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EFFECTS OF ROADSIDE SALT ON NEARBY SOILS IN NW LOWER MICHIGAN

By

Marcia Lynn Talicska

A THESIS

Submitted to
Michigan State University
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ABSTRACT

EFFECTS OF ROADSIDE SALT ON NEARBY SOILS IN NW LOWER MICHIGAN

By

MARCIA LYNN TALICSKA

Widespread use of sodium chloride as a deicing agent on roads poses a potential threat to nearby soils. Sodium cations in meltwater infiltrate into soils adjacent to roads and may adsorb onto clay minerals. The purpose of this study is to measure sodium using sodium adsorption ratios (SAR), a measure of the extent of sodium saturation, in sandy soils near roads in a temperate, snowy climate. The concentrations of three major cations, Na, Ca, and Mg, were also measured to calculate SAR.

SAR data for soils in Grand Traverse County, Michigan were assessed by sampling at four locations which have different salting application rates but similar soil characteristics. Sampling occurred over one winter season in September 1996, December 1996, and March 1997.

SAR values increased markedly from September to December at each site, indicating deicing operations are the probable source of sodium cations to the soils. At some sites a significant decrease in SAR occurred in March due to rapid melting of surface snow, decreased salting operations, and early spring rains. Only rarely was a correlation between SAR and distance from the road or depth in the soils found for any given time period. The data indicate that soil texture is more significant in determining the adsorption of sodium than salt application rate. Low SAR values in soils throughout the sampling period indicate that sodium is at present not accumulating in roadside soils at the four sampling sites.

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INTRODUCTION

Heavy snowfall and icy road conditions often necessitate the use of chemical deicers to sustain vehicular traffic. Several possible chemical deicers are available: sodium chloride, calcium chloride (Hutchinson, 1970), and calcium magnesium acetate (Frazio, 1994). Sodium chloride (NaCl) is most widely used in Michigan (McDonnell and Lewis, 1972). In Grand Traverse County, trucks release tons of sodium chloride on roadways each winter (Harold Shappar, personal communication, 1996) which are then plowed, along with the snow, onto soils adjacent to the roadway. Upon melting, the sodium and chloride ions infiltrate or run off, possibly interacting with the soil and nearby environment (Scott and Wylie, 1980).

Upon dissolution in water, NaCl dissociates into Na^+ and Cl^- ions that can be readily adsorbed by clay and organic colloids in the soil. The Grand Traverse County area has large acreages of sandy and sandy loam soils with very low cation exchange capacities (Williams, personal correspondence, 1997). Hence, there are a small number of exchange sites available to hold the Na^+ cations (McBride, 1994). In addition to the general lack of clay and organic colloids, sandy soils have high permeabilities and high porosities, which may cause cations to bypass available exchange sites during rapid, vigorous snowmelt, rainfall infiltration episodes. All these factors suggest that Na^+ ions, even though heavily applied, may not accumulate in the sandy soils of Grand Traverse County.

Conversely, additions of large amounts of sodium cations, from deicing salts, increases the normal ionic composition of the soil solution, favoring the adsorption of sodium cations and may even reduce the number of "nutrient" cations adsorbed (Hassett and Banwart, 1992). Sodium cations are then preferentially adsorbed on the surfaces of clays and organic colloids (Hassett and Banwart, 1992). Thus, the conflicting possibilities of the fate of Na^+ ions in the soils of Grand Traverse County justified this study.

Sodium cations are highly mobile in soils and can alter their physical characteristics and their ability to support healthy plants. Dry, cracked soils found adjacent to roadways may be caused by the dispersion of clay colloids due to high amounts of sodium, which reduce the porosity and permeability of the soil (Hassett and Banwart, 1992). Excessive sodium can restrict the availability of macronutrients, like Ca^{2+} and Mg^{2+}, that are necessary for photosynthesis, thus, impeding plant growth. In addition, sodium may aid in the transport of trace metals in the subsurface, possibly contaminating groundwater (Amrheir et al., 1993).

Heavy use of NaCl to remove snow and ice may therefore pose a long-term threat to the environment. Soil solutions that are concentrated with sodium cations deprive root systems of water, proper drainage, and vital macronutrients. If the sodium from deicing is not accumulating in the soils, it is probably being flushed through the soil profile and may be entering the groundwater. Several major aquifers in Massachusetts, for example, contain water that has been categorized as saline and unusable for drinking and irrigation due to long-term deicing practices (McConnell and Lewis, 1972).

The sodium adsorption ratio (SAR) is used in this study to ascertain the exchangeable sodium percentage within a soil, equilibrated with a given solution (Hassett and Banwart, 1992). The purpose of this study is to measure the amount of sodium saturation, using SAR and sodium concentrations per se, in sandy roadside soils in Grand Traverse County, Michigan. The SAR date will be used to answer the following questions:

1) Do sites near roads with high salt application rates have SAR values above 10mmol/L relative to sites far from the roads?

2) As the distance from the roadway increases is there any trend in SAR values?

3) As depth increases at each sampling site is there any trend in SAR values?

4) Are there seasonal trends in SAR values?

5) Is sodium being concentrated in the soils adjacent to any of the four roadway sites?

Four roadside locations in Grand Traverse County were sampled three times over the course of a year to determine if the seasonal application of NaCl to roadways affects soils continually or only seasonally. Sampling locations were chosen based on salt application rates, soil series, and special characteristics (absence of ditch, hills, or curves in or along the roadway). To assess the variability in cation exchange three sites with similar soil series but different salt application rates (high, medium, and low) were sampled. The fourth research site is located on a sandy soil, and was established to compare sodium adsorption between soil types of differing texture, both of which have high salt application rates.

BACKGROUND

The use of sand on roads to provide traction during winter storms has gradually been replaced by the use of chemical deicing agents (Scott and Wylie, 1980). Deicing salts applied to snowy road surfaces dissolve in water, lowering the freezing point of the water and salt (or snow) mixture below that of pure water, allowing snow and ice to melt (Figure2.1; Scott and Wylie, 1980). Two salts, sodium chloride (NaCl) and calcium chloride ($CaCl_2$), are the most widely

1) Salt is spread on surface

2) Salt melts through snow/ ice, forming brine

3) Remaining snow/ice floats on brine, breaking bond with road surface

4) Vehicular traffic breaks through the surface, reducing the snow/ice to plowable slush that is moved to the sides of the road

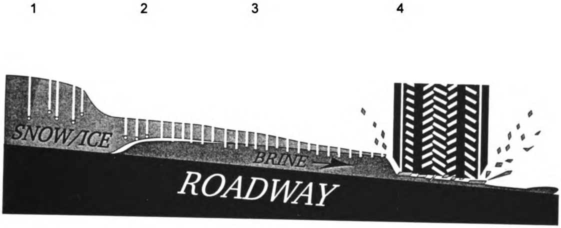


Figure 2.1. How salt works on the roadway surface (after The Salt Institute, 1990).

used agents for deicing (McDonnell and Lewis, 1972). Chemical agents are less likely to be blown off the road than is sand, they need less application time, work quickly, and require no clean-up in the spring (Scott and Wylie, 1980). After salt is applied to the roadway it can enter the environment through several avenues (Figure 2.2)(Frazoi, 1994). The two predominant mechanisms of salt transfer are: runoff of salt-laden meltwater from the road surface onto the right-of-way, and piling up of salt-contaminated snow and ice onto the road right-of-way where it melts, possibly infiltrating into the soil (Frazoi, 1994).

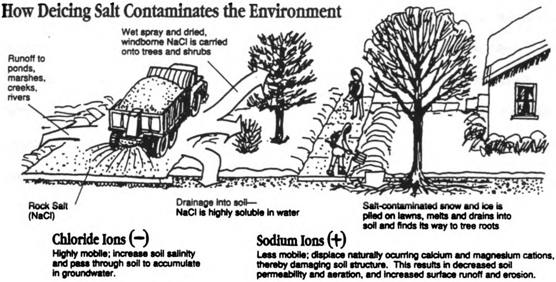


Figure 2.2. How deicing salt contaminates the environment (after Frazoi, 1992).

SAR

The sodium adsorption ratio (SAR) is the ratio between soluble sodium and some soluble divalent cations. It can be used to predict the exchangeable sodium percentage of soil equilibrated with a given solution (Hassett and Banwart, 1992). SAR is defined as:

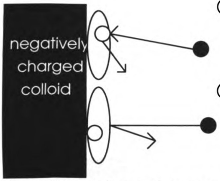
$$\mathrm{SAR} = \frac{\{NA\}}{\sqrt{\dfrac{\{Ca\} + \{Mg\}}{2}}}$$

where { } is the analytical concentration of the ions in the saturation extract expressed in mmol/liter (Jurinak et al., 1984). SAR is used to determine the potential sodium hazard in soils and irrigation water (Szabolcs, 1989).

The amount of soil exchange sites occupied by Na^+ is a function of the relative concentrations of Na^+ and the other competing cations (e.g., Ca^{2+}, Mg^{2+}, Al^{3+}, and K^+)(McBride, 1994). Since hydrogen is not a major nutrient cation it is not considered. Exchangeable Al^{3+} can be disregarded, because it is not usually associated with soils containing significant amounts of exchangeable Na^+ (McBride, 1994). The potassium ion rarely occupies a significant amount of exchangeable sites, and thence, K^+ concentrations are disregarded in the SAR equation. The SAR equation combines Ca^{2+} and Mg^{2+} to account for the ion valence (2+) which is more important than ion size when predicting ion exchange relations (Bresler, et al., 1982).

Cation Exchange Processes

Cation exchange is the reversible process of interchanging a cation(s) in solution for a cation(s) on the negatively charged surface of a clay or organic colloid (Figure 2.3)(Hassett and Banwart, 1992). In order for adsorption to occur, the attractive forces between the solid soil surface and the cation must overcome both the attractive forces between the solution component (solute) and the soil solution (solvent), and any repulsive forces between the soil surface and the adsorbing species (Hassett and Banwart, 1992).



(a) Cation in solution randomly moves into the hemisphere of motion of an exchangable ca when the cation is removed from the surface exchange occurs.

(b) Cation in solution ramdomly moves into the hemisphere of motion of an exchangable ca when the cation is close to the surface exchange does not occur.

Figure 2.3. Cation exchange on the soil colloidal surface (after Hassett and Banwart, 1992).

The exchangeability of cations in solution depends on the valences of the adsorbed cations, the hydrated size of the cation, the concentration of the cations in the soil solution, and the density of the negative charges on the colloidal surface (Szabolcs, 1989). In non-saline soils the exchangeability of cations usually increases with increasing valence (Mg>Ca>Na) resulting in Mg^{2+} and Ca^{2+} cations occupying the interlayer regions of swelling clays (Szabolcs, 1989). When salt dissolves at the soil surface the soil solution may become saturated with Na^+ cations. As Na^+ cation concentrations increase the probability that Na^+ cations will be adsorbed increases because the ratio of $\{Na^+\}$: $\{Mg^{2+}\}$ and $\{Ca^{2+}\}$ increases (Hassett and Banwart, 1989). As the concentration of Na^+ cations in the soil solution increases, low valence cations can and do get adsorbed preferentially over high valence cations (Na>Ca>Mg)(Brester, McNeal, and Carter, 1982).

The hydrated size of a cation determines how close the cation can approach the negatively charged colloidal surface (Hassett and Banwart, 1989). Calcium and magnesium cations can get strongly hydrated, while sodium is more weakly hydrated (Hassett and Banwart, 1989). The valence (+2) and hydration energies of Ca^{2+} and Mg^{2+} does (do) not allow close contact with the external, negatively charged colloidal surface (McBride, 1994). Generally, sodium does not have direct contact with the negatively charged colloidal surface because of its low valence (+1) and hydration energy (Figure 2.4)(McBride, 1994).

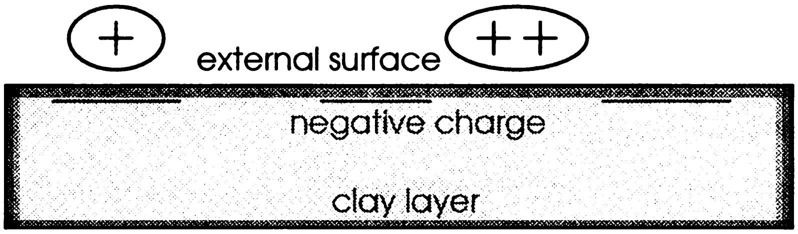


Figure 2.4. The adsorption of monovalent (+1) and divalent (+2) cations on the negatively charged colloidal surface (after McBride, 1994).

Therefore, in conclusion, sodium will readily exchange with adsorbed Ca^{2+} and Mg^{2+} cations when the soil solution becomes saturated with Na^+ cations. In addition, once adsorbed, Na^+ may create more stable electronic bonds on the colloidal surface than do calcium and magnesium (McBride, 1994). Of course, if the soil solution again becomes saturated with Ca^{2+}, Mg^{2+} or another cation, the ionic concentration will change, resulting in the desorption of Na^+ from clay and organic colloids.

Salt-affected soils

Saline, saline-sodic, and sodic are the three basic types of salt- affected soils (Hassett and Banwart, 1992). Saline soils have greater than 15% exchangeable sodium (SAR>10) and pHs less than 8.5 (Hassett and Banwart, 1992). Saline soils have high concentrations of accumulated soluble salts which increases the osmotic pressure of the soil solution (Tomlin, 1997). Generally, saline soils form when dissolved salts are transported to the surface via groundwater; therefore, the water table must be within 2 m of the soil surface

(Henry et al., 1987). Due to the high levels of dissolved salts, the soil colloids are not dispersed but remain flocculated, maintaining good soil permeability.

Saline-sodic soils have greater than 15% exchangeable sodium (SAR>10), but still with pHs less than 8.5 (Hassett and Banwart, 1992). In addition, saline-sodic soils have high electrical conductivities of the saturation extract and high sodium content (Bucholz, 1983). Saline and saline-sodic soils both contain high enough levels of soluble salts, however, to affect the growth of salt-sensitive plants (Schut, 1976).

Sodic soils have greater than 15% exchangeable sodium (SAR>13) and pHs greater than 8.5 (Hassett and Banwart, 1992). In these soils, pedogenic structure is destroyed when two monovalent cations replace one divalent cation on the basal plane of soils (Cooper, 1996). When two monovalent sodium cations replace one divalent cation on the basal plane of swelling clays, the separation distance between soil particles expands, thus weakening the Van der Waals bonds that flocculate the clay double layers (Hassett and Banwart, 1992). The clays become dispersed and soil structure is eventually destroyed. Sodium occupation of exchangeable sites, therefore, results in decreased soil porosity and permeability (Hassett and Banwart, 1992).

Fertility is reduced in sodic soils through chloride poisoning, nutrient loss, and osmosis (Frazoi, 1994). Chloride poisoning occurs when NaCl dissolves, allowing free Cl^- ions to be taken up by roots and carried through the sap stream to leaves, where they may accumulate to toxic levels (Frazoi, 1994). Excessive sodium in the soil also restricts plants' uptake of essential macronutrients like Ca^{2+}, Mg^{2+}, and K^+ (Frazoi, 1994). When soluble salt levels become high, water in the root cells moves out by osmosis, into the soil, causing the plant to wilt, or in extreme cases, die (Tucker, Messick, and McBride, 1996). Trees and shrubs in the Morton Arboretum in Chicago, for example, have salt damage caused by salt spray up to 378 meters from passing freeways (Frazoi, 1994)(Figure 2.5).

Salts in arid and semi-arid soils

Soils in arid and semi-arid climates have notable salinity problems where shallow water tables and high evaporation rates move salty soil water to the surface (Brester, McNeal, and Carter, 1982). Insufficient annual rainfall cannot flush out salts in the surface zone; instead they remain at high concentrations in soils, throughout the year (Brester, McNeal, and Carter, 1982).

Rainfall, mineral weathering, fossil salts, and eolian deposition are the main sources of salt to soils in arid and semi-arid climates (Brester, McNeal, and Carter, 1982). Rainwater is saline because ocean water droplets evaporate in

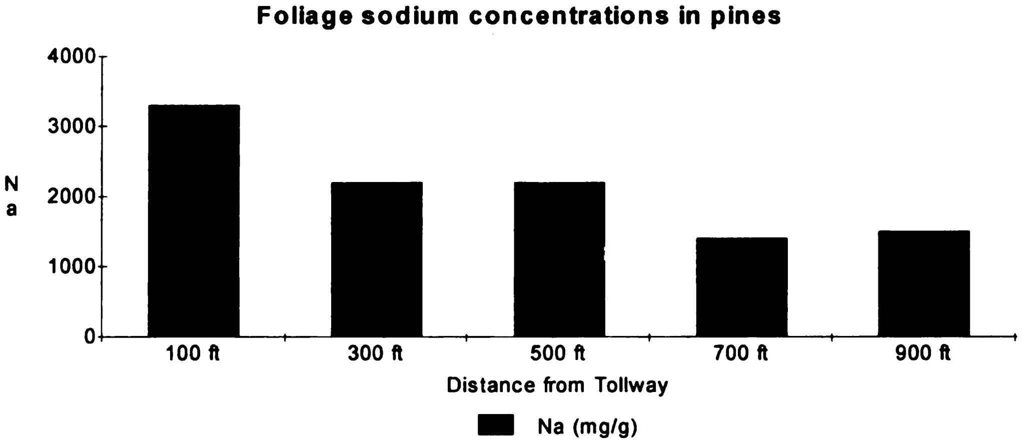


Figure 2.5. Transects extending from the edge of a tollway into Morton Arboretum near Chicago verified the airborne spread of salt to distances of 378 meters. Samples of white pine needles taken at 61 meter intervals in April were used to obtain salt concentrations in foliage (after Frazoi, 1994).

the air, leaving a salt particle behind. The salt particle may eventually act as a condensation nucleus for water during cloud formation (Brester, McNeal, and Carter, 1982). In arid and semi-arid climates mineral weathering rates are low due to low annual rainfall amounts; therefore, unweathered minerals act as a renewable source of salinity (Brester, McNeal, and Carter, 1982). Prior salt deposits or connate (entrapped) solutions present in former marine sediments are termed fossil salts, and contribute the highest amounts of salt to the soil (Brester, McNeal, and Carter, 1982). Fossil salts can be released when an impervious cap that overlays highly saline groundwater weathers, allowing saline water to saturate the soil and rock strata above (Brester, McNeal, and Carter, 1982). Human activities can release fossil salts by: (1) using saline water for irrigation, (2) producing saline drainage waters from newly developed land, and (3) building canals and reservoirs through highly saline strata (Brester, McNeal, and Carter, 1982). Although, arid and semi-arid climates contain several types of soluble salts, NaCl is dominant in the strongly saline soils (Szaboks, 1989).

The source of salt in arid and semi-arid climates differs from the source of salt present in temperate climates, resulting in unique seasonal distribution, climatic variances, and spatial distribution both with depth and distance. Sodium chloride concentrations in arid and semi-arid climates are extremely high and persist throughout the year because the source of salt is an integral part of the landscape (Szaboks, 1989). The source of salt in arid and semi-arid climates does not change drastically because the seasons, at least with respect to rainfall, are not dramatic. In temperate climates the seasons are highly variable; causing leaching of salts in the spring and the possible accumulation of salts in the drier winter in Michigan. Deicing salt on roadways in winter is the main source of salt in some temperate climates.

Salts in temperate climate soils

In comparison to arid and semi-arid climates, salt-affected soils in temperate climates have not been studied extensively. For health and safety reasons, studies involving salt and temperate climates traditionally focus on the infiltration of deicing salts through the soil column to the water table (Howard et al., 1993; Huling and Hollocher, 1972; Hutchinson, 1970; Locat and Gelinas, 1989).

When deicing salts melt, in contact with snow or ice, the bond between the sodium and chloride ions is broken, allowing each to move freely in solution (Frazoi, 1994). Sodium cations may then be adsorbed onto clay minerals (Hutchinson, 1970). Sodium adsorption may then cause the displacement of significant nutrient cations ("bases"), such as Mg^{2+}, Ca^{2+}, and K^{+} (Hutchinson, 1970). Davison (1970) sampled several roadside soils where deicing occurred and found that sodium had displaced Mg^{2+}and Ca^{2+} cations 10 cm to 2 m from the roadway (Table 2.1). Sodium adsorption in temperate climates is complicated where it is then scattered by vehicles onto the soil.

by seasonal climate changes, and the fact that the salt source occurs on roads,

Three parameters must be considered when evaluating SAR variability in roadside soils in temperate climates. First, NaCl may not be distributed equally with depth. When NaCl dissolves in water the Na^{+} ions are very mobile and easily migrate downward in wet soils or toward the surface when dry (Scott and Wylie, 1980). In dry soils, salt and water move upward more frequently, with salt accumulating near the surface where water evaporates (Scott and Wylie, 1980). The rate of salt and water movement depends on the permeability of the soil and the moisture gradients within (Scott and Wylie, 1980). More salt movement occurs in soils with high permeability than in those with low permeability (Scott and Wylie, 1980). Second, as the distance from the roadway (or the distance from the source of the salt) increases, Na^+ levels decrease. The distance salts move away from the road are influenced by: a) *soil properties*, e.g., slope, permeability, texture, structure, moisture content, and cation exchange capacity b) *climate*, e.g., amount and pattern of precipitation, runoff, snowfall and melt, and temperature c) *highway deicing practices*, e.g., salt used, time and number of applications, and snow removal procedures, and d) *snow cover*, e.g., insulation of soils, and amount of salt present in snow (Scott and Wylie, 1980).

Table 2.1. Analysis of saturated extracts of soils from two roadside sites, October 1969 (ionic concentrations in m-equiv./l of extract; E.S.P. in the exchangeable sodium percentage)(after Davidson, 1970).

Site name/ Distance from road	Depth of sample (cm)	Na	Ca & Mg	Cl	ESP
		(ionic concentrations in m-equiv per liter of extract)			
Denton/ 10 cm	0-5	066.24	4.38	4.38	43
	5-10	090.55	1.50	-	62
	10-15	067.26	0.73	32.6	62
Denton/ 2 m	0-5	033.59	3.90	15.1	25
	5-10	043.70	4.28	26.0	30
	10-15	032.20	4.07	22.3	23
Ovington/ 10 cm	0-5	093.24	6.63	43.9	43
	5-10	082.76	9.81	63.7	35
	10-15	153.76	9.23	63.8	52
Ovington/ 2 m	0-5	028.80	4.98	21.3	20
	5-10	031.66	7.15	23.6	29
	10-15	074.37	5.98	36.8	39

Biesboer and Jacobson (1994) measured the distribution of NaCl as distance from the roadway increased. Their study spanned one year, along several highways in Minneapolis/ St. Paul. Figure 2.6 shows that the highest concentrations of NaCl occurred in the winter and spring months (December and May)(Biesboer and Jacobson, 1994). The lowest concentrations of NaCl occurred in summer. NaCl levels were highest in the samples taken nearest the roadway. Sodium chloride levels decrease with distance from the roadway because salt tends to move vertically in most sandy soils, and not laterally. In addition, the amount of salt-laden snow and brine also decreases as the distance from the roadway increases.

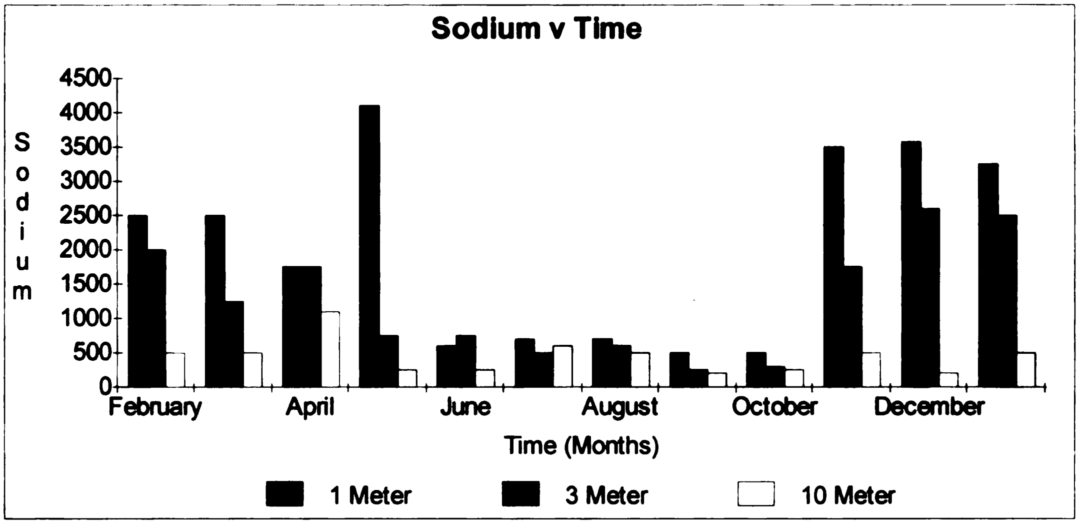


Figure 2.6. Sodium concentrations along a major highway in Minneapolis/ St. Paul, WI. Samples were taken at 1, 3, and 10 meter intervals from the roadway each month for one year (after Biesboer and Jacobson, 1994).

When deicing salt is the main source of sodium, it reduces the amount of sodium loading because salting only occurs in the winter. In addition, the distribution of salt is more spatially limited to soils adjacent to roadways. The spatial distribution of salts differs in each climate due to temperature and source. Because salts move in the soil column with moisture and temperature, climate (especially precipitation) is a significant factor in the movement and concentrations of salts. In temperate climates the source of salt is usually very localized, and the salts are dispersed from this point. In arid and semi-arid climates the salts are not localized because there are several contributing sources (Szaboks, 1989).

Economic costs of salt to the environment

In spite of the environmental impacts of deicing salt, community officials continue to use NaCl as a deicing agent instead of environmentally friendly alternatives like calcium magnesium acetate (CMA)($CaMg_2C_2H_3O_2$)(Frazoi, 1994) for economic reasons. Sodium chloride is inexpensive because it is easy to mine and abundant; CMA must be manufactured in a laboratory, increasing the cost considerably (Frazoi, 1994). However, CMA has no long-term effects on the environment, and NaCl often does (Frazoi, 1994). A study conducted in New York State (Figure. 2.7) concluded that repairs from deicing salt to highways and bridges, and costs of vehicular damage, contamination of water, and corrosion of utility equipment raises the actual cost of salt from $25 per ton to $1450 per ton (Frazoi, 1994).

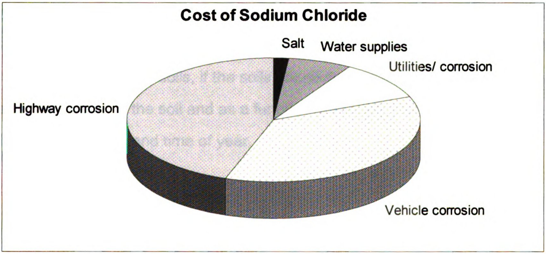


Figure 2.7. Actual long-term cost of NaCl (after Frazoi, 1994).

Problem statement

Grand Traverse County, located in northwestern lower Michigan, uses sodium chloride to melt snow and ice on the roadways during winter months (Harold Shappar, personal correspondence, 1996). The Grand Traverse Road Commission has three rates of deicing application: state trunk lines receive 204 kg/km of pure salt, county primary roads receive 204 kg/km of a 1:1 salt:sand mixture, and county minor roads receive 204 kg/km of a 1:5 salt:sand mixture (Harold Shappar, personal correspondence, 1996). The Road Commission does not monitor the extent of sodium saturation caused by deicing salt infiltrating roadside soils or the accumulation of salt in groundwater or surface waters.

Because excess sodium can potentially alter the soil, possibly lowering soil fertility, excessive use of deicing salt is becoming a topic of concern in this predominately farming area. The main objective of this study is to measure the degree to which salt, as indicated by sodium adsorption ratios (SAR) and sodium concentrations, is accumulating in soils located adjacent to some roadways in Grand Traverse County. Results of the analyses will determine if sodium cations are present in roadside soils, if the soils are sodic, and if the extent of saturation varies with depth in the soil and as a function of the salt application rate, distance from road, and time of year.

STUDY AREA

Location

The study area is centered on Grand Traverse County, in northwestern lower Michigan (Figure 3.1). Four sampling sites were delineated within the county, each of which had one or more of the following soil series: Kalkaska, Mancelona, Montcalm, and Rubicon sands and sandy loams (Table 3.1).

Table 3.1. Study locations and soil series

Site#	***Soil series**	**Site location**
1	Rubicon	SW 1/4 of NW 1/4 Sec. 17,T.25N.,R.11W
2	Montcalm-Kalkaska	SE 1/4 of NW 1/4 Sec. 17,T.26N.,R11W
3	Montcalm-Mancelona	SW 1/4 of SW 1/4 Sec 32, T.27N.,R.11W
4	Mancelona	NE 1/4 of NE 1/4 Sec. 1, T.25N.,R.11W

*Soil series identified by auguring.

Geomorphology

The maximum advance of the Late Wisconsin ice sheet completely covered Michigan (Farrand and Eschman, 1974), and significantly shaped the landscape in Grand Traverse County (Figure 3.2). Retreat of the ice sheet began in pulses, recorded by morainic ridges, some 18,000 years ago (Eschman et al., 1973). The Port Huron moraine, ascending west to east through southern Grand Traverse County, is a remnant of a re-advance of the ice sheet (Eschman et al., 1973). The Port Huron moraine is characterized by steepsided knobs, capped with a moderate thickness of till over sands and fine gravels with undrained depressions associated with stagnant ice margins (Eschman et al., 1973). During the last (Greatlakean) advance of the ice sheet, approximately 11,850 years ago, only the northern third of Grand Traverse County was probably covered with ice (Weber et al., 1990). Recession of the ice sheet left

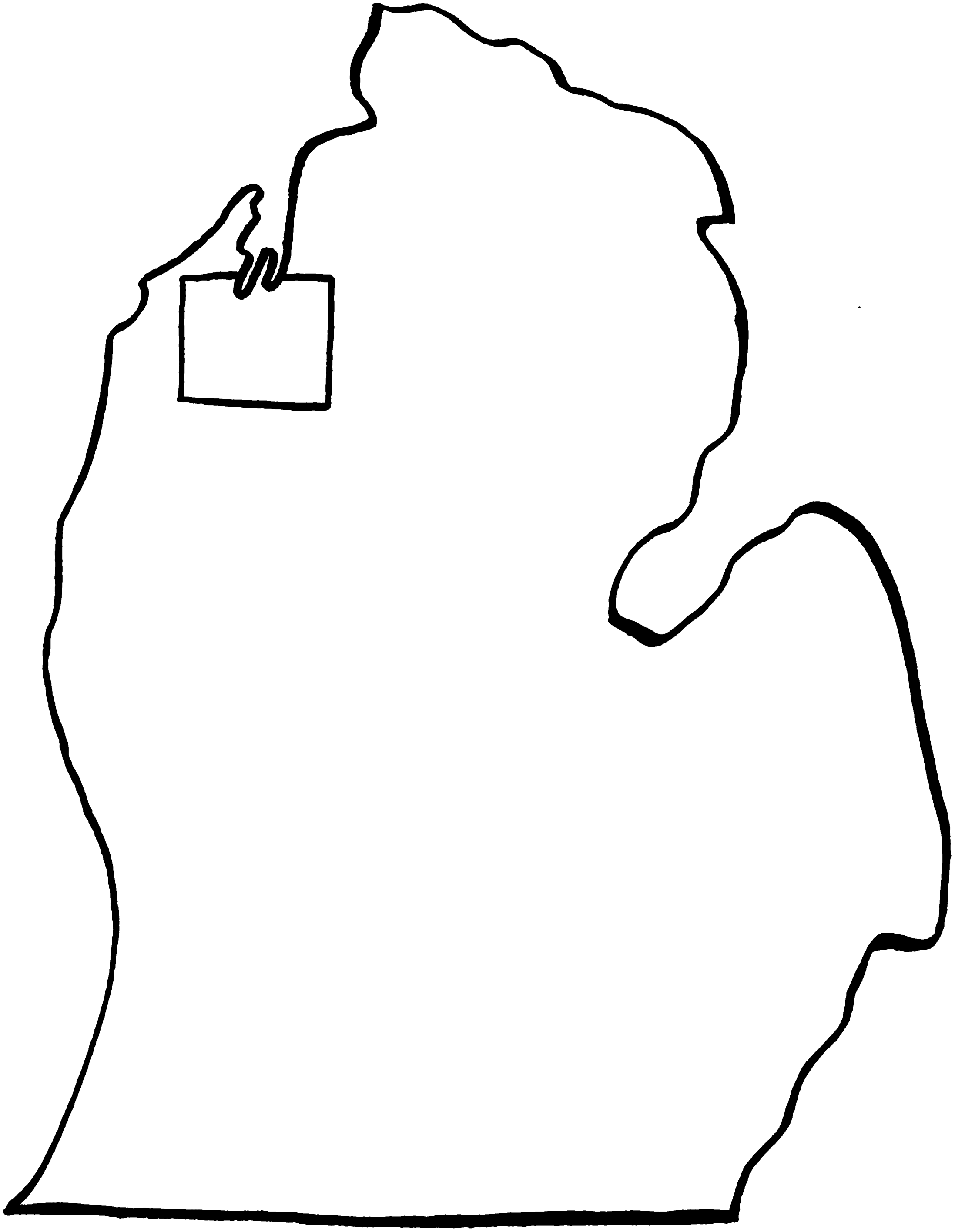


Figure 3.1. Map of Michigan with Grand Traverse County outlined in the northwestern lower corner (Grand Traverse County Road Commission, 1997).

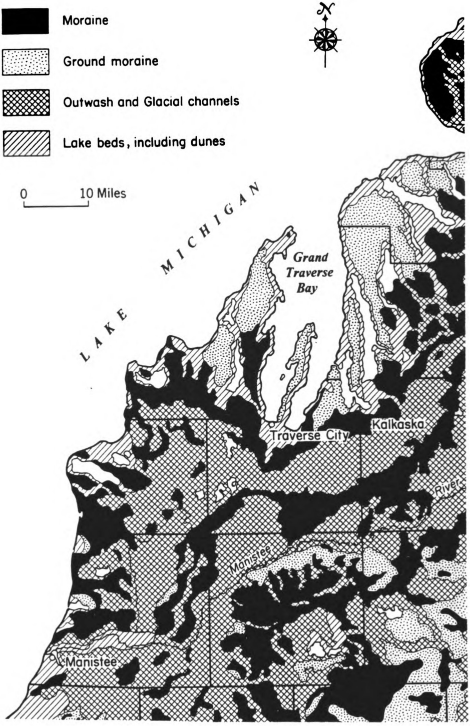


Figure 3.2. Map of Grand Traverse County identifying morainic systems, outwash plains, and other features produced during the Greatlakean glacial advance (Eschman et. al., 1973).

one or more end moraines, trending northwest to northeast through the county (Weber et al., 1990). In Grand Traverse County, the Mancelona Plain is an outwash plain and glacial spillway that lies to the south of the end moraine of Port Huron age. In addition, two large ground moraines with numerous drumlins are located north of the city of Acme (Weber et al., 1990). Benches that were once the bottoms of glacial lakes Algonquin and Nipissing are located along and near Grand Traverse Bay (Weber et al., 1990).

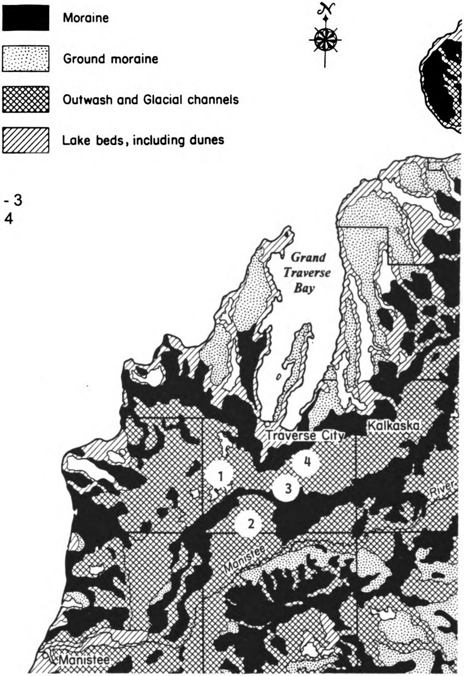
Quaternary geology

Three of the four sites, US31, M37, and Silver Lake Road, are located on outwash plains; the Rusch Road site is located on an end moraine (Eschman et al., 1973)(Figure 3.3). The sites at US31 and Silver Lake are both located on the southern end of the Mancelona Plain (Eschman et al., 1973). M37 is located on another, unnamed outwash plain south of the Port Huron moraine (Eschman et al., 1973). All of these sites contain predominantly fine to coarse sands that are pale brown (10YR 3/1 to 10YR 4/2) to pale reddish brown (10YR 4/4 to 10YR 6/4) in color with occasional layers of gravel and cobbles.

The Rusch Road site is located on a southern ridge of an end moraine composed of sandy glacial drift (Eschman et al., 1973)(Figure 3.3). Sediments in this area are sandy clay loam, sandy loam, or loamy sand in texture, and gray to grayish brown or reddish brown in color (Farrand and Bell, 1982).

Soil series

Field verification of each soil series at each site was performed by Dr. Randall Schaetzl by making one or two borings at each site, but does not account for natural soil variability at each site.



Key
US31 - 1
M37 - 2
Silver Lake - 3
Rusch Rd - 4

Figure 3.3. Map of Grand Traverse County identifying morainic systems and outwash plains in relation to the four sampling sites: (1) US31, (2) M37, (3) Silver Lake, and (4) Rusch Road (Eschman et. al., 1973).

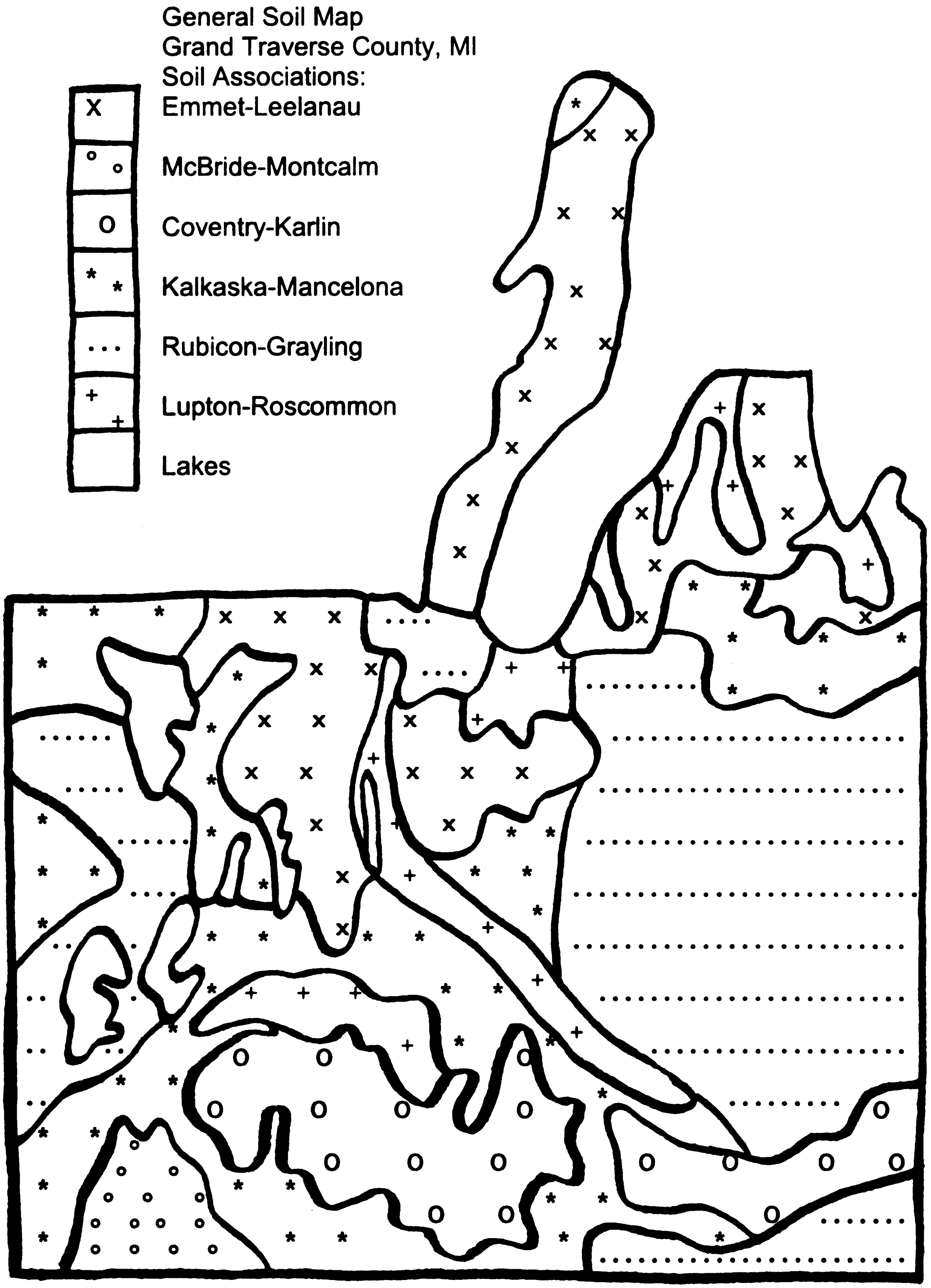


Figure 3.4. General soil map of Grand Traverse County (Weber et al., 1990).

Table 3.2. Mancelona Soil Series: well-drained, level to steep slopes

Horizon	A horizon	E horizon	Bs horizon	Bt horizon	2C horizon
Depth	0-10	10-15	15-33	33-51	51-152+
Color	10YR 3/3	5YR 4/2	5YR 4/6	5YR 3/4	10YR 6/4
Acidity	medium	medium	neutral	mildly alkaline	--------
Thickness range (cm)	5-13	2.5-8	15-30	10-25	--------
Texture	loamy sand	sand	loamy sand	sandy clay loam with limestone pebbles	stratified coarse sand and fine gravel
Structure	weak, fine, granular	single grain, loose	weak, fine, subangular blocky	weak, fine, subangular blocky	single grain; loose
Boundary	abrupt; smooth	clear wavy	clear, wavy	abrupt; irregular	-----------
Other	very friable, moderately low in organic matter		very friable		calcareous

(Weber et. al., 1990)

The four soil series examined in this study comprise approximately 51% of the total soil acreage in Grand Traverse County (Weber et al., 1990)(Figure 3.4). Mancelona soils (Table 3.2) cover 3.6% of the land area in Grand Traverse County (Weber et al., 1990). The A horizon is 5-13 cm thick and has a loamy sand texture that is dark-brown in color and contains moderately low amounts of organic matter (Weber et al., 1990). The Bs horizon is composed of yellowish-red loamy sand due to an accumulation of iron, and is very friable (Weber et al., 1990). The Bt horizon is a dark reddish-brown sandy clay loam with numerous limestone pebbles and some illuvial clay (Weber et al., 1990). The 2C horizon is yellowish-brown in color and composed of stratified, coarse, calcareous sand and fine gravel (Weber et al., 1990).

Montcalm soils (Table 3.3) cover 5.6 percent of the land area in Grand Traverse County (Weber et al., 1990). The A horizon is 15-23 cm thick and composed of a very dark grayish-brown (loamy sand) that is very friable (Weber et al., 1990). The Bs horizon is dark yellowish-brown loamy sand with an accumulation of iron (Weber et al., 1990). The lower B horizon contains illuvial clay lamellae (Weber et al., 1990). The C horizon begins at approximately 91 cm and grades to calcareous sand with depth (Weber et al., 1990).

Kalkaska soils (Table 3.4) cover 13.6 percent of the land area in Grand Traverse County (Weber et al., 1990). The A horizon is dark grayish-brown (loamy sand) with a moderately low organic matter content (Weber et al., 1990). The E horizon is grayish-brown sand (Weber et al., 1990). The upper B horizon (Bh) is dark reddish-brown (loamy sand) due to an accumulation of organic matter (Weber et al., 1990). The Bs horizon below is dark-brown to brown sand with an accumulation of iron (Weber et al., 1990). The BC horizon is a dark yellowish-brown sand that extends to approximately 61 cm (Weber et al., 1990). The C horizon is a pale-brown sand and in some places contain lenses of

Table 3.3. Montcalm Soil Series: well-drained, level to steep slopes

Horizon	Ap horizon	Bs horizon	E/Bt horizon	C horizon
Depth	0-18	18-64	64-91	91-152+
Color	10YR 3/2	10YR 4/4	10YR 5/3 to 5YR 3/4	10YR 5/3
Acidity	slight	medium	medium	medium to slight
Thickness range (cm)	15-23	38-51	20-64	----------
Texture	loamy sand	loamy sand	loamy sand and sandy loam	loamy sand
Structure	weak, medium, granular	weak, fine, subangular blocky	weak, medium subangular blocky	weak, fine, subangular blocky
Boundary	abrupt; smooth	clear; irregular	clear, wavy	----------
Other	very friable	very friable	2.5-13 cm bands of B't seperated by A't bands	grades to calcareous with depth

(Weber et. al., 1990)

Table 3.4. Kalkaska Soil Series: well-drained, level to steep slopes

Horizon	Ap horizon	E horizon	Bh horizon	Bs horizon	BC horizon:	C horizon
Depth	0-15	15-20	20-41	41-61	61-91	91 +
Color	10YR 3/1 to 10YR 4/2	10YR 5/2	5YR 3/2	7.5YR 4/4	10YR 4/4	10YR 6/3
Acidity	slight to medium	medium	strong	strong	strong to slight	medium to slight
Thickness range (cm)	15-20	2.5-20	10-30	15-36	20-36	----------
Texture	loamy sand	sand	loamy sand	sand	sand	sand and some gravel
Structure	weak, fine granular	single grain loose	weak, course subangular blocky	single grain, loose	single grain, loose	single grain, loose
Boundary	abrupt; smooth	abrupt; irregular	gradual; irregular	gradual; irregular	gradual; wavy	-----------
Other	moderately low in organic matter		very friable			

(Weber et. al., 1990)

Table 3.5. Rubicon Soil Series: well-drained, level to steep slopes

Horizon	A horizon	E horizon	Bs horizon	Bs horizon	C horizon
Depth	0-8	8-13	13-46	46-86	86-168+
Color	10YR 2/2	10YR 5/2	7.5YR 4/4	10YR 4/4	10YR 6/4
Acidity	slight	medium	medium	medium	medium
Thickness range (cm)	2.5-10	2.5-10	30-56	25-46	-----------
Texture	sand	sand	sand	sand	sand
Structure	single grain, loose	single grain, loose	single grain, loose	single grain, loose	single grain, loose
Boundary	abrupt, wavy	clear, wavy	gradual; irregular	gradual; irregular	---------
Other					

(Weber et. al., 1990)

reddish-brown sand or loamy sand one to five cm in thickness (Weber et al., 1990).

Rubicon soils (Table 3.5) comprise the largest percent of the land surface of Grand Traverse County, 28.3%, (Weber et al., 1990). The A horizon is dark brown with a thickness of 2-10 cm (Weber et al., 1990). The E horizon is grayish-brown sand with loose soil structure (Weber et al., 1990). The Bs horizon is dark-brown and yellowish-brown sand, whereas the C horizon is light yellowish-brown (Weber et al., 1990).

Vegetation

Vegetation at the sites currently consists of short grasses and alfalfa, except at M37 and Rusch Road sites. The M37 site was partially tilled but had not been in crop production in several years. The Rusch Road site is located along the grassy edge of a fruit farm where rows of apple trees are planted, beginning about 25 m from the roadway.

Climate

Weather systems moving over Lake Michigan dramatically affect on the climate of Grand Traverse County (Table 3.6). Large amounts of lake-effect precipitation in the form of rain, snow, and ice fall on the county each year (Eichenlaub, 1970; Muller, 1966). The average annual precipitation is 76 cm with 226 cm of snowfall (National Oceanic and Atmospheric Administration (NOAA), 1951-80 averages). In addition, Lake Michigan moderates temperatures in the summer and the winter resulting in average minimum temperature of -6.8°C in January and an average maximum temperature of 20.7°C in July.

Table 3.6. Average monthly temperatures and monthly precipitation totals for Grand Traverse County.

Month	**Temperature (C) Average**	**Precipitation (cm) Average**	**Snow (cm) Average**
January	-6.8	5.1	66
February	-6.8	3.6	43
March	-1.4	4.4	28
April	5.8	5.8	8
May	12.1	5.9	0
June	17.5	8.3	0
July	20.7	6.6	0
August	19.5	7.4	0
September	15.3	10.2	0
October	9.3	6.9	3
November	2.9	6.1	20
December	-3.7	5.3	58
	Totals	**76.0**	**226**

(Climatic data from the National Oceanic and Atmospheric Administration (NOAA), 1951-80 averages).

METHODS

Site characteristics

Four research sites, all located in Grand Traverse County in northwestern lower Michigan, were sampled during the course of this research (Figure 4.1). Factors used in the selection of possible sites included vehicular traffic volume, salting application rate, slope, absence of a ditch, and characteristics of soils in and near the right-of-way. Sampling sites included two roadways with high vehicular traffic that have high salt application rates, one roadway with medium vehicular traffic that has an intermediate salt application rate, and one with low vehicular traffic volume and a low salt application rate (Harold Shappar, personal correspondence, 1996). All four sites have roadside soils that are within sandy textural families, which, in general, typify Grand Traverse County area (see

Table 4.1. Sampling sites in Grand Traverse County

Site #	Road	Site location
1	US31 south	SW 1/4 of NW 1/4 Sec. 17,T.25N.,R.11W.
2	M37 south	SE 1/4 of NW 1/4 Sec. 17,T.26N.,R11W.
3	E. Silver Lake Rd.	SW 1/4 of SW 1/4 Sec 32, T.27N.,R.11W.
4	Rusch Rd.	NE 1/4 of NE 1/4 Sec. 1, T.25N.,R.11W.

Site #	*Soil series adjacent to road	Soil series identified by auguring
1	Rubicon	Rubicon
2	Montcalm-Kalkaska	Montcalm-Kalkaska
3	Mancelona	Montcalm-Mancelona
4	Kalkaska	Mancelona

Site #	**Salt and sand application rates (kg/km)
1	204 kg/km pure salt
2	204 kg/km pure salt
3	204 kg/km 1:1 salt:sand mix
4	204 kg/km 1:5 salt:sand mix

*(Weber et. al., 1990)

**(Harold Shappar, personal correspondence, 1996)

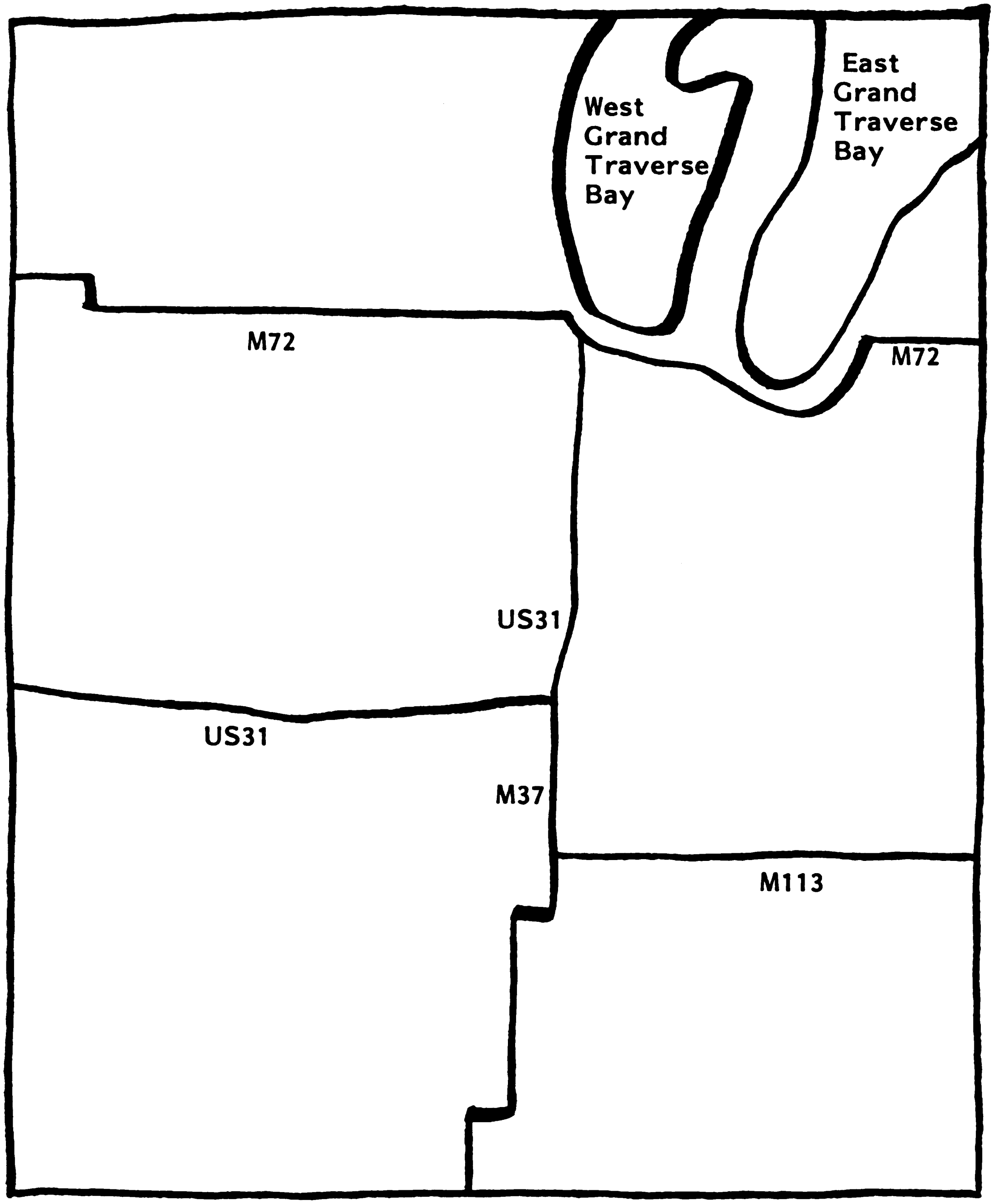


Figure 4.1. General highway map of part of Grand Traverse County, showing study area locations: (1) M37, (2) US31, (3) Silver Lake Road, and (4) Rusch Road (Grand Traverse Road Commission, 1997).

Figure 3.4) (Table 4.1). Positive identification of the soil series adjacent to the roadway was determined by preliminary soil auguring. All four sites are relatively flat, have no ditches, and not located near an intersection or hill.

Field methods

At each site, soils were sampled with a bucket auger, with the depth and position of each sample not measurably exact within each horizon in each boring but an estimate. Samples were taken along three transects, 6 m apart, located perpendicular to the roadway. Five borings were made at intervals of 2 m starting from where the backfill meets the native soil (Hutchinson, 1970). The three, each 10 m in length, yielded fifteen pedon sample sites at each of the four roadside sites (Figure 4.2). At each 2 m boring, three soil samples were taken, using the auger, at approximately 8 cm, 60 cm, and 100 cm depths, to examine any translocation of sodium cations and to locate possible sodium accumulation zones in the subsurface. In effect, a sample was taken from each of the A, B,

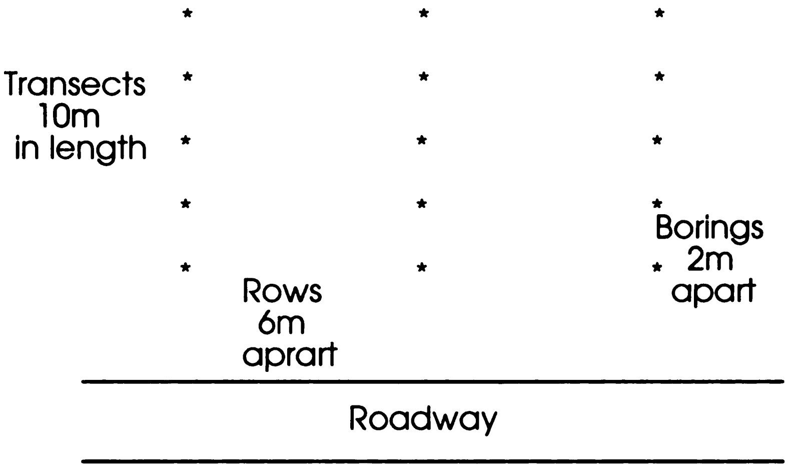


Figure 4.2. Spatial distribution of auguring sites for the collection of soil samples.

and C horizons. Approximately 250 g of soil was removed placed in a plastic bag and labeled with the month,

location, transect number, boring number, and soil horizon type. Sampling occurred at three dates: in early September 1996, in early December 1996, and in early March 1997. A measuring wheel was used to determine the exact location of each site, in reference to a fixed structure, in order to precisely locate the sampling area when snowbanks were present. Each sample bore hole could not be located precisely, therefore subsequent borings were close to the original bore hole.

Laboratory methods

All soil samples were allowed to air-dry on aluminum foil. After air-drying the samples were crushed with a wooden pestle and screened through a 2 mm (10 mesh) sieve (Hesse, 1971). Coarse fragments (> 2mm diameter) were discarded.

Standard procedures approved by the Council on Soil Testing and Plant Analysis (1992) were used to analyze the samples for contents of Na^+, Ca^{2+}, and Mg^{2+} cations. The extractant was made by mixing 77.1 g of ammonium acetate ($NH_4C_2H_3O_2$) with 900 ml of distilled water. Five grams of dried soil were then placed in a 50 ml glass extraction bottle along with 25 ml of extractant reagent. The soil and extractant mixture were then shaken for five minutes on a reciprocating shaker at approximately 180 oscillations per minute. After shaking, the samples were allowed to settle for approximately 24 hours. The filtrate was carefully removed using a pipette and placed in 25 ml plastic containers.

Before cation concentrations could be measured from the soil extract, standard solutions for sodium, calcium and magnesium were made to calibrate the atomic adsorption spectrometer (AA). Standard solutions for calcium ranged from 10 ppm to 140 ppm in intervals of 20 ppm. Magnesium standards ranged from 2 ppm to 30 ppm in intervals of 4 ppm. Sodium standard solutions ranged from 2 ppm to 30 ppm in intervals of 2 ppm. In order to limit the burn-off of the major cations present in the filtrate during atomization, 5% KCl was added to each sample prior to analysis (Sharon Anderson, personal communication, 1996). The concentrations of the individual cations were measured in ppm (or mg/L) from the soil extract using a flame AA. The extract was drawn in the AA and atomized, emitting a specific color, while a wave length of a specified length passed through the flame measuring the concentration of a particular cation. Standards that exceeded the maximum standard when analyzed on the AA were diluted 10 times with distilled water. Concentrations were converted to mmol/L using the following conversion:

$$\frac{(\text{mg})}{(\text{L})} \times \frac{(1\text{ g})}{(1000\text{ mg})} \times \frac{(1\text{ mol})}{(\text{gfw}^*)} \times \frac{(1000\text{ mmol})}{(1\text{ mol})}$$

* gram formula weight of ion

Sodium absorption ratios (SARs) for each sample were then calculated using the concentrations of Na^+, Ca^{2+}, and Mg^{2+} cations in mmol/L with the following formula (McBride, 1994):

$$\text{SAR} = \frac{\{\text{Na}\}}{\sqrt{\frac{\{\text{Ca}\}+\{\text{Mg}\}}{2}}}$$

Sodium, magnesium, and calcium concentrations for each boring, in each horizon, at each site, for each sample period were then entered into an Excel spread sheet to calculate SAR. SAR values were entered in the Statistical Package for Social Sciences (SPSS) for Windows in order to statistically manipulate the data.

RESULTS

Climate data

During the sample period, April 1996 - March 1997, precipitation in the study area often exceeded the 30 year (1951-1980) normals (National Oceanic and Atmospheric Administration (NOAA)(Table 5.1). The normal annual precipitation, recorded at Traverse City, is 76 cm, but during the sample period 161 cm of precipitation was received. In a normal year the total snowfall is 226 cm (Table 3.6 in ***Study Area***), but during the sample period, total snowfall was 511 cm (Table 5.1), a difference of 285 cm. Total monthly precipitation was above normal for 11 of the 12 months during the sampling period. With the exception of four months, April, May, July, and November, temperatures were also above normal during the sampling period.

April 1996 was an extremely wet month (total monthly precipitation 12.3 cm above normal), but with cool temperatures (monthly mean temperature 1.8°C below normal). June, July, and August received abundant precipitation (monthly precipitation 12.9 cm, 7.2 cm, and 0.3 cm above normal, respectively). Monthly mean temperatures in June and August were above normal (1.5°C and 1.5°C, respectively) but temperatures in July were 1.7°C below normal. In September and October, monthly precipitation (12.2 cm and 9.9 cm) and mean temperatures (1.6°C and 10°C) were both above normal (precipitation 2.0 cm and 3.0 cm; temperatures 0.7°C and 0.7°C, respectively)(Table 5.1; NOAA, April-March, 1997). Thus, the soils were wetter than normal during the sampling period.

Heavy precipitation (8.9 cm in the first 10 days) combined with colder than normal November temperatures (1.9°C below normal for the month) produced a maximum snowpack of 50.8 cm on November 10. In early December temperatures were 1.8°C above normal, melting nearly half of the snowpack that had accumulated in late November. December was marked by periodic freezing rain and snow episodes. Often, however, the snow and ice that had accumulated at night would melt by mid-afternoon of the following day. During December 1-

Table 5.1. Selected climatic data for 1996-1997 for Traverse City, MI (NOAA, April 1996-March 1997).

Year		Mean Maximum Temp. (C)	Mean Minimum Temp. (C)	Monthly Mean (C)	1996-1997 Departure from normal* (1951-80)
1996	April	9	-2	4	-1.8
	May	18	5	11	-1.1
	June	24	13	19	+1.5
	July	26	13	19	-1.7
	August	27	14	21	+1.5
	Sept.	21	11	16	+0.7
	Oct.	15	5	10	+0.7
	Nov.	4	-1	1	-1.9
	Dec.	0	-4	-2	+1.7
1997	Jan.	-3	-9	-6	+0.8
	Feb.	0	-8	-4	+2.8
	March	3	-5	-1	+0.4

Year		Precipitation (cm)	Departure from normal (cm)*(1951-80)	Total Snowfall (cm)	Monthly Maximum Snowpack (cm)
1996	April	18.1	+12.3	22.1	7.6
	May	3.6	-2.3	5.1	0
	June	21.2	+12.9	0	0
	July	13.8	+7.2	0	0
	August	7.7	+0.3	0	0
	Sept.	12.2	+2.0	0	0
	Oct.	9.9	+3.0	0	0
	Nov.	14.2	+8.1	74.4	50.8
	Dec.	17.7	+12.4	90.9	20.3
1997	Jan.	27.1	+22.0	210.3	68.6
	Feb.	6.4	+ 2.0	42.9	25.4
	Totals	161.0		511.0	213.4

* A (+) sign denotes above normal and a (-) sign denotes below normal.

15, there was a total of 28.7 cm of snowfall, with an average snowpack of 7 cm. From December 16-31, however, 62.2 cm of snow fell, resulting in an average snowpack of 14 cm. Snowfall in January totaled 210.3 cm, resulting in a maximum monthly snowpack of 68.6 cm on January 21. In February, total monthly snowfall was 64.3 cm with a 48.3 cm (maximum) snowpack on February 5 (NOAA, November-February, 1997).

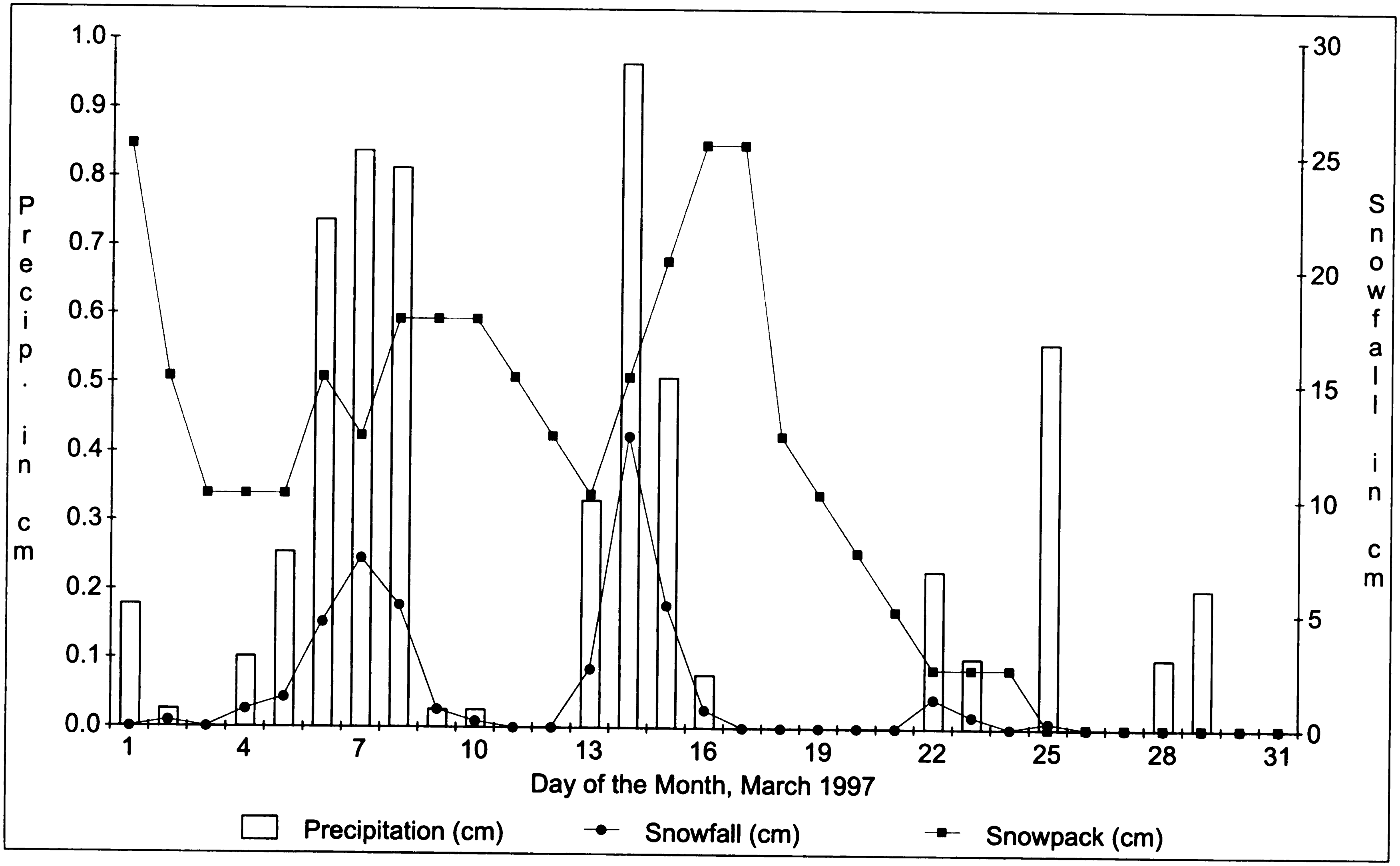
In early March the accumulation and melt of snowpack occurred in pulses; vigorous melting (2-4 cm) of the snowpack began on March 1-3 (Figure 5.1). Significant melting of the snowpack ceased until March 6-8 when 5.7 cm of new snow fell, adding 3 cm to the snowpack. The snowpack again began to melt (average of 2.5 cm per day) between March 10-13. Accumulations of snow on March 13-16 (average of 5.3 cm per day) increased the snowpack by 12.7 cm. Mild temperatures on March 17-31 (average daily temperature 1.5°C) rapidly melted the snowpack (average of 3.2 cm per day) such that by March 25 it was essentially gone (NOAA, March 1997).

In summary, the sample period was wet with above normal temperatures during the winter months (December - March). Precipitation, snowfall and rain, was extremely abundant throughout the year, with the exception of May. Wet and above normal temperatures in the sampling period created favorable conditions for heavy snow during the winter and rapid melting in late March.

SAR and sodium values at the various sampling sites

Application rates of salt differed for three of the four sampling sites. These rates have been practiced in Grand Traverse County for approximately 32 years (Harold Shappar, personal correspondence, 1996). Several studies conclude that long-term salting of the roadways can lead to the accumulation of sodium in roadside soils (Davison, 1970; Scott and Wylie, 1980).

Figure 5.1. Precipitation and snow data for March 1997.



At the four sites in Grand Traverse County the highest mean SAR values coincide with sites that receive that most deicing salt (Table 5.2). The sites near M37 and US31 both received heavy amounts of deicing salt, 204 kg/km of pure salt, and have the highest grand mean SARs when data from all samples from all transects are combined and averaged. Rusch Road received the lowest amount of deicing salt, 40 kg/km of pure salt, and had an intermediate grand mean SAR. Although Silver Lake received a medium amount of deicing salt, 102 kg/km of pure salt, it had the lowest grand mean SAR.

Table 5.2. Average SAR values (mmol/L) for sampling sites, arranged by their deicing rates*

Month	**M37**	**US31**	**Silver Lake**	**Rusch Road**
	Salt Application Rate			
	high	high	medium	low
September	1.2	0.4	0.2	0.7
December	2.7	2.2	0.6	0.7
March	3.1	0.3	0.2	1.3
Grand Mean	2.3	1.0	0.3	0.9

*Data were derived by finding the mean SAR of each site (including all transects and horizons) during the appropriate sampling period. The grand mean is a total average of the mean SARs (including September, December, and March) for each sampling site over the entire sampling period.

The M37 site had the highest *sodium* concentrations throughout the entire sampling period (September, 1.17 mmol/L; December, 3.23 mmol/L; and March, 3.57 mmol/L)(Table 5.3). This increase in the early winter (December) at the M37 site (over 2.5 times the concentrations in September) suggests that sodium was accumulating in the soils due to early winter deicing application operations. Similarly, at the US31 site in December, sodium concentrations (2.45 mmol/L) increased to over six times the concentration in September (0.40 mmol/L). Sodium concentrations at the Silver Lake and Rusch Road sites increased, but only slightly, from September (0.19 mmol/L and 0.60 mmol/L) to December (0.6 mmol/L and 0.66 mmol/L). Based on these data, it appears that sodium accumulated in the soils due to early winter deicing operations. Sodium concentrations continued to increase from December (3.23 mmol/L) to March (3.57 mmol/L) at the M37 site, although the increase was small; other sites saw no change or a decrease in sodium concentrations from December to March. The US31 site had the largest decrease (11 times) in sodium concentrations from December (2.45 mmol/L) to March (0.22 mmol/L). Sodium concentrations at the Silver Lake site decreased slightly from December (0.77 mmol/L) to March (0.23 mmol/L) but did not change at the Rusch Road site. An increase in SARs at the M37 site in March may have been caused by a large influx of sodium from the melting of salt-laden snow, increasing the availability of sodium cations. In addition, large amounts of salt-free melt water at the surface may have infiltrated through the soils, carrying in excess sodium to deep subsurface layers, and thereby reduced SAR values at the remaining three sites.

Table 5.3. Average sodium values (mmol/L) for each sampling site*.

Month	**M37**	**US31**	**Silver Lake**	**Rusch Road**
	Salt Application Rate			
	high	high	medium	low
September	1.17	0.40	0.19	0.60
December	3.23	2.45	0.70	0.66
March	3.57	0.22	0.23	0.66

* Average sodium concentrations were derived by summing the sodium values in mmol/L, at each site from each transect in the given sampling period and dividing by the number of samples (45).

Comparison of the two high deicing application sites with different soil textures

Sites that received more deicing salt did not always have the highest SARs and sodium concentrations, possibly due to soil texture and CEC differences. Loamy sand soils (see ***Study Area***) found at the M37, Silver Lake, and Rusch Road sites contain more clay and organic matter which are capable of adsorbing sodium cations, than US31 (Rubicon series). Sand soils, found at the US31 site, are highly permeable with less clay and organic matter. The lower CEC values make the Rubicon soils here less capable of adsorbing sodium cations, suggesting that salts may flush through these soils and not be concentrated in the soil solution where they may be adsorbed.

Higher SAR values and sodium concentrations at the M37 site are, therefore, probably due to a combination of a high salt application rate and the sandy loam (as opposed to sand) texture for the 1996-1997 time period. Sodium was readily adsorbed in December and March, when deicing salt is either being applied to the roadway or salt is coming out of melting snow. SAR and sodium concentrations are maximal in December at the (sandier) US31 site but decrease markedly by March. The low values in March could be due to the fact that sodium is quickly flushed through the sandy soil profile by rain and snow melt. The effect of different soil textures is apparent when comparing the SAR values and sodium concentrations of the US31 site in September (0.40 mmol/L) and March (0.22 mmol/L) with the Rusch Road site (0.60 mmol/L and 0.66 mmol/L, respectively). Although the Rusch Road site received the lowest amount of deicing salt, its SAR values and sodium concentrations are higher than at the (very sandy) US31 site. These data suggest that texture and CEC are more important than application rate in determining the amount of Na^+ adsorption.

Comparison of the medium and low deicing application sites

It has already been noted that the sites with medium and low salt application rates have lower grand mean SAR values and sodium concentrations than the sites with high salt application rates. Rusch Road had the lowest salt application rate, 40 kg/km of pure salt, but had an intermediate SAR value (0.8 mmol/L) and higher sodium concentrations in September (0.60 mmol/L) and March (0.66 mmol/L), than the Silver Lake site. Although both sites have similar soil textures (see ***Study Area***) the soil at the Rusch Road site is better developed than the soil at the Silver Lake site. The soils at the Silver Lake site have coarse textures, marked by numerous unsorted rocks and pebbles that increase permeability and flowpath channels. In addition, the soils at the Rusch Road site have sandy clay lenses in the Bt horizon that may better retain sodium cations.

In conclusion, sites in Grand Traverse County that received high rates of deicing salt often, but not always, had the highest SAR values or the highest sodium concentrations. The adsorption and retention of sodium appears to also be dependent on the soil texture (which influences both CEC and permeability) as much as deicing salt application rate. Sandy soil profiles adsorb and retain little sodium while profiles of sandy loam or clay loam textures adsorb and retain more sodium throughout the year.

Comparison of SAR values at the high salt application rate sites

Of the two sites that receive the highest amount of deicing salt, the M37 site had the highest grand mean SARs (Table 5.2). The M37 site has Montcalm-Kalkaska soils which have a slightly higher CEC (Table 5.4) than the US31 site, which has Rubicon soils. In addition, Rubicon soils are very sandy with slightly higher permeabilities, reducing the contact time between sodium and the few available negatively-charged, adsorption sites, when compared to the sandy loams or loamy sands at the Montcalm-Kalkaska site.

Comparing the concentrations of Ca^{2+}, Mg^{2+}, and Na^{+} cations at the US31 and M37 sites indicates that there was little change in the concentrations of Ca^{2+} and Mg^{2+} cations over the sampling period (Table 5.5). The Montcalm-Kalkaska soils at the M37 site had a large increase in Na concentrations in December (3.23 mmol/L) and March (3.57 mmol/L) over that of September. This large influx of sodium was from deicing salts applied to the roadway. In late March rain and rapid snowmelt dissolved sodium chloride crystals in snow, releasing sodium cations to the soils. A large increase in sodium concentrations is evident at US31 in December (2.45 mmol/L) compared to concentrations in September (0.40 mmol/L) and March (0.22 mmol/L). Spring and summer rains probably flushed any existing sodium ions through the sandy soils, resulting in low SARs in September and March.

Table 5.4. CEC values and textures of the two sites, M37 and US31, that have the highest salt application rates.

Site	Soil Series	Average CEC*	Texture
M37	Montcalm-Kalkaska	1-15 mmol/100 g	loamy sand
US31	Rubicon	1-6 mmol/100 g	sand

*William Bowman, personal communication (11/05/97)

Table 5.5. Average mean concentrations of Ca, Mg, and Na in mmol/L*

Site/date	Ca (mmol/L)	Mg (mmol/L)	Total Ca + Mg	Na (mmol/L)
M37/Sept	2.22	0.20	2.42	1.17
M37/Dec	2.08	0.45	2.53	3.23
M37/March	2.05	0.11	2.16	3.57
US31/Sept	2.04	0.13	2.17	0.40
US31/Dec	1.88	0.18	2.06	2.45
US31/March	1.88	0.06	1.94	0.22

Although both sites had high salt application rates, the Montcalm-Kalkaska (M37) soils adsorbed more sodium that the Rubicon (US31) soils throughout the sampling period. This trend may be due to the greater availability of negatively-charged adsorption sites at the M37 site, as well as their slower permeabilities.

SAR values with depth

In order to examine trends in SAR with depth, bar graphs depicting the SAR values of all the horizons, at each boring, were made for the individual transects. Comparing the SARs of each horizon within a single boring might suggest a relationship between SAR and depth in a single pedon. If four of the five borings in a transect depict SAR decreasing from the A horizon to the C horizon, I concluded that a depth trend in SAR existed for the soils in that transect. In addition, the opposite trend, SAR increasing with depth, was also evaluated. If four of the five borings depict SAR increasing with depth from the A to the C horizon, an inverse depth trend was assumed to have existed for that transect. If two or more of the borings in a given transect did not show such a depth relationship, I assumed that a depth or inverse depth trend did not exist.

In September, none of twelve transects from the four sites show a depth or inverse depth trend in SAR (Table 5.6). Rather, the data generally indicate that sodium is comparatively most concentrated in the B horizon with the lowest SAR values in the A horizon. Normally, during the summer growing season Ca^{2+} and Mg^{2+} are depleted from the upper soil horizons. Excess Na^{+} may have been eluviated from the A and E horizons eventually accumulating in the B horizon. Any accumulation of sodium cations probably occurred in the clayey Bt horizon due to the abundance of adsorption sites. In addition, Na^{+} remained fairly concentrated in the C horizon, which is not normally affected during the growing season, reducing the likelihood of Na^+ flux out of that horizon.

In December, none of the twelve transects showed a relationship in SAR and depth (Table 5.7). Generally, SARs in the C horizon were higher than those in the A horizon, indicating Na^+ was not concentrating at the surface. Periodic snow fall, deicing applications, melting episodes, and rain may have quickly flushed Na^+ from the A horizon to the horizons below. Some of the December bar graphs have large peaks in SAR for different horizons, separated by extremely low SAR values, which indicates some preferential vertical movement of water through the soil profile (Appendix II).

In March, one of twelve transects taken from the four sites show SAR values, decreasing with depth (Table 5.8). None of the transects showed an inverse relationship between depth and SAR. At M37 in transect three sodium is comparatively concentrated in the A horizon, then the B horizon, followed by the C horizon, compared to calcium and magnesium. The accumulation of sodium in the A horizon may be explained by large amounts of sodium being released at the surface due to rapid melting of heavy salt-laden snow in March (see ***Study area***). However, the majority of transects depict SAR being the lowest in the A horizon compared to the B or C horizons. Rapid melting of surface snow and increased rainfall in March may have carried Na^+ to the lower horizons at these sites.

The absence of depth trends in SAR may be due to preferential flowpaths present in the soils. Preferential flowpaths are present throughout the year because soils in temperate climates that receive early winter lake-effect snowpacks do not freeze (Isard and Schaetzl, 1994). The vertical movement of water through soils is dependent on periodic rain, snow, and melting events that wash sodium through the soils, to various depths, depending on site-specific

Table 5.6. Correlation between SAR and depth, in borings within a transect in September.

Month/site	# borings per transect where C>B>A	# borings per transect where B>C>A	# borings per transect where B>A>C	# borings per transect where C>A>B	# borings with another type of depth trend in SAR	Does transect meet criteria[1] re: decreasing SAR with depth or increasing with depth?
September						
US31 transect 1	1	1	1	1	1-A>C>B	N
US31 transect 2	3	1			1-C≥B>A	N
US31 transect 3	1	1		1	1-C>B≥A, 1-A=B=C	N
M37 transect 1	1	3			1-B≥C>A	N
M37 transect 2		2	2		1-A>B>C	N
M37 transect 3	1	2	2			N
Silver transect 1		2			1-A>B>C, 1-C>B>A 1-B>A≥C	N
Silver transect 2	1	2			2-B≥C>A	N
Silver transect 3		1	1		1-B>A≥C, 1-C>A≥B 1-A=B=C	N
Rusch transect 1	1	1	1	1	1-B≥C>A	N
Rusch transect 2		4			1-A≥B>C	N
Rusch transect 3	1	2			1-B>A≥C, 1-C>B≥A	N

[1] The correlation between SAR and depth was determined by examining the SAR's of the A, B, and C horizons in a given transect. If four of the five borings in one transect had the same correlation in SAR values with depth then I assumed a trend in SAR with depth existed. If four of the five borings did not have any correlation in SAR values with depth than I assumed a trend in SAR with depth in the soils did not exist.

Table 5.7 Correlation between SAR and depth, in borings within a transect in December.

Month/site	# borings per transect where C>B>A	# borings per transect where B>C>A	# borings per transect where B>A>C	# borings per transect where C>A>B	# borings with another type of depth trend in SAR	Does transect meet criteria[1] re: decreasing SAR with depth or increasing with depth?
December						
US31 transect 1			2		2-A>B>C, 1-A>B≥C	N
US31 transect 2		2		1	2-A>B<C	N
US31 transect 3		1	3		1-A>C>B	N
M37 transect 1	2	2		1		N
M37 transect 2	1		2	2		N
M37 transect 3	3			1	1-A>B>C	N
Silver transect 1	1	2		1	1-A>C>B	N
Silver transect 2	1	1			3-A>B>C	N
Silver transect 3	1	1		2	1-A>B>C	N
Rusch transect 1	2	2		1		N
Rusch transect 2	3	1			1-A>B≥C	N
Rusch transect 3	2		1	1	1-A>C>B	N

1 The correlation between SAR and depth was determined by examining the SAR's of the A, B, and C horizons in a given transect. If four of the five borings in one transect had the same correlation in SAR values with depth then I assumed a trend in SAR with depth existed. If four of the five borings did not have any correlation in SAR values with depth than I assumed a trend in SAR with depth in the soils did not exist.

Table 5.8. Correlation between SAR and depth, in borings within a transect in March.

Month/site	# borings per transect where C>B>A	# borings per transect where B>C>A	# borings per transect where B>A>C	# borings per transect where C>A>B	# borings with another type of depth trend in SAR	Does transect meet criteria[1] re: decreasing SAR with depth or increasing with depth?
March						
US31 transect 1	2	1			1-B≥C>A, 1-C>B≥A	N
US31 transect 2	1				1-C>B≥A, 1-A≥B>C, 2-C>B>A	N
US31 transect 3	1	1		1	1-C>B≥A, 1-B≥C>A	N
M37 transect 1			1		3-A>B>C, 1-B≥A>C	N
M37 transect 2			1	2	1-A>B>C, 1-A≥B>C	N
M37 transect 3			1		4-A>B>C	Y
Silver transect 1					2-A>B>C, 1-A≥C>B, 1-B>C≥A, 1-C>A≥B	N
Silver transect 2				1	2-B≥C>A, 1-A>C>B, 1-A=B=C	N
Silver transect 3					2-A=B=C, 1-B≥C>A, 1-A≥C>B, 1-A≥B>C	N
Rusch transect 1		1			2-B≥C>A, 1-B>C≥A, 1-C>A≥B	N
Rusch transect 2	1	2			2-B≥C>A, 1-A>C>B	N
Rusch transect 3	1	2		1	1-A>B>C	N

[1] The correlation between SAR and depth was determined by examining the SAR's of the A, B, and C horizons in a given transect. If four of the five borings in one transect had the same correlation in SAR values with depth then I assumed a trend in SAR with depth existed. If four of the five borings did not have any correlation in SAR values with depth than I assumed a trend in SAR with depth in the soils did not exist.

factors such as slope, aeration, vegetation, and preferential flowpaths. In addition, soil samples taken within each horizon may not reflect the same soil composition due variability of sample depth associated with bucket auger sampling.

Seasonal distribution in SAR

Deicing salt is only applied to roadways during the winter season, allowing time for sodium cations to be released (desorbed) from soils during the late spring, summer, and early fall. Total mean SAR values calculated from the average SAR values during each sampling period support this hypothesis. When salting begins, in December, the total mean SAR of roadside soils is higher (1.6 mmol/L) than in September (0.6 mmol/L)(Table 5.9). In March salting ends, but melting of salt-laden snow and rainfall occurs, resulting in a reduction of the total mean SAR (1.2 mmol/L) from December.

Table 5.9. Seasonal distribution of SAR (mmol/L*)

Site	September	December	March
M37	1.2	2.7	3.1
US31	0.4	2.2	0.3
Silver Lake	0.2	0.6	0.2
Rusch Road	0.7	0.7	1.3
Total Mean	**0.6**	**1.6**	**1.2**

*Data were derived by finding the mean SAR of each site (including all transects and horizons) during the appropriate sampling period. The grand mean is a total average of the mean SARs (including September, December, and March) for each sampling site over the entire sampling period.

At all the sites, the highest average SAR values were either in December or March, never in September. Spring and summer rains probably washed most of the sodium from the soil profile thus reducing the grand mean SAR by September. Sodium becomes readily available in December when deicing salt commenced thus markedly increasing SAR values. An increase in temperature caused heavy infiltration of soil by water from the snow and ice melt and early spring rains which reduced SAR at the sandy soil sites but increased SAR at the loamy sand site.

Average sodium concentrations were also highest in either December or March (Table 5.10). Seasonally, sodium concentrations coincide with average SAR values, except at the Rusch Road site. Sodium concentrations do not change from December (0.66 mmol/L) to March (0.66 mmol/L) but the average SAR value doubles from December (0.6 mmol/L) to March (1.2 mmol/L).

Table 5.10. Seasonal distribution of sodium (mmol/L*)

Site	September	December	March
M37	1.70	3.23	2.45
US31	0.40	2.45	0.22
Silver Lake	0.19	0.70	0.23
Rusch Road	0.60	0.66	0.66

*Average sodium concentrations were derived by adding the sodium in mmol/L at each site from each transect in the given sampling period and dividing by the number of samples taken at each site (45).

In conclusion, when deicing salt is being applied to the roadways, in December, the SAR values increase. As salting decreases and melting of snow and rain occur, in March, the total mean SAR decreases. Spring and summer rains flush sodium through the soils reducing the total mean SAR, such that late-summer (September) values are low.

Distribution of SAR with distance from the road

Salt spray, the pile-up of salt-laden snow adjacent to the roadway, and roadway run-off move sodium-rich snow and water laterally away from the road (McConnell and Lewis, 1972). At the four sampling locations, and in northern

Michigan in general, soils do not freeze (Isard and Schaetzl, 1995) eliminating freeze/thaw layers which may complicate the movement of soil water in the subsurface. Ideally, the input of salt should produce distance-decrease SAR trends, defined as, when distance from the roadway increases, SAR values decrease within a given transect.

In order to determine if a trend existed in SAR as distance from the roadway increased, the soils at each site were evaluated by transect and by horizon. To do this, SAR values for each horizon in each transect of a particular site were examined statistically. I used SPSS for Windows to find the upper and lower bound of the 95% confidence interval for the best-fit linear regression line for SAR data (Table 5.11). If the resulting confidence interval included "zero" in its range, then the slope of the regression line could, statistically, be zero, indicating that SAR cannot be said to be increasing or decreasing in that horizon along the given transect. If the confidence interval did *not* include zero with in its range, then a significant (at 95%) slope in SAR did exist, indicating SAR is either increasing or decreasing in that horizon along the given transect. If the slope of the (significant) regression line is positive, then SAR is presumably increasing as distance from the roadway increases. If the slope of the (significant) regression line is negative than SAR is presumably decreasing as distance from the roadway increases. The rate at which SAR increased or decreased was indicated by the slope of the regression line. The larger the slope the greater the change in SAR with distance.

Statistical analysis confirm that, for all time periods, 100 out of 108 transects do not have SAR values that significantly decreased or increased, with distance from the road, indicating that no trend in SAR exists. Only 8 of 108 transects have SAR values that significantly decrease, as distance from the road

Table 5.11. Correlation between SAR and distance from the road within a given transect.

Site/Date/ Transect/ Horizon	Lower bound of 95% conf. interval for regression equation slope	Upper bound of 95% conf. interval for regression equation slope	Significant (non-zero) slope?*	Slope positive (+) negative (-)	Regression equation (if significant slope)	R^2
US31/Sept/1/A	-.242	.002	N	-		
US31/Sept/2/A	-.403	.093	N	-		
US31/Sept/3/A	-.100	.060	N	-		
US31/Sept/1/B	-.180	.130	N	-		
US31/Sept/2/B	-.194	.890	N	+		
US31/Sept/3/B	-.293	.193	N	-		
US31/Sept/1/C	-.227	.117	N	-		
US31/Sept/2/C	-.659	.069	N	-		
US31/Sept/3/C	-1.97	1.33	N	-		
M37/Sept/1/A	-.222	-.018	Y	-	y=1.32-0.12d	.764
M37/Sept/2/A	-1.02	.291	N	-		
M37/Sept/3/A	-.476	.156	N	-		
M37/Sept/1/B	-.373	-.157	Y	-	y=3.07-0.265d	.937
M37/Sept/2/B	-.369	-.031	Y	-	y=2.60-0.20d	.766
M37/Sept/3/B	-.468	.068	N	-		
M37/Sept/1/C	-.813	.163	N	-		
M37/Sept/2/C	-.316	.024	N	-		
M37/Sept/3/C	-1.54	.669	N	-		
Silver/Sept/1/A	-.025	.055	N	+		
Silver/Sept/2/A	-.049	.049	N	-		
Silver/Sept/3/A	-.564	.374	N	-		
Silver/Sept/1/B	-.193	.233	N	-		
Silver/Sept/2/B	-1.50	1.50	N	-		
Silver/Sept/3/B	-.108	.078	N	-		

Table 5.11. (cont'd.)

Site/Date/ Transect/ Horizon	Lower bound of 95% conf. interval for regression equation slope	Upper bound of 95% conf. interval for regression equation slope	Significant (non-zero) slope?	Slope positive (+) negative (-)	Regression equation (if significant slope)	R^2
Silver/Sept/1/C	-.100	.140	N	+		
Silver/Sept/2/C	-.010	.270	N	+		
Silver/Sept/3/C	-.102	.132	N	+		
Rusch/Sept/1/A	-.276	.106	N	-		
Rusch/Sept/2/A	-.159	.169	N	+		
Rusch/Sept/3/A	.158	.088	N	-		
Rusch/Sept/1/B	-1.33	.858	N	-		
Rusch/Sept/2/B	-.546	.226	N	-		
Rusch/Sept/3/B	-.998	.058	N	-		
Rusch/Sept/1/C	-.471	.331	N	-		
Rusch/Sept/2/C	-.547	.437	N	-		
Rusch/Sept/3/C	-1.60	.723	N	-		
US31/Dec/1/A	-3.02	1.83	N	-		
US31/Dec/2/A	-3.36	.919	N	-		
US31/Dec/3/A	-.125	-.005	Y	-	y = 0.73 - 0.065	0.790
US31/Dec/1/B	-2.48	-.199	Y	-	y = 11.6 - 1.3d	0.764
US31/Dec/2/B	-1.75	1.33	N	-		
US31/Dec/3/B	-3.03	2.69	N	-		
US31/Dec/1/C	-.126	.086	N	-		
US31/Dec/2/C	-.177	.117	N	-		
US31/Dec/3/C	-.100	.077	N	-		
M37/Dec/1/A	-2.65	.738	N	-		
M37/Dec/2/A	-2.33	.924	N	-		
M37/Dec/3/A	-2.21	1.25	N	-		

Table 5.11. (cont'd.)

Site/Date/ Transect/ Horizon	Lower bound of 95% conf. interval for regression equation slope	Upper bound of 95% conf. interval for regression equation slope	Significant (non-zero) slope?	Slope positive (+) negative (-)	Regression equation (if significant slope)	R^2
M37/Dec/1/B	-2.21	1.39	N	-		
M37/Dec/2/B	-3.11	.071	N	-		
M37/Dec/3/B	-.198	.060	N	-		
M37/Dec/1/C	-3.05	.824	N	-		
M37/Dec/2/C	-4.39	4.28	N	-		
M37/Dec/3/C	-4.40	2.01	N	-		
Silver/Dec/1/A	-.839	.199	N	-		
Silver/Dec/2/A	-.061	-.014	Y	-	y=0.405-0.0375d	0.857
Silver/Dec/3/A	-.086	.036	N	-		
Silver/Dec/1/B	-1.89	.547	N	-		
Silver/Dec/2/B	-.083	.093	N	+		
Silver/Dec/3/B	-.104	.054	N	-		
Silver/Dec/1/C	-1.96	.540	N	-		
Silver/Dec/2/C	-.005	.105	N	+		
Silver/Dec/3/C	-.105	.120	N	+		
Rusch/Dec/1/A	-.020	.005	N	-		
Rusch/Dec/2/A	-.054	.079	N	+		
Rusch/Dec/3/A	-.097	-.019	Y	-	y=0.616-0.058d	0.843
Rusch/Dec/1/B	-.014	.033	N	-		
Rusch/Dec/2/B	-.042	.018	N	-		
Rusch/Dec/3/B	-2.41	1.69	N	-		
Rusch/Dec/1/C	-.061	.011	N	-		
Rusch/Dec/2/C	-.039	.059	N	+		
Rusch/Dec/3/C	-1.60	.723	N	-		

Table 5.11. (cont'd.)

Site/Date/ Transect/ Horizon	Lower bound of 95% conf. interval for regression equation slope	Upper bound of 95% conf. interval for regression equation slope	Significant (non-zero) slope?	Slope positive (+) negative (-) slope)	Regression equation (if significant	R^2
US31/Mar/1/A	-.052	.012	N	-		
US31/Mar/2/A	-.147	.017	N	-		
US31/Mar/3/A	-.258	.048	N	-		
US31/Mar/1/B	-1.88	.528	N	-		
US31/Mar/2/B	-1.11	.627	N	-		
US31/Mar/3/B	-.105	-.025	Y	-	y = 0.71 - 0.065	.865
US31/Mar/1/C	-.093	.003	N	-		
US31/Mar/2/C	-.067	.007	N	-		
US31/Mar/3/C	-1.07	.505	N	-		
US31/Mar/3/C	-1.07	.505	N	-		
M37/Mar/1/A	-1.36	1.09	N	-		
M37/Mar/2/A	-1.15	.903	N	-		
M37/Mar/3/A	-.552	.932	N	+		
M37/Mar/1/B	-.421	.571	N	+		
M37/Mar/2/B	-.595	.365	N	-		
M37/Mar/3/B	-.212	.772	N	+		
M37/Mar/1/C	-.636	.366	N	-		
M37/Mar/2/C	-.510	.930	N	+		
M37/Mar/3/C	-.102	.242	N	+		
Silver/Mar/1/A	-.846	.386	N	-		
Silver/Mar/2/A	-.557	.217	N	-		
Silver/Mar/3/A	-.562	.342	N	-		
Silver/Mar/1/B	-.559	.229	N	-		
Silver/Mar/2/B	-.256	.106	N	-		

Table 5.11. (cont'd.)

Site/Date/ Transect/ Horizon	Lower bound of 95% conf. interval for regression equation slope	Upper bound of 95% conf. interval for regression equation slope	Significant (non-zero) slope?	Slope positive (+) negative (-) slope)	Regression equation (if significant	R^2
Silver/Mar/3/B	0.00	0.00	N	-		
Silver/Mar/1/C	-.045	.015	N	-		
Silver/Mar/2/C	-.113	.033	N	-		
Silver/Mar/3/C	-.270	.140	N	-		
Rusch/Mar/1/A	-.036	.016	N	-		
Rusch/Mar/2/A	-.108	.138	N	+		
Rusch/Mar/3/A	-.127	.077	N	-		
Rusch/Mar/1/B	-.035	.045	N	+		
Rusch/Mar/2/B	-.057	.017	N	-		
Rusch/Mar/3/B	-2.72	2.72	N	-		
Rusch/Mar/1/C	-.085	.025	N	-		
Rusch/Mar/2/C	-.798	.538	N	-		
Rusch/Mar/3/C	-6.47	4.38	N	-		

*Using linear regression for the SARs in each horizon for a given transect, the upper and lower bounds of the confidence interval of the slope was determined. If the confidence interval included zero, then a nonsignificant slope exists, indicating SAR is changing little as distance from the roadway increases. If the confidence interval did not include zero than a significant non-zero slope exists, indicating SAR is either increasing or decreasing as distance from the roadway increases.

increases (Table 5.11). None of the transects had a significant increase in SAR with distance.

In September, a significant negative slope existed for 3 of the 36 transects (Table 5.11). All of the transects were located at the M37 site in either the A or B horizon (Table 5.12). The decrease in SAR values as distance from the roadway increases in the A horizon (M37/Sept/1) were (1.3 mmol/L - 0.2 mmol/L) comparable to the reduction in B horizon (M37/Sept/1 and M37/Sept/2) SAR values (2.5 mmol/L - 0.4 mmol/L and 2.3 mmol/L - 0.8 mmol/L).

Table 5.12. Difference between SAR values as distance from the roadway increases.

Month	Site/transect/ horizon	SAR value* (mmol/L) at the first and last boring in a given transect. Distance from road		Difference in SAR between the first boring and the last boring.**
		2 m	10 m	
September	M37/1/A	1.3	0.2	1.1
	M37/1/B	2.5	0.4	2.1
	M37/2/B	2.3	0.8	1.5
December	US31/3/A	0.6	0.2	0.4
	Silver/1/A	3.2	0.1	3.1
	Rusch/3/A	0.5	0.1	0.4
	US31/1/B	10.6	0.1	10.5
March	US31/3/B	0.6	0.1	0.5

* SAR values were calculated using Na, Ca, and Mg concentration in mmol/L.
** The difference between borings were derived by subtracting the SAR value at the 10 m boring from the SAR value at the 2 m boring.

In December, a significant negative slope existed for 4 of the 36 transects (Table 5.11). Three (US31/3, Silver/1, and Rusch/3)(Table 5.12) of the four transects are from A horizon data. The fourth transect (US31/1) is from the B horizon data, and shows a large decrease (10.6 mmol/L - 0.10 mmol/L) in SAR as distance from the road increases.

In March, only one of the 36 transects had a significant negative slope Table 5.11). The transect is from US31 B horizon data (Table 5.12). The change in SAR as distance from the roadway increases (0.6 mmol/L - 0.1 mmol/L) at the site (US31/Mar/3) is small.

There may be correlation in the location (A, B, and C horizons) where the trends in SAR were found (Table 5.12). Five of the eight transects that show SAR decreasing as the distance from the roadway increases are within the A horizon. The A horizon is the upper portion of the soil, making it more susceptible to events occurring at the surface. Melting snow and salt spray from passing vehicles contribute sodium to the soil solution, which infiltrates vertically through the A horizon. Because the source of sodium is the roadway, SAR values should be high near the road and decrease as the distance from the road increases. The remaining four transects were for the B horizon, and could be due to the eluviation of sodium from the upper A horizon. The lack of significant negative slopes for C horizon data may be due to preferential vertical flowpaths and high soil permeabilities that allow dissolved salt in water to move quickly to the lower horizons.

Although only 8 of 108 SAR values in a given transect had significant negative slopes, most of the best-fit regression lines also have negative slopes. These data indicate that SAR *is* slightly higher near the roadway and decreases as distance increases, but that the change is usually not dramatic.

The pile-up of snow adjacent to the roadway, roadway run-off, and salt spray from passing vehicles moves salt laterally for great distances from the road (Frazio, 1994). Based on the lack of strong trends in SAR with distance from the roadway, the dispersion of sodium is not even and continuous but dependent on preferential vertical flow paths within the soil profile that may redirect salt-laden melt water and rain. In addition, the soil sample composition may not be the same in each sample, due to bucket auger sampling, which may lead to greater variability in SARs values within a given transect. Better trends in SAR values with distance may have been apparent if the length of the transects had been extended from 10 m to 20-25 m from the road.

Control data

In March, extra samples were taken at each site to ensure sodium measured in the soils during the study originated from sodium chloride crystals used to de-ice the roadway rather than from mineral weathering. Soil samples were taken from the A, B, and C horizons approximately 35 m from the road at each site. SARs and sodium concentrations were extremely low, 0.0 ppm to 0.2 ppm, at each site in each horizon (Table 5.13) which strongly supports deicing salt *is* the source of sodium in these roadside soils.

Table 5.13. Control soil sample SARs (mmol/L) and sodium concentrations (mmol/L) taken in March

Site/horizon	sodium*	SAR*
M37/A	0.0	0.0
M37/B	0.0	0.0
M37/C	0.0	0.1
US31/A	0.0	0.0
US31/B	0.0	0.0
US31/C	0.0	0.0
Silver Lake/A	0.0	0.0
Silver Lake/B	0.1	0.0
Silver Lake/C	0.1	0.1
Rusch/A	0.0	0.1
Rusch/B	0.1	0.2
Rusch/C	0.1	0.2

*Sodium concentrations of the soil filtrate were measured by an atomic absorption spectrometer (AA) in mg/L and converted to mmol/L. Sodium concentrations (Table 5.9) were extremely low at all of the sampling locations, therefore, deicing salt is the apparent source of sodium in the soils.

Sodic problems in Grand Traverse County

Regardless of the location, salt application rate, or time of year, SAR and sodium concentrations were low in soils sampled in Grand Traverse County. Sodium becomes problematic in soils when the SAR values exceed 13 mmol/L (Szaboks, 1989). At the M37 site in December two samples exceeded 13 mmol/L Na^+ (Table 5.14). At the Rusch Road site in March, one sample exceeded 13 mmol/L Na^+. All of the above samples were from the C horizon, indicating sodium may be moving through the soils but is not accumulating in the upper horizons. Although, no soil, vegetative, or cracking was visible at each of the three sites.

Table 5.14. Sites with SAR values that exceeded 13 mmol/L*

Site/date/transect/boring/horizon	SAR
M37/Dec/2/3/C	17.2
M37/Dec/3/1/C	16.0
Rusch/Mar/3/2/C	22.7

* SAR values were calculated using the concentrations of Na, Ca, and Mg.

Conclusions

Abundant snow and ice during winter months forces the Grand Traverse Road Commission to apply heavy amounts of sodium chloride to roadways. Cold air passing over the warm waters of Lake Michigan may drop several feet of lake-effect snow on the county in one short winter storm. The County Road Commission has used NaCl to remove snow and ice from the roadways for approximately 32 years. Long-term use of NaCl as a deicing agent, if it accumulates in soils, has potential negative effects, such as altering soil structure by deflocculating clay particles, reducing porosity and permeability, and depleting soils of macronutrients. Clayey and organic-rich soils can adsorb more sodium cations than sandy or sandy loam soils, due to the plate-like structure and high number of adsorption sites located on the surfaces of clay and organic colloids.

The sampling period was marked by heavy amounts of precipitation, both rain and snow, combined with above normal temperatures. In early winter, intermittent snow, ice, and rain resulted in periodic melting and freezing episodes. Total winter snowfall was 285 cm above normal, which quickly melted in late March.

Three of the four sampling sites used in this study had different salt application rates. Sites undergoing high rates of salt application also had high SAR values and sodium concentrations in December. US31 and M37 received high rates of deicing salt and had the highest SAR values and sodium concentrations in December. The US31 site is composed of sand textured soils that have little or no organic matter, higher permeabilities, and lower CECs than do those with sandy loam textures which compose the M37 site. Differing soil textures may explain why SAR values and sodium concentrations are low in

September and March at the US31 site but remain high at the M37 site throughout the sampling period.

Sites that received medium and low amounts of sodium did have intermediate SAR values and sodium concentrations in December but not in September or March. The Rusch Road site received the lowest amount of sodium but had higher SAR values and sodium concentrations than US31 and Silver Lake in September and March. The Silver Lake site received medium amounts of salt but had the lowest SAR values and sodium concentrations in September and March. The Silver Lake site is composed of sandy soils where sodium cations remain in the soil solution due to the sparse number of negatively charged adsorption sites, resulting in a low SAR. Sandy loam soils, compose the Rusch Road site, have clay lenses with more organic matter, lower permeabilities, and higher CECs than do sand soils. Therefore, I conclude that sandy loam soils at the sites in this study are more likely to adsorb sodium cations, increasing SAR.

Evaluation of the soil chemistry of the A, B, and C horizons of each boring in a given transect indicates that Na^+ is not being concentrated in the A horizon. In September and December none of the transects show any clear trends in SAR with depth. In September and December, sodium was comparatively concentrated in the B horizon possibly due to eluviation of Na^+ from overlying A and E horizons. In December, large spikes or increases in SAR from one boring to the next on the bar graphs depict preferential vertical movement of water and Na^+ through the horizons and possible variability in soil sample composition at each site. In March, the third transect at the M37 site depicted SAR values decreasing with depth from the A horizon to the C horizon (A>B>C). Sodium may have been temporarily concentrated in the A horizon due to the recent melting of salt-laden snow at the surface. The remaining transects in March depict low sodium concentrations in the A horizon and higher Na^+ values in the B and C horizons. This trend may have been caused by rapid melting of snow and rainfall that probably flushed Na^+ to the lower horizons.

When initial wintertime salting occurred, in December, the total mean SAR values and sodium concentrations of roadside soils rises. Thus, December SAR values were higher than they are for September, indicating the adsorption of Na^+ cations is dependent on the season. SAR values at M37 increased in March while the sodium concentration decreased, indicating Ca^{2+} and Mg^{2+} cations are being flushed by rain and meltwater, from the soils, more easily than Na^+ cations. A marked reduction in total mean SAR values from December to March at US31, Silver Lake, and Rusch Road sites may be caused by rain and rapid melting of salt-laden snow that can flush sodium quickly through sandy soils. Eventually, spring and summer rains flush most of the sodium through the soils reducing SAR values and sodium concentrations, resulting in low late-summer values.

SAR values of each horizon in a given transect do not support any trends in SAR with distance from the road, possibly due to the short length of the sampling transects and lack of conformity between soil sample depth and location at each site. Only 8 transects depict trends whereby SAR decreases with distance from the road, while the remaining 100 transects did not show any statistically significant trends in SAR with distance. Five of the eighth transects represent the A horizon data and show a decrease in SAR with distance from the road. The A horizon represents the upper portion of the soil which makes it susceptible to the application of deicing salt along the roadway, the dispersion of salt to the adjacent soils, and the infiltration of sodium through the soils. The source of salt is the roadway, therefore SAR values should be high near the road and decrease as the distance from the road increases.

The lack of strong trends in SAR with distance from the road indicates that sodium is not dispersed continuously, but dependent on preferential flowpaths within the soil profile that may redirect salt-laden melt water and rain. A lack of consistant sampling depth and locations within each horizon may result in differing soil compositions, altering SAR calculations. Strong trends in SAR with distance from the road may have been observed if the length of the transects had been extended several more meters.

Sodium concentrations in soils some 35 m from the road did not exceed 0.2 ppm, indicating mineral weathering or other sources were not the source of sodium at the remaining sample sites.

Overall, SAR values at the four sampling sites are not currently high enough to cause serious damage to the soils in Grand Traverse County. SAR values must exceed 13 mmol/L, to be considered hazardous to soil structure. In December, three samples, two at M37 and one at Rusch Road, had SAR values greater than 13 mmol/L but were probably a result of intense salting during icy conditions. Because high amounts of sodium are not accumulating in the soils, it is likely that Na^+ is migrating to the groundwater, potentially causing a long-term threat to this resource.

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Appendix I

Cation concentrations (Ca, Mg, and Na) and SAR values for each boring at each site in September, December, and March

September							
M37	calcium	calcium	magnesium	magnesium	sodium	sodium	SAR
sample	mg/L	mmol/L	mg/L	mmol/L	mg/L	mmol/L	mmol/L
11A	123.8	3.1	4.6	0.2	38.4	1.7	1.3
11B	81.7	2	4.3	0.2	60.8	2.6	2.5
11C	25.8	0.6	1.7	0.1	49.6	2.2	3.6
12A	149.3	3.7	8.8	0.4	18.8	0.8	0.6
12B	81.1	2	3.8	0.2	44.8	1.9	1.9
12C	83.1	2.1	4.4	0.2	18.9	0.8	0.8
13A	184.9	4.6	8.2	0.3	16.8	0.7	0.5
13B	90.4	2.3	4.5	0.2	44.8	1.9	1.8
13C	63.3	1.6	3.1	0.1	15.7	0.7	0.7
14A	155.8	3.9	11.1	0.5	12.8	0.6	0.4
14B	62.7	1.6	4.5	0.2	17.9	0.8	0.8
14C	28.1	0.7	2.1	0.1	10.4	0.5	0.7
15A	158.8	4	16	0.7	8.6	0.4	0.2
15B	29	0.7	2.8	0.1	6.4	0.3	0.4
15C	27	0.7	2.3	0.1	5.1	0.2	0.4
21A	163.3	4.1	6.4	0.3	134.4	5.8	4
21B	38.7	1	1.7	0.1	38.4	1.7	2.3
21C	30.5	0.8	2.1	0.1	27.2	1.2	1.8
22A	196.2	4.9	8.7	0.4	10	0.4	0.3
22B	81.3	2	4	0.2	38	1.7	1.6
22C	34.6	0.9	1.8	0.1	10	0.4	0.6
23A	129.1	3.2	7.3	0.3	25.6	1.1	0.8
23B	88.4	2.2	4.5	0.2	41.6	1.8	1.7
23C	41	1	2.1	0.1	13.1	0.6	0.8
24A	164.7	4.1	12.1	0.5	5.8	0.3	0.2
24B	49.3	1.2	2.7	0.1	12.2	0.5	0.6
24C	25.4	0.6	1.4	0.1	5.3	0.2	0.4
25A	163	4.1	13.5	0.6	14.8	0.6	0.4
25B	51.3	1.3	5	0.2	15.7	0.7	0.8
25C	136.7	3.4	1	0	9.2	0.4	0.3
31A	161.3	4	6.3	0.3	62.4	2.7	1.9
31B	62.8	1.6	2.6	0.1	46.4	2	2.2
31C	34.2	0.9	2	0.1	28.8	1.3	1.8
32A	191.8	4.8	5.5	0.2	3	0.1	0.1
32B	67.6	1.7	4.5	0.2	67.2	2.9	3
32C	38.7	1	2	0.1	59.2	2.6	3.6
33A	158.9	4	9.4	0.4	28.8	1.3	0.8
33B	82.9	2.1	3.7	0.2	40	1.7	1.7
33C	52.2	1.3	2	0.1	24	1	1.3
34A	113.6	2.8	7.1	0.3	15.6	0.7	0.5
34B	74.9	1.9	4.5	0.2	27.2	1.2	1.2
34C	23.7	0.6	0.2	0	4.6	0.2	0.4
35A	104.4	2.6	8.9	0.4	3.6	0.2	0.1
35B	61.3	1.5	6.1	0.3	24	1	1.1
35C	35	0.9	2.9	0.1	3.3	0.1	0.2

Appendix I.1. Calcium, magnesium, and sodium concentrations in mg/L measured by atomic absorption then converted to mmol/L.

September							
US31	calcium	calcium	magnesium	magnesium	sodium	sodium	SAR
sample ID	mg/L	mmol/L	mg/L	mmol/L	mg/L	mmol/L	mmol/L
11A	102.7	2.6	3.8	0.2	30.4	1.3	1.1
11B	71.1	1.8	2.9	0.1	4.8	0.2	0.2
11C	19.4	0.5	1.0	0.0	12.3	0.5	1.0
12A	107.6	2.7	4.0	0.2	8.6	0.4	0.3
12B	61.7	1.5	2.3	0.1	17.0	0.7	0.8
12C	29.7	0.7	1.1	0.0	13.3	0.6	0.9
13A	132.2	3.3	9.4	0.4	9.3	0.4	0.3
13B	79.3	2.0	3.7	0.2	12.7	0.6	0.5
13C	38.4	1.0	1.8	0.1	6.6	0.3	0.4
14A	113.6	2.8	10.4	0.4	1.6	0.1	0.1
14B	59.9	1.5	3.5	0.1	10.5	0.5	0.5
14C	17.5	0.4	1.6	0.1	2.7	0.1	0.2
15A	110.5	2.8	8.3	0.3	0.8	0.0	0.0
15B	61.2	1.5	3.6	0.1	1.3	0.1	0.1
15C	9.8	0.2	0.5	0.0	6.8	0.3	0.8
21A	80.7	2.0	2.8	0.1	35.2	1.5	1.5
21B	81.2	2.0	2.5	0.1	44.8	1.9	1.9
21C	52.3	1.3	1.6	0.1	52.8	2.3	2.8
22A	62.4	1.6	3.2	0.1	3.1	0.1	0.1
22B	82.2	2.1	2.9	0.1	17.6	0.8	0.7
22C	27.4	0.7	1.3	0.1	8.9	0.4	0.6
23A	85.3	2.1	3.4	0.1	1.9	0.1	0.1
23B	89.4	2.2	3.3	0.1	9.3	0.4	0.4
23C	25.7	0.6	0.9	0.0	7.6	0.3	0.6
24A	90.2	2.3	3.6	0.1	0.8	0.0	0.0
24B	55.3	1.4	1.2	0.0	2.7	0.1	0.1
24C	23.0	0.6	0.6	0.0	1.6	0.1	0.1
25A	299.5	7.5	5.1	0.2	0.7	0.0	0.0
25B	193.0	4.8	3.0	0.1	2.5	0.1	0.1
25C	16.9	0.4	0.3	0.0	0.6	0.0	0.1
31A	250.0	6.2	3.9	0.2	3.4	0.1	0.1
31B	132.7	3.3	1.2	0.0	3.3	0.1	0.1
31C	100.7	2.5	3.7	0.2	3.2	0.1	0.1
32A	96.9	2.4	4.4	0.2	9.4	0.4	0.4
32B	113.4	2.8	2.9	0.1	32.0	1.4	1.1
32C	23.3	0.6	0.7	0.0	8.5	0.4	0.7
33A	100.9	2.5	4.6	0.2	1.6	0.1	0.1
33B	87.6	2.2	3.3	0.1	2.8	0.1	0.1
33C	27.1	0.7	1.3	0.1	5.8	0.3	0.4
34A	87.2	2.2	3.5	0.1	1.0	0.0	0.0
34B	107.9	2.7	3.9	0.2	3.7	0.2	0.1
34C	18.4	0.5	0.9	0.0	2.1	0.1	0.2
35A	113.0	2.8	5.0	0.2	1.9	0.1	0.1
35B	97.1	2.4	3.2	0.1	1.7	0.1	0.1
35C	43.2	1.1	1.2	0.0	4.5	0.2	0.3

Appendix I.2. Calcium, magnesium, and sodium concentrations in mg/L measured by atomic absorption then converted to mmol/L.

September							
Silver Lake	calcium	calcium	magnesium	magnesium	sodium	sodium	SAR
sample ID	mg/L	mmol/L	mg/L	mmol/L	mg/L	mmol/L	mmol/L
11A	226.0	5.6	8.2	0.3	1.9	0.1	0.0
11B	129.7	3.2	4.6	0.2	4.1	0.2	0.1
11C	36.6	0.9	1.4	0.1	1.5	0.1	0.1
12A	226.0	5.6	9.0	0.4	5.6	0.2	0.1
12B	60.3	1.5	2.6	0.1	9.6	0.4	0.5
12C	25.6	0.6	1.5	0.1	3.7	0.2	0.3
13A	107.8	2.7	9.4	0.4	1.1	0.0	0.0
13B	38.6	1.0	2.6	0.1	16.0	0.7	1.0
13C	15.3	0.4	1.2	0.0	6.3	0.3	0.6
14A	111.4	2.8	13.1	0.5	4.6	0.2	0.2
14B	200.7	5.0	14.8	0.6	3.9	0.2	0.1
14C	128.1	3.2	3.4	0.1	0.8	0.0	0.0
15A	131.7	3.3	15.2	0.6	1.8	0.1	0.1
15B	43.6	1.1	4.6	0.2	8.3	0.4	0.5
15C	36.0	0.9	3.7	0.2	0.9	0.0	0.1
21A	287.8	7.2	8.3	0.3	0.9	0.0	0.0
21B	47.8	1.2	3.0	0.1	1.2	0.1	0.1
21C	36.5	0.9	1.3	0.1	0.9	0.0	0.1
22A	162.4	4.1	7.8	0.3	3.6	0.2	0.1
22B	63.7	1.6	2.8	0.1	6.8	0.3	0.3
22C	126.0	3.1	3.6	0.1	6.9	0.3	0.2
23A	112.1	2.8	16.4	0.7	5.3	0.2	0.2
23B	33.3	0.8	2.9	0.1	10.1	0.4	0.6
23C	141.7	3.5	8.1	0.3	12.0	0.5	0.4
24A	129.0	3.2	14.5	0.6	3.3	0.1	0.1
24B	51.0	1.3	5.4	0.2	6.5	0.3	0.3
24C	39.8	1.0	3.8	0.2	11.3	0.5	0.6
25A	108.6	2.7	12.7	0.5	1.2	0.1	0.0
25B	46.5	1.2	2.3	0.1	2.3	0.1	0.1
25C	19.8	0.5	1.9	0.1	0.7	0.0	0.1
31A	397.7	9.9	11.7	0.5	2.9	0.1	0.1
31B	65.2	1.6	2.6	0.1	1.8	0.1	0.1
31C	24.6	0.6	1.0	0.0	0.7	0.0	0.1
32A	128.4	3.2	6.0	0.2	5.5	0.2	0.2
32B	100.6	2.5	7.8	0.3	13.1	0.6	0.5
32C	38.2	1.0	3.2	0.1	2.6	0.1	0.2
33A	129.9	3.2	14.8	0.6	0.6	0.0	0.0
33B	60.4	1.5	3.8	0.2	5.9	0.3	0.3
33C	41.1	1.0	4.2	0.2	1.6	0.1	0.1
34A	125.7	3.1	16.1	0.7	4.3	0.2	0.1
34B	81.1	2.0	7.3	0.3	3.8	0.2	0.2
34C	21.9	0.5	2.1	0.1	0.8	0.0	0.1
35A	92.1	2.3	10.4	0.4	1.6	0.1	0.1
35B	45.4	1.1	3.3	0.1	1.5	0.1	0.1
35C	15.1	0.4	1.2	0.0	10.4	0.5	1.0

Appendix I.3. Calcium, magnesium, and sodium concentrations in mg/L measured by atomic absorption then converted to mmol/L.

September							
Rusch	calcium	calcium	magnesium	magnesium	sodium	sodium	SAR
sample ID	mg/L	mmol/L	mg/L	mmol/L	mg/L	mmol/L	mmol/L
11A	146.20	3.60	6.50	0.30	15.50	0.70	0.50
11B	62.50	1.60	3.10	0.10	6.00	0.30	0.30
11C	25.00	0.60	1.70	0.10	8.30	0.40	0.60
12A	182.20	4.50	10.60	0.40	41.60	1.80	1.10
12B	39.10	1.00	1.90	0.10	25.60	1.10	1.50
12C	17.50	0.40	1.00	0.00	9.80	0.40	0.90
13A	275.60	6.90	13.90	0.60	5.00	0.20	0.10
13B	76.90	1.90	3.80	0.20	38.40	1.70	1.60
13C	30.10	0.80	1.60	0.10	28.80	1.30	2.00
14A	146.30	3.70	10.50	0.40	7.50	0.30	0.20
14B	49.00	1.20	0.60	0.00	8.00	0.30	0.40
14C	21.90	0.50	2.00	0.10	4.10	0.20	0.30
15A	107.70	2.70	7.80	0.30	3.30	0.10	0.10
15B	54.90	1.40	8.30	0.30	3.70	0.20	0.20
15C	45.50	1.10	9.00	0.40	3.20	0.10	0.20
21A	517.70	12.90	19.20	0.80	3.40	0.10	0.10
21B	138.30	3.50	2.50	0.10	42.60	1.90	1.40
21C	25.00	0.60	1.50	0.10	2.60	0.10	0.20
22A	256.70	6.40	10.90	0.40	1.90	0.10	0.00
22B	77.70	1.90	3.00	0.10	28.80	1.30	1.20
22C	34.50	0.90	1.30	0.10	10.10	0.40	0.60
23A	142.30	3.60	9.80	0.40	24.00	1.00	0.70
23B	36.80	0.90	1.60	0.10	36.80	1.60	2.30
23C	22.70	0.60	1.90	0.10	27.20	1.20	2.10
24A	98.50	2.50	9.20	0.40	2.60	0.10	0.10
24B	60.20	1.50	5.80	0.20	13.30	0.60	0.60
24C	90.30	2.30	18.60	0.80	4.40	0.20	0.20
25A	310.20	7.70	18.80	0.80	3.10	0.10	0.10
25B	140.30	3.50	27.70	1.10	4.70	0.20	0.10
25C	79.50	2.00	8.40	0.30	6.80	0.30	0.30
31A	353.90	8.80	14.00	0.60	2.80	0.10	0.10
31B	51.00	1.30	1.80	0.10	81.60	3.50	4.30
31C	24.50	0.60	1.00	0.00	20.80	0.90	1.60
32A	311.30	7.80	13.20	0.50	28.80	1.30	0.60
32B	41.10	1.00	2.20	0.10	22.40	1.00	1.30
32C	27.10	0.70	1.70	0.10	9.00	0.40	0.60
33A	189.10	4.70	11.20	0.50	3.60	0.20	0.10
33B	70.90	1.80	4.60	0.20	13.60	0.60	0.60
33C	36.10	0.90	2.00	0.10	15.80	0.70	1.00
34A	134.40	3.40	9.50	0.40	1.80	0.10	0.10
34B	65.20	1.60	5.10	0.20	2.60	0.10	0.10
34C	38.60	1.00	3.30	0.10	3.90	0.20	0.20
35A	100.60	2.50	10.70	0.40	1.30	0.10	0.00
35B	64.00	1.60	7.60	0.30	3.40	0.10	0.20
35C	18.60	0.50	2.50	0.10	0.90	0.00	0.10

Appendix I.4. Calcium, magnesium, and sodium concentrations in mg/L measured by atomic absorption then converted to mmol/L.

December							
M37	calcium	calcium	magnesium	magnesium	sodium	sodium	SAR
sample ID	mg/L	mmol/L	mg/L	mmol/L	mg/L	mmol/L	mmol/L
11A	102.80	2.60	9.50	0.40	256.60	11.50	9.50
11B	146.20	3.60	11.90	0.50	14.50	0.60	0.40
11C	48.00	1.20	7.80	0.30	224.00	9.70	11.20
12A	64.40	1.60	8.80	0.40	5.20	0.20	0.20
12B	121.70	3.00	13.70	0.60	241.60	10.50	7.80
12C	59.70	1.50	4.40	0.20	13.50	0.60	0.60
13A	52.00	1.30	15.00	0.60	5.00	0.20	0.20
13B	101.20	2.50	4.60	0.20	10.40	0.50	0.40
13C	42.50	1.10	2.30	0.10	5.00	0.20	0.30
14A	69.70	1.70	14.80	0.60	1.00	0.00	0.00
14B	85.80	2.10	8.10	0.30	7.60	0.30	0.30
14C	30.10	0.80	2.80	0.10	4.30	0.20	0.30
15A	74.00	1.80	18.70	0.80	0.80	0.00	0.00
15B	73.40	1.80	10.70	0.40	1.80	0.10	0.10
15C	45.30	1.10	5.40	0.20	3.20	0.10	0.20
21A	132.40	3.30	7.90	0.30	211.20	9.20	6.80
21B	100.10	2.50	21.80	0.90	299.20	13.00	10.00
21C	30.20	0.80	2.20	0.10	15.50	0.70	1.00
22A	98.80	2.50	21.00	0.90	16.70	0.70	0.60
22B	38.00	0.90	12.00	0.50	209.60	9.10	10.70
22C	80.40	2.00	5.10	0.20	4.80	0.20	0.20
23A	100.40	2.50	16.90	0.70	203.20	8.80	7.00
23B	106.30	2.70	5.90	0.20	15.80	0.70	0.60
23C	69.20	1.70	3.90	0.20	384.00	16.70	17.20
24A	62.00	1.50	13.80	0.60	2.90	0.10	0.10
24B	126.10	3.10	9.50	0.40	2.90	0.10	0.10
24C	57.30	1.40	5.20	0.20	15.70	0.70	0.80
25A	70.40	1.80	17.10	0.70	1.00	0.00	0.00
25B	78.50	2.00	8.30	0.30	2.40	0.10	0.10
25C	77.10	1.90	10.10	0.40	4.80	0.20	0.20
31A	90.80	2.30	7.30	0.30	27.00	1.20	1.00
31B	63.10	1.60	5.70	0.20	16.50	0.70	0.80
31C	48.60	1.20	14.40	0.60	348.80	15.20	16.00
32A	123.60	3.10	21.60	0.90	249.60	10.90	7.70
32B	100.40	2.50	9.40	0.40	2.20	0.10	0.10
32C	59.90	1.50	3.30	0.10	0.90	0.00	0.00
33A	112.40	2.80	27.40	1.10	4.70	0.20	0.10
33B	80.40	2.00	10.80	0.40	10.30	0.40	0.40
33C	109.50	2.70	6.90	0.30	254.40	11.10	9.00
34A	127.70	3.20	11.70	0.50	1.00	0.00	0.00
34B	124.40	3.10	12.30	0.50	3.30	0.10	0.10
34C	108.60	2.70	9.50	0.40	220.80	9.60	7.70
35A	110.10	2.70	26.60	1.10	1.90	0.10	0.10
35B	97.90	2.40	16.60	0.70	3.30	0.10	0.10
35C	55.30	1.40	7.60	0.30	3.20	0.10	0.20

Appendix I.5. Calcium, magnesium, and sodium concentrations in mg/L measured by atomic absorption then converted to mmol/L.

December							
US31	calcium	calcium	magnesium	magnesium	sodium	sodium	SAR
sample ID	mg/L	mmol/L	mg/L	mmol/L	mg/L	mmol/L	mmol/L
11A	33.60	0.80	17.60	0.70	211.20	9.20	10.40
11B	82.40	2.10	5.30	0.20	260.80	11.30	10.60
11C	52.10	1.30	1.90	0.10	6.50	0.30	0.30
12A	99.60	2.50	3.60	0.10	17.40	0.80	0.70
12B	117.90	2.90	3.60	0.10	176.00	7.70	6.20
12C	75.20	1.90	2.20	0.10	5.40	0.20	0.20
13A	114.30	2.90	5.50	0.20	155.20	6.70	5.40
13B	83.30	2.10	4.80	0.20	14.80	0.60	0.60
13C	26.60	0.70	1.20	0.00	7.80	0.30	0.60
14A	89.90	2.20	5.40	0.20	224.00	9.70	8.80
14B	60.00	1.50	3.80	0.20	9.50	0.40	0.50
14C	60.50	1.50	1.70	0.10	3.90	0.20	0.20
15A	105.20	2.60	5.80	0.20	11.60	0.50	0.40
15B	108.70	2.70	5.40	0.20	2.90	0.10	0.10
15C	49.20	1.20	2.40	0.10	1.90	0.10	0.10
21A	132.80	3.30	7.70	0.30	379.20	16.50	12.20
21B	158.00	3.90	16.40	0.70	182.40	7.90	5.20
21C	35.00	0.90	1.40	0.10	4.10	0.20	0.30
22A	79.80	2.00	3.10	0.10	11.10	0.50	0.50
22B	61.80	1.50	2.90	0.10	4.50	0.20	0.20
22C	40.50	1.00	1.60	0.10	13.10	0.60	0.80
23A	80.90	2.00	2.90	0.10	6.60	0.30	0.30
23B	100.70	2.50	4.30	0.20	99.20	4.30	3.70
23C	41.60	1.00	1.90	0.10	6.30	0.30	0.40
24A	74.40	1.90	4.10	0.20	1.20	0.10	0.10
24B	103.70	2.60	5.10	0.20	164.80	7.20	6.10
24C	56.90	1.40	2.40	0.10	11.20	0.50	0.60
25A	100.10	2.50	7.00	0.30	6.80	0.30	0.30
25B	56.50	1.40	3.20	0.10	3.10	0.10	0.20
25C	30.70	0.80	1.50	0.10	1.80	0.10	0.10
31A	129.60	3.20	6.10	0.30	18.00	0.80	0.60
31B	121.60	3.00	4.30	0.20	11.30	0.50	0.40
31C	63.10	1.60	1.50	0.10	8.70	0.40	0.40
32A	42.00	1.00	3.90	0.20	7.20	0.30	0.40
32B	57.50	1.40	2.10	0.10	217.60	9.50	10.80
32C	35.30	0.90	3.10	0.10	0.60	0.00	0.00
33A	82.40	2.10	5.50	0.20	13.10	0.60	0.50
33B	86.00	2.10	3.00	0.10	13.80	0.60	0.60
33C	30.50	0.80	1.00	0.00	5.90	0.30	0.40
34A	105.40	2.60	5.90	0.20	3.50	0.20	0.10
34B	110.50	2.80	4.50	0.20	214.00	9.30	7.70
34C	29.10	0.70	1.00	0.00	3.60	0.20	0.30
35A	108.60	2.70	10.20	0.40	4.50	0.20	0.20
35B	56.30	1.40	3.80	0.20	5.70	0.20	0.30
35C	31.40	0.80	1.90	0.10	2.30	0.10	0.20

Appendix I.6. Calcium, magnesium, and sodium concentrations in mg/L measured by atomic absorption then converted to mmol/L.

December							
Silver Lake	calcium	calcium	magnesium	magnesium	sodium	sodium	SAR
sample ID	mg/L	mmol/L	mg/L	mmol/L	mg/L	mmol/L	mmol/L
11A	132.00	3.30	10.60	0.40	100.80	4.40	3.20
11B	79.20	2.00	4.40	0.20	166.40	7.20	7.00
11C	98.70	2.50	10.20	0.40	200.00	8.70	7.20
12A	101.60	2.50	12.00	0.50	8.80	0.40	0.30
12B	142.30	3.60	7.20	0.30	8.50	0.40	0.30
12C	111.60	2.80	6.20	0.30	10.60	0.50	0.40
13A	42.00	1.00	17.80	0.70	4.50	0.20	0.20
13B	87.20	2.20	7.60	0.30	9.50	0.40	0.40
13C	100.40	2.50	6.00	0.20	6.20	0.30	0.20
14A	112.80	2.80	22.00	0.90	7.80	0.30	0.20
14B	100.60	2.50	7.60	0.30	4.20	0.20	0.20
14C	162.40	4.10	16.70	0.70	8.20	0.40	0.20
15A	112.80	2.80	35.30	1.50	1.80	0.10	0.10
15B	24.40	0.60	29.20	1.20	5.60	0.20	0.30
15C	109.20	2.70	37.50	1.50	8.30	0.40	0.20
21A	128.40	3.20	28.40	1.20	10.40	0.50	0.30
21B	80.40	2.00	15.60	0.60	6.00	0.30	0.20
21C	42.70	1.10	4.80	0.20	2.60	0.10	0.10
22A	60.20	1.50	21.00	0.90	8.20	0.40	0.30
22B	32.40	0.80	18.00	0.70	3.40	0.10	0.20
22C	21.80	0.50	5.60	0.20	1.60	0.10	0.10
23A	144.00	3.60	30.00	1.20	8.60	0.40	0.20
23B	47.20	1.20	3.10	0.10	4.20	0.20	0.20
23C	65.30	1.60	4.90	0.20	1.60	0.10	0.10
24A	97.20	2.40	22.30	0.90	1.50	0.10	0.10
24B	58.00	1.40	4.20	0.20	9.80	0.40	0.50
24C	75.20	1.90	4.70	0.20	7.00	0.30	0.30
25A	48.00	1.20	32.60	1.30	1.20	0.10	0.00
25B	128.10	3.20	7.80	0.30	3.10	0.10	0.10
25C	26.20	0.70	39.20	1.60	13.20	0.60	0.50
31A	142.30	3.60	41.80	1.70	14.80	0.60	0.40
31B	80.60	2.00	10.30	0.40	9.80	0.40	0.40
31C	21.00	0.50	9.70	0.40	7.30	0.30	0.50
32A	114.70	2.90	33.20	1.40	7.10	0.30	0.20
32B	98.20	2.50	16.20	0.70	3.20	0.10	0.10
32C	50.60	1.30	8.30	0.30	1.20	0.10	0.10
33A	139.20	3.50	17.80	0.70	2.10	0.10	0.10
33B	62.50	1.60	5.00	0.20	1.60	0.10	0.10
33C	69.20	1.70	4.00	0.20	6.80	0.30	0.30
34A	132.80	3.30	34.30	1.40	3.50	0.20	0.10
34B	61.00	1.50	4.20	0.20	6.10	0.30	0.30
34C	72.80	1.80	6.60	0.30	3.90	0.20	0.20
35A	148.00	3.70	40.00	1.60	9.50	0.40	0.30
35B	105.60	2.60	12.60	0.50	1.70	0.10	0.10
35C	40.00	1.00	40.40	1.70	14.10	0.60	0.50

Appendix I.7. Calcium, magnesium, and sodium concentrations in mg/L measured by atomic absorption then converted to mmol/L.

December							
Rusch	calcium	calcium	magnesium	magnesium	sodium	sodium	SAR
sample ID	mg/L	mmol/L	mg/L	mmol/L	mg/L	mmol/L	mmol/L
11A	124.00	3.10	7.30	0.30	3.50	0.20	0.10
11B	77.60	1.90	4.80	0.20	2.60	0.10	0.10
11C	55.90	1.40	5.10	0.20	4.70	0.20	0.20
12A	99.30	2.50	6.60	0.30	1.10	0.00	0.00
12B	49.10	1.20	2.90	0.10	1.50	0.10	0.10
12C	32.40	0.80	10.20	0.40	5.70	0.20	0.30
13A	71.50	1.80	6.00	0.20	1.90	0.10	0.10
13B	96.10	2.40	9.20	0.40	3.30	0.10	0.10
13C	40.70	1.00	3.60	0.10	2.00	0.10	0.10
14A	89.10	2.20	7.80	0.30	0.90	0.00	0.00
14B	63.50	1.60	5.90	0.20	1.40	0.10	0.10
14C	35.70	0.90	6.10	0.30	1.70	0.10	0.10
15A	91.50	2.30	6.80	0.30	0.80	0.00	0.00
15B	53.90	1.30	6.00	0.20	1.00	0.00	0.00
15C	32.30	0.80	4.20	0.20	0.80	0.00	0.00
21A	58.80	1.50	9.90	0.40	1.30	0.10	0.10
21B	89.30	2.20	6.00	0.20	4.80	0.20	0.20
21C	37.80	0.90	2.40				

Appendix I.8. Calcium, magnesium, and sodium concentrations in mg/L measured by atomic absorption then converted to mmol/L.

December							
M37	calcium	calcium	magnesium	magnesium	sodium	sodium	SAR
sample ID	mg/L	mmol/L	mg/L	mmol/L	mg/L	mmol/L	mmol/L
11A	102.80	2.60	9.50	0.40	256.60	11.50	9.50
11B	146.20	3.60	11.90	0.50	14.50	0.60	0.40
11C	48.00	1.20	7.80	0.30	224.00	9.70	11.20
12A	64.40	1.60	8.80	0.40	5.20	0.20	0.20
12B	121.70	3.00	13.70	0.60	241.60	10.50	7.80
12C	59.70	1.50	4.40	0.20	13.50	0.60	0.60
13A	52.00	1.30	15.00	0.60	5.00	0.20	0.20
13B	101.20	2.50	4.60	0.20	10.40	0.50	0.40
13C	42.50	1.10	2.30	0.10	5.00	0.20	0.30
14A	69.70	1.70	14.80	0.60	1.00	0.00	0.00
14B	85.80	2.10	8.10	0.30	7.60	0.30	0.30
14C	30.10	0.80	2.80	0.10	4.30	0.20	0.30
15A	74.00	1.80	18.70	0.80	0.80	0.00	0.00
15B	73.40	1.80	10.70	0.40	1.80	0.10	0.10
15C	45.30	1.10	5.40	0.20	3.20	0.10	0.20
21A	132.40	3.30	7.90	0.30	211.20	9.20	6.80
21B	100.10	2.50	21.80	0.90	299.20	13.00	10.00
21C	30.20	0.80	2.20	0.10	15.50	0.70	1.00
22A	98.80	2.50	21.00	0.90	16.70	0.70	0.60
22B	38.00	0.90	12.00	0.50	209.60	9.10	10.70
22C	80.40	2.00	5.10	0.20	4.80	0.20	0.20
23A	100.40	2.50	16.90	0.70	203.20	8.80	7.00
23B	106.30	2.70	5.90	0.20	15.80	0.70	0.60
23C	69.20	1.70	3.90	0.20	384.00	16.70	17.20
24A	62.00	1.50	13.80	0.60	2.90	0.10	0.10
24B	126.10	3.10	9.50	0.40	2.90	0.10	0.10
24C	57.30	1.40	5.20	0.20	15.70	0.70	0.80
25A	70.40	1.80	17.10	0.70	1.00	0.00	0.00
25B	78.50	2.00	8.30	0.30	2.40	0.10	0.10
25C	77.10	1.90	10.10	0.40	4.80	0.20	0.20
31A	90.80	2.30	7.30	0.30	27.00	1.20	1.00
31B	63.10	1.60	5.70	0.20	16.50	0.70	0.80
31C	48.60	1.20	14.40	0.60	348.80	15.20	16.00
32A	123.60	3.10	21.60	0.90	249.60	10.90	7.70
32B	100.40	2.50	9.40	0.40	2.20	0.10	0.10
32C	59.90	1.50	3.30	0.10	0.90	0.00	0.00
33A	112.40	2.80	27.40	1.10	4.70	0.20	0.10
33B	80.40	2.00	10.80	0.40	10.30	0.40	0.40
33C	109.50	2.70	6.90	0.30	254.40	11.10	9.00
34A	127.70	3.20	11.70	0.50	1.00	0.00	0.00
34B	124.40	3.10	12.30	0.50	3.30	0.10	0.10
34C	108.60	2.70	9.50	0.40	220.80	9.60	7.70
35A	110.10	2.70	26.60	1.10	1.90	0.10	0.10
35B	97.90	2.40	16.60	0.70	3.30	0.10	0.10
35C	55.30	1.40	7.60	0.30	3.20	0.10	0.20

Appendix I.9. Calcium, magnesium, and sodium concentrations in mg/L measured in atomic absorption then converted to mmol/L.

March							
US31	calcium	calcium	magnesium	magnesium	sodium	sodium	SAR
sample ID	mg/L	mmol/L	mg/L	mmol/L	mg/L	mmol/L	mmol/L
11A	154.00	3.80	3.20	0.10	7.80	0.30	0.20
11B	50.60	1.30	3.60	0.10	19.40	0.80	1.00
11C	21.60	0.50	0.40	0.00	8.00	0.30	0.70
12A	88.00	2.20	1.20	0.00	6.60	0.30	0.30
12B	68.80	1.70	0.80	0.00	7.60	0.30	0.40
12C	12.20	0.30	0.40	0.00	3.80	0.20	0.40
13A	76.20	1.90	1.20	0.00	4.00	0.20	0.20
13B	36.40	0.90	0.80	0.00	5.00	0.20	0.30
13C	6.20	0.20	0.40	0.00	2.60	0.10	0.40
14A	135.60	3.40	2.80	0.10	3.40	0.10	0.10
14B	6.80	0.20	0.80	0.00	1.80	0.10	0.20
14C	2.20	0.10	0.40	0.00	1.20	0.10	0.30
15A	62.20	1.60	2.00	0.10	1.20	0.10	0.10
15B	9.00	0.20	0.40	0.00	0.60	0.00	0.10
15C	1.40	0.00	0.40	0.00	1.00	0.00	0.30
21A	92.80	2.30	0.80	0.00	15.40	0.70	0.60
21B	143.00	3.60	1.60	0.10	18.60	0.80	0.60
21C	8.80	0.20	0.40	0.00	2.00	0.10	0.30
22A	76.00	1.90	2.00	0.10	3.80	0.20	0.20
22B	63.40	1.60	1.20	0.00	8.00	0.30	0.40
22C	11.40	0.30	0.40	0.00	3.60	0.20	0.40
23A	287.00	7.20	2.00	0.10	1.40	0.10	0.00
23B	153.20	3.80	0.80	0.00	5.20	0.20	0.20
23C	8.40	0.20	0.40	0.00	2.20	0.10	0.30
24A	123.00	3.10	3.20	0.10	1.80	0.10	0.10
24B	127.20	3.20	1.60	0.10	2.80	0.10	0.10
24C	13.40	0.30	1.60	0.10	1.60	0.10	0.20
25A	116.00	2.90	0.80	0.00	1.20	0.10	0.00
25B	68.60	1.70	1.20	0.00	1.40	0.10	0.10
25C	20.20	0.50	0.80	0.00	1.20	0.10	0.10
31A	75.00	1.90	2.40	0.10	16.20	0.70	0.70
31B	178.60	4.50	1.20	0.00	19.60	0.90	0.60
31C	11.60	0.30	0.40	0.00	10.40	0.50	1.20
32A	77.00	1.90	2.40	0.10	1.40	0.10	0.10
32B	57.60	1.40	0.80	0.00	9.00	0.40	0.50
32C	9.60	0.20	0.40	0.00	3.40	0.10	0.40
33A	293.80	7.30	2.40	0.10	2.60	0.10	0.10
33B	225.00	5.60	1.20	0.00	7.60	0.30	0.20
33C	9.00	0.20	0.40	0.00	1.80	0.10	0.20
34A	104.50	2.60	2.40	0.10	3.60	0.20	0.10
34B	146.40	3.70	2.40	0.10	5.20	0.20	0.20
34C	6.80	0.20	0.40	0.00	1.80	0.10	0.30
35A	101.60	2.50	2.80	0.10	2.00	0.10	0.10
35B	50.20	1.30	1.60	0.10	2.00	0.10	0.10
35C	4.80	0.10	0.80	0.00	1.20	0.10	0.20

Appendix I.10. Calcium, magnesium, and sodium concentrations in mg/L measured by atomic absorption then converted to mmol/L.

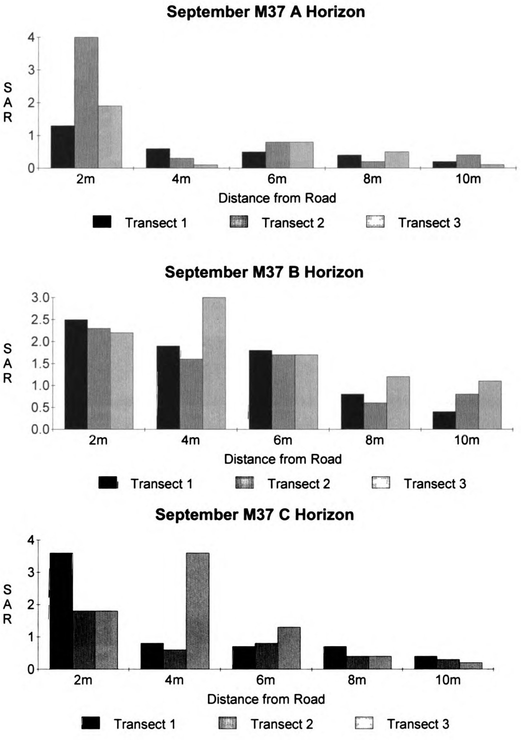
March							
Silver Lake	calcium	calcium	magnesium	magnesium	sodium	sodium	SAR
sample ID	mg/L	mmol/L	mg/L	mmol/L	mg/L	mmol/L	mmol/L
11A	63.80	1.60	2.40	2.60	25.60	1.10	0.80
11B	42.80	1.10	0.80	1.80	20.40	0.90	0.70
11C	280.00	7.00	1.60	11.50	15.00	0.70	0.20
12A	90.20	2.30	4.00	3.70	13.80	0.60	0.30
12B	146.80	3.70	2.00	6.00	7.80	0.30	0.20
12C	200.20	5.00	3.20	8.20	5.20	0.20	0.10
13A	267.00	6.70	4.40	11.00	4.60	0.20	0.10
13B	54.60	1.40	1.60	2.20	1.40	0.10	0.00
13C	129.80	3.20	4.00	5.30	2.40	0.10	0.10
14A	73.90	1.80	3.20	3.00	1.40	0.10	0.00
14B	25.20	0.60	1.20	1.00	1.40	0.10	0.10
14C	136.40	3.40	1.40	5.60	1.00	0.00	0.00
15A	146.80	3.70	3.60	6.00	1.00	0.00	0.00
15B	25.20	0.60	0.80	1.00	1.00	0.00	0.00
15C	5.40	0.10	0.40	0.20	0.80	0.00	0.10
21A	90.20	2.30	2.00	3.70	27.20	1.20	0.70
21B	17.80	0.40	0.80	0.70	7.60	0.30	0.40
21C	14.80	0.40	0.80	0.60	8.80	0.40	0.50
22A	59.40	1.50	3.60	2.40	7.00	0.30	0.20
22B	175.80	4.40	2.40	7.20	5.80	0.30	0.10
22C	13.40	0.30	1.20	0.60	4.20	0.20	0.30
23A	223.60	5.60	4.40	9.20	4.20	0.20	0.10
23B	17.00	0.40	0.80	0.70	1.20	0.10	0.10
23C	49.60	1.20	2.80	2.00	1.60	0.10	0.10
24A	105.00	2.60	4.40	4.30	1.80	0.10	0.00
24B	12.40	0.30	0.80	0.50	1.00	0.00	0.10
24C	10.40	0.30	0.80	0.40	1.20	0.10	0.10
25A	126.00	3.10	4.40	5.20	1.40	0.10	0.00
25B	18.60	0.50	0.80	0.80	1.60	0.10	0.10
25C	4.60	0.10	0.40	0.20	0.60	0.00	0.10
31A	143.00	3.60	3.60	5.90	8.20	0.40	0.20
31B	105.20	2.60	0.80	4.30	5.80	0.30	0.10
31C	164.20	4.10	2.00	6.80	10.80	0.50	0.20
32A	312.80	7.80	3.20	12.90	7.20	0.30	0.10
32B	366.00	9.10	3.20	15.10	7.40	0.30	0.10
32C	134.80	3.40	3.60	5.50	4.80	0.20	0.10
33A	88.00	2.20	3.60	3.60	2.20	0.10	0.10
33B	20.60	0.50	1.20	0.80	2.20	0.10	0.10
33C	7.20	0.20	1.20	0.30	1.20	0.10	0.10
34A	89.00	2.20	3.60	3.70	1.80	0.10	0.00
34B	5.80	0.10	0.80	0.20	1.00	0.00	0.10
34C	6.80	0.20	0.80	0.30	1.20	0.10	0.10
35A	227.60	5.70	4.00	9.40	4.20	0.20	0.10
35B	18.20	0.50	1.20	0.70	1.00	0.00	0.10
35C	100.60	2.50	4.00	4.10	1.60	0.10	0.00

Appendix I.11. Calcium, magnesium, and sodium concentrations in mg/L measured by atomic absorption then converted to mmol/L.

March							
Rusch	calcium	calcium	magnesium	magnesium	sodium	sodium	SAR
sample ID	mg/L	mmol/L	mg/L	mmol/L	mg/L	mmol/L	mmol/L
11A	106.40	2.70	0.60	0.00	3.50	0.20	0.10
11B	79.80	2.00	0.80	0.00	2.60	0.10	0.10
11C	23.60	0.60	0.40	0.00	4.70	0.20	0.40
12A	74.80	1.90	0.80	0.00	1.10	0.00	0.00
12B	38.60	1.00	0.60	0.00	1.50	0.10	0.10
12C	9.60	0.20	0.20	0.00	5.70	0.20	0.70
13A	69.40	1.70	1.20	0.00	1.90	0.10	0.10
13B	51.60	1.30	0.80	0.00	3.30	0.10	0.20
13C	31.00	0.80	0.80	0.00	2.00	0.10	0.10
14A	82.40	2.10	1.20	0.00	0.90	0.00	0.00
14B	46.60	1.20	1.80	0.10	1.40	0.10	0.10
14C	52.80	1.30	1.40	0.10	1.70	0.10	0.10
15A	89.40	2.20	1.80	0.10	0.80	0.00	0.00
15B	29.00	0.70	1.00	0.00	1.00	0.00	0.10
15C	10.20	0.30	0.60	0.00	0.80	0.00	0.10
21A	86.20	2.20	0.60	0.00	1.30	0.10	0.10
21B	36.20	0.90	0.40	0.00	4.80	0.20	0.30
21C	17.00	0.40	0.20	0.00	3.00	0.10	0.30
22A	61.40	1.50	1.00	0.00	0.50	0.00	0.00
22B	24.20	0.60	0.40	0.00	0.80	0.00	0.10
22C	6.60	0.20	0.20	0.00	1.70	0.10	0.30
23A	64.20	1.60	1.40	0.10	0.90	0.00	0.00
23B	53.20	1.30	0.80	0.00	3.50	0.20	0.20
23C	15.00	0.40	0.40	0.00	1.80	0.10	0.20
24A	46.80	1.20	1.40	0.10	8.30	0.40	0.50
24B	68.40	1.70	1.20	0.00	2.10	0.10	0.10
24C	11.40	0.30	0.60	0.00	1.60	0.10	0.00
25A	49.00	1.20	1.00	0.00	0.80	0.00	0.00
25B	55.60	1.40	1.40	0.10	1.30	0.10	0.10
25C	27.60	0.70	0.80	0.00	6.20	0.30	0.40
31A	96.80	2.40	1.80	0.10	13.10	0.60	0.50
31B	57.40	1.40	0.60	0.00	1.10	0.00	0.10
31C	51.60	1.30	0.80	0.00	1.60	0.10	0.10
32A	126.60	3.20	1.60	0.10	10.20	0.40	0.30
32B	31.60	0.80	0.40	0.00	190.40	8.30	13.00
32C	9.60	0.20	0.20	0.00	184.00	8.00	22.70
33A	104.60	2.60	1.80	0.10	8.60	0.40	0.30
33B	40.80	1.00	1.60	0.10	179.20	7.80	10.60
33C	19.60	0.50	0.60	0.00	5.90	0.30	0.50
34A	83.60	2.10	1.00	0.00	1.30	0.10	0.10
34B	68.20	1.70	1.20	0.00	2.90	0.10	0.10
34C	8.00	0.20	0.40	0.00	10.40	0.50	1.40
35A	41.60	1.00	0.80	0.00	2.80	0.10	0.20
35B	20.40	0.50	0.60	0.00	0.90	0.00	0.10
35C	7.80	0.20	0.40	0.00	2.40	0.10	0.30

Appendix I.12. Calcium, magnesium, and sodium concentrations in mg/L measured by atomic absorption then converted to mmol/L.

Appendix II
Bar graphs depicting SAR values in each horizon for each boring at each site in September, December, and March in order to evaluate any trends in SAR with depth

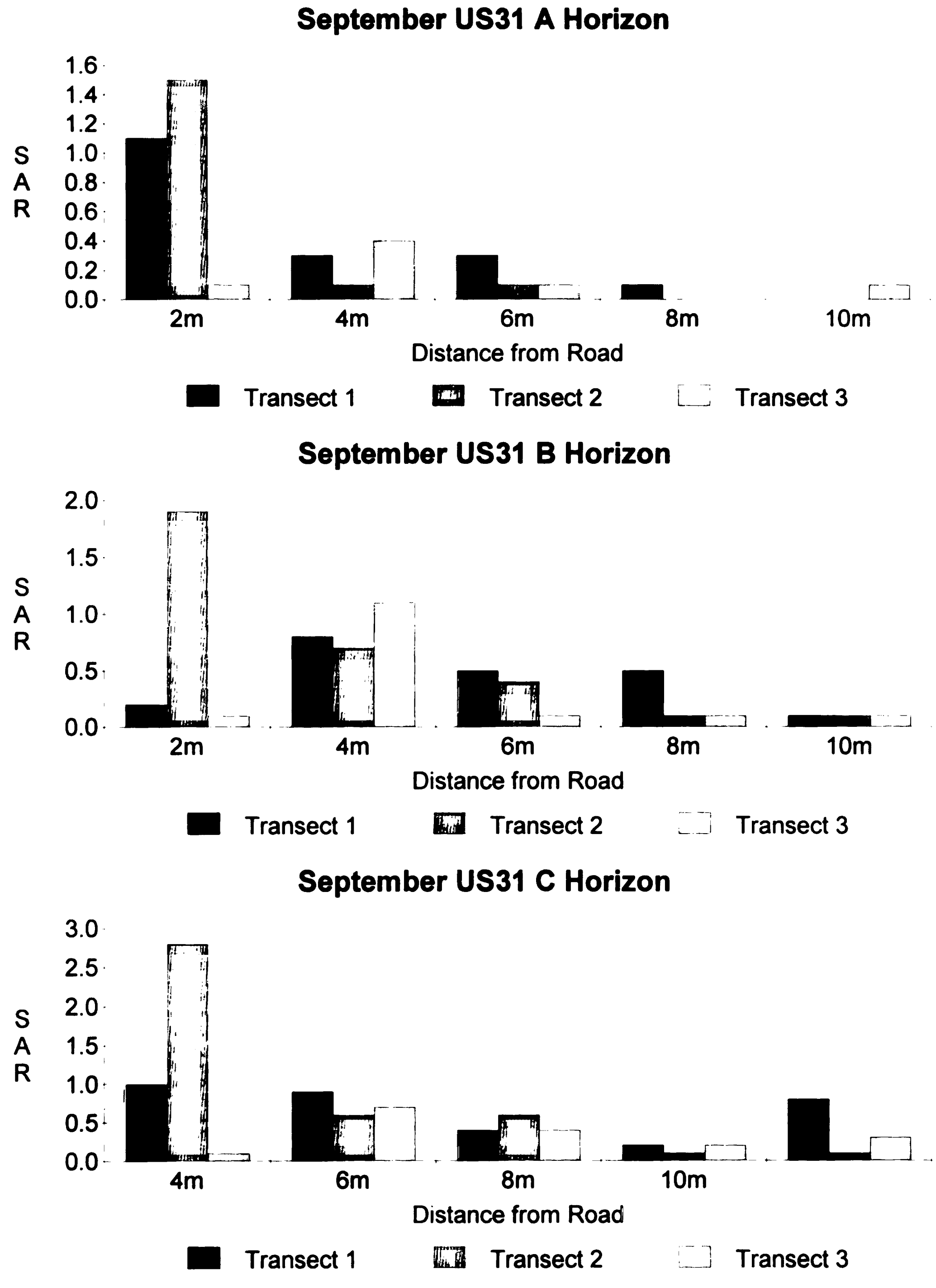


September M37 A Horizon

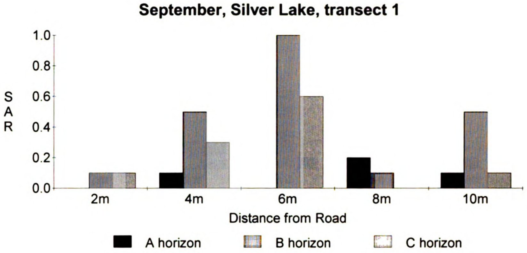
September M37 B Horizon

September M37 C Horizon

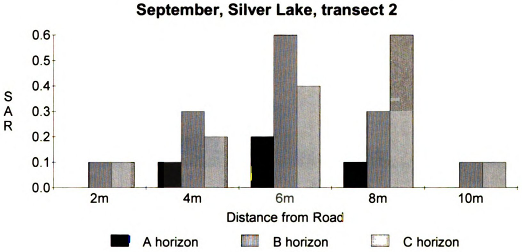
Appendix II.1. Bar graphs depicting SAR values with depth in the A, B, and C soil horizons.



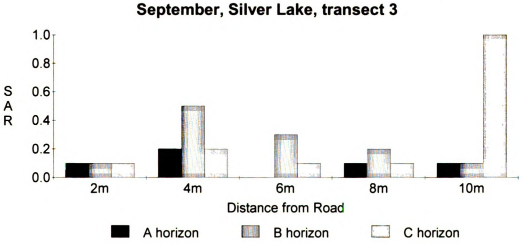
Appendix II.2. Bar graphs depicting SAR values with depth in the A, B, and C soil horizons.



September, Silver Lake, transect 1

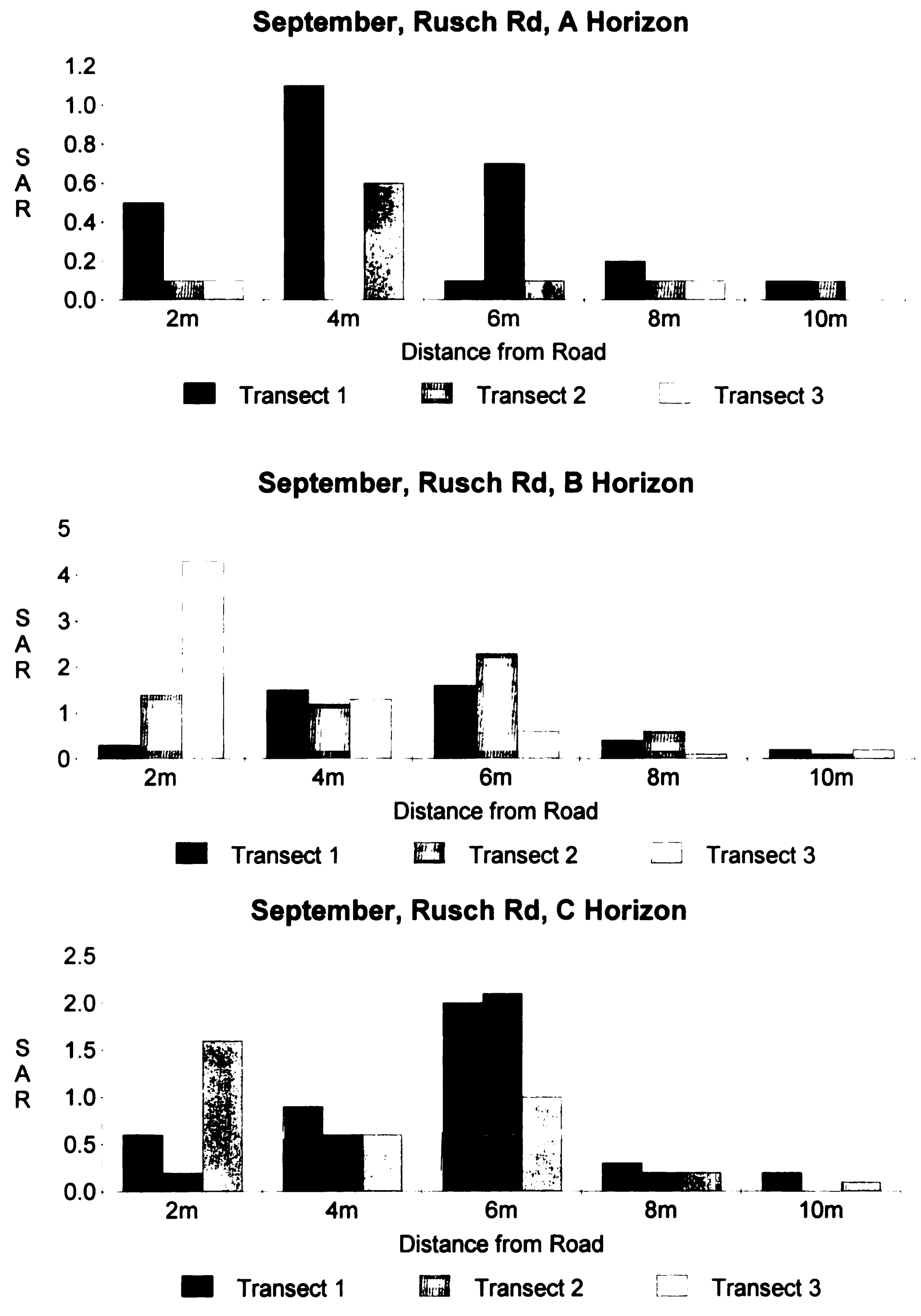


September, Silver Lake, transect 2

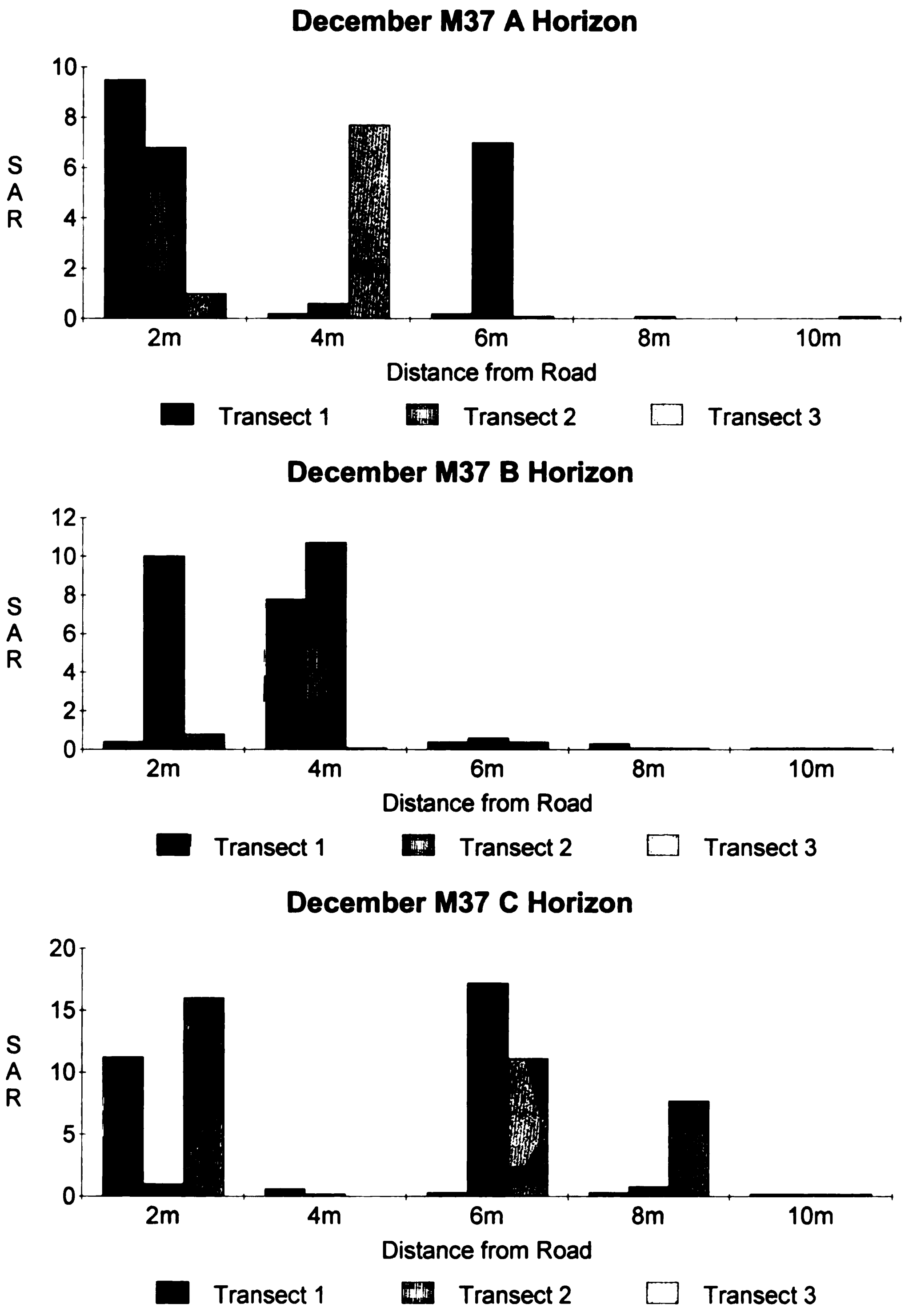


September, Silver Lake, transect 3

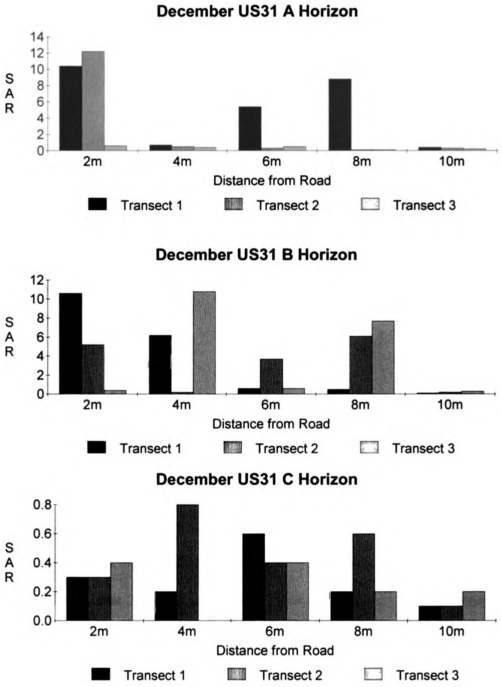
Appendix II.3. Bar graphs depicting SAR values with depth in the A, B, and C soil horizons.



Appendix II.4. Bar graphs depicting SAR values with depth in the A, B, and C soil horizons.

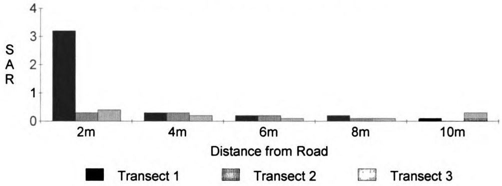


Appendix II.5. Bar graphs depicting SAR values with depth in the A, B, and C soil horizons.

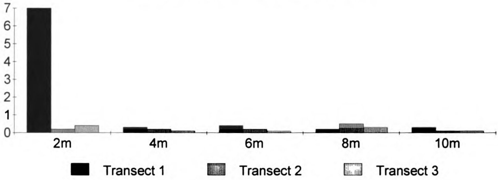


Appendix II.6. Bar graphs depicting SAR values with depth in the A, B, and C soil horizons.

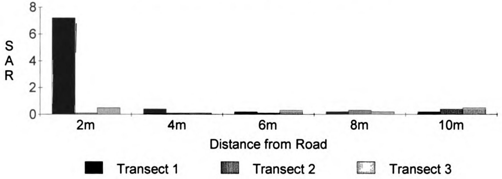
December, Silver Lake, A Horizon



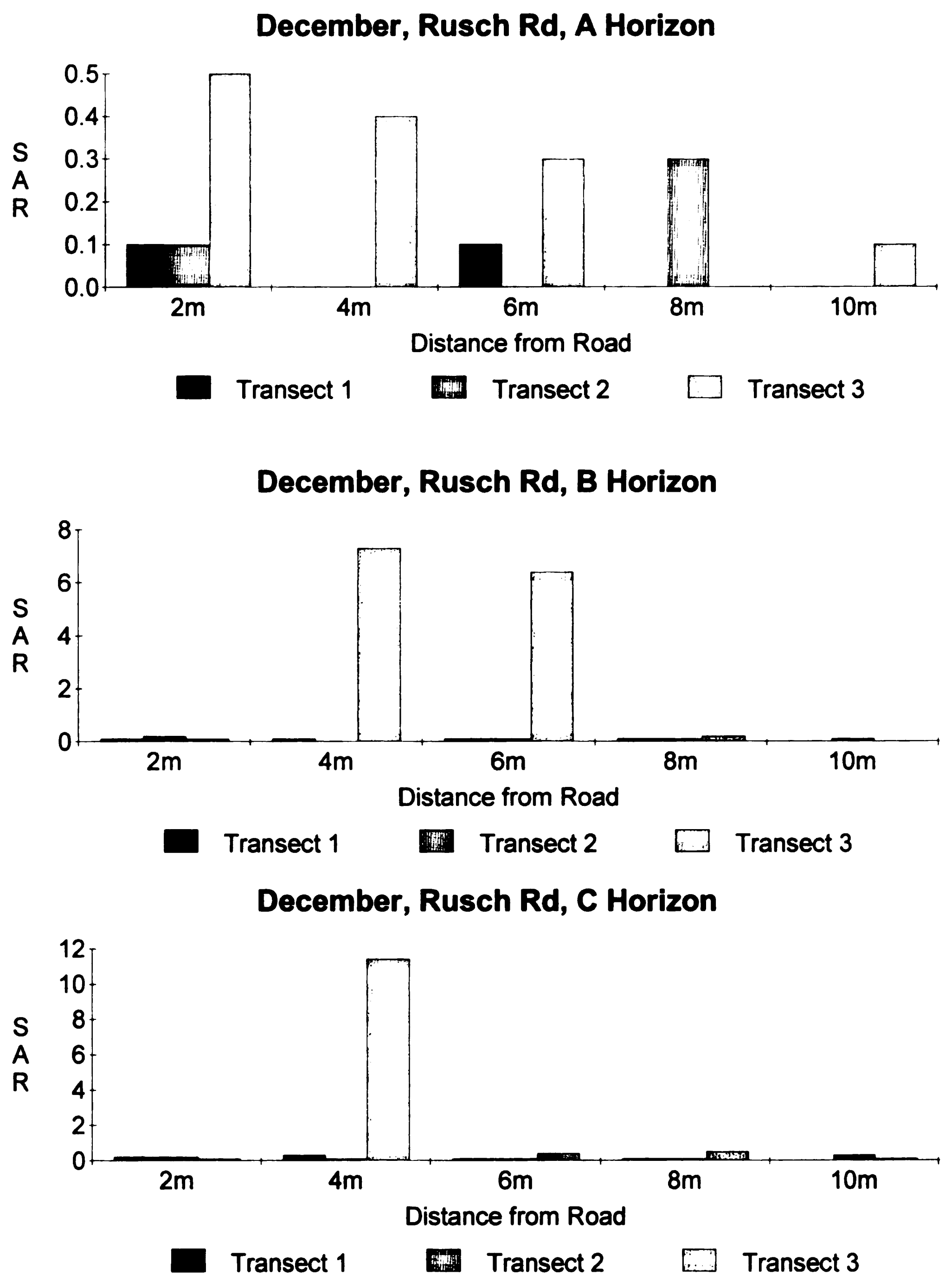
December, Silver Lake, B Horizon



December, Silver Lake, C Horizon

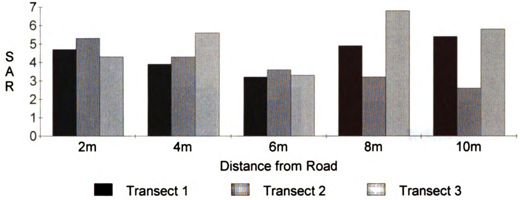


Appendix II.7. Bar graphs depicting SAR values with depth in the A, B, and C soil horizons.

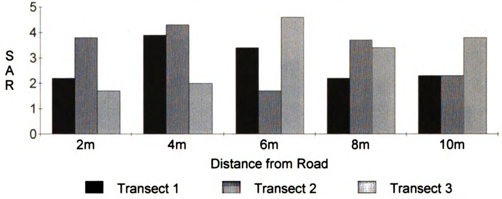


Appendix II.8. Bar graphs depicting SAR values with depth in the A, B, and C soil horizons.

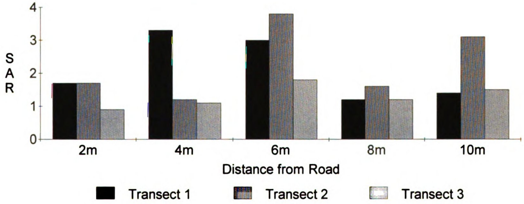
March M37 A Horizon



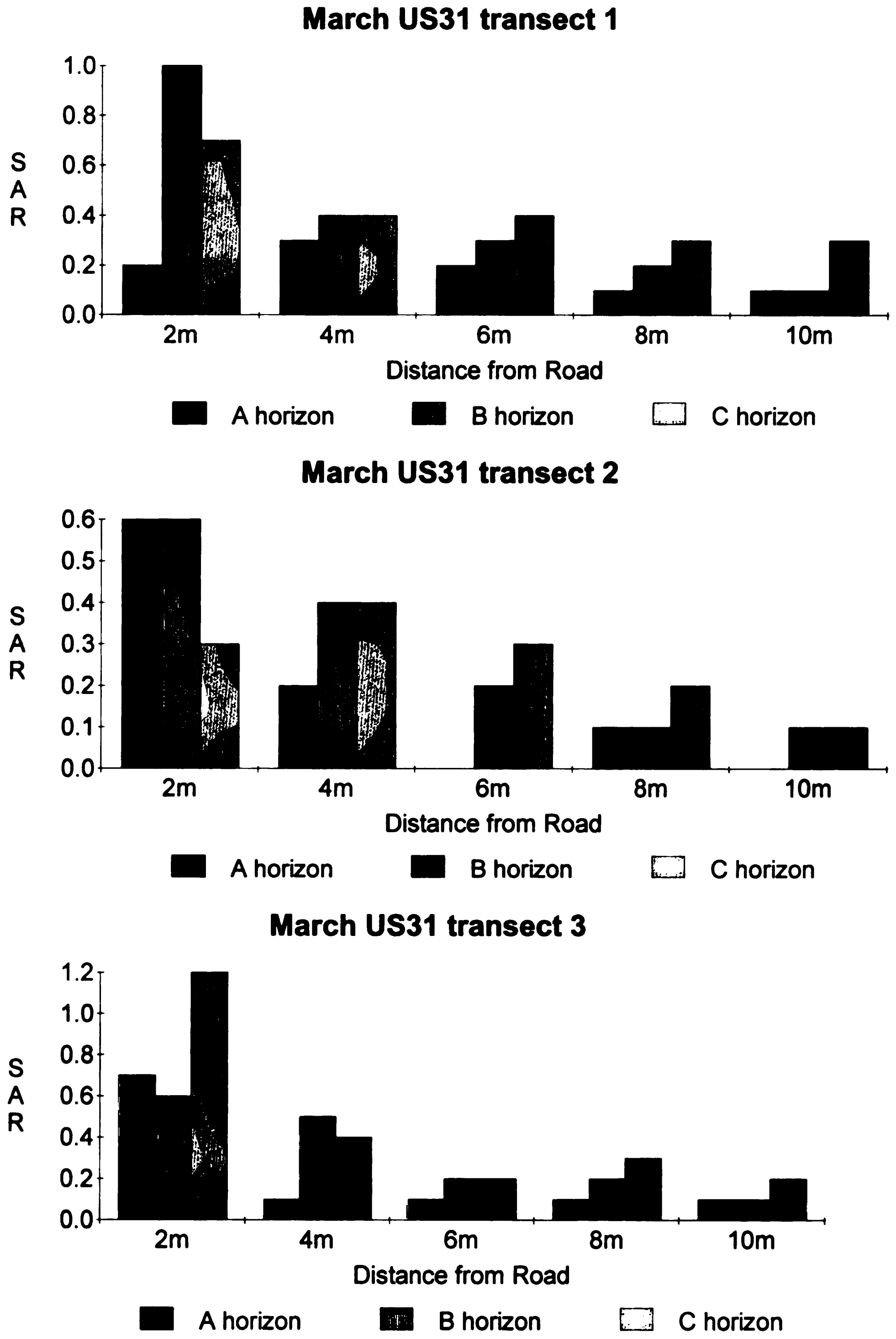
March M37 B Horizon



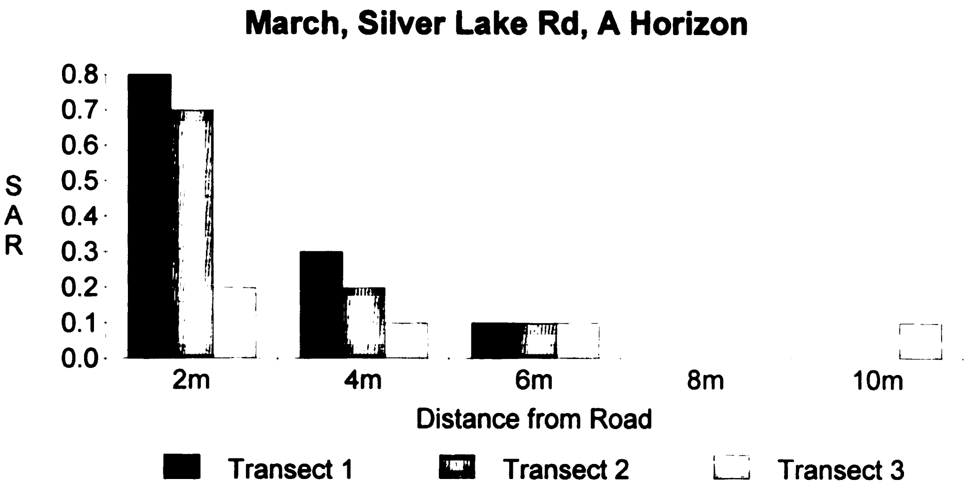
March M37 C Horizon

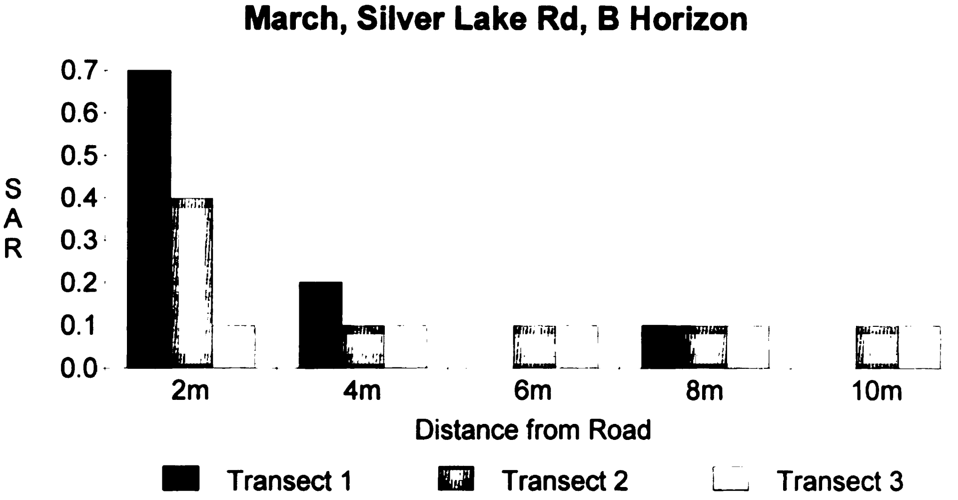


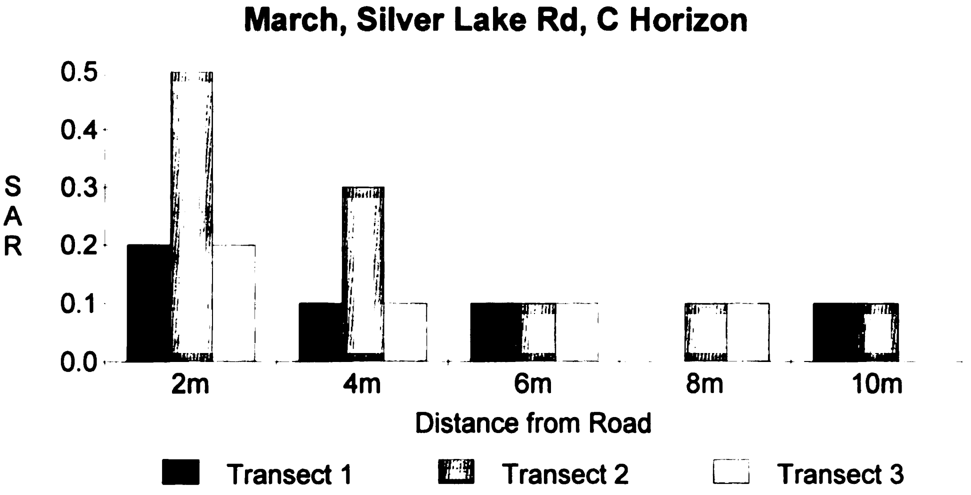
Appendix II.9. Bar graphs depicting SAR values with depth in the A, B, and C soil horizons.



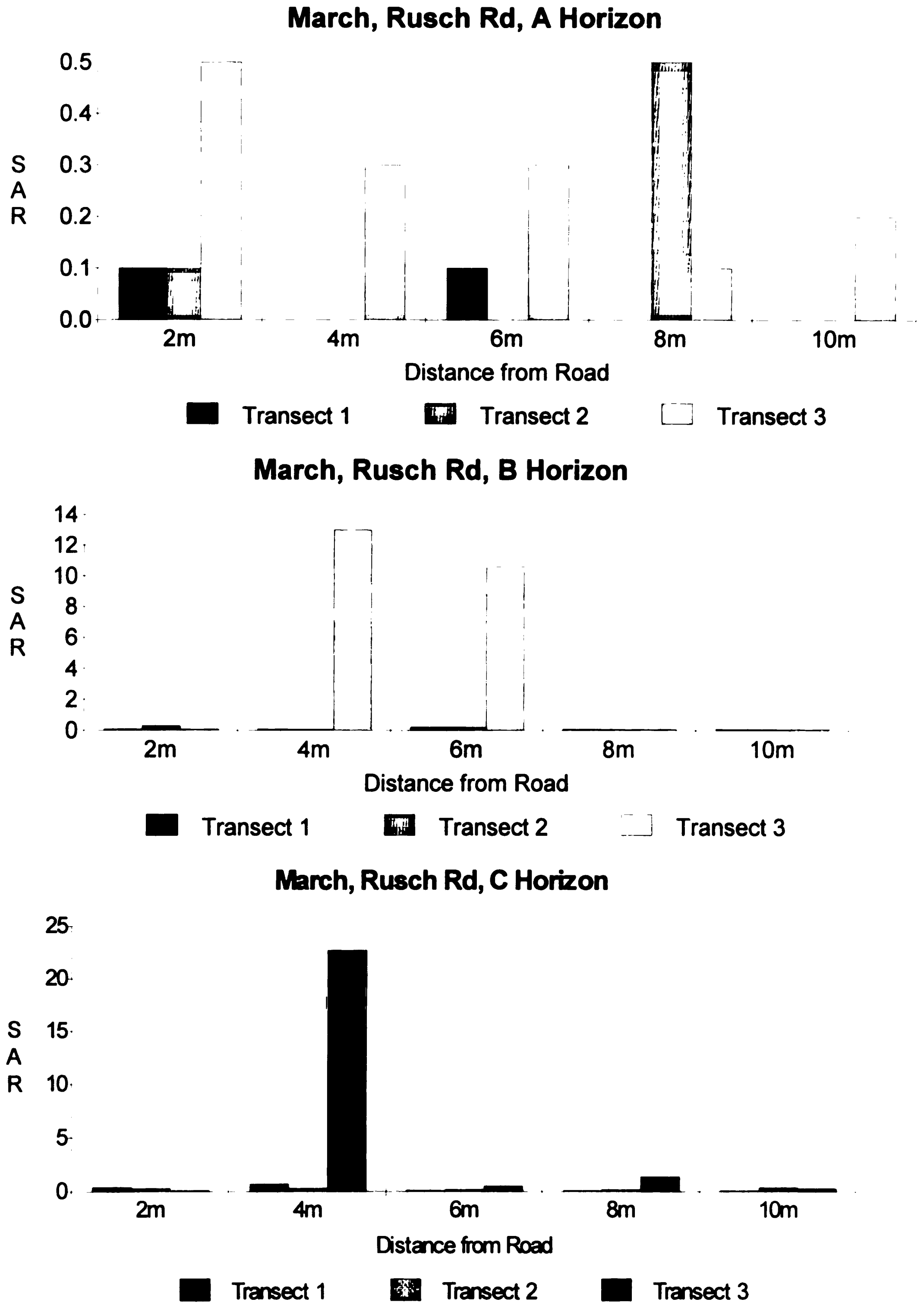
Appendix II.10. Bar graphs depicting SAR values with depth in the A, B, and C soil horizons.


March, Silver Lake Rd, A Horizon


March, Silver Lake Rd, B Horizon


March, Silver Lake Rd, C Horizon

Appendix II.11. Bar graphs depicting SAR values with depth in the A, B, and C soil horizons.


March, Rusch Rd, A Horizon

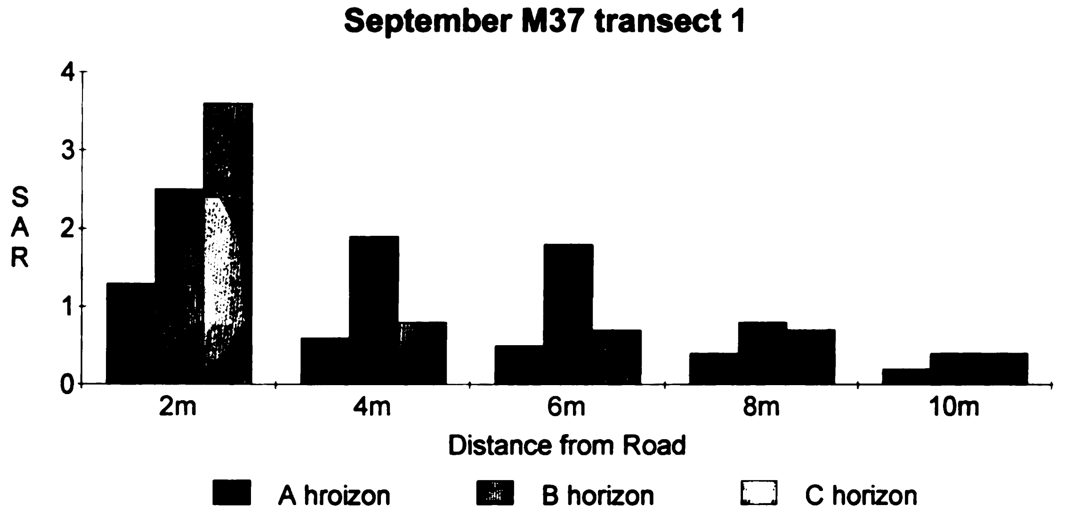
March, Rusch Rd, B Horizon

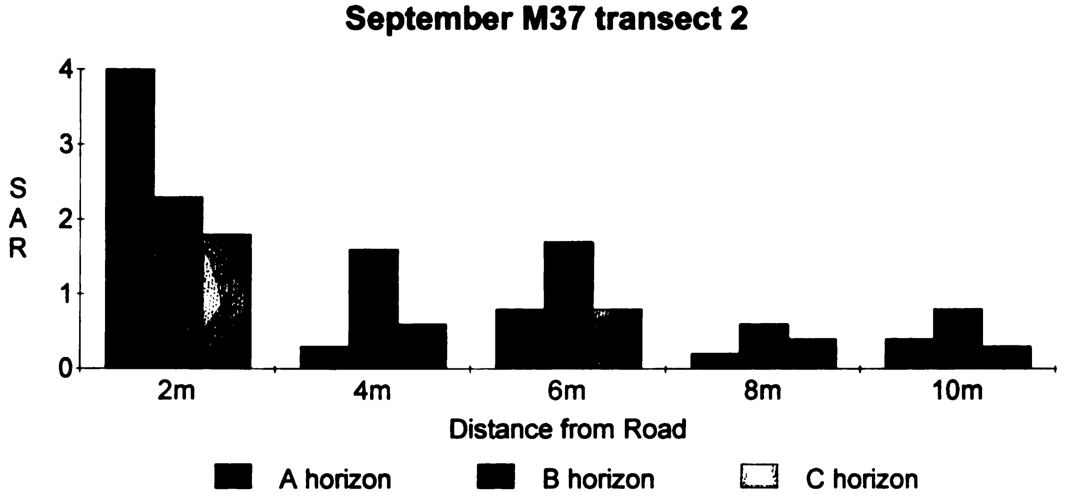
March, Rusch Rd, C Horizon

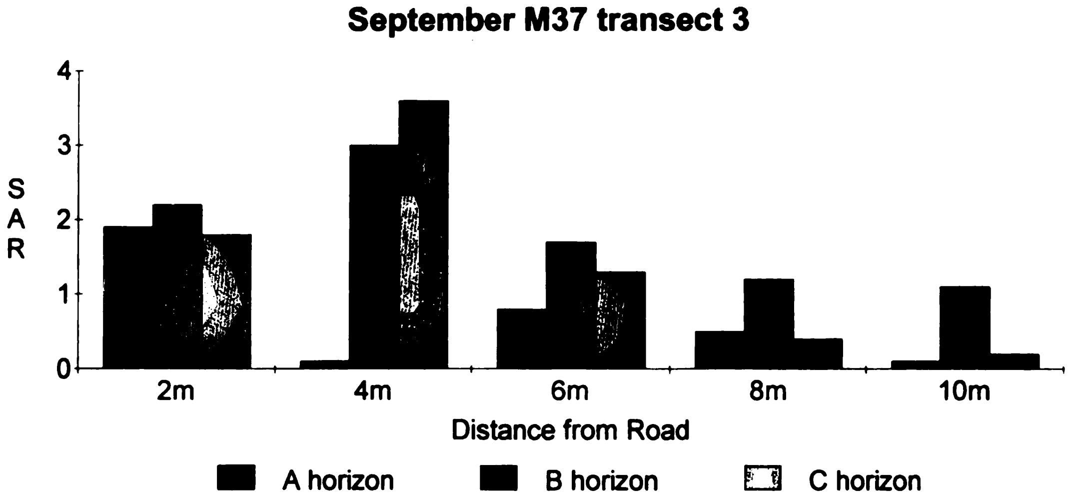
Appendix II.12. Bar graphs depicting SAR values with depth in the A, B, and C soil horizons.

Appendix III

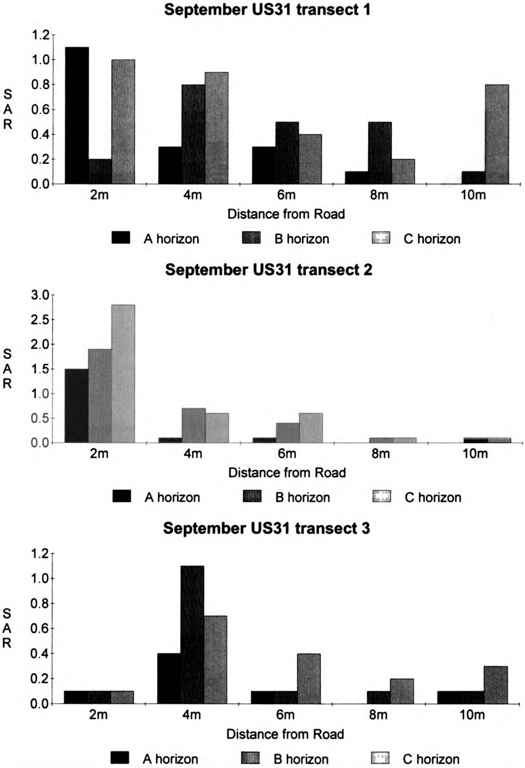
Bar graphs depicting SAR values in each horizon for each transect at each site in September, December, and March in order to evaluate any trends in SAR with distance from the road



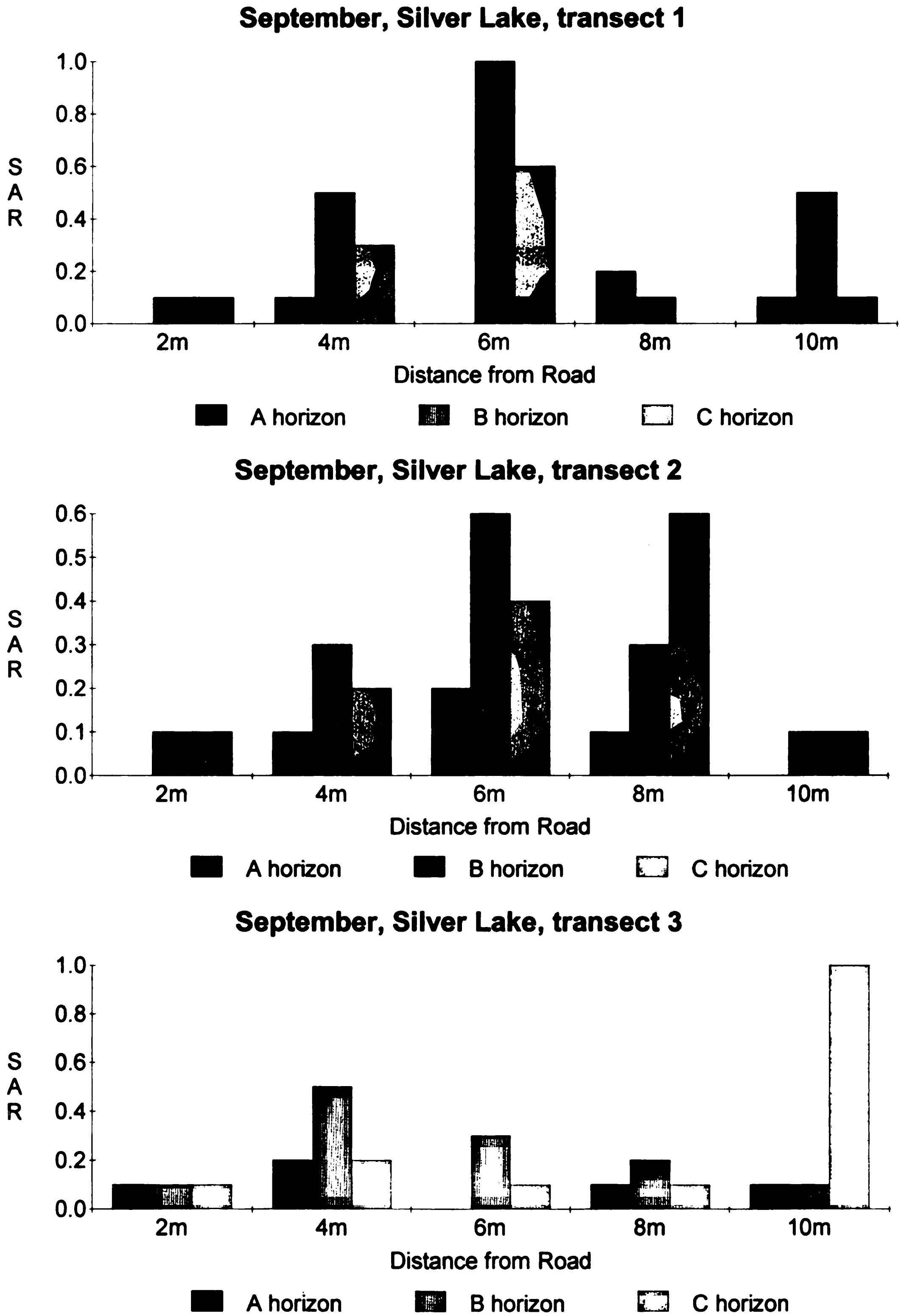




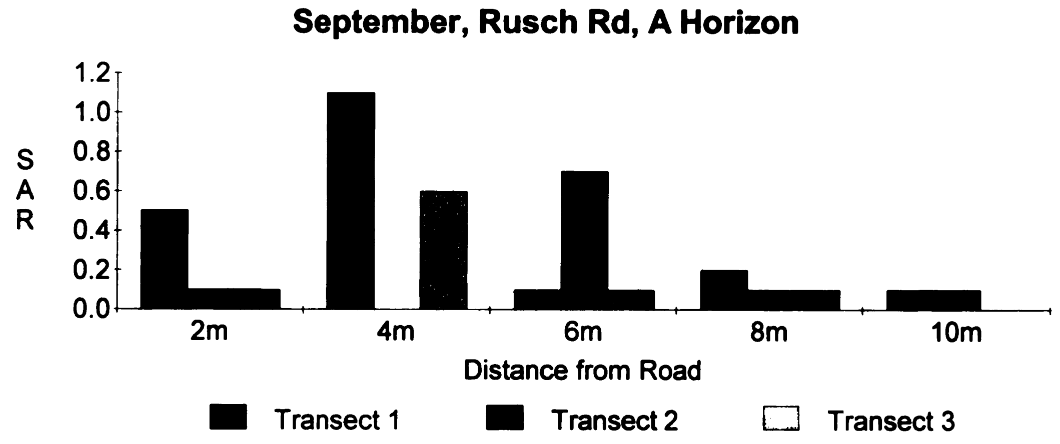
Appendix III.1. Bar graphs depicting SAR values with distance from the roadway for each transect.

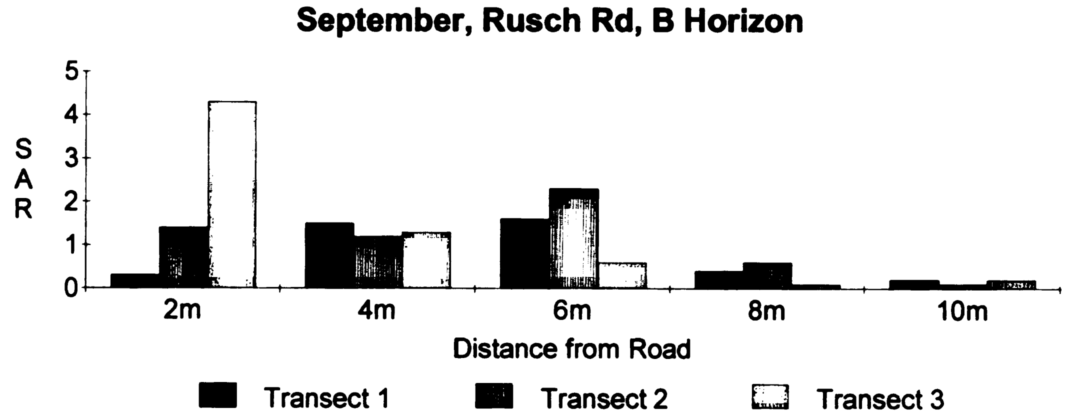


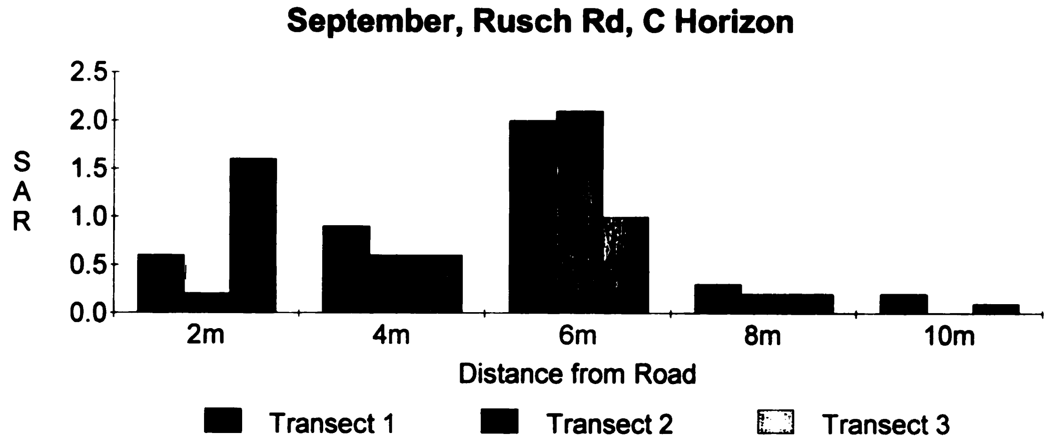
Appendix III.2. Bar graphs depicting SAR values with distance from the roadway for each transect.



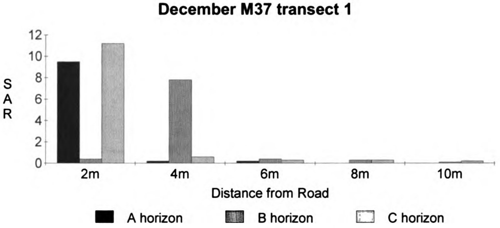
Appendix III.3. Bar graphs depicting SAR values with distance from the roadway for each transect.

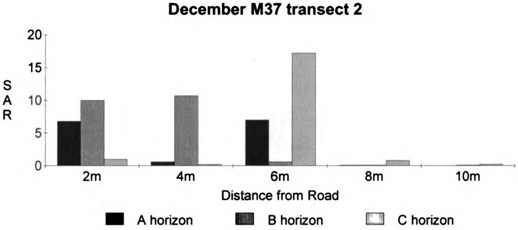


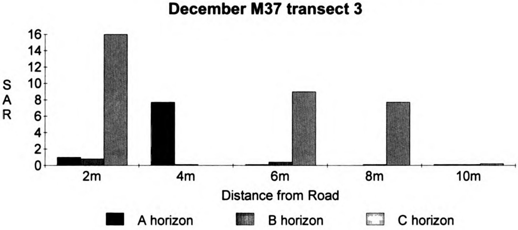




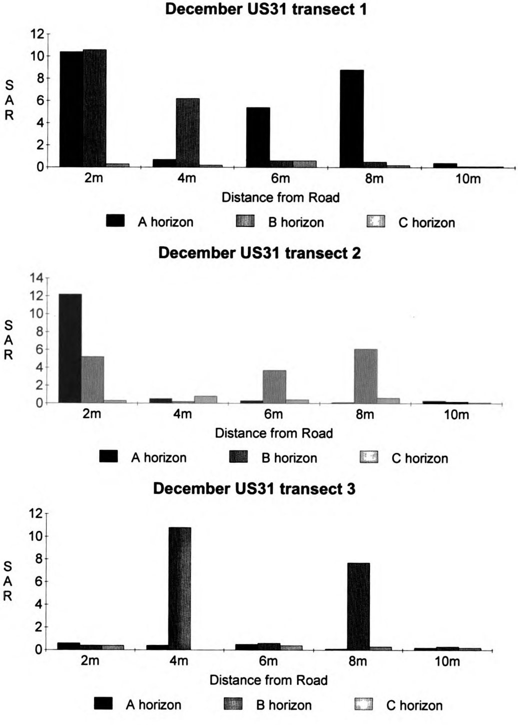
Appendix III.4. Bar graphs depicting SAR values with distance from the roadway for each transect.



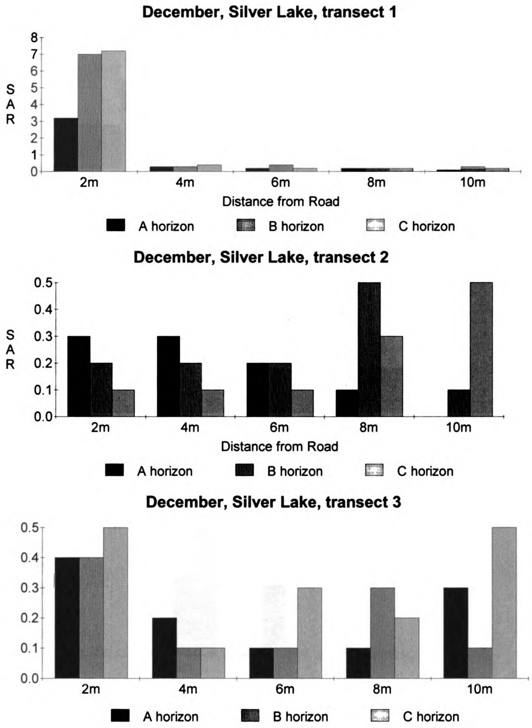




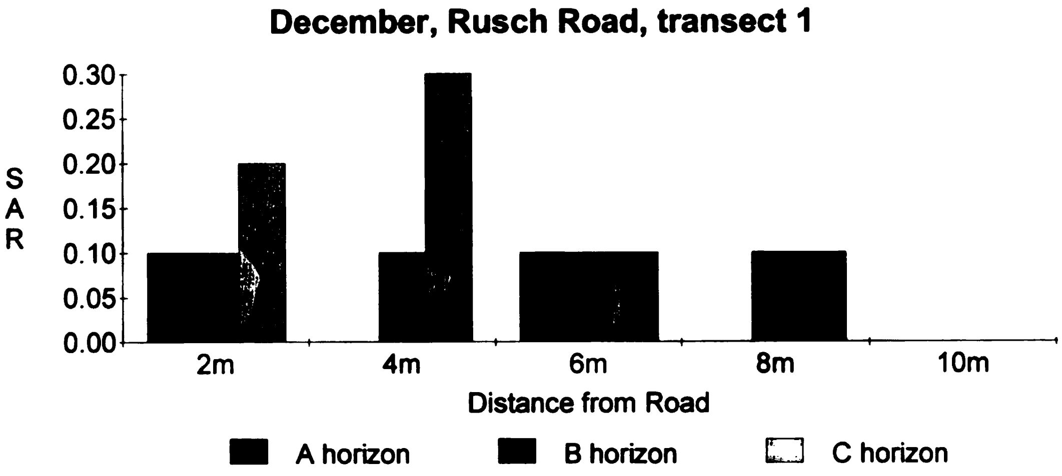
Appendix III.5. Bar graphs depicting SAR values with distance from the roadway for each transect.

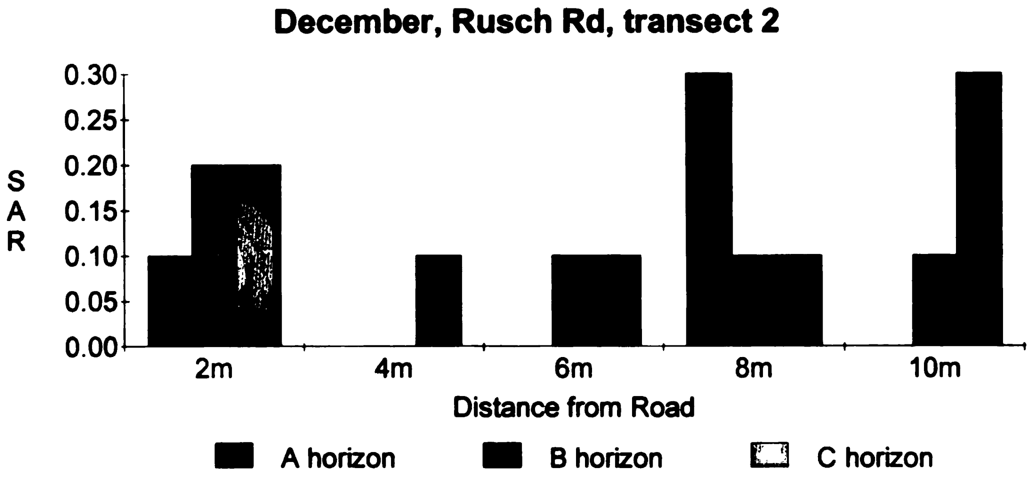


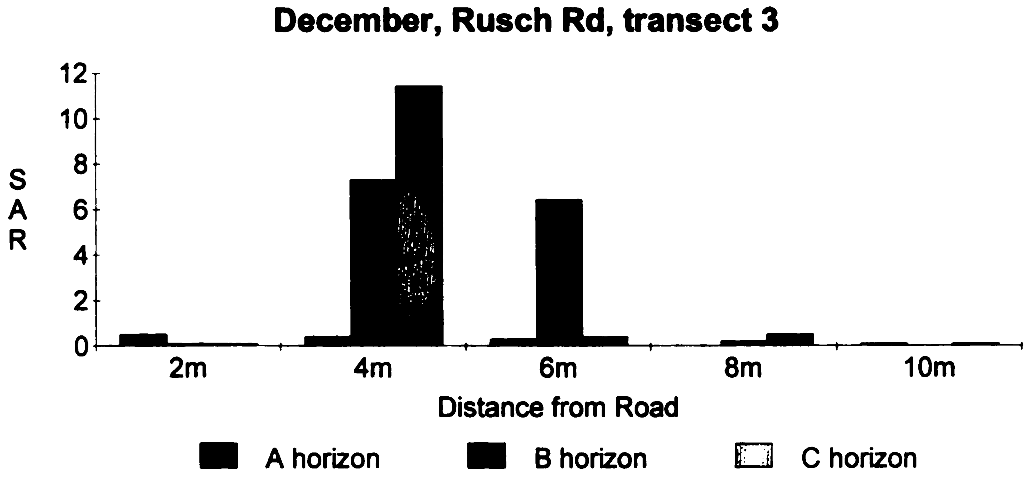
Appendix III.6. Bar graphs depicting SAR values with distance from the roadway for each transect.



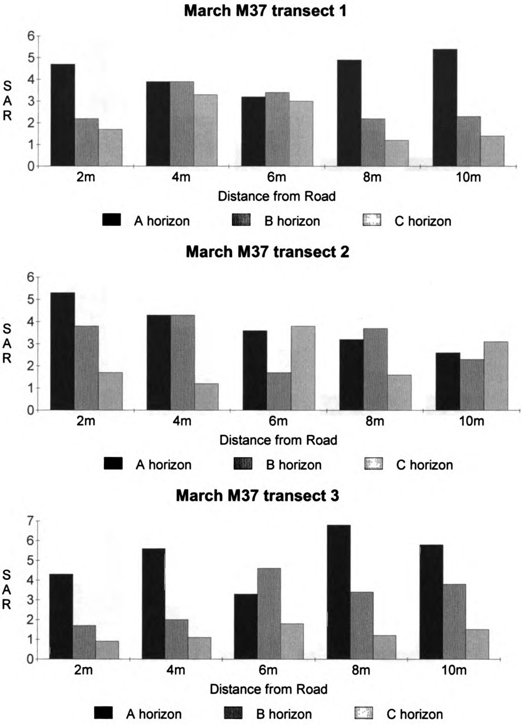
Appendix III.7. Bar graphs depicting SAR values with distance from the roadway for each transect.


December, Rusch Road, transect 1

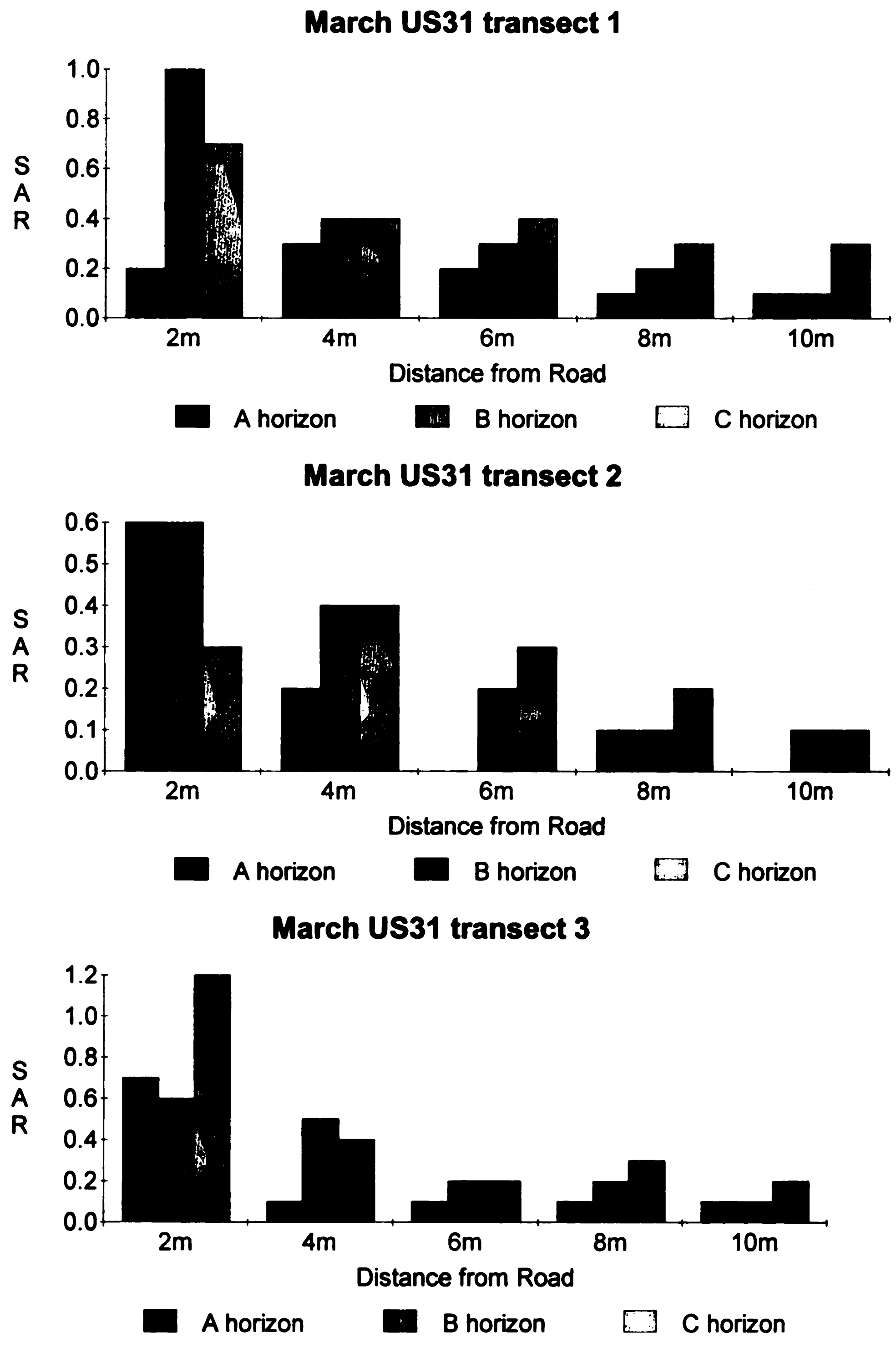

December, Rusch Rd, transect 2


December, Rusch Rd, transect 3

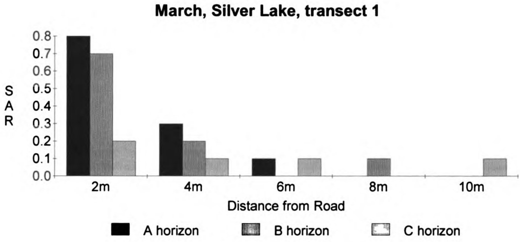
Appendix III.8. Bar graphs depicting SAR values with distance from the roadway for each transect.

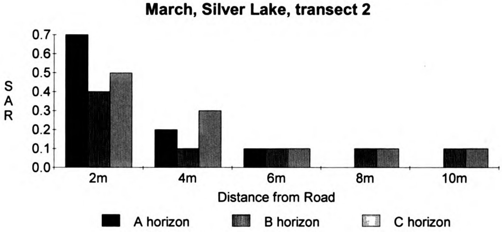


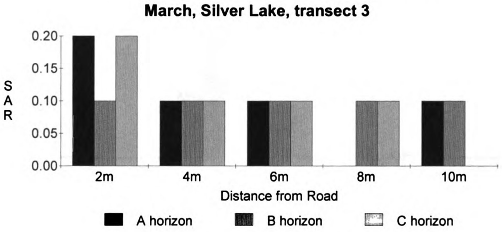
Appendix III.9. Bar graphs depicting SAR values with distance from the roadway for each transect.



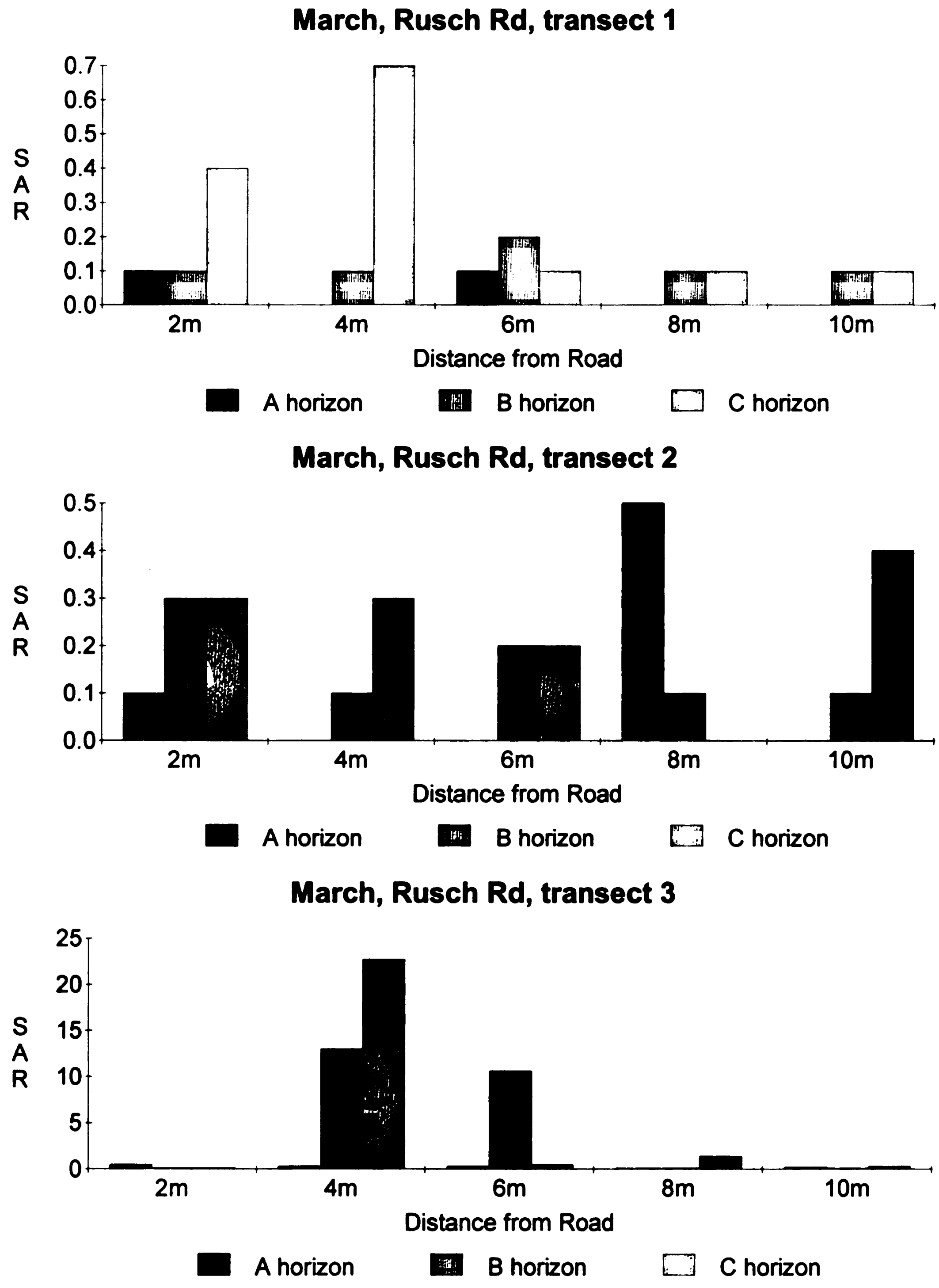
Appendix III.10. Bar graphs depicting SAR values with distance from the roadway for each transect.







Appendix III.11. Bar graphs depicting SAR values with distance from the roadway for each transect.



Appendix III.12. Bar graphs depicting SAR values with distance from the roadway for each transect.

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