SASKATCHEWAN'S 15 YEAR STUDY OF THE ENVIRONMENTAL IMPACTS GENERATED BY DEICING SALT

Y. C. Jin[1], P. L. Gutiw[1] and R. A. Widger[2], G. Liu[2]

1. Faculty of Engineering, University of Regina, Regina, Canada
2. Saskatchewan Highways and Transportation, Regina, Canada

ABSTRACT: Salt (sodium chloride) has been widely used as a deicing agent on highways and urban streets for over half a century. During the 1980's, the public in Saskatchewan raised some questions about the impacts of salt use on the environment adjacent to highways. In order to position the Department of Highways and Transportation to answer these questions in the future, a joint research study was initiated with the Faculty of Environmental Systems Engineering, University of Regina, on the impact of deicing salt on a newly built section of Saskatchewan highway. A detailed soil and ground water sampling plan was implemented and the background salinity data was recorded by sampling at each pre-selected site in the fall 1992 before the newly constructed highway section opened. The amount of deicing salt applied annually has been monitored since the highway section was constructed. Soil and water samples have been taken from the pre-selected sites on an ongoing basis. A total of ten vadose sampling sites, fourteen surface water sampling sites, and three ground water monitoring wells have been sampled in the study area. The first stage study started immediately after the background sampling and lasted until the end of 1997. The second stage commenced in the fall of 2000 and was completed in 2005. A third program has just started. Thousands of samples have been tested for contaminant concentrations including sodium, chloride and other salinity contributing ions. Saturation percent, electrical conductivity (EC), total dissolved solids (TDS), sodium adsorption ration (SAR) and pH were determined as well. A database has been developed for the storage, management, and analysis of the sample results. This paper describes the research project, the test results, the database capabilities, the accomplishments to date and the future plans for the site.

1. INTRODUCTION

To achieve the objectives of providing safe road conditions in the winter, highway deicing has been an important issue for most of the highway agencies in North America. Deicing salt (sodium chloride) has been the predominant deicing agent used in most of the countries in the world because of its efficiency and cost effectiveness

In the 1980's, salt was reported to have detrimental impacts on the environment and Saskatchewan had experienced a few concerns about the impact of salt on vegetation adjacent to the highway. At the time, there was no long term monitoring research available that showed the impact of deicing salt on the environment and could be relied on for guidance in answering questions. Saskatchewan Highways and Transportation and the University of Regina designed a long-term study in 1992. The study sought to obtain a good understanding of the long-term environmental impacts caused by the use of deicing salt on highways. The long term research project was designed on a new ten kilometre section of Saskatchewan Highway No. 46 between Balgonie and Pilot Butte. Located east of Regina, this two lane paved highway was built to reduce the traffic volume on the Trans-Canada Highway by providing alternative access to Regina's North Industrial Area. The new highway was built on new location so it was identified as an ideal site to develop a long term salt monitoring research project since there was no previous impacts to affect the research.

The 10 kilometer Highway No. 46 starts at station 0+000 at its junction with the TransCanada Highway West of Balgonie and goes to northwest from Balgonie for about 1km, after crossing the CPR Main line, it then turns and goes west with the last 2.5km angling to the southwest (Figure 1). The glacial geology map of the area shows the highway crossing two glacial moraine landforms, with the study area mainly consisting of sand and gravel deposits in the west part and till deposit in the east. The Avonhurst Aquifer underlies the area. The soil profile at the study area is classified as Chernozemic Dark Brown soils by the

National Soil Survey Committee (NSSC). Soil textures vary from moderately coarse textured sandy loam to silty loam.

The local climate is semi-arid to sub-humid. Weather data from the Regina Environment Canada observation station shows mean temperatures below freezing point in the study area from the November to March. Annual precipitation for the area ranges from 273mm (1984) to 586mm (1991) with a mean of 388mm for the period from 1971 to 2000. Most precipitation occurs between May and September, accounting for 69 percent of the year's total precipitation.

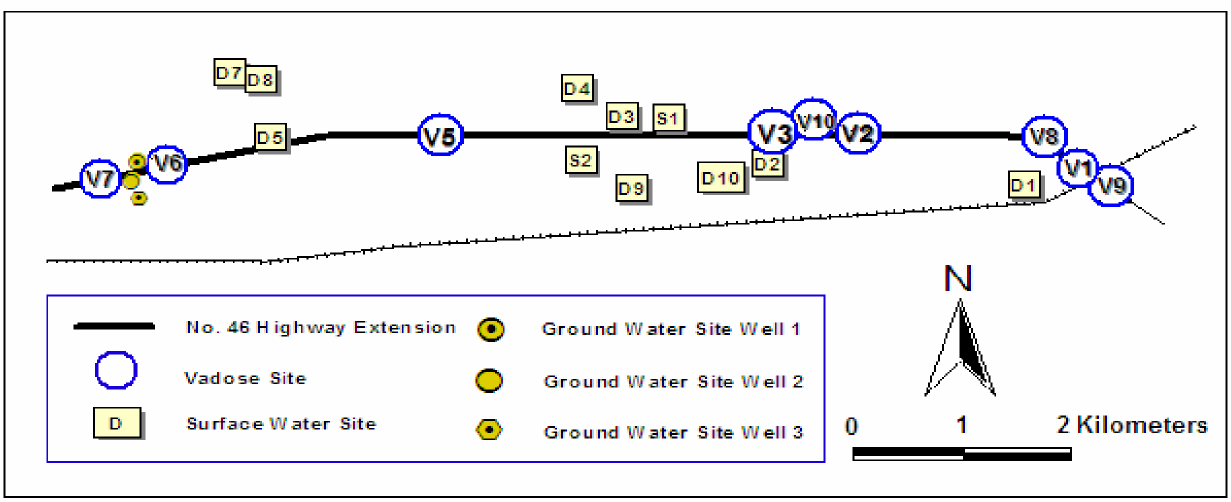
A detailed sampling plan was designed and the background salinity data was recorded by sampling in each pre-selected site along the newly constructed highway in the fall 1992 before it officially opened to traffic. After the highway section opened to traffic and the various amount of deicing salt has been applied every year, soil and water samples have been taken from the pre-selected sites on an ongoing basis. Three ground water monitoring wells, ten surface water sampling sites, and seven vadose sampling sites have been selected in the study area. Initially all sites were sampled annually and then the sampling activities continued with less intensive frequency. Some new sampling sites have been selected based on previous results to increase clarity of sample results as a means of identifying and characterizing the deicer ion migration and accumulation within the roadside area for continued long term monitoring. The sampled soil and water have been tested for sodium and chloride ions concentration as well as other salinity contributing ions, electrical conductivity (EC), and pH. A database has been developed for the storage, management, and analysis of the large amount of sampled and tested data.

The following sections in this paper describe the sampling methodology, the data management and database application, samples of the initial analysis of the spatial distribution of sodium and chloride ion levels from selected sites, publications to date, general conclusions and the future plans for the site.

2. SAMPLING METHODOLOGY

By the end of 2002, ten vadose sampling sites, fourteen surface water sites and 3 ground water sites had been selected for monitoring. The approximate locations of those sites still under monitoring are shown in Figure 1.

Figure 1. The locations of sampling sites at the Saskatchewan Highway No.46 Extension.



A summary of the main sampling sites is shown in Table 1 which shows that surface water sampling sites cover three types of surface water features including reservoirs, dugouts and sloughs. Ground water sampling wells are placed in the sandy soil area near Pilot Butte.

Table 1. Sampling sites descriptions.

Site	Type	Station	Description
V1	vadose	0+475	road cross section, silty till
V2	vadose	3+050	road cross section, silty till
V3	vadose	3+395	road cross section, silty till
V5	vadose	6+675	road cross section, sand
V6	vadose	9+225	road cross section, sand
V7	vadose	9+615	closed drainage point, sand
V8	vadose	0+900	silty till, with super high elevation
V9	vadose	0+325	silty till
V10	vadose	3+315	silty till, comparable site with V3
D1	surface water	1+300	pre-construction dugout
D2	surface water	3+600	downstream larger reservoir
D2X	surface water	3+600	upstream smaller reservoir
D3	surface water	5+050	construction borrow pit
D4	surface water	5+400	pre-construction dugout
D5	surface water	8+150	construction borrow pit
D7	surface water	8+500	dugout
D8	surface water	8+400	dugout
D9	surface water	5+100	dugout
D10	surface water	4+100	dugout
S1	surface water	4+450	slough area
S2	surface water	5+400	slough area
W1	ground water	9+255	D50.8mm × 13.5m PVC monitoring well 1
W2	ground water	9+290	D50.8mm × 13.7m PVC monitoring well 2
W3	ground water	9+285	D50.8mm × 11.7m PVC monitoring well 3

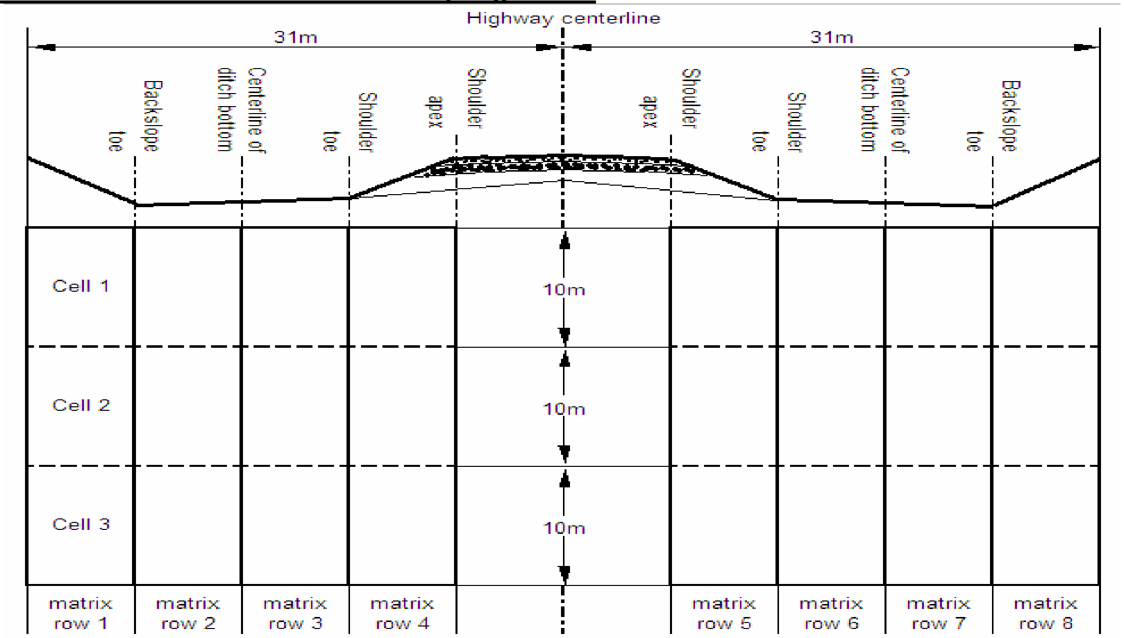
The vadose sampling activities have followed a sampling matrix as shown in Figure 2. In this sampling strategy, eight matrix rows were segregated into two opposing parts over each roadside of the Highway No. 46. with a constant width of 30 meters along the highway section longitudinally, each row has been divided equally into three cells. Thus a total of 24 matrix cells were assigned for each vadose sampling site. At each side of the highway, the lateral boundaries of the matrix rows were determined by five locations: (1) the shoulder apex, (2) the shoulder toe, (3) the midpoint of the ditch bottom, (4) the back slope toe, and (5) the road allowance boundary (the right of way) at 31 meters from the road center line. For referencing purposes the matrix rows are numbered from 1 to 8 beginning with the back slope area in the north ditch and ending with the back slope area in the opposing ditch areas (Gutiw and Jin, 1998).

All vadose samples were taken randomly within each matrix row by utilizing a drill truck with a 6" solid stem auger. Sampling depths were 10 mm, 100 mm, 300 mm, 700 mm, 1,500 mm and 3,100 mm with 2,300 mm added since 2000.

3. THE DATABASE FOR DATA MANAGEMENT

All the samples obtained were sent for chemical testing and the test results were reported in paper forms. In the early years, Microsoft Excel spreadsheets were utilized to store the sampling data. However, with more and more data gathered, spreadsheets were no longer an efficient storehouse, especially when a specific set of data was required for data analysis. A database system was needed for data storage, management, and analysis. Microsoft Access 2000 was used to develop the relational database system with a user friendly interface. The database system achieved four aspects of sampling data management: new test data input, data storage, data queries, and data presentation. Nine basic tables store the information of vadose data, surface water data, ground water data, sampling sites, sampling date, matrix locations and depth etc. respectively. The relationships of the tables are shown in Figure 3.

Figure 2. The illustration of vadose sampling matrix.



3.1. Data Input

The data of new sampling results can be fed into the database directly through the Data Input component. Past sampling data was imported from the Excel spreadsheets. To achieve this, a piece of Visual Basic Applications (VBA) code was developed for each Excel data file to convert the existing data into a 2D spreadsheet whose column heads were exactly the same as the Access table structure.

3.2. Querying and Presenting Data

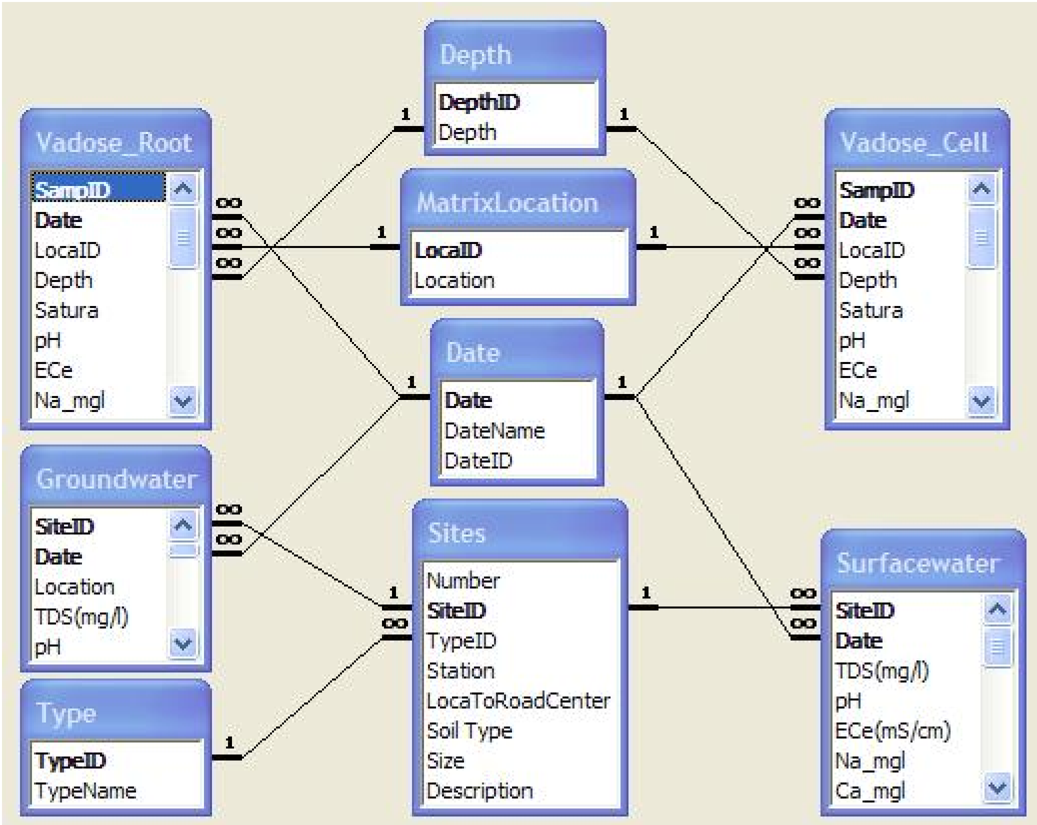
Tables, queries, forms and reports are designed and generated for the purpose of analyzing and presenting data. In this application, queries are used to combine fields from multiple tables and convert those text-type fields in tables into number-type fields. Access Crosstab Query was used to group data and to perform simple statistical calculations such as the mean, maximum, minimum and standard deviation values. For example, if the sodium ion levels of ground water sites over the years are of interest, a Crosstab Query can transform all the ground water data into a spreadsheet with site name and statistical results as row heads and sampling time as column heads (Table 2).

Based on generated queries, well-designed custom forms and reports (layouts) make data retrieving and data presenting easy. Users can obtain any set of data by setting one of the affecting variables, such as sample site, sampling time, matrix location and depth, or their combination. The underlain Access Macros and VBA codes drive the performance of forms and reports. The variables matrix location and depth accompanying the vadose sampling site make the data set more complicated than the surface data and the ground water data. For each interested ion level, the total four variables (site, time, matrix location and depth) have to be arranged in a layout in the form of two variables as group head, one as column head and one as row head.

Table 2. Sodium ion level of ground water sampling data under a Crosstab Query.

Site	Count	Mean	Min	Max	StDev	Var	1992-12	1993-06	…	2002-11
Well 1	49	5.5	4	8	1.1	1.1	6	6	…	7
Well 2	47	24.2	20	28	1.8	3.4	25	28	…	26
Well 3	49	7.6	5.9	10	1.0	1.0	10	9	…	7

Figure 3. The relationships of tables in the database system.



4. SAMPLING RESULTS

Vadose sampling site V6 (Figure 1) is selected as an example to show the distribution of salinity ion levels in view of their site characteristics and relative integrated data.

4.1. Vadose Sampling Results

4.1.1 Background Salinity

The background samples of vadose site V6 were taken in November 1992 before the highway section was opened. The successive sampling activities were conducted twice a year thereafter. The comparable background salinity ion levels are depicted in Figure 5 and Figure 6. The background salinity ion can be considered as naturally existing in different soils in the area.

From Figure 5 and Figure 6, some observations can be made for the background salinity at the sampling Site V6:

(1) Having the maximum values on the surface part of row 4 and row 5, both the sodium and chloride concentrations at the sample Site V6 present positive proportional relationships with depth.

(2) The sodium and chloride concentration at the sample Site V6 show that relative constant levels are gained from the depth of 700 mm.

Figure 5. The background Na^+ level at the sampling Site V6

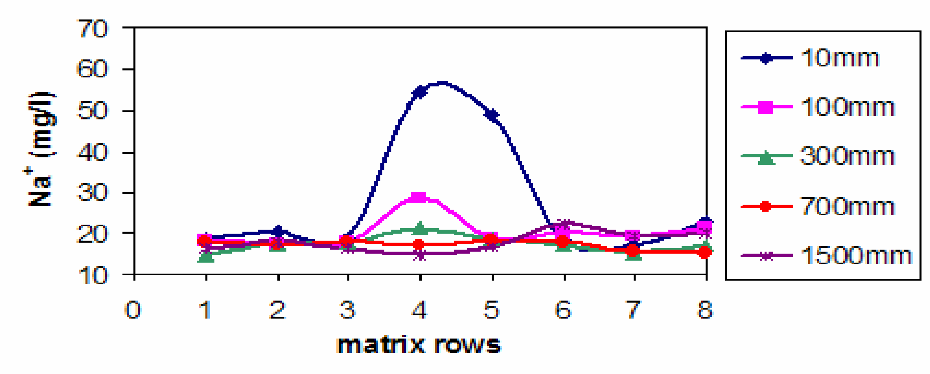
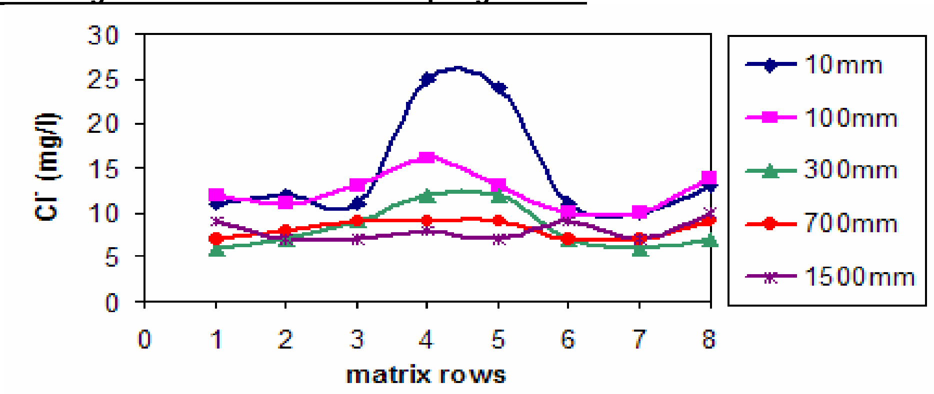


Figure 6. The background Cl^- level at the sampling Site V6



4.1.2 Vertical Distribution of Salt Ions

The vertical distributions of salt ions after 10 years of salt application for the highway section is shown. The data from row 4 is used to show the vertical distribution at the sample Site V6. Figure 7 and Figure 8 illustrate the sodium and chloride ion levels at row 4 of the sample Site V6. From the figures, significant increases of salinity ions can be observed at the sample Site V6 compared to the background salinity levels. This indicates the accumulation salinity ions at the sample Site V6. The vertical transport of salt ions was clearly seen in Figure 8, in which the concentration waves passed from the depth of 10 mm to 1,500 mm.

4.1.3 Lateral Distribution of Salt Ions

The sampled data from the depth of 100 mm and 1,500 mm are used to show the lateral salt ion distribution at the sample Site V6 over the ten years of salt application. Figure 9 shows the comparison at the depth of 100 mm while Figure 10 shows it at the depth of 1,500 mm.

At the sample Site V6 (Figure 9), high concentrations of ions focused at the location of matrix row 5 through row 7, while the lowest concentrations appeared in matrix row 1 and row 8. The overall trend for the lateral distribution of the salt concentration is that at each side of the highway, high concentration of salt ions decreases with the distance from the highway shoulder lines.

For the depth of 1500 mm as shown in Figure 10, salt concentrations are less than that of 100 mm depth. It is interesting to note that for the sand soil type sample site 6, the salt ions concentration level seems to increase over the years. This is especially obvious at the 1,500 mm depth.

Figure 7. The Na^+ level at matrix row 4 of the sample site V6

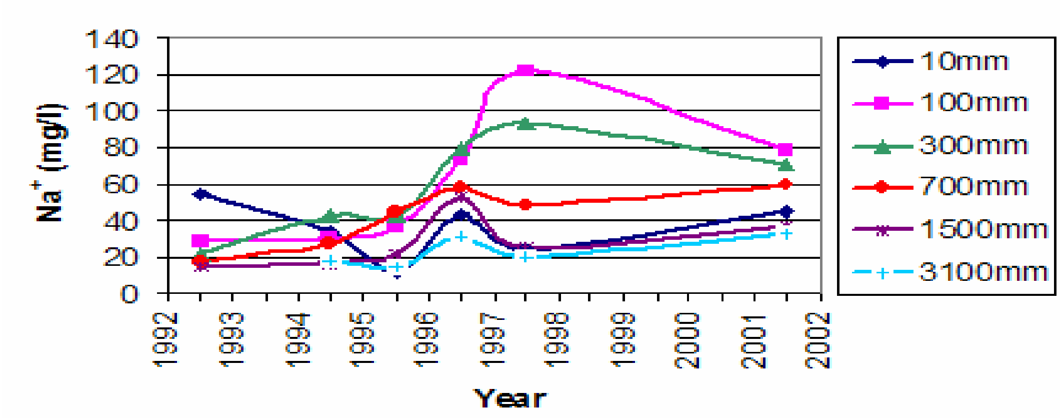
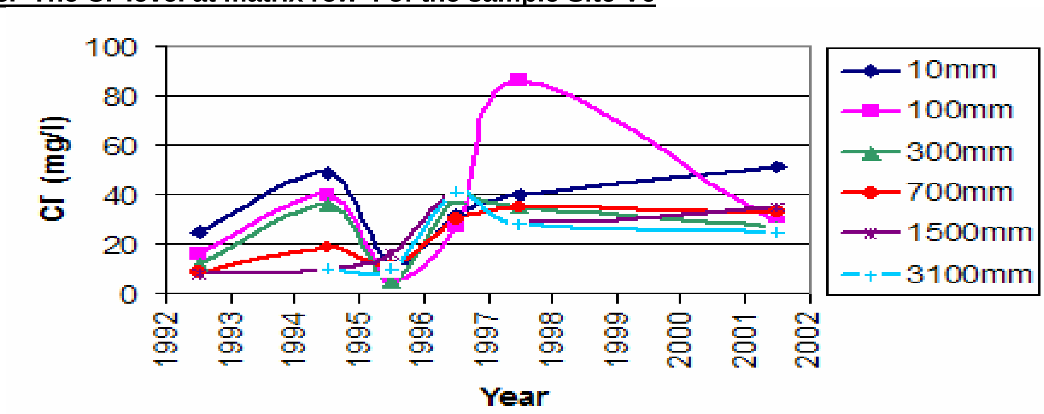


Figure 8. The Cl^- level at matrix row 4 of the sample Site V6



5. PUBLICATIONS

The following list is the publications that have been completed to date from the site.

Gutiw, P. M.Sc. 1998, Thesis U of R, Roadside Salinity Changes Generated by Pavement Deicer Application on a Saskatchewan Highway.

Gutiw, P. and Jin, Y.C. 1998. *Roadside* Salinity *Changes Generated by Pavement Deicing Practices on a Saskatchewan Highway.* Deicing and Dustbinding - Risk to Aquifers. Proceedings of an International Symposium, NHP Report No.43. Helsinki, Finland, 23-30.

Gutiw. P.L, A study on the environmental impacts generated by deicing practices on a Saskatchewan Highway (Saskatchewan Highway #46 extension), Phase II/Years 1,2,3 and 5 – 1997 - Analysis and report, prepared for the Department of Saskatchewan Highway and Transportation.

Gutiw, P.L., and Jin, Y.C. (2001). "Long term monitoring of soil salinity along Saskatchewan Highway #46 Extension Phase III – Contract UR9102 Extension: Year 1 Report." University of Regina, Saskatchewan, Canada.

Liu, G., Jin, Y.C., Gutiw, P.L. and Widger, A. June 2004 "Spatial distribution of deicing salt in roadside areas along Saskatchewan Highway #46 after 10 years in service." TR-96, *5th Transportation Specialty Conference of the Canadian Society for Civil Engineering*, Saskatoon, Saskatchewan, Canada

Liu. G, Faculty of Engineering, University of Regina, Regina, SK. July 2004, Environmental Impacts of Deicing Salts along Saskatchewan Highway No.46 Extension - Sampling Database Applications, User's Manual

Figure 9. Lateral distribution comparison of salt ions in Site V6 at 100mm depth.

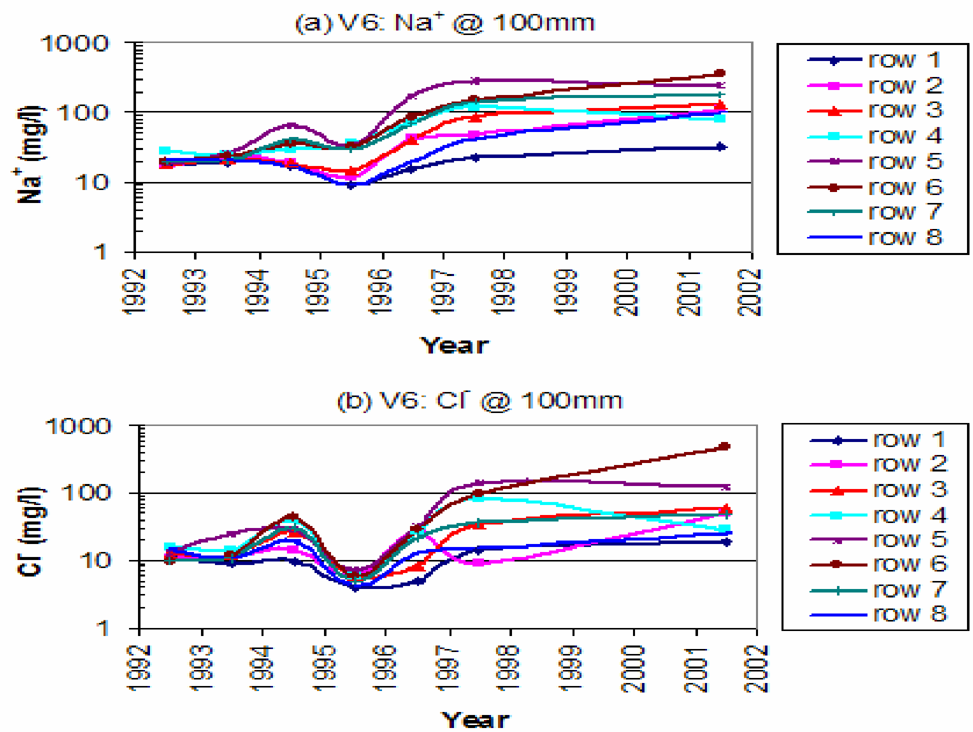
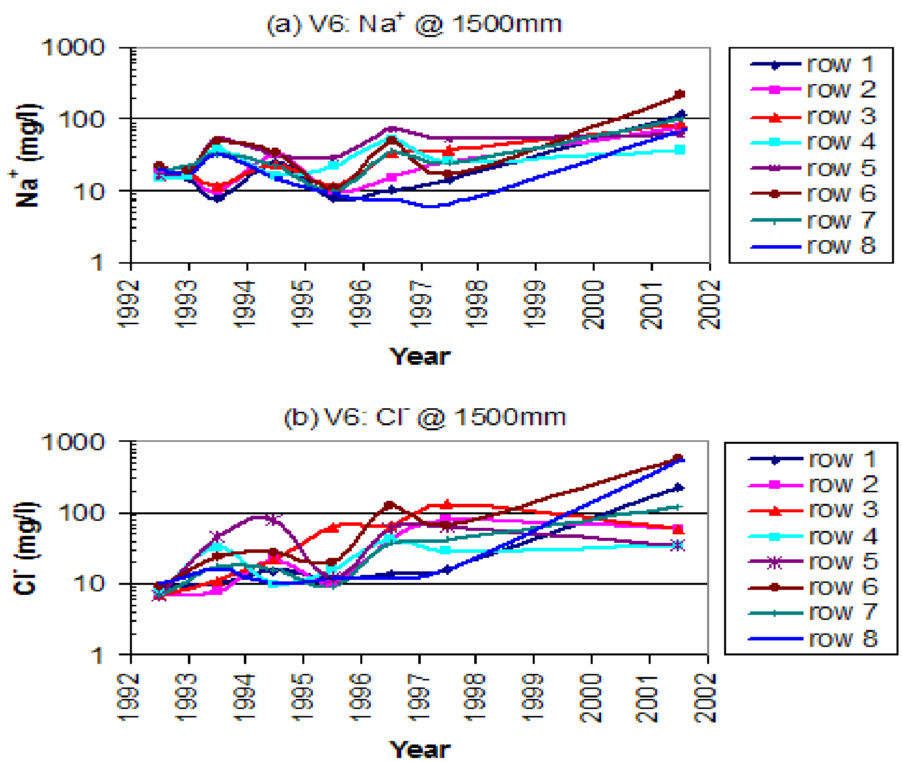


Figure 10. Lateral distribution comparison of salt ions in Site V6 at 1500mm depth.



Liu. G, Jin. Y.C. and Liu. A, June 2005, Trend Analysis of Road Salt Impacts on Groundwater Salinity at a Long-term Monitoring Site, 5th International Conference of Transportation Professionals, Xi'an, China.

Liu. G, Jin. Y.C. and Liu. A,. Nov.2005. A Long-term Monitoring Study of Impacts Generated by Deicing Salts in Ambient Environment along Saskatchewan Highway #46 Extension, 4th Asia Pacific Conference on Transportation and the Environment, Xi'an, China.

Liu. G, M.Sc. 2006, Univ. of Regina, Salinity Analysis and Trend Detection for the Ambient Environment of a Highway Section in Saskatchewan Subject to the Use of Deicing Salt.

6. CONCLUSIONS

The results of the initial 10 years of monitoring the impacts of the deicing salt use on a highway roadside have been analysed. The application of a database system to the large amount of data collected makes the data management and analysis more efficient and reliable and will make future analysis and modelling possible. The results generally showed that by the end of 2002, after 10 years of deicing salt application, there is a slightly increase of ion levels at the selected site. However, levels have not changed significantly and the environmental impacts are minimal along this highway The study indicates that although there has been some accumulation of salt in the soil after winter, it is insignificant due to the groundwater flow and the sandy nature of the subsurface. A different set of geological characteristics could have lead to an entirely different outcome. The fact that Highway #46 does not have high deicer application rates could also be a reason for this insubstantial impact of deicer application. The results also showed that the distribution of salt along the roadway was related to processes other than just snow melt and runoff. Drifting and snow removal equipment such as speed plows impact the distribution of salt along the highway.

7. FUTURE PLANS

Ongoing monitoring of the site will continue to obtain long term data trends. A new testing methodology will be introduced to reduce testing cost and allow more flexibility in checking other sites. The feasibility of the new method will be tested as a alternative or an augmentation to the existing method. The new testing methodology will be applied to a site from Highway #1 with different materials and higher salt application rates.

The new testing methodology, electrical resistivity tomography is an inexpensive and widely used non-invasive geophysical technique for the investigation of near surface resistivity. In principle, it measures the voltage generated by a transmission of current between electrodes placed in the earth (typically at the surface, but also in boreholes or buried underground). Normally, apparent (bulk or effective) electrical resistivity is then calculated and these are used to create pseudo sections and these are then interpreted and inverted to determine subsurface resistivity anomalies. This method has been successfully used in a number of environmental applications such as detection of lechate in landfills, underground water in deserts, underground features, both natural and man made, draw down from pumping wells, petroleum and quantification of total ions as a function of electrical resistivity in the subsurface.

All of the above applications are related because the electrical resistivity Tomography detects subsurface electrical resistivity values which are dependent on the nature and amount of fluids in the subsurface and the amount of electrical conductivity they impart to the soil, be it lechate, water, petroleum or in this case, ionization of salts due to deicer application.

A preliminary study was carried out to see if this technique could be applied to the proposed study. Electrical resistivity, Na+, Ca++, Mg++ and K+ ion concentrations of the soil samples from the previous years of study for site V2 were used. In the first step, all the ions in a layer for each borehole sample for years 1992, 1993 and 1995 were added separately for site V2. Data from 1992 to 1995 were then used to find the relation between E.C and total ions as shown in figure 1. Using the relation between E.C and

Total ions, the total ions for the year 1997 were estimated and compared with the actual values as shown in Figure 2. A similar method was used to find the amount of Sodium, Calcium and Magnesium as well.

ACKNOWLEDGEMENTS

This study is funded by Saskatchewan Highways and Transportation. Samplings were conducted under the assistance of Saskatchewan Highways and Transportation. Sampling tests were conducted by ETL Enviro.Test, a division of ETL Chemspec Analytical Limited.