Influence of Road Salting on the Nutrient and Heavy Metal Levels in Stream Water

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ABSTRACT

The increased use of forested areas for winter recreation in the mountains has resulted in substantial road development and maintenance activities such as road salting. This study evaluated the influence of road salt on levels of nutrients, heavy metals, and sediment in streams as modified by topography. As a result of an extremely low snow pack, salt inputs and stream discharge were low. This reduced losses of nutrients and salt from the below road areas; however, the losses which did occur were strongly linked to the road salting practice. All study areas showed an accumulation of road salt because of the low discharge. The addition of massive quantities of sodium caused the release of other cations and significantly altered soil structure. The breakdown of soil structure appeared to be the major reason for large losses of sediment and heavy metals from the below road areas. Most streams had very low levels of dissolved heavy metal ions.

Because of the low snow pack and discharge it was difficult to evaluate a mulching and revegetation treatment. Most of the differences between watersheds seemed a result of topographic features. Steep slopes and a large road area to below road area ratio appear most influencial in altering water quality.

INTRODUCTION

Forests, typically occupying areas of thin soil or steep topography and supplied with abundant precipitation, are the source of much of the water that reaches streams and lakes. This is especially true in New Mexico. Forest drainage ordinarily carries a minimal concentration of nutrient elements. Nevertheless, its aggregate amount is sufficient to transport large quantities of dissolved and suspended material into streams and lakes each year. This material significantly affects the production and health of these aquatic systems.

> "Because New Mexico is primarily a semi-arid region, those few perennial streams within the state have considerably more influence upon the lives and livelihood of the region's inhabitants than any other element of the physical environment. Therefore any alteration, modification, or subtle change of this resource must be carefully evaluated." (Clark 1972)

The forested areas supplying stream water are subject to a relatively large number of human pressures which involve some disturbance. A major use of New Mexico forests is for recreation, both in summer and winter. The increased use of forested areas for winter recreation and second homesites has resulted in substantial road development, improvement, and maintenance activities such as road salting. The use of road salt to maintain ice-free roads has long been an accepted practice.

A survey of the literature on the effects of road salting reveals many studies, primarily in the north central and northeastern states, which report similar findings. Road salt, mainly sodium chloride, is very mobile, quite rapidly contaminates ground water, and is toxic to most vegetation. Very little information can be found in western states, especially in the Rocky Mountain Region where road salt is used heavily. While many of the effects discovered in eastern states no doubt will also occur in New Mexico, the influence of steep terrain has not been documented.

Another aspect relating to the effects of road salt on water quality has been almost completely ignored by previous researchers. That is the influence of salting practices on amounts of heavy metals entering water courses. Our previous work indicated that significant amounts of heavy metals are found in streams draining salted roads.

It is imperative that we know whether land management practices can be developed to reduce the adverse effects of road salt on water quality. If acceptable procedures cannot be developed then decisions must be made concerning whether road salting should be continued based upon its benefits and problems. In any case a sound knowledge of its effects on all aspects of water quality is critical.

OBJECTIVES

The specific objectives of this study were:

1) To quantify the effects of road salting on levels of nutrients, heavy metals, and sediment in stream water.
2) To identify road and topographic characteristics which modify the effects of road salt on water quality.
3) To quantify the influence of soil additives and revegetation on water quality improvement in areas of road salting.

RESEARCH PROCEDURES

In order to quantify the influence of any activity on water quality both the water chemistry and the hydrological cycle must be studied. This can best be accomplished by using the ecosystem concept and performing the studies on gauged watershed ecosystems (Bormann and Likens, 1967). The ecosystem is a part of the surrounding biosphere connected by a system of inputs and outputs. Knowledge of these input-output relationships is critical in quantifying any impact to either the aquatic or terrestrial ecosystem (Likens and Bormann 1970).

The small watershed approach to ecosystem studies is a concept which used the nutrient-cycle, hydrologic-cycle interaction to its advantage. From continuous measurement and analysis of precipitation and sedimentation entering a watershed the temporal input of any element can be calculated in terms of grams per hectare. Geologic input, alluvium and colluvium, would not occur because there would be no transfer between adjacent watersheds.

The major output of an element would be geologic output, dissolved and particulate matter in either stream water or seepage water. A weir, anchored to the bedrock, will force all drainage water from the watershed to flow over a notch where it can be accurately measured. Chemical analyses of dissolved and particulate matter in the outflowing water provide an estimate of geologic output expressed as grams of an element lost per hectare of watershed. This is also a measure of nutrient input to the stream ecosystem. This data is very important in quantifying total amount of an element which will be transported to a downstream area.

In an ecosystem influenced by road salting practices, there will be an additional input of elements in the salt. Including these inputs in the calculation of element budgets for the watershed allows us to quantify the effect of the practice on both the terrestrial and aquatic ecosystems.

The study area contains gauged watersheds underlain by tight bedrock which will be used to evaluate the effects of road salting practices on water quality. The surfaced road which services these gauging stations is salted during the winter months. The gauging station is located above the road and gives us detailed hydrological measurements on the undisturbed portion of the watershed. This data (i.e. precipitation, discharge, evapotranspiration) can be used to quantify the hydrological cycle on the disturbed portion of the watershed below the road (Fig. 1).

The study area contains 8 gauged and one ungauged watersheds underlain by a tight bedrock which prevents losses due to deep seepage (Fig. 2). These watersheds represent vegetational communities ranging from pinon-juniper (2365m) to alpine tundra (3734). A paved two-lane road system services the Hyde State Park and Santa Fe Ski Basin and is kept open during the winter by road maintenance and road salting procedures. Four of the gauged watersheds were chosen for the study: Watershed 15, Rio en Medio; Watershed 8, N. Fork Tesuque Creek; Watershed 7, Middle Fork Tesuque Creek; and Watershed 6, S. Fork Tesuque Creek (See Fig. 2).

Specific Methods

1) Element Inputs.

Seven precipitation stations have been established over the elevational gradient to measure inputs. These contain recording gauges, storage gauges, and 5 of the stations contain polyethylene gauges for collecting samples for chemical analysis. Weekly collections were made and analyzed for Ca^{++}, Mg^{++}, Na^{+}, K^{+}, Cl^{-}, $SO_4^{=}$. During periods of no precipitation the collectors were washed with deionized water and analyses made to estimate dry fallout. Equations were developed for precipitation and element input over elevation to calculate the integrated input of elements over the elevational range of each watershed.

Figure 1. Watershed 6 (S. Fork Tesuque Creek) and the below road area subject to raod salt.

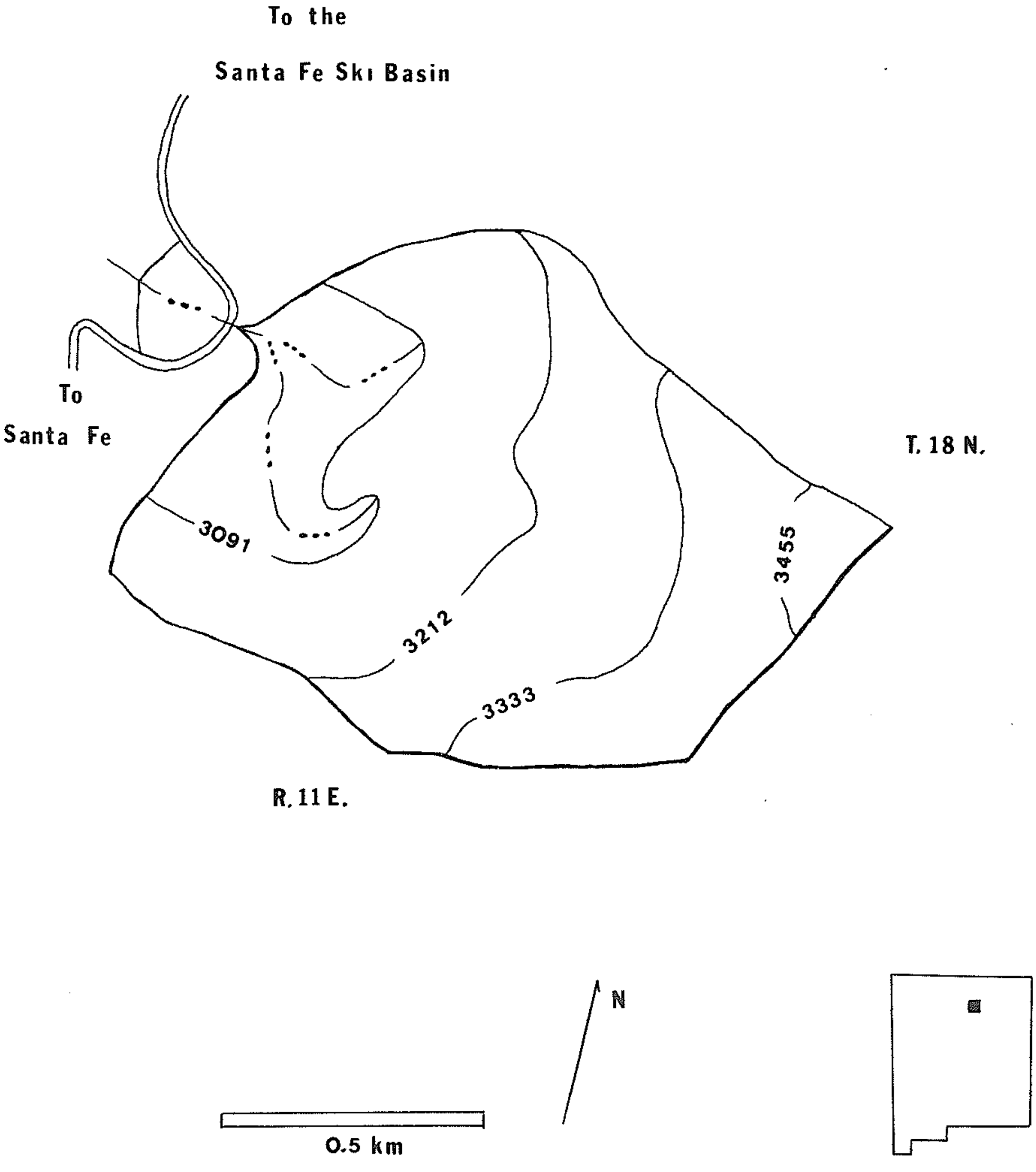
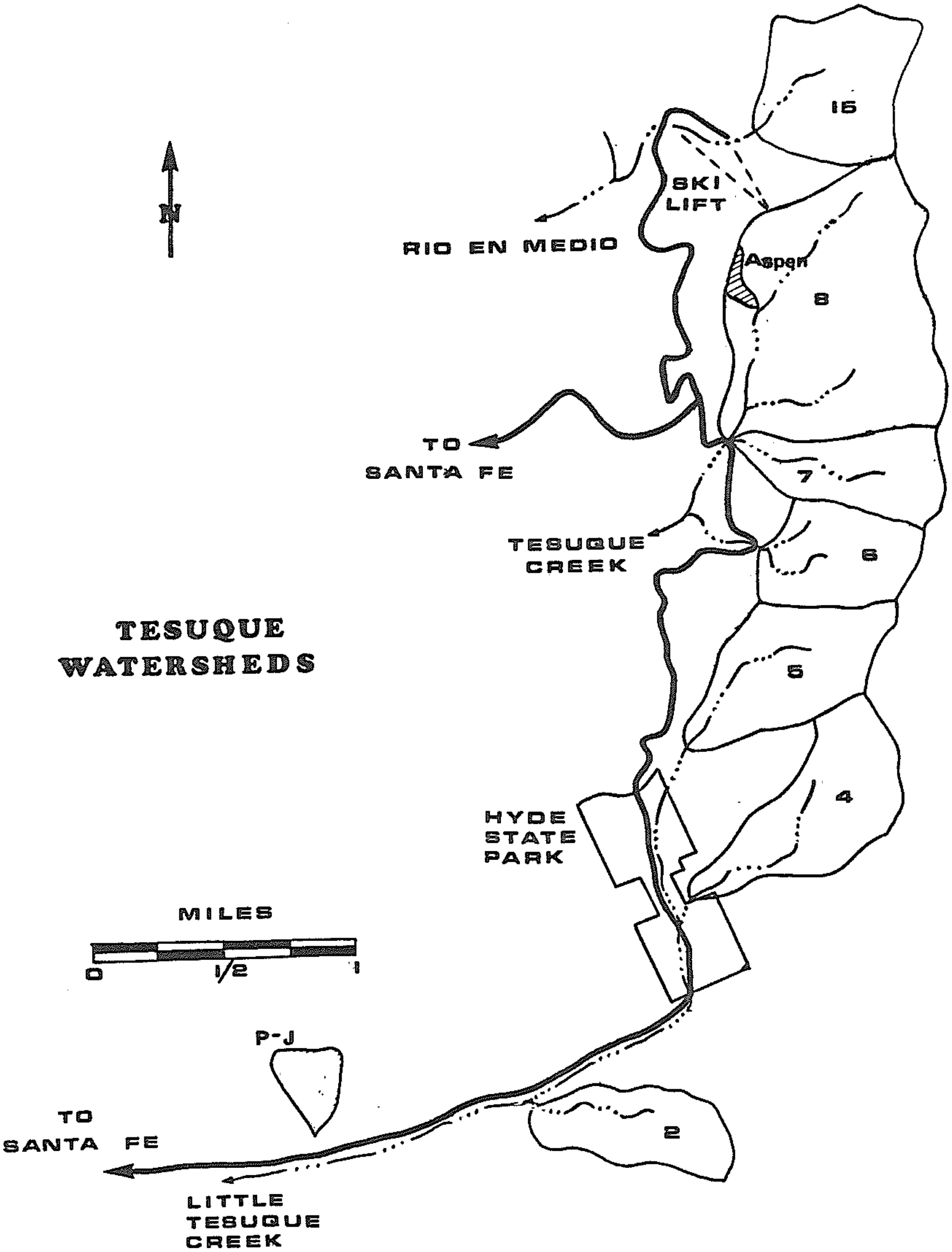


Figure 2. Tesuque Watershed Study Area.



The input of road salt was calculated by an evaluation of the number of salting trips, the application rate, and the road length in the watershed. A chemical analysis of the salt allowed calculation of element input.

2) Element outputs.

Weekly stream collections were made both above and below the road for each study watershed. More frequent collections were made during the high discharge rates of spring snow melt and the summer storm season. Analyses were made for Ca^{++}, Mg^{++}, Na^{+}, K^{+}, Cl^{-}, $SO_4^{=}$, Pb^{++}, Cu^{++}, Zn^{++}, and sediment.

Samples for analysis for the major nutrients were collected in acid washed, 500 ml polyethylene bottles which were pretreated with acid for sample preservation. Stream samples for heavy metal analysis were collected in acid washed 1 liter amber linear polyethylene bottles.

3) Downstream chemistry.

At weekly intervals during the period April through November water samples were taken at specific points downstream from the road to identify changes with distance from the point source.

4) Chemical analyses.

Cations were analyzed by atomic absorption spectrophotometry using the flame methodology. Lanthanum chloride was added for analyses of Ca^{++} and Mg^{++} to prevent interferences. Heavy metals were analyzed by either the flame or graphite furnace methods depending on the metal concentration. For heavy metal analysis the entire one liter sample was filtered through a 0.45 micrometer cellulose membrane filter. The filtrate was analyzed directly with no further preparation. The filter was digested in equal volumes of HNO_3 and HCl (Anderson 1974), brought up to a final volume of 25 ml and analyzed. Anions were analyzed by standard methods for a Technican Autoanalyzer II system.

5) Mulching and revegetation experiment.

One of the watersheds (watershed 6, S. Fork Tesuque Creek) had hay mulch and grass seed applied along the downslope side of the road within the watershed boundaries (Fig. 1). The mulch application rate was 1000 kg/ha for a 15m distance below the road. Grass seed of the proper species mixture was supplied by the United States Forest Service.

RESULTS

Hydrology

The 1976-77 water year was another of those record setting years in New Mexico -- this time record low discharge. Table 1 shows the hydrologic data for the watersheds studied and while the precipitation was not a record low (1973-74 was lower), the discharge was. The reason for the record low discharge was that very little precipitation as snow occurred during the winter months. The little snow that did accumulate went into soil moisture recharge where it was subject to evapotranspiration during the spring and summer months. The result was a record high evapotranspiration rate and a record low discharge. Unfortunately, these conditions detracted considerably from our research program. Since a very low snowfall occurred, a reduced amount of road salt was applied which lessened our ability to detect differences in our treatments. In addition, the highway department did not apply road salt early in the winter season because the ski area was not open. We have not been able to obtain records of road salt application; however, based on the number of storms which deposited more than 0.25 cm of moisture, I estimate that road salt was applied on 15 occasions. By contrast, during the 1972-73 and 1973-74 winters an estimated 40 road salting applications were made (Gosz 1975a, 1977).

Table 1. Hydrologic characteristics for the study watersheds during the period October 1, 1976 to September 30, 1977. Values are cm of moisture.

Watershed	Precipitation	Discharge	Evapotranspiration
15	71.3	26.0	45.3 (63.5%)
8	65.1	18.8	46.3 (71.1%)
7	64.9	16.0	48.9 (75.3%)
6	62.9	9.9	53.0 (84.3%)

Stream Chemistry

Major Nutrients:

Table 2 shows weighted average concentrations (mg/l) of nutrients from stream water collected above and below the road on several watersheds. In most cases concentrations below the road were greater suggesting an added source. Sulfate was the only compound which showed a reversal of that trend -- lower concentrations below the road on two of the watersheds. This would suggest that $SO_4^=$ is being removed from solution in the stream near the road, but the mechanism is not known at this time.

For the other elements the increase below the road identifies an increased loss from the watershed area near and below the road. We now must identify whether this represents a real loss from the watershed or an addition to the watershed, such as road salt.

Table 3 shows the total losses for the water year per unit area of watershed (kg/ha). These values integrate element concentrations, stream discharge, and watershed drainage area above and below the road to facilitate comparison. In general very similar cation losses (per unit of land area) occurred for the above and below road portions of watersheds 6, 7, and 8. For watershed 15 the below road losses of Ca^{++}, Mg^{++}, and Na^+ were substantially larger than the above road losses. Potassium was the only cation which showed greater above road losses, and that occurred on watershed 15. Of the anions studied Cl^- showed increased losses below the road in all watersheds with watershed 15 substantially greater than the others. Sulfate losses were similar above and below the road on two watersheds but markedly less below the road on watershed 15.

Before attempting to interpret these results it is of value to look at input - output budgets for the nutrients (tables 4, 5, 6). These budgets

Table 2. Weighted (by discharge) average concentrations (mg/l) in stream water above and below a road subject to road salting during the 1976-77 water year.

Watershed	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	$SO_4^{=}$
S. Fork Tesuque (6)						
above road	3.14	1.24	2.60	0.63	0.59	4.79
below road	3.49	1.31	3.13	0.67	1.79	4.86
Middle & N. Fork Tesuque (7, 8)						
above road	2.70	0.90	2.12	0.70	0.37	3.46
below road	2.76	0.90	2.31	0.71	0.90	3.31
Rio en Medio (15)						
above road	2.87	0.68	1.91	0.55	0.37	3.04
below road	5.33	1.16	4.60	0.88	8.49	2.58

Table 3. Loss of some cations and anions from watershed areas above and below a road subject to road salting. Values are kg/ha for the period October 1, 1976 to September 30, 1977.

Watershed	Ca^{++}	Mg^{++}	K^{+}	Na^{+}	Cl^{-}	$SO_4^{=}$
S. Fork Tesuque (6)						
above Road	3.1	1.2	0.6	2.6	0.6	4.7
below road	3.3	1.2	0.6	2.9	1.7	4.6
Middle & N. Fork Tesuque (7, 8)						
above road	4.9	1.7	1.3	3.9	0.6	6.3
below road	5.0	1.6	1.3	4.1	1.6	6.0
Rio en Medio (15)						
above road	7.5	1.8	1.4	5.0	1.0	7.9
below road	13.5	3.0	0.5	31.7	65.3	5.4

Table 4. Budgets for above and below the road on watershed 15 (Rio en Medio) during the 1976-77 water year. Values are kg/ha.

	Precipitation Input	Road Salt Input	Stream Output	Net Change
Ca^{++}				
above road	5.4	—	7.5	-2.1
below road	5.4	1.5	13.5	-9.6
Mg^{++}				
above road	0.5	—	1.8	-1.3
below road	0.5	0.2	3.0	-2.3
K^{+}				
above road	1.0	—	1.4	-0.4
below road	1.0	0.9	0.5	+1.4
Na^{+}				
above road	0.6	—	5.0	-4.4
below road	0.6	115.5	31.7	+84.4
Cl^{-}				
above road	1.9	—	1.0	+0.9
below road	1.9	196.8	65.3	+133.4
$SO_4^{=}$				
above road	10.0	—	7.9	+2.1
below road	10.0	3.5	5.4	+8.1

Table 5. Budgets for above and below the road on watersheds 7 & 8 (N. and Middle Fork Tesuque Creek) during the 1976-77 water year. Values are kg/ha.

	Precipitation Input	Road Salt Input	Stream Output	Net Change
Ca^{++}				
above road	5.4	___	4.9	+0.5
below road	5.4	1.6	5.0	+2.0
Mg^{++}				
above road	0.5	___	1.7	-1.2
below road	0.5	0.2	1.6	-0.9
K^{+}				
above road	1.0	___	1.3	-0.3
below road	1.0	1.0	1.3	+0.7
Na^{+}				
above road	0.6	___	3.9	-3.3
below road	0.6	122.7	4.1	+119.2
Cl^{-}				
above road	1.9	___	0.6	+1.3
below road	1.9	209.1	1.6	+209.4
$SO_4^{=}$				
above road	10.0	___	6.3	+3.7
below road	10.0	3.8	6.0	+7.8

Table 6. Budgets for above and below the road on watershed 6 (S. Fork Tesuque Creek) during the 1976-77 water year. Values are kg/ha.

	Precipitation Input	Road Salt Input	Stream Output	Net Change
Ca^{++}				
above road	5.4	—	3.1	+2.3
below road	5.4	0.7	3.3	+2.8
Mg^{++}				
above road	0.5	—	1.2	-0.7
below road	0.5	0.1	1.2	-0.6
K^{+}				
above road	1.0	—	0.6	+0.4
below road	1.0	0.4	0.6	+0.8
Na^{+}				
above road	0.6	—	2.6	-2.0
below road	0.6	53.6	2.9	+51.30
Cl^{-}				
above road	1.9	—	0.6	+1.3
below road	1.9	91.3	1.7	+91.5
$SO_4^{=}$				
above road	10.0	—	4.7	+5.3
below road	10.0	1.6	4.6	+7.0

identify the net change per unit of watershed area (inputs minus outputs).

The precipitation input was calculated from an analysis of precipitation volume and chemical composition over the elevational gradient of each watershed. The road salt input (to below road areas) was calculated from an estimate of the number of road salt applications, application rate, and chemical composition of the salt. The application rate for the salt mixture was estimated at 1087 kg per kilometer of road during each salting occasion (Gosz 1975a, 1977). Chemical analysis of the sand - salt mixture showed it to be 9.8% Na^+, 16.7% Cl^-, 0.3% $SO_4^=$, 0.13% Ca^{++}, 0.08% K^+, 0.015% Mg^{++}, 0.000061% Pb^{++}, 0.00033% Cu^{++}, and 0.000012% Zn^{++}. Virtually all of the remainder was mineral sand (less than 0.6 cm diameter).

The only significant output of these chemicals was assumed to be stream output (Likens and Bormann 1970).

From all of the tables presented, several well defined patterns are apparent. The nutrient output (kg/ha) of a certain element (e.g. Ca^{++}) is a function of discharge. Discharge volumes decrease from high elevation watersheds to low elevation watersheds (i.e. 15 to 6, table 1) and this affects the amount of material washed from the system. The discharge factor overrides a general reverse pattern shown in the weighted average ion concentrations of higher concentrations at lower elevations (e.g. compare above road concentrations for watersheds 6 through 15, table 2). This pattern also is found among years with different hydrologic conditions -- the greater the annual discharge, the greater the ion loss per unit of watershed (Gosz 1975b). Since precipitation inputs tend to be much less variable over the elevational range as well as on a year to year basis, the net change of natural watersheds (above road conditions) is primarily influenced by stream outputs. Hence, net losses of natural watersheds tend to be largest at the higher elevations. In an extremely dry year, as we have had, precipitation inputs may exceed stream outputs and in that case the smallest accumulation of a given element will occur at the highest elevations, the largest accumulation at the lower elevations.

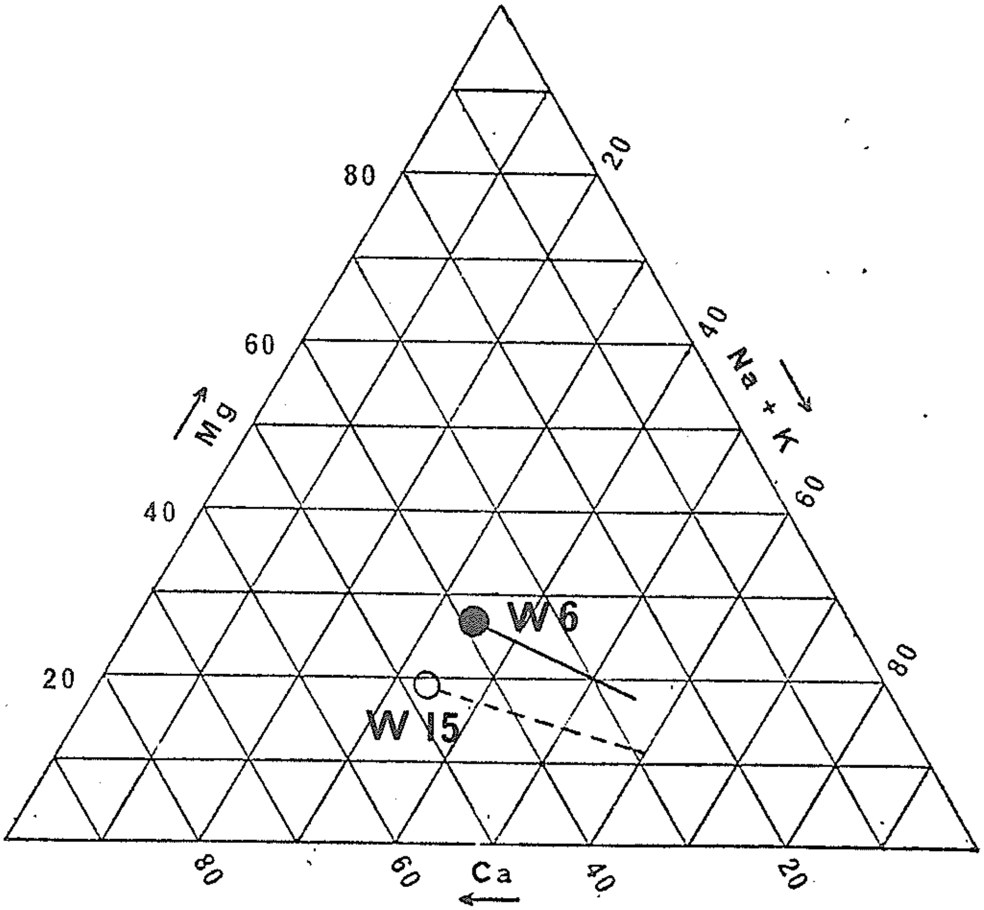
The below road portions of each watershed had an additional significant input due to road salt. Since the salt was 98% Na Cl, these elements were primary additions. The pattern of increased element loss in stream water at higher elevations can also be seen for the below road budgets. The two exceptions to this generalization are for K^+ and $SO_4^=$ on watershed 15. One major difference for the below road area of watershed 15 is that it has a parking lot (for an adjacent ski area) and a treeless area which occupy a significant portion of the area. Potassium is a very important biological element, strongly correlated with presence of organic biomass, but easily leached from both living and dead organic material (Gosz et al. 1973, Tukey 1970). The absence of organic matter in a parking lot and a reduction in tree canopy which can have K^+ leached from it may explain the reduced K^+ content of that stream. In contrast, the below road areas of watersheds 6, 7, and 8 are forested and contain more deciduous species (i.e. aspen, Populus tremuloides, alder, Alnus) near the stream which have high K^+ concentrations. It is possible that this is the reason for the large difference in $SO_4^=$ outputs in watershed 15.

The net changes (gain or loss) for the below road areas do not follow the pattern of highest loss (smallest accumulation) at higher elevations because of the variable input of road salt. The salt additions are a function of the length of road in the watershed and the area of the watershed below the road.

The influence of the low precipitation can be seen in the below road budgets of all watersheds in that only a small portion of the Na^+ and Cl^- which was added was washed out. This also was reported for the 1973-74 water year (Gosz 1975a). It appears that in very wet years an excess of water causes a loss of all of the salt applied that year plus some of the accumulation of any previous dry years. This would seem to be desirable since it would result in relatively low levels of Na^+ and Cl^- in stream water during both wet and dry years; however, there may be adverse effects where the salt accumulates as will be discussed later.

Since such a small amount of the salt input was removed there arises a question of whether the differences in average concentrations above and below the road are due to road salt. A technique which can help to answer that question is trilinear plotting (Gosz 1975a, 1977). If one considers only the major dissolved cationic species in milliequivalents per liter and lumps K^+ (which changes very little in concentration) and Na^+ together, the composition of most natural waters can be closely approximated in terms of 3 cationic species. These would be Ca^{++}, Mg^{++}, and $(K^+ + Na^+)$. If the values of these 3 are expressed as percentages of the total milliequivalents per liter of cations, the composition of the water can be represented by a trilinear plotting technique (Fig. 3). Each vertex represents 100% of a particular ion or group of ions $(K^+ + Na^+)$. The composition of the water with respect to cations is indicated by a point plotted in the triangle. The three coordinates at each plotted point add to 100%. The most useful application of this technique is in testing water quality to determine whether a particular water may be a simple mixture of others or whether it is affected by solution or precipitation of a single salt. It can be easily shown that the analysis of any mixture of waters A and B will plot on the straight line

Figure 3. Trilinear plot of water quality for watersheds 6 (solid circle) and 15 (open circle). Above road water quality plots in the respective circles for the two watersheds. Below road water quality plots along the lines.



AB in the plotting field (where points A and B are for the analyses of the two waters) if the ions do not react chemically as a result of mixing (Hem 1970). Or, if solutions A and C define a straight line pointing toward the Na^+ vertex, the more concentrated solution represents the more dilute one spiked by addition of a Na^+ salt. These characteristics make this method ideal for evaluating the different sources of nutrients in an area in relation to water quality. Figure 3 demonstrates the plotting method for watersheds 6 and 15. These two watersheds demonstrated the smallest and largest differences, respectively, between the above and below road losses of cations (Table 3). The circles represent the natural water quality above the road for each watershed. Regardless of the season or discharge conditions the water quality above the road falls into the area of the circle. The line for each area represents the range of water chemistry characteristics below the road during the 1976-77 water year. These lines show that water quality below the road ranges between natural water quality and water which has had Na^+ added to it. The interpretation is that water quality below the road is primarily affected by the solution of road salt. During the spring snow melt, water quality analyses from below the road plot on the line near the Na^+ plus K^+ vertex. During the fall and winter months (before snow melt) water quality analyses plot near the circle representing natural water quality. In spite of the fact that this was a very low snowfall and spring discharge year, this technique shows good sensitivity in identifying the modification of water quality by road salt.

An additional and important question concerning the influence of road salt involves the distance downstream that the effect becomes apparent. Figures 4, 5, and 6 show stream concentrations of Ca^{++}, Na^{++}, and Cl- at a number of

Figure 4. Calcium concentrations (mg/l) at a number of distances below the road on Watershed 15 (Rio en Medio).

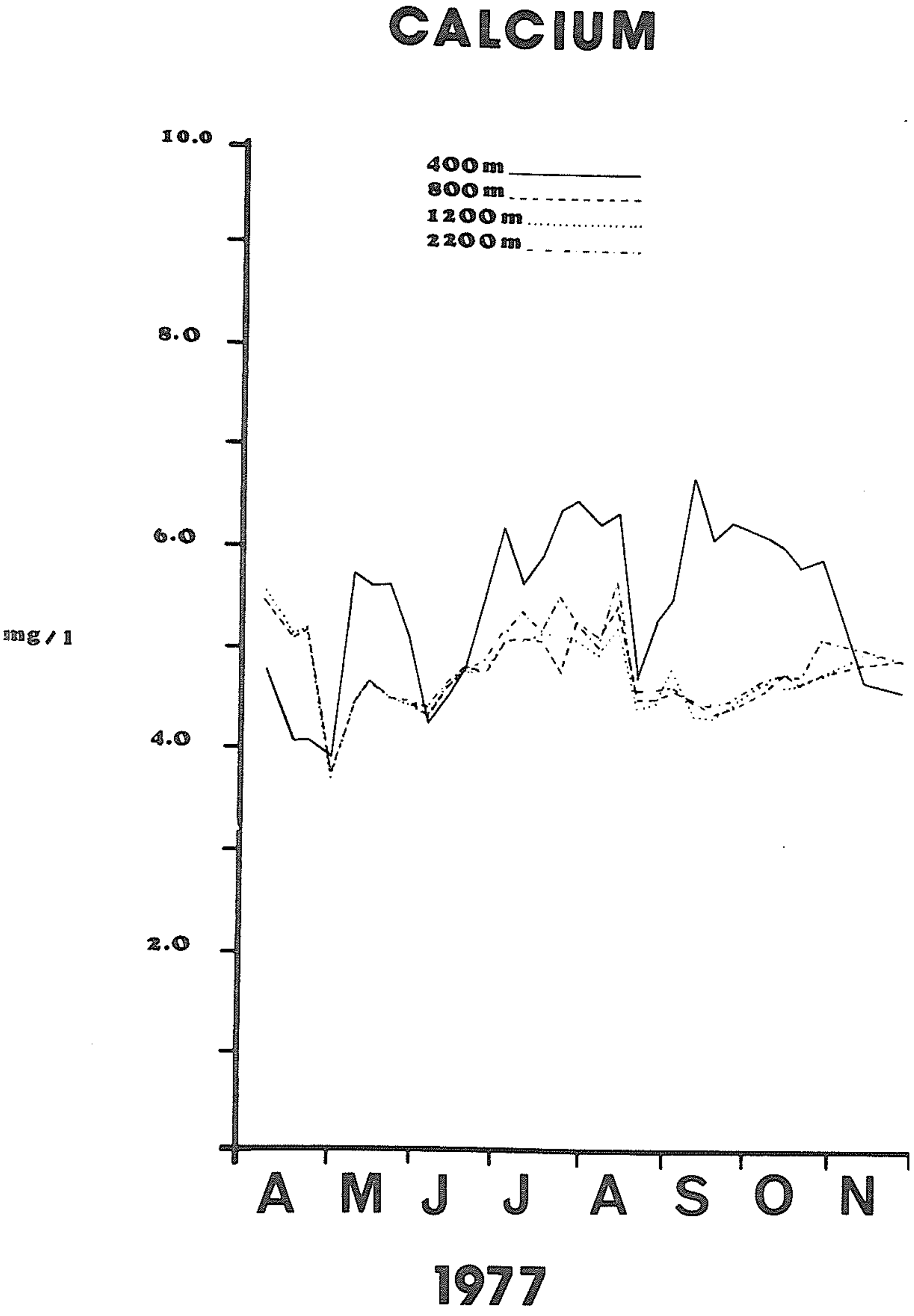


Figure 5. Sodium concentrations (mg/l) at a number of distances below the road on Watershed 15 (Rio en Medio).

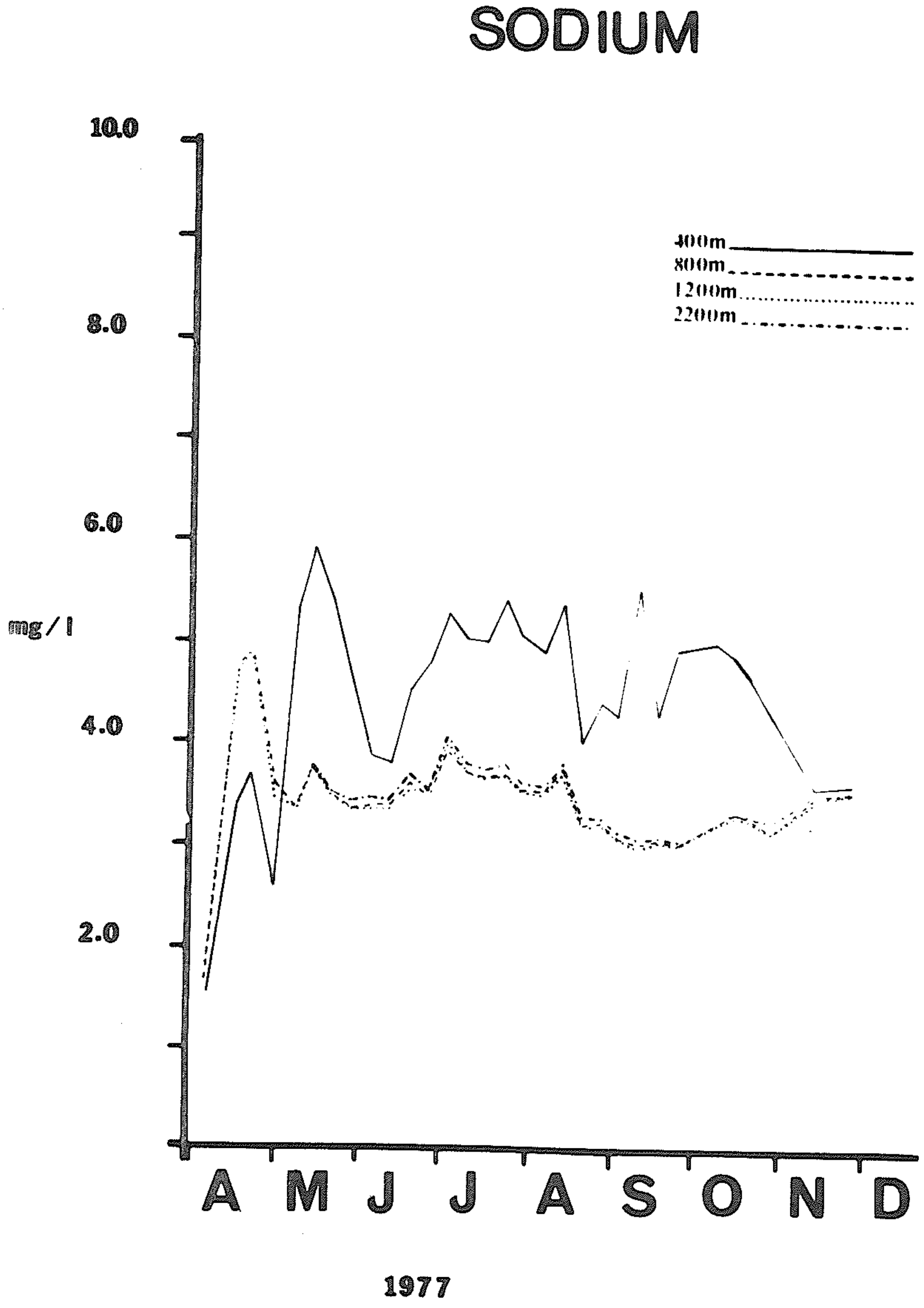
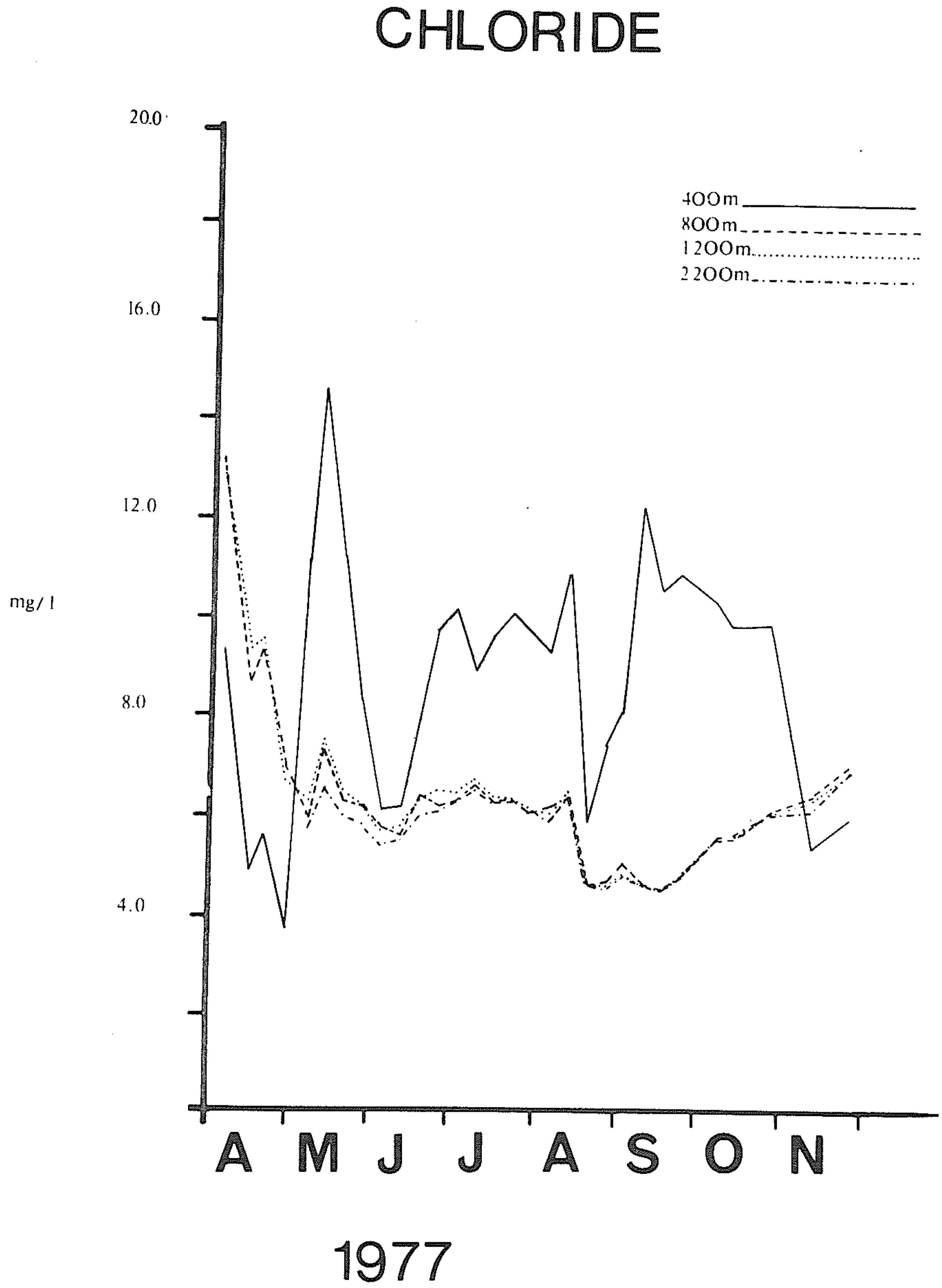


Figure 6. Chloride concentrations (mg/l) at a number of distances below the road on Watershed 15 (Rio en Medio).



distances below the road. These figures show elevated concentrations at 400 m below the road, however, the 800m, 1200m and 2200m distance were similar. An interesting pattern occurs during April when the concentrations at 400 m are markedly lower than the further distances. This is due to the input of another tributary (Winsor Creek) between the 400 m and 800 m sampling points. Winsor Creek also is influenced by road salting practices and figures 7, 8, and 9 show that in April Ca^{++}, Na^{+}, and Cl^{-} concentrations were much greater in Winsor Creek than in the Rio en Medio below the road. These differences are thought to be differences in snow melt characteristics along the salted road as well as length of road and distance from the stream.

These figures point out several features regarding water quality changes. First, water quality improvements downstream appear to be affected primarily by dilution. Since the highest discharge rates occur at higher elevations the dilution effect will be greatest for tributaries near the road (unless they are influenced by salt). The stream discharge from land areas further downstream (lower elevations) will be smaller and less able to dilute the added salt concentrations. These patterns no doubt hold for salts and nutrients which are not strongly required by organisms. Concentrations of elements such as N, P, K may be modified by instream processes.

Second, because the snow pack (hence, spring discharge) was so low, a great deal of salt was left which entered the stream during summer precipitation storms. This caused the below road stream concentrations to be relatively high all year. During years with high spring discharge the salt is more effectively flushed out of the system and concentrations during the summer return to near normal levels (Gosz 1975a). Third, even though road salt has little Ca^{++} the pattern of Ca^{++} concentration is similar to Na^{+} and Cl^{-}. Our previous work has shown that Mg^{++}, K^{+}, and presumably others also follow the same pattern. It appears that Na^{+} removes cations from exchange sites in

Figure 7. Calcium concentrations in Windsor Creek (below road) and above and below the road in Watershed 15 (Rio en Medio).

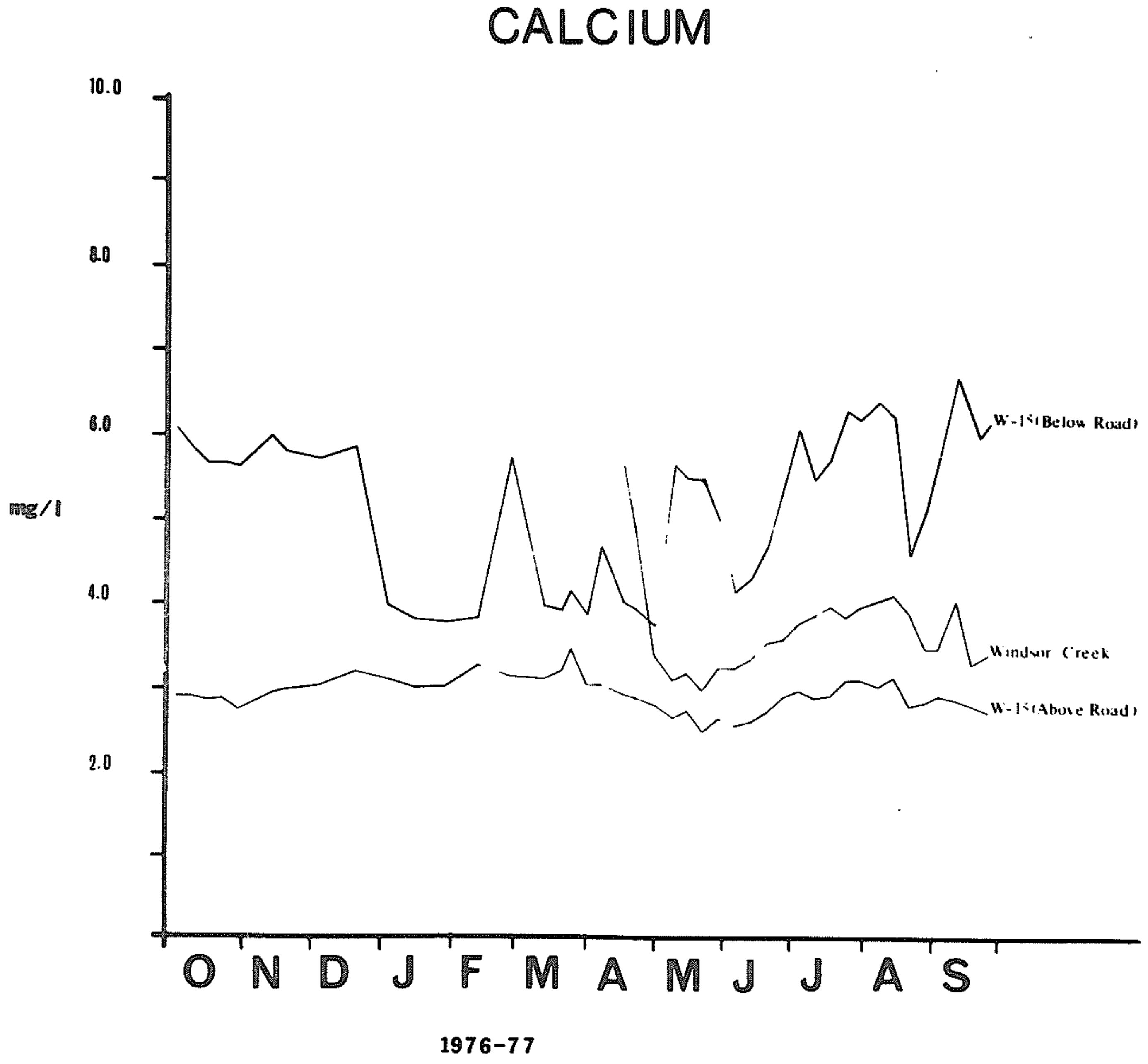


Figure 8. Sodium concentrations in Windsor Creek (below road) and above and below the road in Watershed 15 (Rio en Medio).

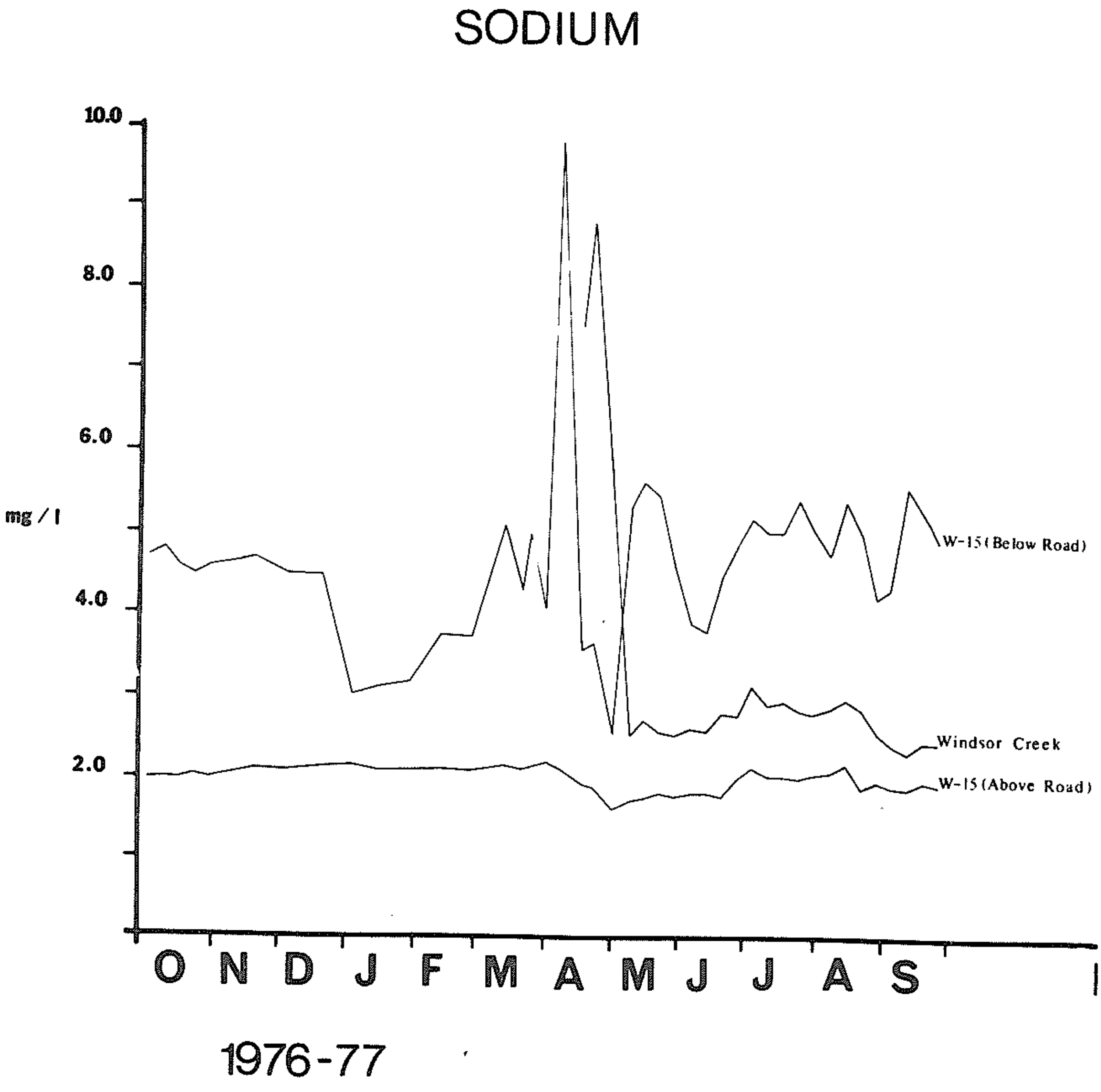
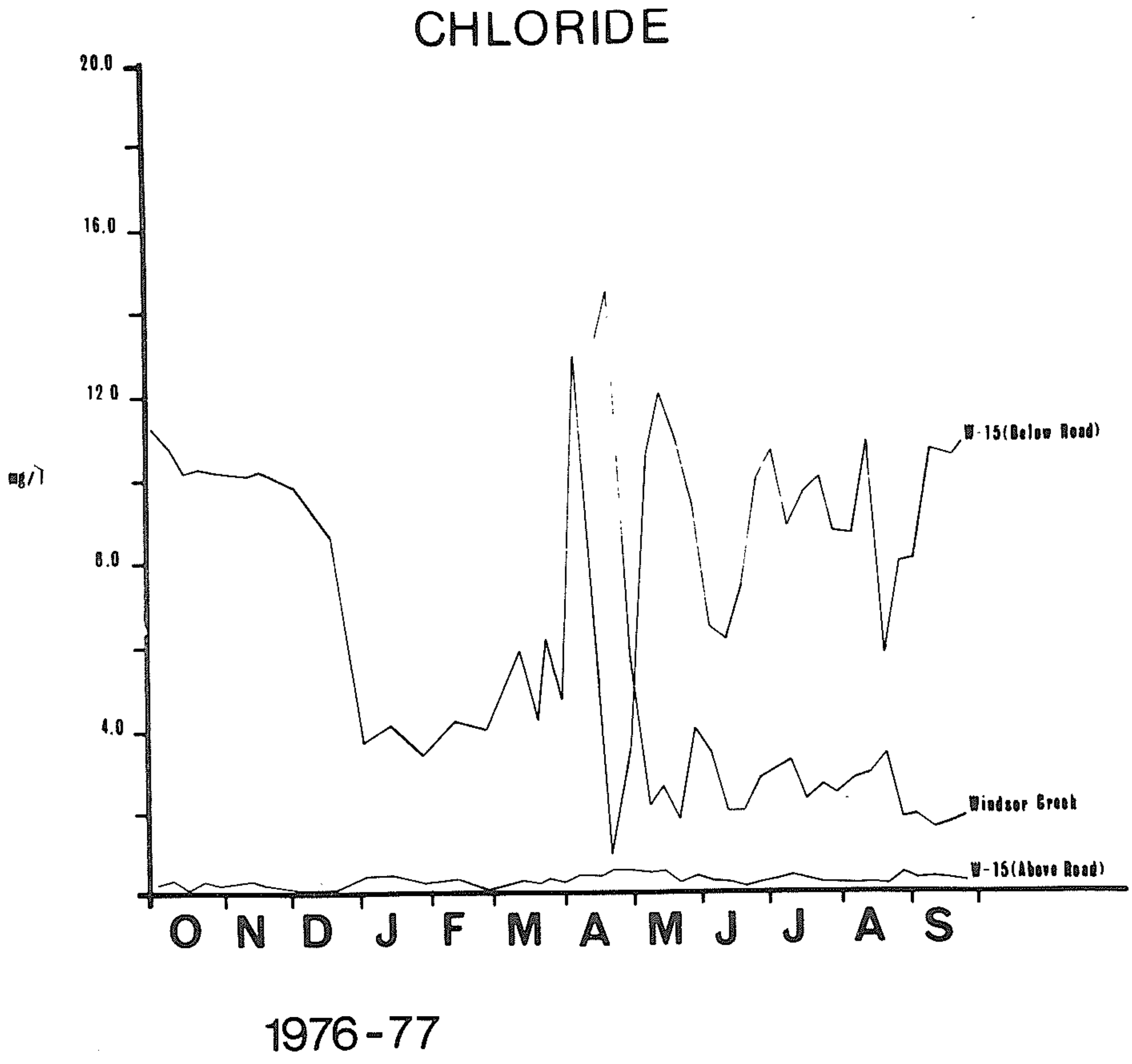


Figure 9. Chloride concentrations in Windsor Creek (below road) and above and below the road in Watershed 15 (Rio en Medio).



the soil system by mass action and the drainage water carries them to the stream. This can represent a real loss of elements important in maintaining site productivity and no doubt is involved in the damage to roadsite vegetation.

Heavy Metals:

Our analyses showed very low concentrations of Pb^{++}, Zn^{++}, and Cu^{++} in road salt and as a result very small quantities were added to roadside areas. Table 7 shows the salt input and stream output values for the study watersheds. It can be seen that the below road areas lost significantly ($P<.01$) more heavy metal quantities than the above road areas and that the below road losses were much larger than the inputs from road salt. This suggests that there were factors operating in the below road areas which caused the release of these metals from the soils. Table 8 shows very pertinent information identifying the fact that all of the Pb^{++} and Cu^{++} lost was attached to particulate material. The majority of Zn^{++} lost for watersheds 6, 7, and 8 also was attached to particulate material; however, for watershed 15 the soluble form was dominant. The large loss of soluble Zn^{++} may be due to the difference in geology over the watersheds. Watersheds 6, 7, and 8 have igneous Embudo granite while the watershed 15 bedrock is gneiss (metamorphic). The soluble Zn^{++} levels increased in the below road streams of all watersheds; however, the interaction with the geology of watershed 15 caused a significantly greater effect ($P<.05$).

It would seem that the large increases in particulate heavy metal losses below the road could be explained most easily by increased sediment losses. Table 9 supports this idea by showing that watersheds which had the greatest losses of particulate heavy metals also had the greatest particulate losses.

Table 7. Road salt input and stream output for heavy metals. Values are grams/ha for the 1976-77 water year

Watershed	Lead		Zinc		Copper	
	Road Salt Input	Stream Output	Road Salt Input	Stream Output	Road Salt Input	Stream Output
S. Fork Tesuque (6)						
Above Road	---	0.2	---	0.4	---	0.3
Below Road	0.3	5.3	0.1	44.9	0.2	3.9
Middle and N. Fork Tesuque (7,8)						
Above Road	---	0.2	---	0.7	---	0.2
Below Road	0.8	20.5	0.2	144.1	0.4	22.1
Rio en Medio (15)						
Above Road	---	0.2	---	1.7	---	0.3
Below Road	0.7	7.5	0.1	262.2	0.4	13.7

Table 8. Loss of heavy metals from watershed areas above and below a road subject to road salting. Values are grams/ha for the period October 1, 1976 to September 30, 1977.

Area	Zinc		Lead		Copper	
	Soluble	Particulate	Soluble	Particulate	Soluble	Particulate
Watershed 6						
Above Road	0.05	0.32	0.0	0.17	0.0	0.30
Below Road	15.6	27.1	0.0	5.1	0.0	3.7
Watershed 7,8						
Above Road	0.21	0.46	0.0	0.22	0.0	0.17
Below Road	34.9	111.0	0.0	20.8	0.0	22.4
Watershed 15						
Above Road	1.1	0.60	0.0	0.20	0.0	0.30
Below Road	204.2	58.0	0.0	7.5	0.0	13.7

Table 9. Inputs and outputs of particulate matter for the study watersheds. Values are kg/ha for the 1976-77 water year.

Watershed	Particulate Matter	
	Road Salt Input	Stream Output
S. Fork Tesuque (6)		
Above Road	0	2.5
Below Road	399.0	11.3
Middle and N. Fork Tesuque (7,8)		
Above Road	0	3.8
Below Road	913.6	781.1
Rio en Medio (15)		
Above Road	0	4.2
Below Road	781.9	257.5

Only watersheds 7 and 8 had a particulate loss approaching the input from road salt. These results parallel the nutrient results for this year in that the watersheds accumulated material added in road salting.

Tables 10, 11, and 12 identify the correlations among heavy metals and particulate levels for the study watersheds. In most cases there were additional significant correlations found for below road areas or the correlation coefficients increased (more of the variation explained).

The results suggest that the heavy metals and sediment leaving the below road area are materials that were on the site (natural soil and organic matter) and not the sand added in the road salting practice. This means that the salt is mobilizing these materials followed by transport to the streams. The most probable reaction is that of Na^+ altering the physical properties of the soil.

The effects of Na^+ on soil physical properties result primarily from the breakdown of the granular soil structure. Calcium and Mg^{++} in the proper proportions maintain soil in good condition of tilth and structure because their divalent charge and low hydration cause them to be tightly held by soil colloids enhancing the coagulation of colloid particles. Monovalent Na^+ which is highly hydrated is not tightly held by colloid particles, permitting individual particles to repel each other and to stay in dispersion (Brady 1974). In most normal soils Ca^{++} and Mg^{++} are the principal cations held by the soil in replaceable or exchangeable form, with Na^+ consisting of a small percentage (i.e. 3 to 7% , McKee and Wolf 1963). An increase of the percentage Na^+ to as much as 12 or 15% causes the granular soil structure to begin to break down when the soil is moistened. Various changes take place resulting in the sealing of pores and a decrease in soil permeability. With further increases in the Na^+ percentage, the soil continues to deteriorate and its pH increases to the level of alkali soils (McKee and Wolf 1963).

Table 10. Significnat nonparametric correlation coefficients ($P<.05$) for heavy metal levels (μg/l), sediment (mg/l), and stream discharge (cfs) above and below the road on Watershed 6 (S. Fork Tesuque Creek) during 1976-1977. (Soluble=Sol., Particulate=Part.)

	Sediment	Sol. Zn	Part. Zn	Sol. Pb	Part. Pb	Sol. Cu	Part. Cu	Stream Discharge
				Above Road				
Sediment	---						.46	
Sol. Zn		---						
Part. Zn			---					-.40
Sol. Pb				---				
Part. Pb					---		.46	
Sol. Cu						---		
Part. Cu							---	
Stream Discharge								---
				Below Road				
Sediment	---	.46	.60		.75		.47	
Sol. Zn		---	.36		.39			
Part. Zn			---		.68		.50	-.32
Sol. Pb				---				
Part. Pb					---		.52	
Sol. Cu						---		
Part. Cu							---	
Stream Discharge								---

Table 11. Significant nonparametric correlation coefficients ($P<.05$) for heavy metal levels (µg/l), sediment (mg/l), and stream discharge (cfs) above and below the road on Big Tesuque Creek during 1976-77. All correlations above the road on W-8 were nonsignificant. (Soluble=Sol., Particulate=Part.)

Above Road (W-7)

	Sediment	Sol. Zn	Part. Zn	Sol. Pb	Part. Pb	Sol. Cu	Part. Cu	Stream Discharge
Sediment	---		.39		.34			
Sol. Zn		---						
Part. Zn			---		.43		.38	
Sol. Pb				---				
Part. Pb					---			
Sol. Cu						---		
Part. Cu							---	
Stream Discharge								---

Below Road (W 7, W 8)

	Sediment	Sol. Zn	Part. Zn	Sol. Pb	Part. Pb	Sol. Cu	Part. Cu	Stream Discharge
Sediment	---		.40		.40			
Sol. Zn		---						
Part. Zn			---		.51		.42	
Sol. Pb				---				
Part. Pb					---			
Sol. Cu						---		
Part. Cu							---	
Stream Discharge								---

Table 12. Significant nonparametric correlation coefficients (P<.05) for heavy metals (µg/l), sediment (mg/l), and stream discharge above and below the road on the Rio en Medio (Watershed 15) during 1976-77. (Soluble=Sol., Particulate= Part.)

Above Road

	Sediment	Sol. Zn	Part. Zn	Sol. Pb	Part. Pb	Sol. Cu	Part. Cu	Stream Discharge
Sediment	---							
Sol. Zn		---						
Part. Zn			---				.42	
Sol. Pb				---				
Part. Pb					---			
Sol. Cu						---		
Part. Cu							---	
Stream Discharge								---

Below Road

	Sediment	Sol. Zn	Part. Zn	Sol. Pb	Part. Pb	Sol. Cu	Part. Cu	Stream Discharge
Sediment	---		.58		.80		.54	-.34
Sol. Zn		---			-.33			
Part. Zn			---		.67		.49	
Sol. Pb				---				
Part. Pb					---		.60	
Sol. Cu						---		
Part. Cu							---	
Stream Discharge								---

In a normal soil Ca^{++} is present in higher concentrations than Na^+ because of its prevelance in the common minerals of rocks and of soil (Hem 1970) and because of the greater affinity that Ca^{++} has for soil exchange sites (Brady 1974). It is easier for Ca^{++} to replace Na^+ in the exchange complex than for Na^+ to replace Ca^{++}, and unless the Na^+ in the soil solution is considerably in excess of the Ca^{++}, no Ca^{++} will be replaced. However, in areas subject to road salting Na^+ is greatly in excess of Ca^{++} and Mg^{++} and through mass action replaces these ions on the exchange complexes. This appears to be the explanation for the high concentrations of Ca^{++}, Mg^{++} and K^+ below the road.

Watershed Characteristics:

There are a number of watershed characteristics which vary among the study watersheds: slope, road length, shoulder width, and below road area. Watershed 15 has the least slope, smallest road area, and smallest below road area (Table 13). There is a highly significant negative correlation (-0.81) between slope and road shoulder width and as a result this watershed has the widest road shoulders. Watershed 6 has the opposite characteristics: greatest slope, largest road area, and largest below road area. Since watershed 6 demonstrated the lowest total loss of sediment and heavy metals (Tables 8, 9) it would seem that the ratio of below road area to road area is a prime factor in regulating loss. Although watershed 6 has 1½ times the road area of watershed 15, the watershed area below the road on W 6 is relatively large resulting in a large ratio (41 versus 19 for W 15). The large watershed area below the road presumably would act in two ways: as a dilution effect (reducing the per unit area application rate); and as a filter (vegetation and organic matter reducing the movement of particulate material). Watersheds 7, 8 have a road length similar to W 6 and a below road area similar

Table 13. Physical characteristics of the below road areas of the study watersheds.

Watershed	Slope (%)	Road (km)	Area (ha)
6	18	.56	16.8
7 and 8	18	.50	6.5
15	12	.35	4.9

to W15 resulting in a road/below road ratio very similar to W15. The loss of sediment and heavy metals from the below road area of W 7 and W 8 is quite large, however, which may be a result of the interaction of a steeper slope with the relatively small below road area. For particulate and heavy metal loss it would seem that the most adverse watershed characteristics would be a combination of steep slope, large road area, and small below road area. These characteristics would be found where a road passed through a drainage basin with steep almost parallel side slopes forming a rather narrow canyon bottom. This would minimize the ratio of below road to road area. If the drainage bottom was V shaped (fan shaped) the below road area would increase markedly even though the slope did not change from the previous example.

INFLUENCE OF SOIL ADDITIVES AND REVEGETATION ON WATER QUALITY IMPROVEMENT

One of the objectives of this study was to test a mulching and seeding treatment for its ability to reduce the influence of road salt on water quality. Unfortunately the low snowfall and subsequent low road salt addition prevented a valid test of this procedure. Results from past studies have shown that mulch and humate application can increase the moisture content of the site which allows more plant growth (as well as reduced Cl^- toxicity, Piatt and Gosz, submitted for publ.). This should reduce erosion by decreasing discharge (greater evapotranspiration) and covering the soil surface. Our treatment area was the below road area of watershed 6 and this area demonstrated very low losses of sediment, nutrients, and heavy metals. Because of the low salt input and reduced spring discharge the mulching and seeding treatment cannot be separated from the influence of the watershed characteristics. I feel confident in answering only one question concerning this treatment. There was concern that if this treatment was able to reduce sediment entering the stream but not the heavy metal levels in the stream that very complex reactions were occurring between road salt and heavy metals or the organics holding the heavy metals. Our results show that in the treated watershed the heavy metals are attached to sediment and decreasing sediment decreases heavy metals in the stream.

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