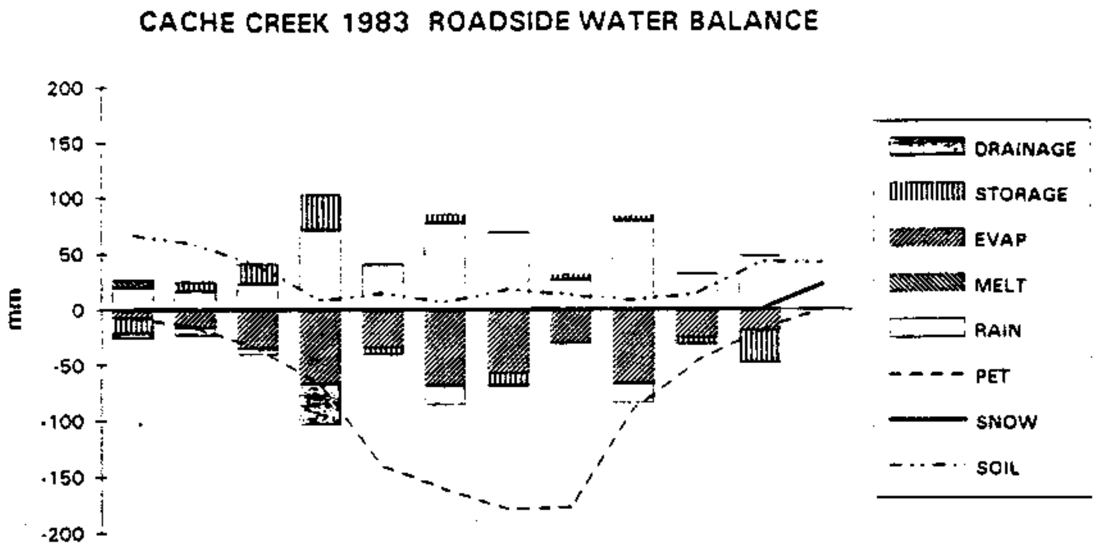
Figure 3, the Cache Creek water balance is based upon seven years of data from the Cache Creek AES (Atmospheric Environment Service) Climate station. In general climate of the area is characterized by an annual total precipitation of 281 mm; a May to September climate moisture deficit of 337 mm; and an annual snow fall of 10 mm.

Figure 3 Cache Creek 1983 Water Balance



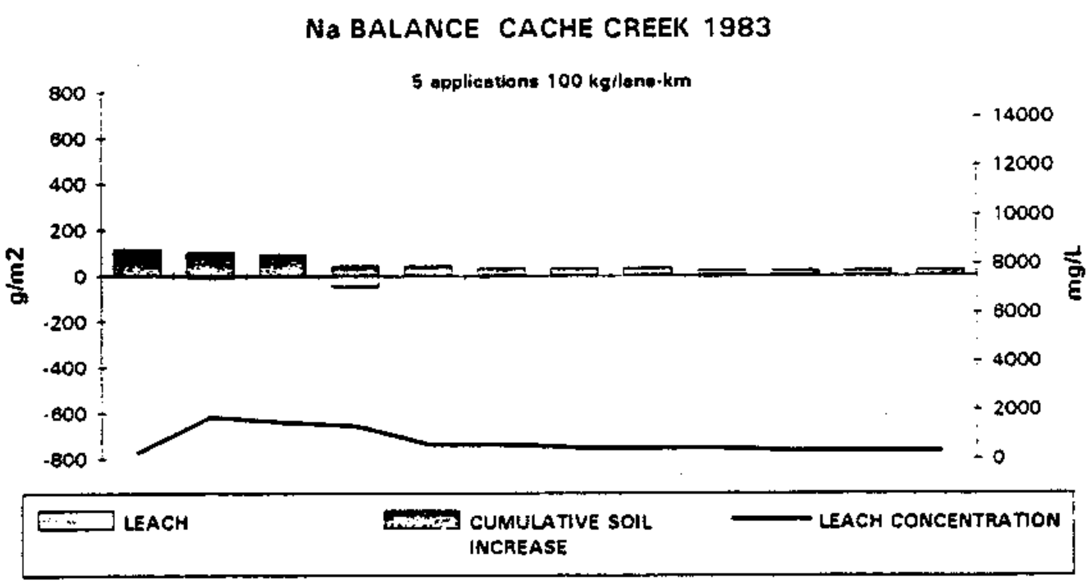
In Figure 3 the months of the year are shown along the x axis, beginning with January at the far left. In the spring some moisture is initially available in the soil, however potential evapotranspiration greatly exceeds this and moisture is limiting throughout the growing season. Figure 4 shows that the water balance of the roadside environment is greatly altered primarily by increased water inputs from drainage of the road surface. However, evapotranspiration in this warm climate exceeds the available moisture content creating a greater moisture deficit during the growing season. Soil moisture storage along the roadside is slightly greater during the winter but decreases more rapidly and earlier in the spring than in Figure 3.

Figure 4 Cache Creek 1983 Roadside Water Balance



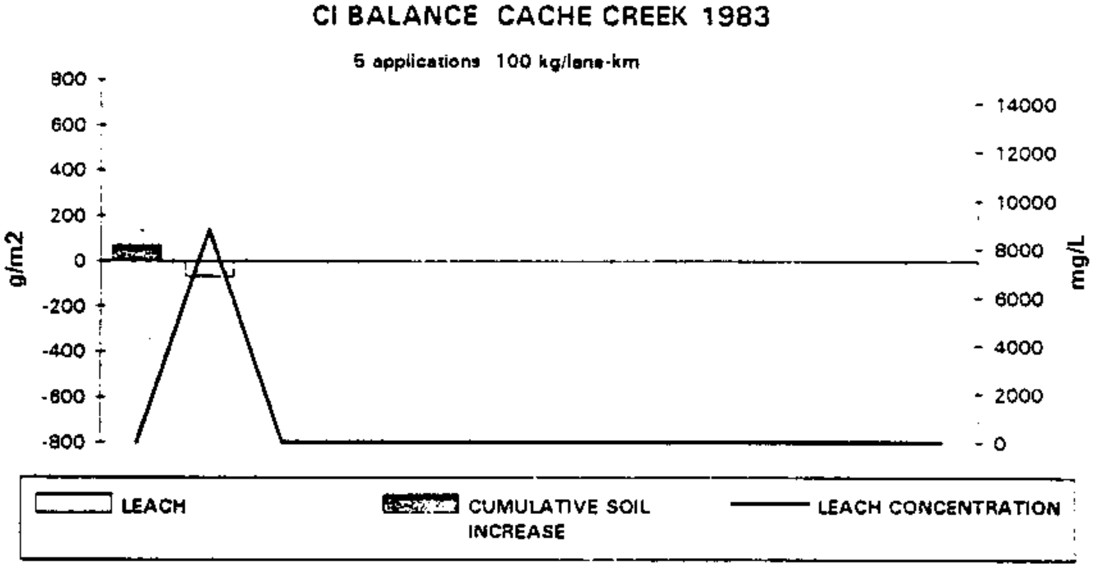
Focusing upon the sodium concentration in the soil of Cache Creek, Figure 5 shows there is a potential for cumulative increases each year. Leach concentrations will increase in the spring and then slowly decrease throughout the growing season, but do not reach zero.

Figure 5 Cache Creek 1983 Na Balance



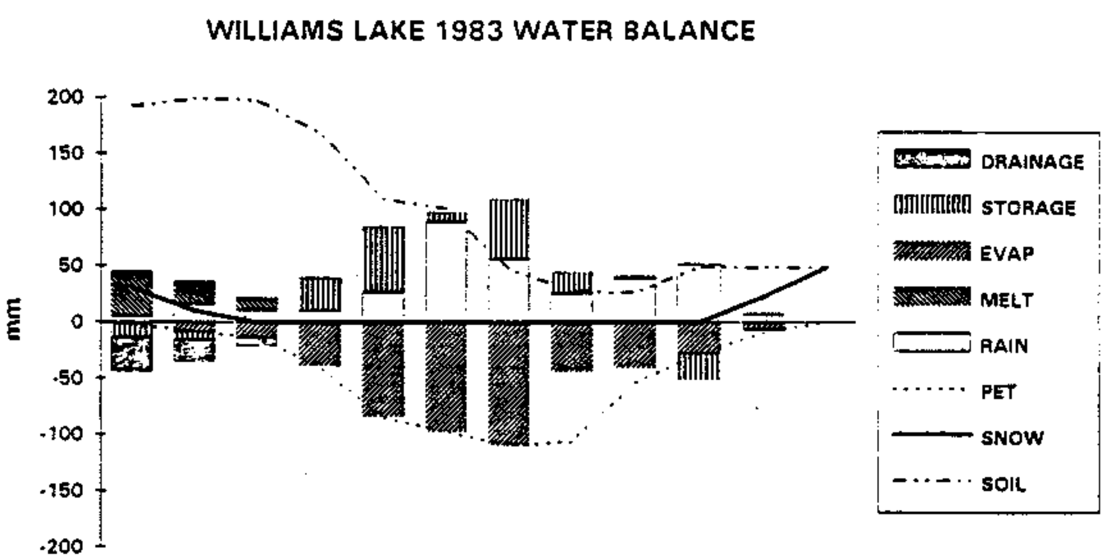
In contrast to sodium, chlorine concentrations in the soil are expected to be completely removed early after the spring melt. The chlorine concentrations in the leachate quickly reach zero and no chlorine accumulates in the soil form one season to the next (see Figure 6).

Figure 6 Cache Creek 1983 Cl Balance



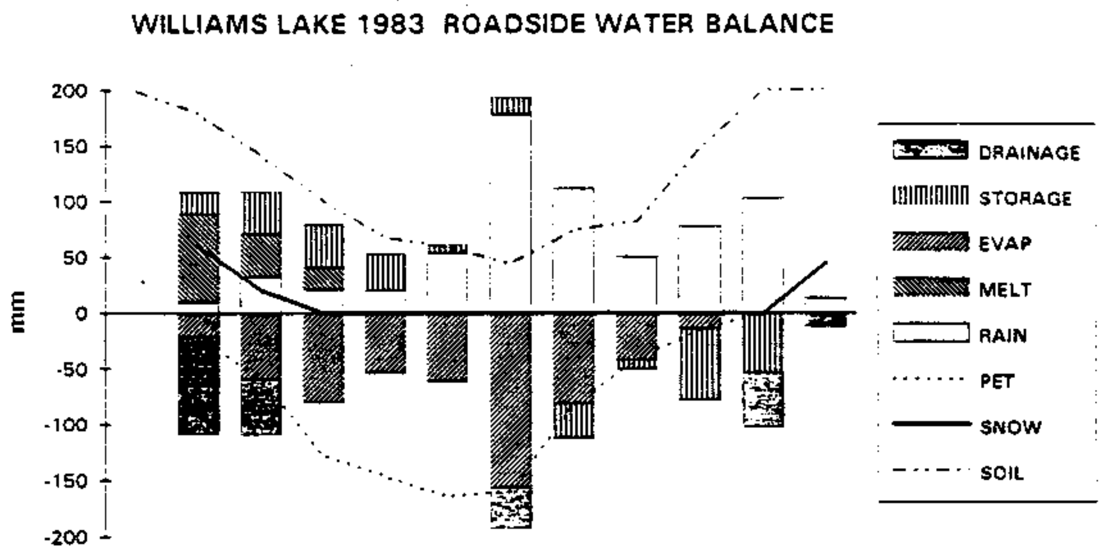
In contrast to Cache Creek, the climate of Williams Lake is slightly wetter and receives approximately 10 times more snow. Based upon data from Environment Canada Atmospheric Environment Service stations at Williams Lake the area is characterized by; a mean annual temperature of 4.2° C; a May to September climate moisture deficit of 200 mm and an annual snow fall of 108 mm. Figure 7 shows the hydrology for Williams Lake.

Figure 7 Williams Lake 1983 Water Balance



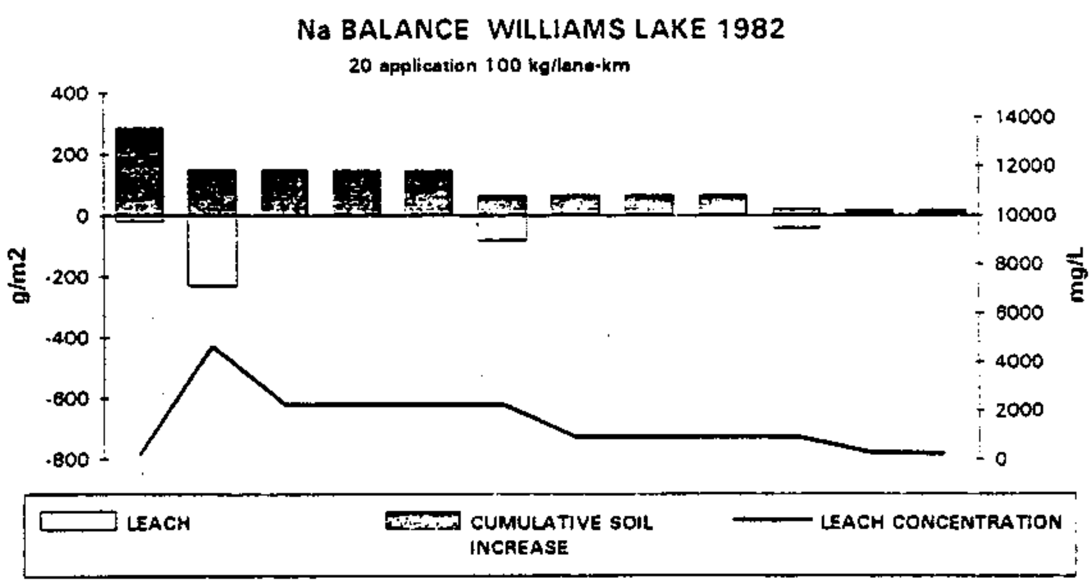
The most dramatic effect of the road on the Williams Lake hydrology is increased soil moisture storage during the autumn. The soil moisture deficit is increased by the presence of the road during the growing season and sharply decreases in the autumn.

Figure 8 Williams Lake 1983 Roadside Water Balance



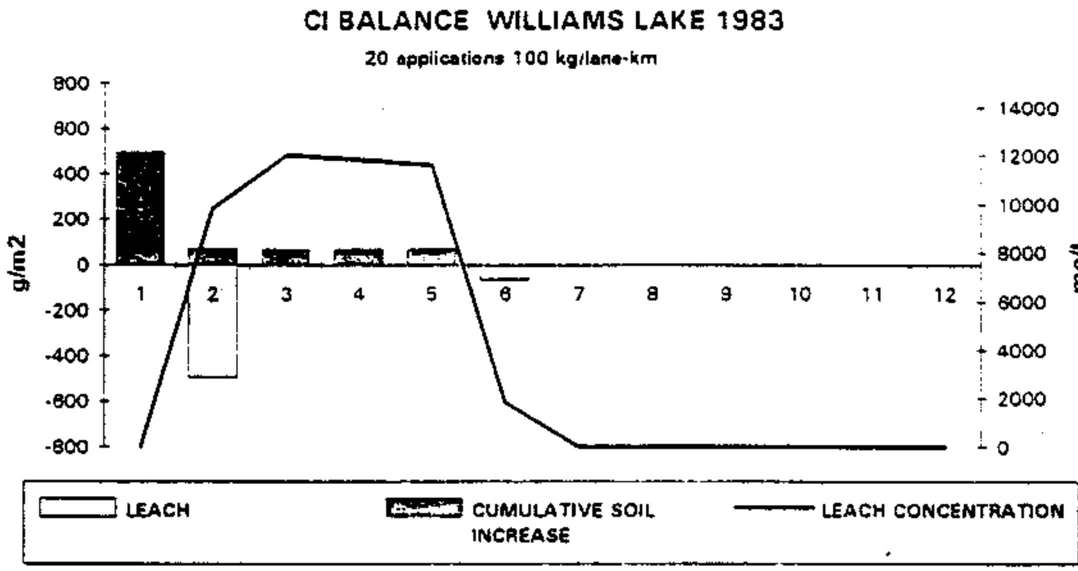
Williams Lake receives more snow than Cache Creek thus the salt applications are greater. Because of the greater snow melt at Williams Lake more sodium is leached during the early spring melt. This causes slightly less sodium to accumulated at the end of the season, (as shown in Figure 9) compared to Cache Creek.

Figure 9 Williams Lake 1983 Na Balance



With increased salt applications Cl⁻ remains longer in the soil after the spring melt. This occurs even though the majority of the chlorine is transferred into the soil leachate in the early summer months. As with Cache Creek the leachate concentration reaches zero, but three to four months later, in the growing season.

Figure 10 Williams Lake 1983 Cl Balance



3.4 Freeze Concentrations of Impurities in Snow

Presented by Mr. Reider Zapf-Gilje, P.Eng., Golder Associates

Johannessen and Henriksen first studied snow melt in the early seventies in Norway. They found that the first fraction of melt water from a melting snowpack contains a much higher concentration of ions than that of the bulk (or average) snow of which the pack is comprised. This process is known as spring 'acid flush' (containing similar pollutants as in acid rain) and can have severe ecological effects on lakes and streams. In the seventies most of Norway's lakes had experienced fish-kills and were virtually dead water bodies.

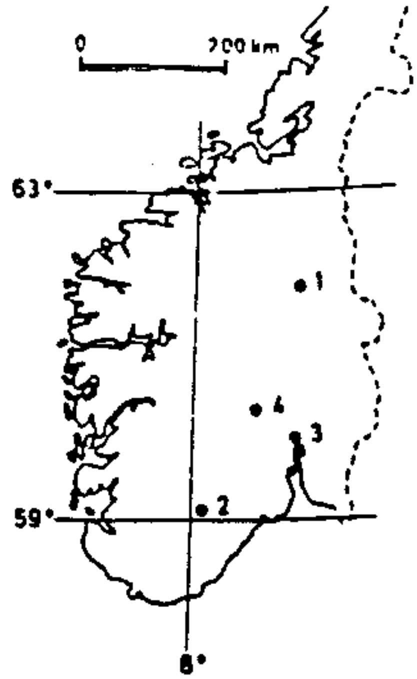
Generally the initial 20% of the melt water will contain 90% of the total contaminants within the snowpack. The remaining 80% of the melt is much more dilute since it contains only 10% of the solutes. Figure 11 shows that the initial 25% of the melt water volume was up to 5 times more concentrated compared to the rest of the melt (which contained a concentration factor of less than 1).

Figure 12 shows a well established fact that when solutions freeze, the dissolved substances are rejected by the ice crystals as they form to create areas of concentrated solutes and virtually pure ice. The first cylinder on the left contains a solution of NaCl, glucose, clay and $CaCO_3$. The progression of freezing (from the bottom) shows that by the third cylinder virtually all the contaminants are concentrated in a surface layer. The underlying ice is almost pure H_2O, with only a very small amount of salt dissolved in the ice. The second group of three cylinders shows that when particles with high resistance to flow (in this case sludge) are added and mixed during freezing, lenses of these particles form.

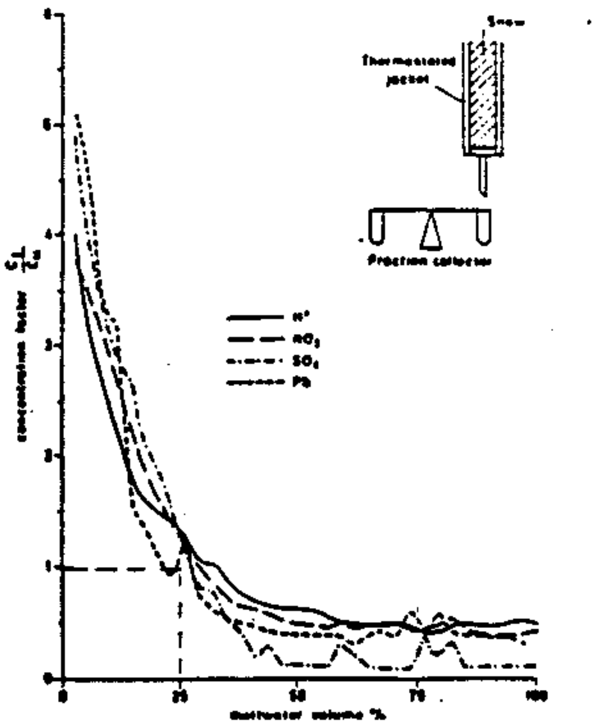
Snow in a snow pack continually changes in response to thermal radiation, pressure and humidity changes in the environment to which it is exposed, the process of 'ripening'. Ripening often transforms newly fallen soft snow into 'corn' snow. The natural melt & freeze periods provide opportunities for the exclusion of dissolved material from the re-forming snow grains. Impurities impose a considerable strain on the rigid hexagonal lattice structure of ice and are pushed ahead of the forming ice into the pore water (solution).

This action of impurities becoming concentrated in the early melt, leaving the later runoff relatively pure, has been applied to treating land with snow made from sewage effluent. The was proposed to provide a low cost method of separating nutrients from secondary sewage sludge as well as obvious benefits for northern communities. The concentrated melt water solution, which comes off slowly at the beginning of the melt season, would percolate into the soil where the nutrients could be adsorbed and later removed by plant uptake and bacterial degradation. Later in the season when the melt water is relatively uncontaminated, the majority of the melt water could run-off the land.

Figure 11 Johannessen and Henriksen: Chemistry of Snowmelt



Map of southern Norway showing snow-sampling locations. 1. Storefjell, 2. Fyresdal and Valebjørg, 3. Blindern and 4. Gulsvik and Langtjern.



Concentration factors for H^+ (calculated from pH), SO_4, NO_3 and Pb in fractions of melt water from snow sample 1. C_l is the concentration in the lth fraction, and C_w the concentration in the bulk snow. Insert is a schematic diagram of the laboratory lysimeter.

Figure 13 shows the degree of concentration versus the impurity atomic weights for the Kamloops effluent snowmaking project. This project concluded that the major fraction of the impurities present in the snowpack were released in the early portion of the melt. However, there was a substantial difference in the degree of concentration between various impurities present in the snowpack (see Figure 13) and those of the original lagoon effluent. (Other experiments have shown that the degree of concentration is almost independent of the initial concentration of impurities within the snow.) The passage of Kamloops meltwater through a 1m soil column buffered out the effects of this concentration phenomenon.

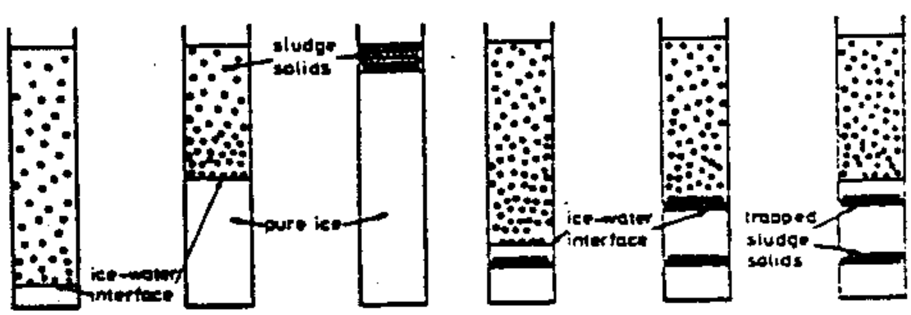
Preferential elution, (the more rapid loss of some ions from the snow pack than others) has been readily observed in the composition of meltwaters. The elution sequence established is:

$$SO_4^{2-} > NO_3^- > NH_4^+ > K^+ > Ca^{2+} > Mg^{2+} > H^+ > Na^+ > Cl^-$$

Sodium and chloride are expected to be enriched in residual leached snow packs. This is generally borne out by field observations.

A field experiment with brine irrigated snowpacks demonstrated that salt moved through the snowpack and became concentrated in the early melt fraction. The relationship between fraction of impurities and fraction of melt can be modeled as a simple exponential decay process as shown in Figure 14.

Figure 12 Vertical Migration Of Particles In Front Of A Freezing Plane.



Low resistance to water flow.

High resistance to water flow.

Figure 13 Degree Of Concentration Versus Impurity Atomic Weight

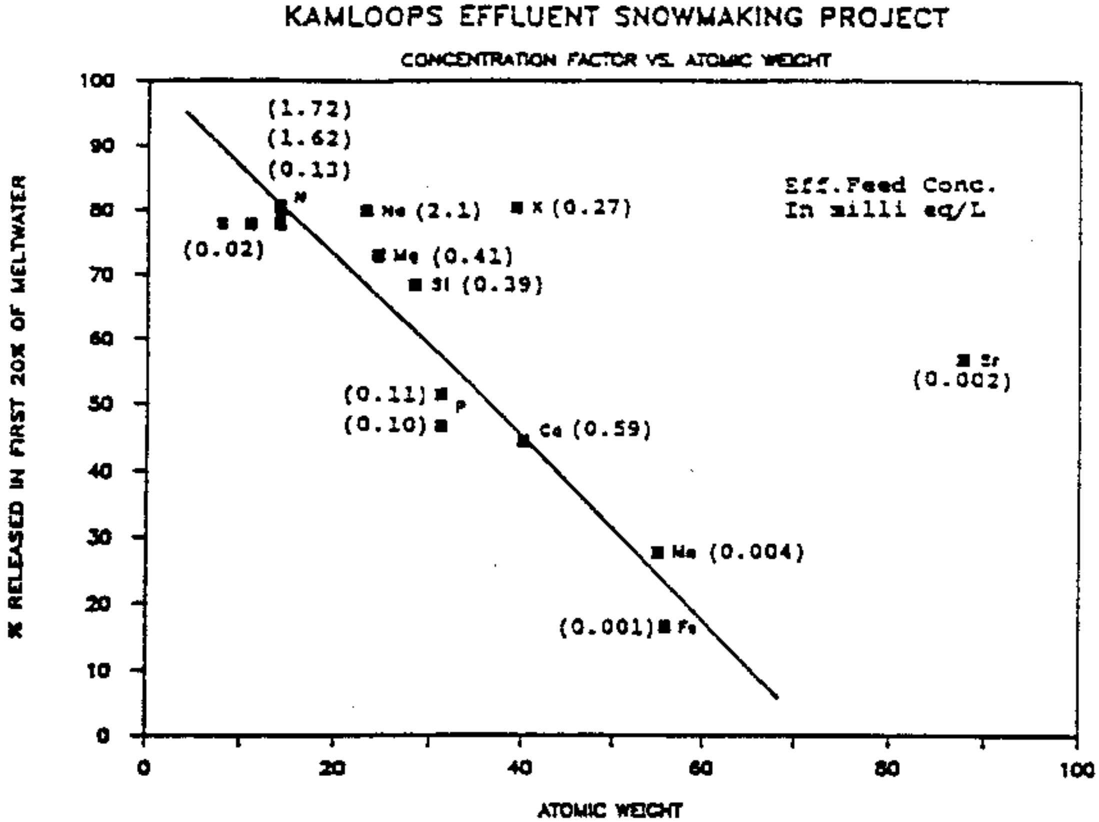
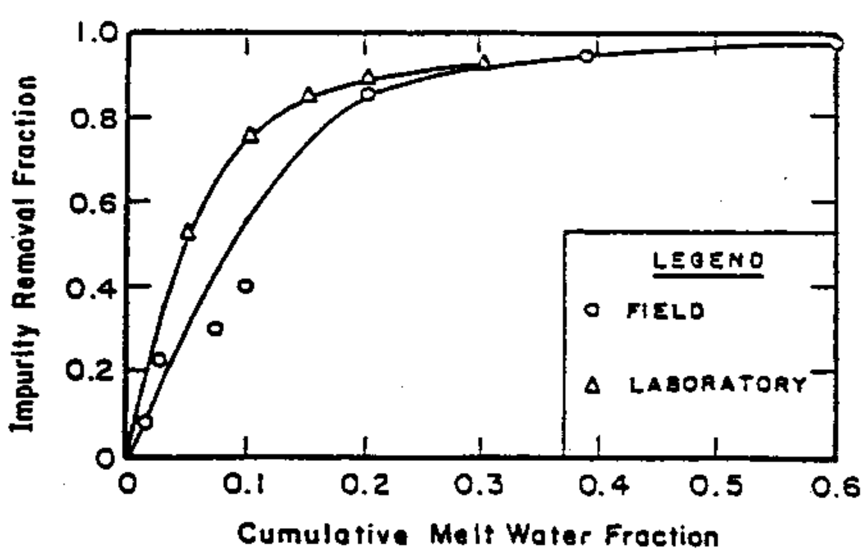


Figure 14 Impurity Removals From Brine Irrigated Snowpacks

R. ZAPF-GILJE *et al.*



3.5 The Roadside as a Receiving Environment

Presented by Ms. Gerry Davis, P.Ag., Ministry of Forests, Nelson Region.

Deicing salts are used to maintain winter roads in safe conditions and NaCl is the primary deicing agent because it is effective and economical.

The ecosystem adjacent to our roads and highways is the receiving environment for this salt. Deicing salt is dispersed into the roadside environment through spray and splash from passing traffic, surface water runoff, and infiltration through the soil. In cases where roads are adjacent to streams and lakes, direct deposition may also occur. Groundwater is another potential pathway for salt dispersal to streams and lakes.

The term 'injury' refers to the less than perfect state of health of a tree at any point in time. 'Decline' refers to the interaction of a number of interchangeable stress factors (abiotic and biotic) which produce a gradual general deterioration in the health of the tree and often result in tree death

3.5.1 Inter-related factors

The effect of salt on the heath of the roadside ecosystem depends on many inter-related factors. This is a list of some of the more obvious factors and includes:

1. Winter highway maintenance in particular annual salt application on a lane/km basis; months applied; and snow removal procedures (blower distances).

2. Highway feature including: traffic volume, road gradient, length of road and width of road shoulder. The distance of salt migration has been shown to directly increase with increasing traffic velocity. Road length and gradient and type of road influence the amount of surface runoff during snow melt. Further, studies report the effects of salt on roadside soil and vegetation decreases with increasing distance from the road.

3. Highway drainage (ditch/culvert) is another factor which influences the potential effects of deicing salt on the roadside environment since it governs whether surface runoff during melt is dispersed or concentrated in specific areas.

4. Climate governs snow load; snow melt profile, and residence time of salt in the soil and groundwater and is thereby and influencing factor. Droughty conditions may also influence some specie's tolerance to salt.

5. Site characteristics are also important including such factors as: topography, soil, depth to groundwater, slope, and species tolerance to salt.

6. Other stress factors are insects and disease and air pollution and pesticide applications.

Equally important is the last item on the list; stress factors other than salt. An accounting of stress factors other than salt is needed to understand the role of salt in roadside tree decline. Stress factors commonly work in tandem such that a stressed tree is more susceptible to other stress agents. For example, a tree which is drought stressed will become more susceptible to salt stress if the soil water potential is further reduced by the presence of salt in the soil.

Many of the factors listed above, and others, will be discussed today as objectives of Phase III, so this talk will be focused on other factors, since it will have direct bearing on site selection and study site monitoring.

As you know in 1991, Soilcon and Phero Teck undertook a reconnaissance level investigation into the injury and decline of roadside trees at 17 sites throughout southern B.C.. Deicing salt had been identified as a possible cause of this decline. Since some of the visual symptoms of salt injury are generic to other stress factors, it was necessary to investigate the obvious (salt) stress factor as well as the less obvious factors which might be involved. In the final analysis, salt was identified as a major stress factor at most sites, but it was never identified as the only stress factor involved in roadside tree decline.

To provide a framework within which to evaluate the role of the various potential stress factors each was assigned into one of three general groupings used by plant pathologists. The first of these three groups includes predisposing factors.

Predisposing Factors are factors which alter the tree's ability to withstand or respond to injury inducing agents. These factors involve long-term slowly changing influences such as climate, and site & soil conditions. Examples may include poor soil conditions (e.g. low rooting volume), forest dynamics (e.g. competition or suppression), air pollution from automobile exhaust, and long term local pollution sources.

Inciting Factors are factors which are short in duration, although their effects may be long-term and may be physiological or biological in nature. Such influences may be insect defoliators, late spring frost, short-term but severe drought, and periodic herbicide applications.

Contribution Factors is the third stress factor which was considered on the reconnaissance survey. These include a collection of environmental elements as well as biological agent such as wood rot and decay fungi and wood and bark boring insects.

As an injury agent deicing salt would primarily fall under the inciting group.

If the objective of Phase III is to understand the effects of road salt on the 'functioning' of the roadside ecosystem, it will be important to select sites where the role of stress factors other than salt, is kept to a minimum. But, having identified that other stress factors are involved in tree decline, these factors should be monitored and quantified over time.

3.5.2 Potential B.C. Stress Factors

This section will briefly review the potential stress factors investigated in the reconnaissance study. In doing so, missing ones can be identified. Figure 15 provides an overview of some of the stress factors at each site.

- **Predisposing:** Under the umbrella of the predisposing group, 4 factors were considered: 1) long-term climate, 2) site and soil factors, 3) forest dynamics and 4) air pollution.

  1. The climate assessment was subjective based on such factors as biogeoclimatic subzone, aspect and slope. The sites assigned a 1 were located in hot arid biogeoclimatic subzones where site conditions would be expected to exacerbate climate moisture deficits.

  2. Site/soil factors were restricted to two sites where the summer highway maintenance practices of road widening and grading had resulted in overbank disposal of soil and rock debris. The result was significant tree bole burial. The soil was underdeveloped, and the weight of soil/rocks would contribute to poor root gas exchange.

  3. The forest dynamics assessment involved a subjective field assignment of competition and suppression.

  4. Air pollution included an investigation for automobile pollution through soil and vegetation analysis for heavy metals, such as Pb and Cd. A preliminary review of the potential pollution point sources in each of the study areas was undertaken with the assistance of the MOE.

- **Inciting:** Six inciting stress factors were investigated.

  1. A variety of foliar insects and diseases were identified and are listed at the bottom of Figure 5. Shân Krannitz ranked each of the species on abundance an severity of injury.

  2. Short and long term climate data from Environment Canada and Atmospheric Environment Service stations was used to identify in particular climate patterns which might indicate significant climate moisture deficits. Where data permitted monthly averages were compared to 15 year normals for climate moisture deficits, precipitation and snow. was

  3. The role of salt as an inciting stress factor was investigated through documentation in injury patterns and symptoms. Foliar and soil analysis and indirect observations regarding highway characteristics were also used.

  4. Herbicides are used along highway rights of way as well as along hydro, gas and telephone rights of way for brush control, roadside soil sterilization and spot treatment of noxious weeds. The role of herbicides as an inciting stress factor was primarily investigated through MOE historical records on herbicide use.

  5. Mechanical injury was a common inciting stress factor on many sites. At many sites historical and current human activities have significantly impacted the integrity of the roadside forest ecosystem. Activities which were identified as causing mechanical injury included: overbank disposal of rock and soil, historical selective harvesting (typically for Christmas trees) and mechanical injury due to all terrain vehicles use as well as from older harvesting equipment (many of the sites showed signs of skidder activities).

  6. Mechanical injury would potentially exacerbate other stress factors including drought, salt and insects and diseases. This potential for interaction would be true for most stress factors.

Contributing: As shown in Figure 15 a variety of wood borers, bark beetles and some root rots were found across a number of sites. Wood borers and bark beetles in particular act as secondary agents and are attracted to weakened and injured trees, and Shân felt their presence was secondary as contributing to tree injury.

3.5.3 Summary

The roadside environment for the most part has been noticeably disturbed by historical and current human activities. If we are to use the roadside environment as our laboratory it is important that stress factors identified as being involved in the decline of roadside trees (in addition to salt), are monitored and quantified in Phase III.

The effect of salt can not be investigated in isolation of other potential stress factors.

Figure 15 Potential Stress Factors Contributing to Tree Injury and Decline

	Predisposing				Inciting						Contributing	
Site	Climate	Site/ Soil Factors[1]	Forest Dynamics[2]	Air Pollution[3]	Insects: Foliar[4]	Pathogens: Foliar[5]	Climate	Salt	Herbicides	Mechanical Injury	Insects: Wood & Bark[6]	Pathogens: Wood & Bark[7]
1/Sunday Summit	0	0	0	0	0	0	1-2	3	0	2	1	2
2/CPR Hill	0	0	0	0	0	0	1-2	3	0	1	0	0
3/Lost Creek	0	0	0	0	0	3	NA	0	0	0	0	0
4/Anarchist Mt.	1	0	0	0	0	0	1	3	0	0	2(Py)	0
5/Beaverdell	0	0	2(Pl)	0	0	0	1-2	3(Fd) 2(Pl)	0	1	1-2(Fd) 3(Pl)	0
6/LacLeJeune	0	0	0	0	0	0	2	3	0	0	0	1
7/Barnhartvale	1	0	0	1	2(Fd)	0	1-2	3	0	0	2(Fd)	0
8/Lillooet	1	1 Ca/Mg	0	0	0-1	0	1-2	3	0	2	2(Fd)	0
9/Goldbridge	0	1 Cl	0	0	2(Fd)	0	1	2-3	0	2	2(Fd)	1-2
10+11/Loon Lk	1	0	0	1	0	1	1-2	3	0	1	2(Fd)	1-2
12/Chasm	0	0	0	0	0	2	1	3	0	0	0	1
13/100 Mile H	0	0	1(Pl)	0	0	1(Pl)	1-2	3	0	1	0	2(Pl)
14/Horse Lk	0	0	2(Pl)	0	0	0	1	3	0	0	0	2
15/Hanceville	0	0	2(Pl)	0	0	0	1-2	3	0	0	3(Pl)	2(Pl)
16/Dog Creek	0	0	1	0	0	0	1-2	3	0	0	2(Fd) 1(Pl)	0
17/Williams Lk	0	0	0	0	0	0	1-2	3	0	1	2(Fd)	1

Ratings: 0 - none; 1 - minor; 2 - moderate; 3 - major

Predisposing Factors
[1] ie., soil compaction
[2] ie., suppression, competition
[3] ie., vehicle emission pollution; point source pollution

Inciting Factors
[4] Insects: Foliar
Douglas Fir Tussock Moth (*Orgyia pseudotsugata*); *Scythropus* Weevil (*Scythropus californicus*); Pine Needle Scale (*Chionaspis pinifoliae*); Sequoia Pitch Moth (*Synanthedon sequoiae*); Spruce Budworm (*Cho... occidentalis*); Spruce Cooley Aphid (*Adelges cooleyi*);
[5] Pathogens: Foliar
Elytroderma Disease (*Elytroderma deformans*); Juniper Broom Rust (*Gymnosporangium nidus-avis*); Lodgepole Pine Dwarf Mistletoe (*Arceuthobium americanum*); Lophodermella Needle Cast (*Loph... concolor*); Red Band Needle Blight (*Scirrhia pini*); Spruce Broom Rust (*Chrysomyxa arctostaphyli*);

Contributing Factors
[6] Insects: Wood & Bark Tissues
Ambrosia Beetle Spp. (*Gnathotrichus, Platypus & Xyleborus* spp.); Buprestid wood borers (Family Buprestidae); *Ips* spp. (*Ips pini* & other *Ips* spp.); Douglas Fir Beetle (*Dendroctonus pseudotsugae*); Mountain Pine Beetle (*D. ponderosae*); Red Turpentine Beetle (*D. valens*); Western Pine Beetle (*D. brevicomis*);

[7] Pathogens: Wood & Bark Tissues
Armillaria Root Rot (*Armillaria ostoyae*); Atropellis Stem Canker (*Atropellis piniphila*); Blackstain Root Disease (*Leptographium wageneri*); Cronartium Stem Rust (*Cronartium* spp.); Elytroderma Disease (*E. deformans*); misc. Heart Rot; Juniper Broom Rust; Laminated Root Rot (*Phellinus weirii*); Lodgepole Pine Dwarf Mistletoe (*Arceuthobium americanum*); Stalactiform Stem Rust (*Cronartium coleosporioides*) Gall Rust (*Endocronartium harknessii*);

3.6 Salt Symptoms and Salt/Pest Interactions

Presented by Gerry Davis for Shân Krannitz, RPF, MPM, Phero Tech Inc.

3.6.1 Tree Injury Symptoms

Salt can be absorbed both through the roots and foliage. Visual injury symptoms for both modes of uptake are similar. Injury symptoms include needle-tip and marginal bronzing with a clear demarcation between necrotic (dead) and healthy tissue. The severity of needle-tip browning progresses from older to younger needles. Second and third year old needles can be up to 50% brown. With increasing necrosis and needle-tip dieback needles are lost. Advanced needle drop results in thinning crowns with reduced height and diameter of growth. Severe injury results in a progression of increasingly severe defoliation, dieback and ultimately death.

In the reconnaissance study, visible injury symptoms were observed on all conifer species in the study plots. In terms of apparent relative resistance to salt injury, Ponderosa pine (Py) was the most resistance and Douglas fir (Fd) clearly was the most susceptible with Lodgepole pine (Pl) somewhere in between. While injury symptoms were observed on Engelemann Spruce this species was not present at any of the study plots. Similar relative ratings for Py, Fd and Pl are reported in the literature. It has been suggested that Py is more resistant to the effects of salt spray because of increased needle thickness and thicker cuticular waxes.

Roadside patterns of salt injury observed in the reconnaissance study were consistent with those reported in literature. Tree injury tends to decrease with increasing distance from the highway and decreasing exposure to highway winds and spray. In most cases visible tree injury is limited to a narrow band within 20 m of the road's shoulder, although the penetration distance will also reflect such factor as drainage (e.g. culverts) and highway characteristics (e.g. curves traffic volume). At one site minor visible injury was observed 50 m or more fro the highway due to a combination of traffic and natural wind and salt spray.

Because the injury symptoms are similar for both root and foliar salt uptake it is difficult if not impossible to evaluate the relative role of each. Soil salt, however; might be suspected when needles sheltered from spray show as much damage as exposed needles. (Salt spray symptoms tend to occur on areas of the tree which receive the salt spray.) In the literature, information on the relative role of foliar versus root salt uptake in roadside environment was unavailable. Based on visual injury and lab results we felt that both sources of salt were involved in roadside tree injury at most sites.

Only a few scientific studies have attempted to diagnose the cause of salt injury in trees. Salt injury symptoms may be due to toxic, nutritional or osmotic effects. The limited research available suggests that the visual salt symptoms are primarily associated with high Cl tissue concentrations. In the case of salt spray, Cl is possibly toxic. Cl concentrations are often used as diagnostic criteria when assessing salt damage.

3.6.2 Forest Health

The two main health objectives in the reconnaissance study were:

1. To review the role of current and/or historical insect and disease infestation as stress factors in the decline of roadside trees.
2. To provide professional opinion on whether the priming of forest pest populations by salt-damaged roadside trees present a risk to the adjacent forested crown land.

As you saw in the stress factors list Shân detected a wide range of insects and diseases. This reflected the large number of sites investigated and the variety of biogeoclimatic zones and forest types represented. No one insect or disease was prevalent across all sites although Douglas fir beetle in particular is a secondary agent and is attracted to weakened and injured trees.

Shân Krannitz felt that the levels of insects and diseases other than Douglas fir beetle and Armillaria root rot were similar to those commonly found in similar forest stands. Further no detectable patterns were found between their levels and injured roadside trees. At a number of sites, there were no insects or diseases of consequence.

3.6.3 Conclusions

It was the professional opinion of Shân Krannitz that the forests of southern BC did not appear to be at risk due to the priming of forest pest populations by salt damaged roadside trees. However, Douglas fir beetle and to a lesser extent Amarillia root rot were found to be secondary agents associated with damaged or dead roadside trees. This was particularly true of Douglas fir beetle which was frequently found in roadside Douglas fir but not in adjacent stands. Stresses or injured roadside host trees there fore appear to enhance the incidence of Douglas fir beetle and possibly Armillaria root rot in a local area.

3.6.4 Recommendations

Although the forest of southern BC do not appear to be at risk, pest population should be monitored over the long term at roadside damage sites; either in conjunction with, or independently from this study. Monitoring is important because biological organisms are not static and neither are their environments.

3.7 Road Salt and Aquatic Resources

Paul H. Whitfield[1]

Sodium and chloride are common chemicals in the natural environment. The addition of road salt has several potential effects on aquatic systems through direct and indirect impacts on systems and processes. The nature of sodium and chloride in aquatic systems is outlined. The application of road salt generates transient events in aquatic systems, examples from recent measurements show significant increases in conductivity of streams during periods of road salting .

The concentration of sodium and chloride in natural systems across British Columbia. The concentrations observed are a function of the hydrologic cycle. In interior snow melt runoff systems, concentrations of both sodium and chloride are a function of the ground water contribution in a watershed. This results in the highest stream concentrations being observed during the late winter low flow period. In coastal rainfall runoff or rain on snow runoff situations high concentrations of sodium and chloride are generally found in the inter-event low flow period.

Road salt impacts will not be independent of other type environmental change. In our work, we are examining and observing road salt impacts on streams in the context of urbanization. Figure 16 shows a conceptualization of the impacts of urbanization of rainfall runoff processes in the lower Fraser Valley. Other human activities, such as the use of road salt need not considered in isolation, rather the ecosystem should be the focus.

Sodium and chloride are both mobile species, and are chemically active. The enhancement of sodium and chloride levels in streams through road salt applications can change the chemical situation by altering the partitioning of chemical reactions by their activity and concentration. The addition of salt can cause acidification. Much of the literature on acid rain and its effect contains evidence of the impact of sea-salt increasing the hydrogen ion supply in watersheds. Short term pulses of acid release during snow melt is one of the principle impacts on aquatic life due to acid rain. Short-term acidification (lowering pH) may also result from road salt applications.

---

[1]Head, Environmental Networks Division, Environmental Surveys Branch, Environment Canada, 224 West Esplanade, North Vancouver, B.C., V7M 3H7

The addition of salt can also affect the chemical equilibrium which normally binds heavy metals to sediments and large organic compounds rendering them unavailable. High concentrations of salt can cause the displacement of metals from sediments and soils, making them available to aquatic life. Contaminants in soils and sediments along roadways could be mobilized by the introduction of road salt into the aquatic system (eg. Feick et al, 1972).

Road salt also contains materials which are environmental contaminants. Analyses of road salt shows the presence of contaminants such as lead. These materials may enter the aquatic system or the adjacent soils as a result of the application. Cyanide compounds are used as anti-caking agents in preparation of the salt. Some of these compounds when exposed to sunlight release free cyanide which is highly toxic to aquatic life.

The application of road salt for deicing can significantly alter the concentrations in the streams directly adjacent to the areas of application (Peters and Turk, 1981; Scott, 1980; Van de Voorde et al., 1973; Kunkle, 1972; Demers and Sage, 1990, and; Crowther and Hynes, 1977). Concentrations of sodium and chloride have been found to increase by up to thirty-one times. Road salt may also contaminate ground water (Huling and Hollocher, 1972).

Increased levels of sodium and chloride can increase invertebrate stream drift (Crowther and Hynes, 1977). Invertebrate drift is a measure of impact on aquatic insects. Typically, a certain number of organisms drift downstream naturally. These authors report that additions of road salt increase the number of organism which drift. This is generally accepted as a negative impact on the aquatic community. Increased drift can be also caused by additions of sediments, toxic chemicals and other contaminants.

In some areas of the province ecosystems are impoverished with respect to chloride. Here, the concentrations of chloride in at very low levels, and there is some evidence that chloride concentrations are affected by vegetation. How ecosystems which are conditioned to exist under a low chloride regime react when subjected to high concentration is not known. One might speculate that the organisms have developed mechanisms which allow it to extract chloride without regulating the levels, hence might be at risk when chloride is freely available.

Many studies consider salt concentrations on a long term basis. The effect on the aquatic system is more likely a function of the transient nature of the movement of road salt in the aquatic environment. Transients are significant deviations from normal conditions which have a duration from seconds to days. They are particularly difficult to collect data on because the events are rare relative to the density of data. Transients are a significant feature of many environments. Often, ecological impacts are the result of transients, not long term averages. Some transients are characteristic of system functioning, while others are symptomatic of human impacts. Whitfield and Wade (1992) report observations on road salt generated transients.

Specific conductances in Kanaka Creek (35 µsiemens/cm) are much lower than in the headwaters of the Serpentine River (150 µsiemens/cm). Figures 17 and 18 show two cases where very high conductivities were observed. In Figure 17 we see a peak in conductivity observed in early February 1990 which had a maximum value of about 45 µsiemens/cm (base level was about 20) and a duration of about 1.6 days. In the Serpentine River, over the same time period, two such peaks were observed (Figure 18). The first of these peaks had a maximum value of about 460 µsiemens/cm (base level was about 150) and a duration of 12 hours; the second peak had a maximum value of 630 µsiemens/cm and lasted about 22 hours. Each of these events started in the afternoon. The first event of the Serpentine started on the evening of 30 January; the next two events started on the evening of 1 February. The weather during this period was cold with moderate snowfalls. Sanding and salting of roads in these areas took place during this time period (Table 2).

The observed conductivity peaks are co-incident with thaw periods following a cold period when sanding and salting of the roads in the watersheds took place, and are followed by increased water levels reflecting the melting of snow. Water levels in each stream are relative to an arbitrary datum. These transient events are the results of the combination of weather conditions and man's activity. Such instream events could be identified by the significant increases in conductance coupled with low water temperatures, with local increases in stream temperature (these occur during melting days during cold periods). Similar peaks have been observed during other similar periods.

Coincident to these conductance peaks in the Serpentine River are pH depressions. These depressions are relatively large, about 0.8 pH units. These depressions appear to be typical results from wintry periods in the Lower Fraser Valley. We do not know, at present, the ecological significance of these events. In the Serpentine River, with increasing urbanization of its watershed, we can expect such events to increase in both frequency and magnitude. The observed conductances are the highest values observed in the Serpentine River. While the Kanaka Creek peak values were not extraordinary, they reflect a more than doubling of conductance. These peaks reflect large increases in the concentrations of salts. These is believed to be the direct consequence of thawing coupled with sanding and salting of road surfaces. Organisms living in small streams during winter are subject to many stresses during winter conditions. It would appear that when salt is being used to remove snow and ice from road surfaces, and thawing conditions exist, there is rapid movement of salt into streams. These large increases in salt concentration, though short in duration, have the potential for significant impacts on the aquatic biota of these small streams during winter conditions. The ecological consequences of these salt pulses needs to be evaluated. Alternate sanding and salting practices might be an effective way to reduce the potential ecological consequences of current practices.

Table 2 Weather Conditions And Sanding And Salting Activities
From January 26 to February 7 1990.

Data	Max T°C	Min T°C	Weather	Kanaka Creek (Maple Ridge)	Serpentine River (Surrey)
26 January	3.0	-3.0	snow	sanding/ salting	sanding/ salting
27 January	2.5	0.5	rain		sanding/ salting
28 January	6.0	2.5	rain		sanding/ salting
29 January	4.0	0.0	rain		sanding/ salting
30 January	4.5	0.5	sleet	sanding/ salting	sanding/ salting
31 January	-2.0	-3.5	snow	sanding/ salting	sanding/ salting
1 February	1.5	-0.5	snow	sanding/ salting	sanding/ salting
2 February	3.0	1.0	rain		sanding/ salting
3 February	4.5	2.5	rain		sanding/ salting
4 February	5.0	2.0	rain		sanding/ salting
5 February	4.5	3.5	rain		
6 February	3.0	0.5	snow	sanding/ salting	sanding/ salting
7 February	3.0	0.0	snow		sanding/ salting

More recent results are shown in Figures 19 - 22. In each case significant increases in stream conductance of up to 16 times background levels were observed in the hours following salting of roads in the watersheds.

Summary: Transient events resulting form road salt applications have been reported. The biological consequences of these events is not known but likely includes some or all of the processes discussed above. Some of the negative impacts might be reduced by changing application dynamics, sand/salt mixture options, and the removal of other contaminants form the road salt.

References

Crowther, R.A., and H.B.N. Hynes. 1977. The effect of road deicing salt on the drift of stream benthos. Environ. Pollut. 14:113-126.

Demers, C.L., and R.W. Sage. 1990. Effects of road deicing salt on chloride levels in four Adirondack streams. Water, Air, and Soil Pollution 49:369-373.

Huling, E.E. and T.C. Hollocher, 1972. Groundwater contamination by road salt: Steady-state concentrations in East Central Massachusetts. Science 176:288-290.

Feick, G., R.A. Horne, and D. Yeaple. 1972. Release of mercury from contaminated freshwater sediments by the runoff of road deicing salt. Science 175:1142-1143.

Kunkle, S.H. 1972. Effects of road salt on a Vermont stream. Journal AWWA May 1972 290-295.

Ohno, T. 1990. Levels of total cyanide and NaCl in surface waters adjacent to road salt storage facilities. Environ. Pollut. 67:123-132.

Peters, N.E., and J.T. Turk. 1981. Increases in sodium and chloride in the Mohawk River, New York, from the 1950's to the 1970's attributed to road salt. Water Resources Bulletin 17:586-597.

Scott, W.S. 1980. Road salt movement into two Toronto streams. J. Environmental Engineering Div (ASCE) 106:547-560.

Van de Voorde, H., M. Nijs, and P.J. van Dijck. 1973. Effects of road salt in winter. Environ. Pollut. 5:213-218.

Whitfield, P.H., and N.L. Wade. 1992. Monitoring transient water quality events electronically. Water Resources Bulletin 28:703-711.

Wilcox, D.A., and R.E. Andrus. 1987. The role of *Sphagnum fimbriatum* in secondary succession in a road salt impacted bog. Can. J. Botany 65:2270-2275.

Figure 16 Impacts of Urbanization of rainfall runoff

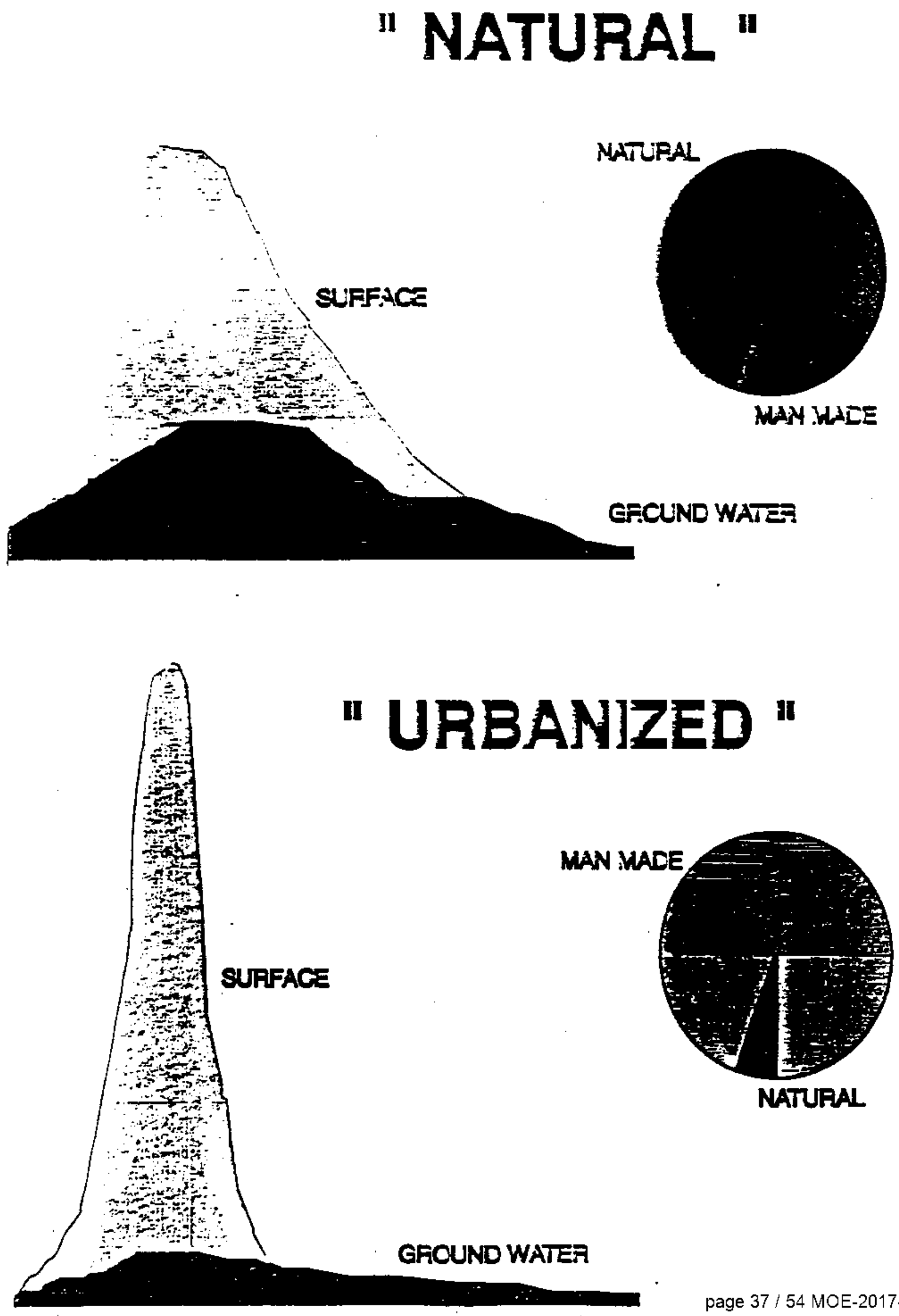


Figure 17 Kanaka Creek - January 30 to February 5 1990.

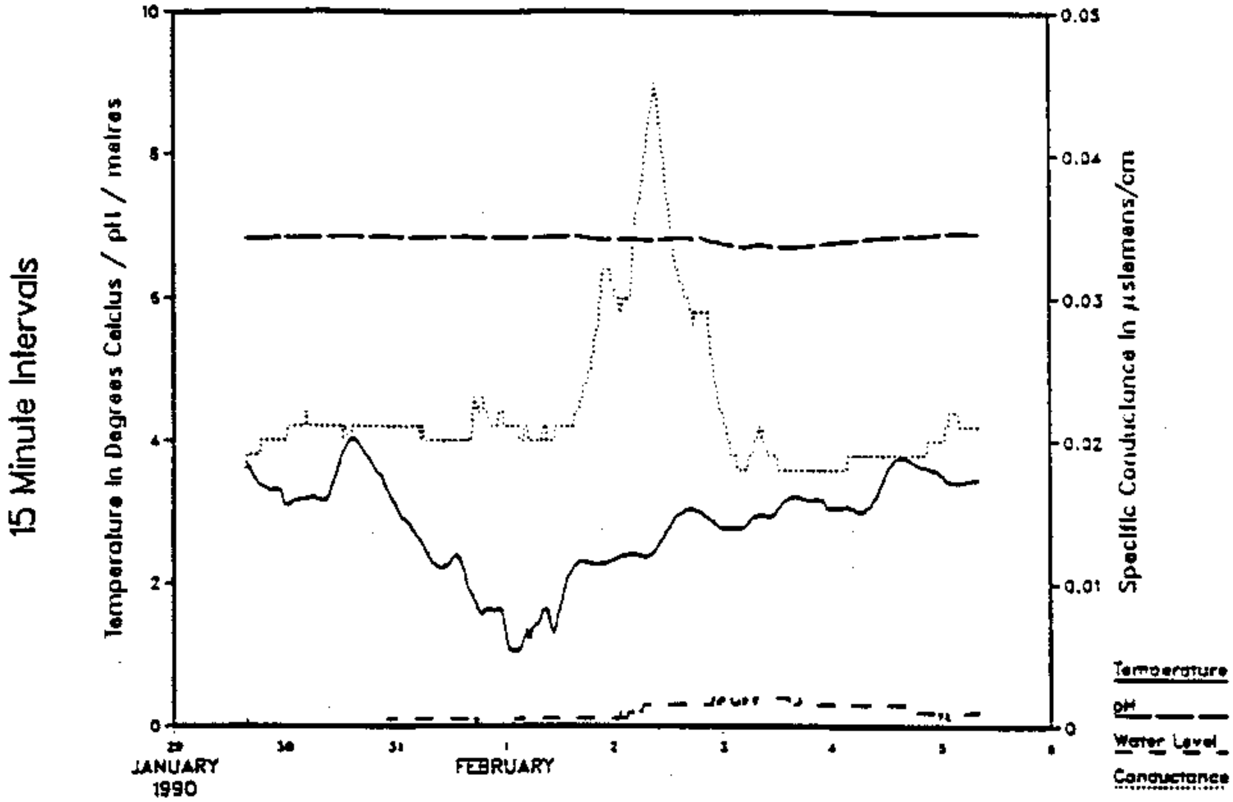


Figure 18 Serpentine River - January 30 to February 5 1990

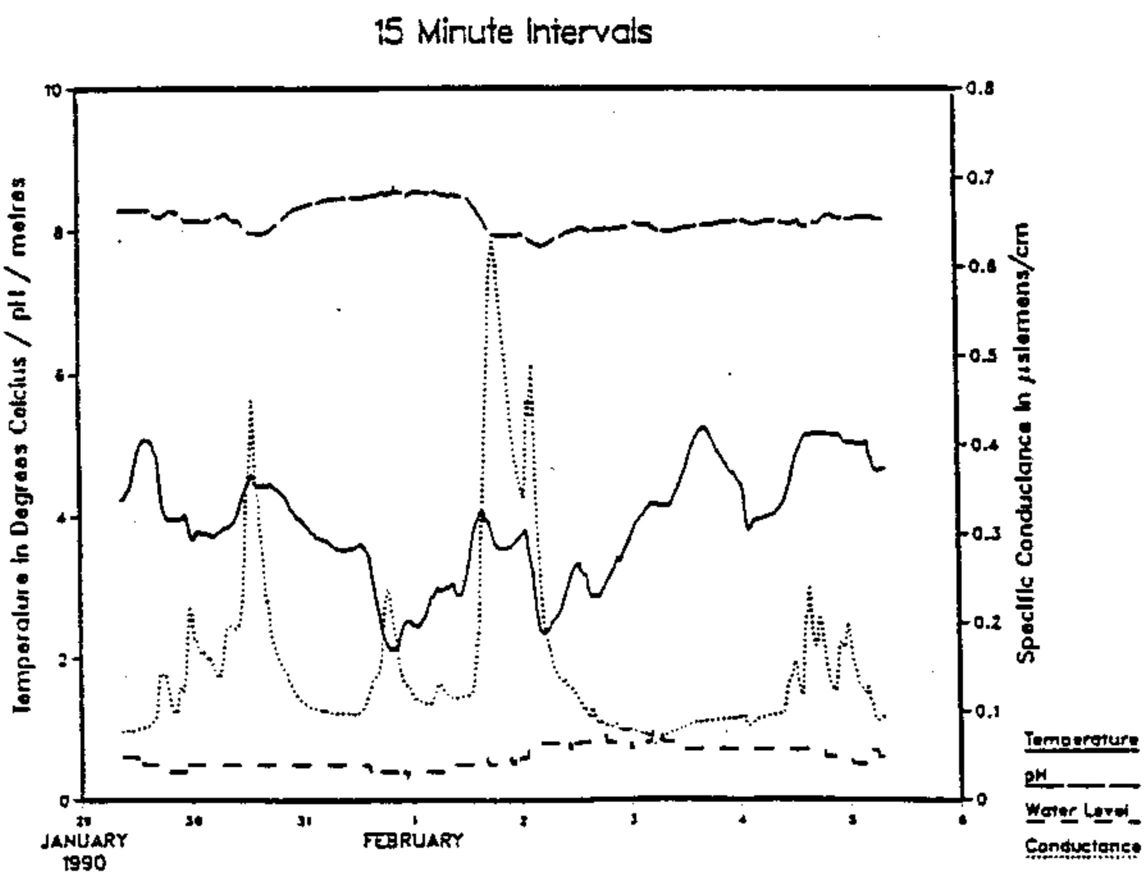


Figure 19 Kanaka Creek - December 22 1992 to January 31 1992

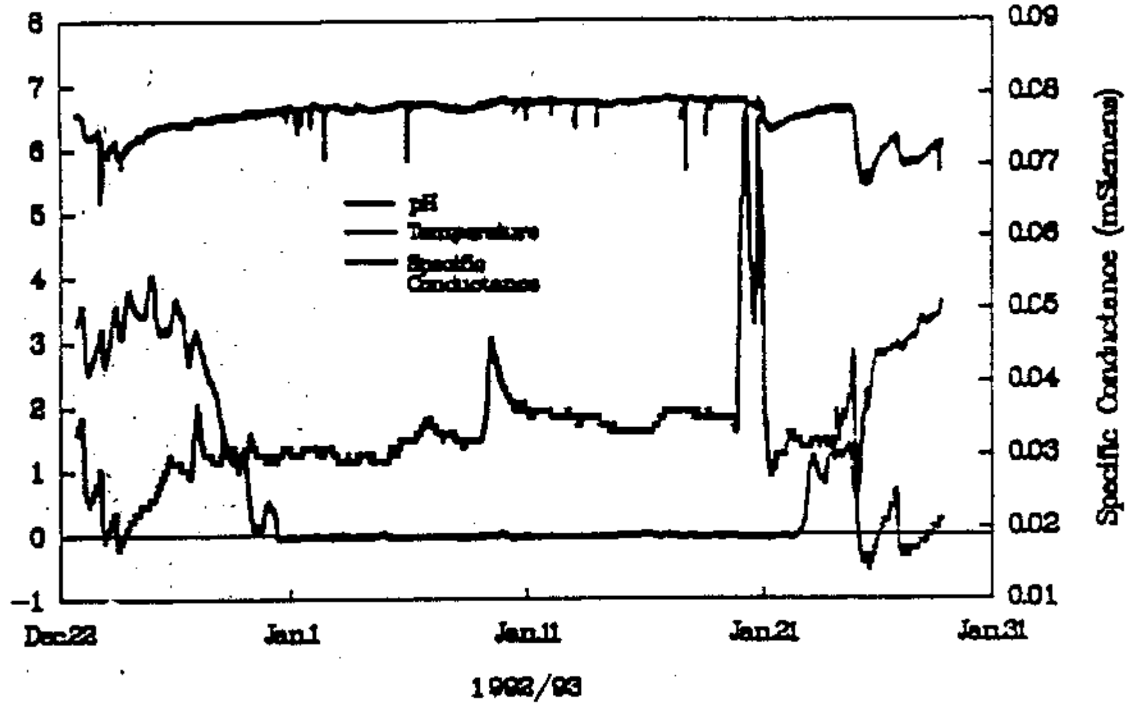


Figure 20 Serpentine River - December 22 1992 to January 31 1992

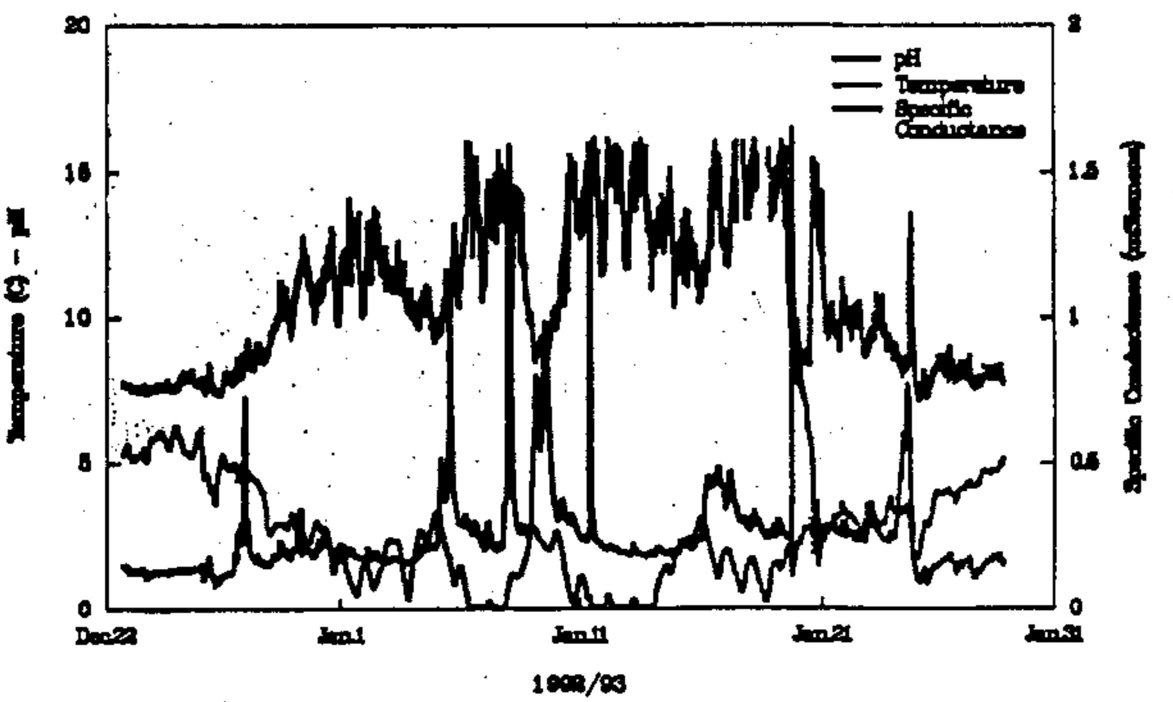


Figure 21 Kanaka Creek - February 1993

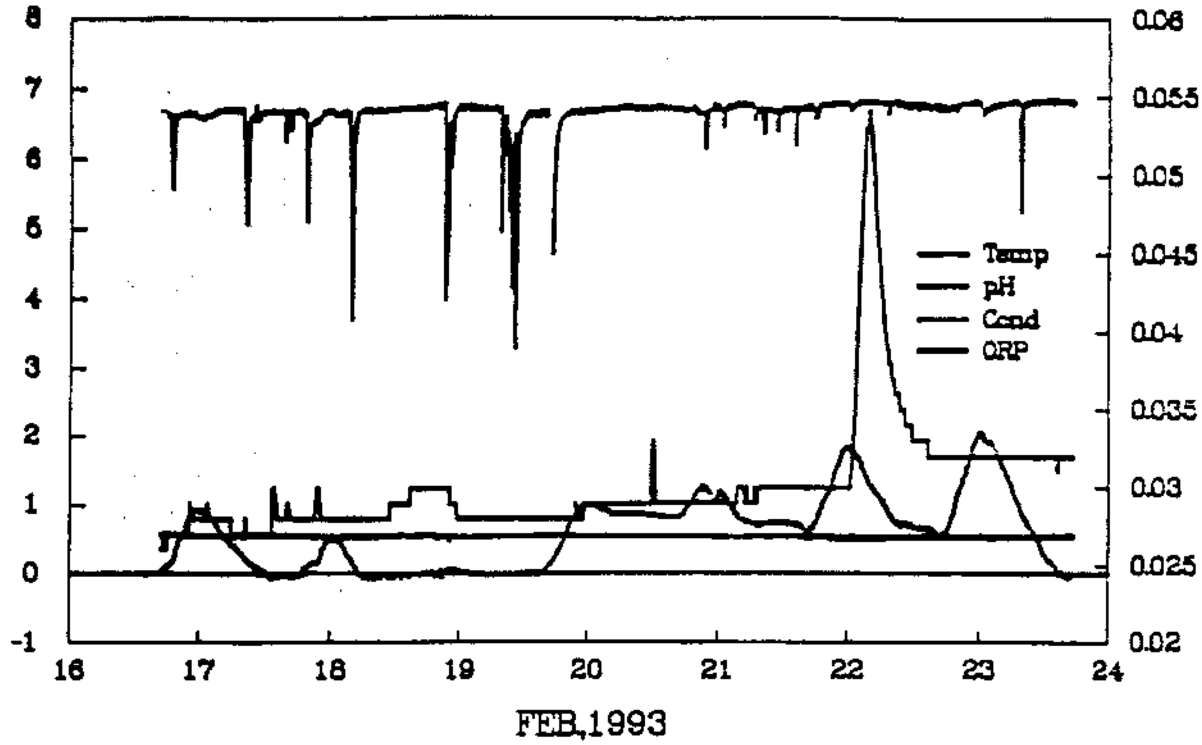
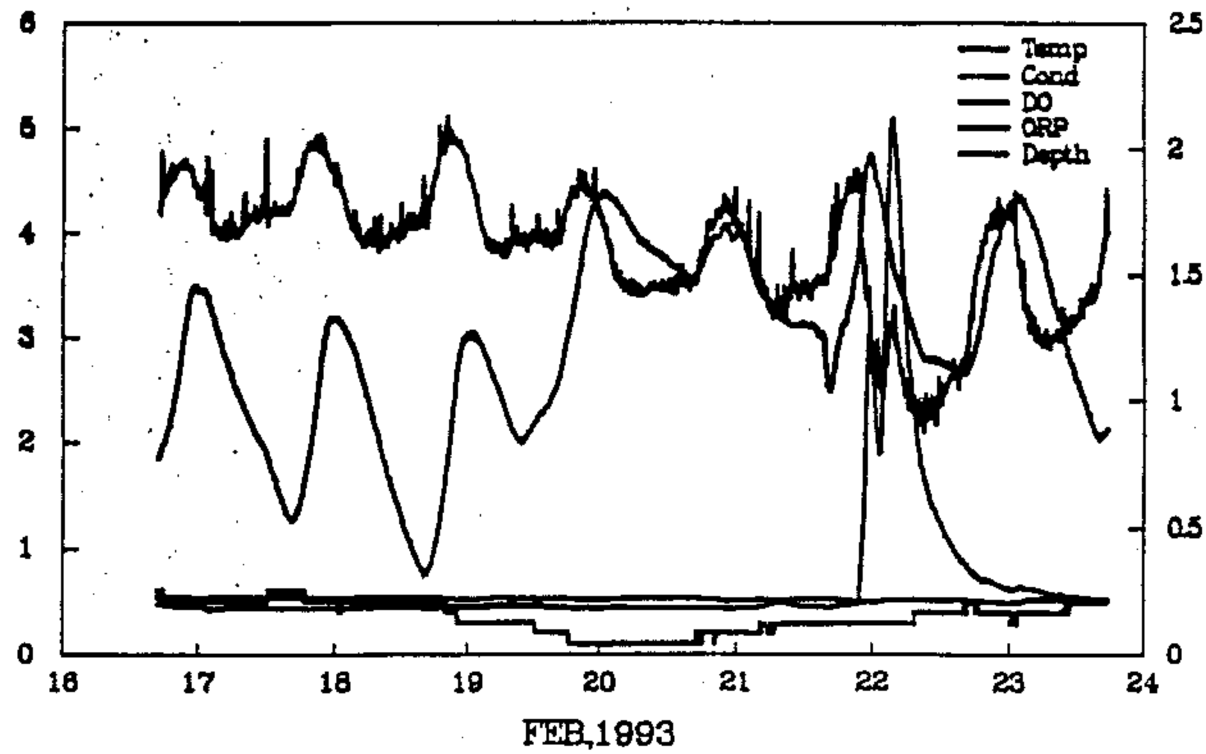


Figure 22 Serpentine River - February 1993



4.0 Can Impact and Effectiveness be Balanced? - Conclusions

The **Flow of Road Salt Though the Environment Workshop** succeeded in its objective. This objective was to recommend direction for future environmental research on the use of Road Salt and to develop Terms of Reference for such research. The workshop concluded that past research both on terrestrial and aquatic systems had shown that the use of road salt can have significant effects on vegetation and the environment. What is not known is if these effects could be avoided with more skillful application of salt while still achieving the current road maintenance standards. If not, fundamental changes rather than technical solutions may be required. In summary, the research proposes to determine if the effectiveness of road salt as a deicing agent can be balanced with the environment impact of salt.

The following proposed Terms of Reference are based on the general consensus which developed during the workshop. The Terms of Reference are divided into section on Objectives, Methodology, and Analysis. All major points were arrived by group consensus. Additional detail has been added by Michael Goldstein and Lynn Jarvis following the workshop.

4.1 Objectives

The sense of the workshop was to establish limited research objectives which could be achieved in two years. It was felt that long-term research could not be recommended until the gravity of the problem is better understood. It was widely agreed that the research objectives for the next two years should be:

> **Can the present road maintenance standard be achieved while keeping salt-use below the intensity at which significant harm may occur to roadside ecosystems or to downstream aquatic and groundwater systems?**

In other words, what is the scope of the problem? Can minor technical fixes, such as better salt scheduling and improved operator training remedy the problem, or are more drastic measures necessary? These could include salt alternatives or amendments to the current road maintenance standard.

The workshop was also successful in realizing several secondary objectives. The workshop brought together experts from a variety of disciplines. Although they were all involved in the fate of de-icing salt in the environment, generally the participants had not previously communicated. Information was exchanged between the MOTH, MOE and MOF personnel and environmental scientists. This exchange increased the understanding of all groups about the challenges face by others. While a detailed conceptual model of the fate of salt was not completed during the workshop, much progress was made on the methods necessary to develop such a model.

4.2 Methodology

4.2.1 Basic Strategy

The workshop discussed possible methodologies to achieving the objectives outlined above. Two basic strategies were compared. The first discussed was the laboratory strategy. In this research method test section(s) of a road would be completely managed so that variables such as application rates and frequencies could be controlled without impacting the present operations or highways users. These sections of road would be separate from the Provincial road network.

The second basic strategy is operational trials. In this approach sections of the existing road network are used for research. The operation approach has the advantage of allowing operational problems to be studied. It is also less expensive and can be implemented within in a shorter time period.

It was a consensus of the workshop that operational trials were more appropriate for the next research phase, but that 'laboratory' road sections would be required if major changes to road maintenance policy are necessary. The following factors favored operational trials.

1. Traffic patterns are integral to de-icing operations, and would be hard to implement in the 'laboratory' approach.

2. Current MOTH maintenance standards could be easier implemented using the operational approach.

3. The cost of the operational approach would be less.

4. It would be hard to implement laboratory trials within two years.

5. More literature study and investigation of efforts to handle road salt in the United States and other jurisdictions are needed prior to laboratory studies to avoid duplication.

4.2.2 Experimental Sites

There was considerable discussion on the number and location of experimental sites. It was felt that a single site would not cover the range of climate and road conditions that need to be addressed. Ideally, 3 sites in each climate region were discussed, however; there was general agreement that the costs would be excessive for the limited and initial research objectives. There was general agreement that this research objective could be achieved with 2 to 5 sites.

Mr. Dennis Bilkel of the MOTH stated that the Ministry is committed to a research in the Loon Lake area. The MOTH project will look at abatement strategies for road salt impacts. It was felt that while the objectives of the MOTH project were not the same as those proposed by the workshop, a substantial advantage would be realized by coordinating both projects. It was recommended that the two projects coordinate wherever possible. In particular, techniques and research findings should be shared. It was felt that a research site near or very similar to Loon Lake might duplicate efforts and should therefore be avoided.

There was general agreement that if the data from the Loon Lake project is shared the required number of experimental sites could be reduced to 2-4. Further suggestions were that at least one site should be on a Class A road as well as one or more on Class B.

Several site locations were discussed. In particular the portion of the Coquihalla Highway between Merrit and Kamloops. This site had the advantage of being relatively new so that the impacts from past salt application has not built-up over decades. Further, accurate records of salt applications should be available for the entire history of the road (since May of 1986). It was also suggested that another site be located on a Class B road in the Kootenay district. but no conclusions were reached.

4.2.3 Experimental Site Characteristics

The workshop discussed the following characteristics that experimental sites should have:

1. The opportunity to monitor aquatic and ground water systems of a small basin.
2. A variety of road conditions such as slopes and turns.
3. A variety of vegetation damage classes.
4. Be in an area where environmental affects of road salt are likely to be significant.

In the morning discussions it became apparent that visible impacts on roadside vegetation could not be used as indicators of aquatic impacts. Mr. Whitfield's presentation showed impacts on the aquatic systems in the Lower Fraser Valley where no vegetation damage had been noted. It was therefore felt that monitoring aquatic systems would be necessary within the experimental sites.

Bridges and other places where roadways cross water courses may provide good monitoring situations. It is recommended that the proposed aquatic and groundwater monitoring locations be determined prior to final selection of experimental sites.

The workshop felt that the experimental sites should include a section of road and surrounding environment, rather than be limited to a point on the road. There were several reasons for this:

1. The amount of salt applied may be affected by local road conditions.
2. Local topographic and drainage factors may concentrate or disperse salt over a relatively short section of the roadside.
3. Impact intensity varies with vegetation type, which may be more diverse over a road section than for a roadside point.

It was generally felt that the monitoring of aquatic groundwater systems could best be obtained by having an experimental site cover a small basin. This would facilitate mass balance calculations to determine the partitioning of salt into the various environmental sectors. While no firm size of experimental site was selected, road lengths of 1 to 5 km were discussed. Ideally, experimental sites would consist of a micro watershed.

There was an underlying assumption that if impacts from salt are likely at the sites (and various environments) studied, then any conclusions drawn about the basic environmental integrity and deicing use, would be conservative and hold for most of the Province.

4.2.4 Study Duration

The amount of salt used varies from year to year in response to weather conditions. The MOTH stated that one winter may only require one-quarter the deicing chemicals of another season. A multi-year study would be required to investigate year-to-year variations.

At the same time the Ministry of Highways needs to know the severity of the problem as soon as possible so that the MOTH can scale their response. It was generally agreed that a two year study would supply enough information on year-to-year variation so that a model of the fate of salt could be constructed and tested. The model could then be used to determine long-term impacts by inputting long-term climate data. Such climate data is available from many MOTH yards in addition to Environment Canada weather stations.

4.2.5 Study Integration

The workshop felt that a multi-disciplinary approach was needed for the research project to be successful in achieving its objectives. The logical project organization would be along traditional discipline lines. The following four study areas are suggested:

1. road maintenance 2. snow and climate 3. soils and vegetation, and 4. groundwater and aquatic systems.

The coordination of these discipline areas may be complicated by the fact that special expertise is likely needed in each area. It is a real possibility that this expertise would come from different organizations and possibly from different sources of funding. Coordination would also be needed to avoid duplication.

The workshop thought that such cooperation by persons with varied backgrounds and affiliations was both possible and practical. Good communication and agreement of objectives were seen as key factors. It was recognized the MOTH would have a large role to play in such a group effort. As well Environment Canada, currently studying aquatic effects of salt to urban streams should have significant input.

The following section describes the research methods and measurements which the workshop recommended. These are divided into four study areas (as listed above). The study areas are arranged by the general order of salt flow. That is from road to snow pack, to soil, then vegetation, and finally aquatic and groundwater systems.

4.2.6 Measurements

4.2.6.1 Road Maintenance

The basic objective of the road maintenance measurements would be to determine the efficacy of deicing salt and to supply the other disciplines with detailed information on salt application. The relationship between the amount of salt applied and the standard to which roads are maintained under a given set of climatic conditions is referred to as salt efficacy.

The objectives of the road maintenance section are to determine:.

1. How much salt is being applied?
2. When is the salt being applied?
3. What are the theoretic and operational considerations governing the decisions to apply salt?
4. To what standards are the roads maintained?
5. What are the constituents and contaminants in the salt?

Salt application trucks have a automatic-feed device which applies salt at a given rate per kilometer regardless of the truck's speed or direction. Prior to the privatization of road maintenance, these devices were calibrated on a regular basis. As part of this study this calibration should be checked on the experimental plot. The calibration should determine the variability of the deicing application as well as average application. The salt application should be measured under different road conditions such as slopes and inclines. Once the trucks are calibrated only the frequency and rate of application will need to be recorded.

For each salt application the criteria used in decision making (when and how much?) should be documented. This should include any input data used such as climate information from the maintenance yard climate stations. Initially, the salt application criteria used on the experimental plot should be the same as for the surrounding area. Once all disciplines have had sufficient time to analyze present practices alternate salt application criteria can be developed.

It will be necessary to analyze the standard to which roads are maintained in the experimental plots. This type of assessment is currently done by the Ministry of Highways to check contractors. During the experiment, these assessments will be needed every few days during the salt application season. This will allow a detail assessment of salt efficacy.

The people doing the road maintenance assessments should be independent of the individuals making the salt application decisions. Communication between these two functions should be restricted until after completion of the experimental period. If more than one person is making the road maintenance assessments correlation will be needed to maximize uniformity.. It is important that these assessments be made in a systematic way.

During the workshop three major sources for salt were identified. These sources were Utah, Saskatchewan and Chili. In addition to sodium and chloride, salt can contain various minor constituents. These include ferrous cyanide, arsenic, lead and other metals. These are referred to as salt components in this report. Several samples of road salt should be taken at the start of the experiment. All environmentally significant components should be followed throughout the experimental site. This would include analyzing the soil, vegetation, aquatic, and groundwater systems. Additionally, the particle and aggregate size of the salt should be determined as these can effect efficacy.

4.2.6.2 Snow and Climate

The importance of climate was discussed frequently during the workshop. Short-term climate events such as snowfalls and warm and cold fronts control salt-use. Long-term climate controls vegetation patterns and groundwater flow. Annual climate variation also controls speed of snow melt. The snow and climate tasks are broken into the following topics: climate monitoring and partitioning of snow melt.

Climate Monitoring: On-site detailed climate measurements will be needed throughout the experimental period. This scale of measurement justifies the use of automated datalogging equipment. Frequent measurement of snowpack conditions will be needed for hoarding areas throughout the winter. Climate was not recognized as an independent discipline during the workshop. All three other discipline areas require climate and snow information. Climate and snow measurements are separate due to the specialized equipment needed. Table 3 gives the recommended measurements and their frequency for measuring and reporting.

Table 3 Climate Measurement

Parameter	Device	Frequency	Reporting
Rainfall	Precipitation Gauge	Continuous	Daily Total
Snowfall	Level Indicator	Hourly	Daily Max/Min
Air Temperature	Thermister	5 min.	Daily Max/Min/Avg
Road Surface Temperature	Thermocouple	5 min.	Daily Max/Min/Avg
Upper Snowpack Temperature	Thermocouple	Hourly	Daily Max/Min
Lower Snowpack Temperature	Thermocouple	Daily	Daily
Soil Temperature	Thermocouple	5 min.	Daily Max/Min/Avg
Stream Temperature	Thermocouple	5 min.	Daily Max/Min/Avg
Solar Radiation	Solarimeter	Continuous	Daily Total
Wind Speed	Anemometer	Continuous	Daily Max/Avg
Wind Direction	Automated Vane	Continuous	Daily Avg Vector/SD
Soil Moisture Tension	Soil Moisture Block	Daily	Daily
Stream Flow	Level Indicator	5 min	Hourly Avg
Stream Electrical Conductance	Specific Ion Electrode	5 min	Hourly
Stream pH	pH Probe	5 min	Hourly if > normal
Stream Chloride Concentration	Specific Ion Electrode	5 min.	Hourly

Table 3 contains monitoring of stream flow, electrical conductance, pH, and chloride. These are clearly within the aquatic discipline but have been included on Table 3 since they require frequent readings (supplied by a datalogger). All the devices listed in Table 3 can be run by a single datalogger with a thermocouple multiplexor.

Partitioning of Snow Melt: Several road salt abatement strategies rely on altering the initial flow of salt from the road to the environment. For this reason the initial flow of salt from the road needs to be partitioned as it leaves the road. There are three basic mechanisms: spray, ditch flow, and direct flow from melting snow. By establishing lysimeters along each of these flow paths the flow of water and salt along these paths can be determined. Lysimeters are catching and storage devices that allow a portion of each of these flow paths to be sampled. The samples can be analyzed for salt components. By dividing the intercepted water, by fraction of the flow (that the lysimeter was likely to intercept), an estimate of the total flow along that pathway can be estimated. The fraction of flow that the lysimeter catches is estimated by the lysimeter's spatial area within a plot. A minimum of five lysimeters for each of these flow paths will be required to estimate the variability of these measurements. In the second year the number of lysimeters can be changed based upon statistical analysis of the first year lysimeter results.

4.2.6.3 Soils and Vegetation

The workshop concurred with the conclusions reached by Davis et al. (1990), that road salt has incited significant tree damage in areas where hydrology and climate acted as predisposing factors. The workshop felt that this conclusion warranted continued research on road salt and soil and vegetation interactions. The main objective of the new research should be to quantify the relationships between the dose of road salt applied and tree injury. Since many factors such as climate, hydrology and soils, influence this relation the product of this research should be a predictive model. The task of the soils and vegetation discipline are broken down into the following topics: initial surveys and soils & vegetation sampling.

Initial Surveys: The first task of the soils and vegetation discipline will be to make a soil and vegetation surveys of the entire experimental site. Detail soil and vegetation maps will be prepared of the experimental site. As part of the vegetation survey, the experimental site will also be mapped by the intensity of salt injury to vegetation.

Soil and Vegetation Sampling: Based on the map units a series of monitoring sites will be chosen. To improve correlation, it is recommended that soil and vegetation monitoring plots be at the same locations In order to correlate changes in soil and vegetation to salt application repeated monitoring rather than a single spot sampling program (as was the case in Davis et al 1990) will be necessary. Regular sampling of soil and foliar sodium and chloride concentrations at several plots in each experimental site are necessary to develop and test a predictive model. These sampling plots should be chosen to reflect different damage classes.

The workshop did not reach any conclusion as to sampling frequency. Monthly sampling of both soil and foliar sodium and chloride would be reasonable during the period of, and just after, snow melt. The sampling frequency could be reduced at other times during the year. Composting of samples from within a plot would help to reduce laboratory costs. Individual sample tests should be conducted at least twice during the experiment to estimate within plot variability.

In addition, the soil and vegetation should be tested for all environmentally significant contaminants in the de-icing chemicals being applied. This could include cyanide and metals. A limited number of screening samples should be taken for other factors such as pesticides and metals, which are not related to road salt.

Characterization testing is needed to describe the soil parameters which affect the partitioning of the components in the salt being applied. Characterization analysis would be needed at the start and end of the experiment. For modeling purposes soil should be sampled and tested from three depths. Table 4 gives the suggested soil analyses. Table 5 gives the suggested analyses for foliar samples.

Table 4 Soil Analyses

Parameter	Frequency
pH	Weekly During Melt
Electrical Conductivity	Weekly During Melt
Exchangeable Sodium	Weekly During Melt
Chloride	Weekly During Melt
Extractable Metals	Twice per Year
Total Metals	Twice per Year
Free Cyanide	Twice per Year
Total Cyanide	Once per Year
Cation Exchange Capacity	Once per Year
Exchangeable Cations.	Once per Year
Soil Water Retention	Once per Year
Saturated Hydraulic Conductivity	Once per Year
Particle Size Distribution	Once per 2 Years

Table 5 Foliar Analyses

Parameter	Frequency
Foliar Sodium	3 Times Per Year
Foliar Chloride	3 Times Per Year
Foliar Metals	Once in the Autumn

Vegetation should be monitored for sodium and chloride concentrations at the same time and on the same plots as soils. Different plant species will accumulate different concentrations of salt components. Conifers are of particular interest for visual and economic reasons. Conifer vegetation can also be sampled throughout the year. For these reasons vegetation monitoring should concentrate on the dominant conifer species. Foliar samples can be taken of deciduous species in the fall to show the accumulation of de-icing components throughout the growing season.

The same sampling and analytical methods as employed by Davis et al (1990) can be employed in the Phase III research.

4.2.6.4 Groundwater and Aquatic

Water serves as the circulatory system of the environment. Eventually most of the salt applied to roads will enter either streams or groundwater systems, or both. Several types of impacts to aquatic systems from road applications of salt need to be studied. These are:

1. Direct physical affects such as the increase in the concentration of salt components in streams and groundwater.

2. Indirect physical affects such as the lowering of pH due to hydrogen being displaced from the soil exchange complex by sodium.

3. Direct biological affects such as behavioral changes to fish and invertebrate populations that can be attributed to a change in the concentration of de-icing components.

4. Indirect biological affects such as the alteration in fish populations caused by affects on food species.

Small basins are recommended for experimental sites to study these affects. The tasks of the aquatic disciplines are broken down into four topics: initial surveys, stream characteristics, groundwater resources, and stream ecology.

Initial Surveys: The first task in the groundwater and aquatic discipline will be to describe the aquatic system of each experimental site in terms of hydrology and aquatic biology. Any deviation from a normal basin should be noted. (It may be necessary to locate and survey a similar small basin in the immediate area which does not receive salt to accomplish this.) This survey should include both surface and groundwater systems.

Stream Characteristics: Once experimental sites are surveyed for aquatic resources, a series of monitoring points needs to be established. Mr. Whitfield's talk pointed out that some of salt's affects on streams last only hours. Periodic stream sampling would likely miss such events. Even such short duration events can have significant ecological consequences. While continuos measurement systems are expensive, the workshop agreed that at least one sampling point downstream of the road should be equipped with continuous measurement systems for stream flow, electrical conductivity (or specific conductance), stream temperature, pH, and chloride concentrations.

Periodic stream samples should be taken to determine the concentration of other de-icing components such as sodium, ferrous cyanide, and trace metals conductance. During these sampling periods the stream flow, electrical conductivity, temperature, pH, and chloride should also be determined to check the calibration of the monitoring equipment. It was recommended to sample the stream above the test section of road to determine the seasonal natural inputs to the small basin.

Groundwater Resources: It is expected that groundwater flow rates and the concentration of salt components in groundwater will vary more slowly than streams. A limited number of groundwater sampling piezometers should be constructed in the experimental area. Dr. Zapf-Gilje stated that groundwater systems can be modeled with a limited amount of experimental data. Periodic measurements of groundwater depth and de-icing component concentrations at one point above and two spots below the road should be sufficient to determine the affect of road salt on groundwater resources.

Steam Ecology: The interaction of the physical and chemical characteristic of streams and their ecological resources are complex. The public thinks mainly of fish when it considers environmental impacts on streams; however fish are depended upon food species which include invertebrates and aquatic plants. Fish, invertebrates, and aquatic plants are all affected as well as effect the physical and chemical environment of the stream.

It will be necessary to survey the ecological resources of streams within as well as downstream from the experimental sites. This may include sampling of fish and invertebrate populations at specific times during the years. In addition to analyzing the size of populations, laboratory analysis of fish, invertebrate and aquatic plants may reveal abnormal concentrations of de-icing components.

4.3 Analysis

The prime research objective to determine is:

> **Can the present road maintenance standard be achieved while keeping salt-use below the intensity at which significant harm may occur to roadside ecosystems or to downstream aquatic and groundwater systems?**

It is possible that more salt is now being applied to roads than necessary, to achieve the current road maintenance standard. If the research project shows that significant environmental damage is occurring due to the use of road salt, it may be possible to reduce or reschedule the use of salt while achieving the current road maintenance standard. The following analysis strives to answer the basic research objective without altering current salting practices.

Two separate determinations are proposed to answer the above question. The first will be to determine the **maximum environmentally acceptable salt application.** This is the rate and/or total application of de-icing salt which can be applied with acceptable environmental consequences. The second question will be to determine the **minimum salt maintenance demand.** This is the minimum rate and total annual application of deicing salt which can be applied while achieving the current road maintenance standard. Both of these quantities are climate and site specific. They will be determined for each experimental site, based upon the worst (highest salt demand) year in ten.

The minimum salt maintenance demand will be estimated by the road maintenance discipline. It will be based on a detailed review of each salt application during the experiment. Minimum salt-use policy algorithms will be developed which will achieve the road maintenance standard for each category of snowfall event. This set of algorithms will then be applied to estimated snow conditions for the worst year in ten.

The maximum environmentally acceptable salt application will be determined by making a dose/response curve for soil, vegetation, streams and groundwater for each experimental site. The use of a predictive model is necessary since it is unlikely that the actual salt application during the monitoring period will be at the maximum environmentally acceptable level.

The first step in the analysis of the data will be to estimate the hydrology of the site. A water balance should be constructed from precipitation and snow melt, through partitioning the snow melt into groundwater, soil, ditch, and spray pathways. The water will then be traced to either transpiring vegetation, stream flow, or groundwater.

The all important path of salt components will be overlaid onto the hydrological cycle. The concentration of salt components in the aquatic plants and organisms will then be compared to the measured amount of salt reaching these organism during the experimental period. By comparing the results for two years and several sites a more general model of application vs. uptake can be developed. This relationship will depend upon climatic factors such as snowfall and temperature as well as site factors (such as soils, topography and vegetation).

Maximum allowable uptake values will have to estimated for the key species in each experimental site. These will be based partially on scientific literature and partially on the ecological monitoring of the experimental sites.

By working back from the maximum uptake values using the dose/response curves, the maximum environmentally acceptable salt application regime can be estimated for each experimental site.

If the **maximum environmentally acceptable salt application is** significantly below the **minimum salt maintenance demand** then research into salt alternatives and/or altering road maintenance standards should be considered. If these two quantities are relatively close, then technical improvements such as the adoption of more rigid soil application criteria will be sufficient.