MAPPING SOIL SALINITY USING FOUR-PROBE RESISTANCE TECHNIQUES

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Introduction

The conventional way of mapping saline areas is by taking soil samples in the field, mixing with water to make a saturated paste, extracting the soil solution under vacuum and determining the salt concentration of the extract. To make an accurate map of a large area requires collection and analysis of numerous samples which soon becomes tedious and expensive. A faster and more direct method is required if dryland salinity problem areas are to be mapped quickly and inexpensively. A method which shows considerable promise for meeting this need is the four-probe bulk soil conductivity method.

Electrical conductance in soils is mostly via pore water and the dissolved electrolytes it contains. With the exception of sodic soils, the contribution of soil minerals to conductance is minimal. In saline soils electrical conductance is a function of ionic strength in the soil solution, the volumetric moisture content and tortuosity. The effect of tortuosity is related to soil type, hence for a given soil only the other two factors remain. As a soil dries out the remaining water increases in salt concentration and its ability to conduct electricity increases. A decrease in volumetric moisture content is at least partially offset by increasing electrolyte strength until salt precipitation starts. Thus bulk soil electrical conductance can be expected to yield reasonably concrete data on soil salt concentrations over a range of moisture contents.

The four-probe method of obtaining bulk soil electrical conductance readings was originally developed for dryland salinity applications by Rhoades and Halvorson (1977). An electrical potential field is

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set up on two electrodes and the bulk soil resistance is read between the other two electrodes. The Wenner electrode configuration consists of four equispaced electrodes with the electrical current being applied to the outer ones. The depth of the volume of soil sampled is approximately equal to the spacing between electrodes. By starting with the electrodes closely spaced and increasing the spacing in increments, readings can be obtained for the depth of soil required by the investigation. For dryland salinity investigations in a discharge area, the salt concentration in a plant root zone of approximately 120 cm depth is of greatest interest.

Method and Location

For the Wenner array of electrodes, the apparent bulk soil conductivity is calculated as:

$$EC_a = \frac{1000}{2\pi a} \cdot \frac{f_t}{R} \qquad (1)$$

where R is the measured resistance (ohms) between the inner electrodes; f_t is the temperature correction factor to adjust the reading to a reference temperature of 25^0C (available from Rhoades and Halvorson, 1977, or U.S. Salinity Laboratory Staff, 1954); a is the spacing between electrodes (cm); and EC_a is the apparent electrical conductivity (mmhos/cm). For this configuration the EC_a represents a volume of soil of about πa^3 and a depth approximately equal to a.

By assuming that layers of soil behave like resistors in parallel, the electrical conductivity of a specific layer (EC_x) can be determined from a sequence of readings by increasing the probe spacings using the relationship:

$$EC_x = (EC_{a(i)} \cdot a(i) - EC_a(i-1) \cdot a(i-1))/(a(i) - a(i-1)) \qquad (2)$$

where a(i) and a(i-1) represent the electrode spacing (cm) for the i^{th} and one previous to the i^{th} reading; $EC_{a(i)}$ and $EC_a(i-1)$ represent the apparent electrical conductivity for the corresponding spacings; and EC_x is the apparent value representing the depth increment from a(i-1) to a(i).

The four-probe method of obtaining EC_a values was applied to the Baildon site in south-central Saskatchewan. The site was located approximately 27 km south of Moose Jaw on the northern slopes of the Cactus Hills. The hills rise several hundred meters above the problem site and there are numerous sloughs located in the highlands. These sloughs are replenished by runoff from surrounding steep slopes. A drilling log of a well on the site showed considerable hydrostatic pressure which indicates the presence of a regional groundwater flow system. Although this regional groundwater may not in itself contribute to the surface salinity problem, it definitely restricts downward movement in a more surficial flow system.

Prior to the EC_a investigation a 61 m X 61 m (200 ft X 200 ft) grid had been laid out over the problem area and a topographical map had been

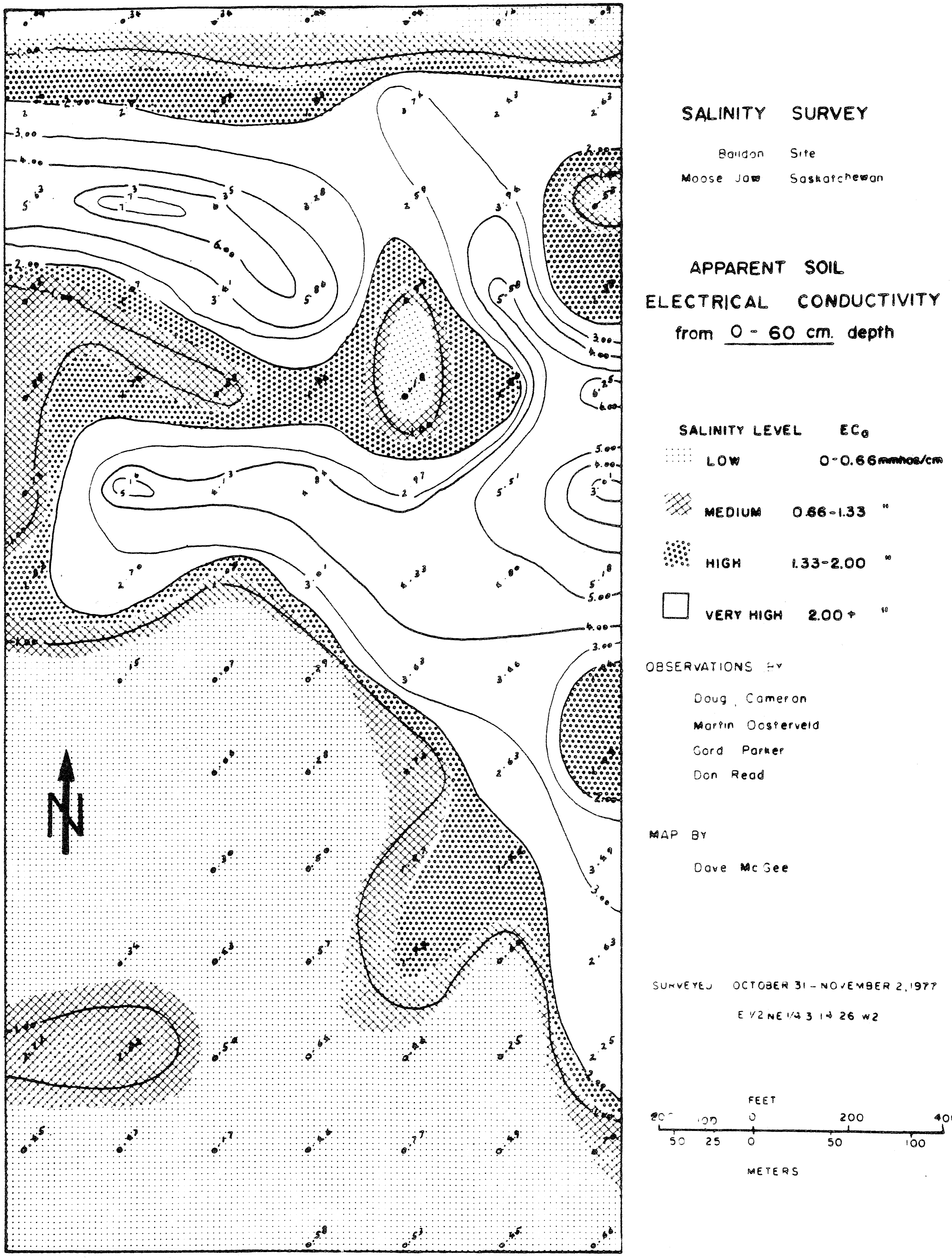
SALINITY SURVEY
Baildon Site
Moose Jaw Saskatchewan
APPARENT SOIL
ELECTRICAL CONDUCTIVITY
from 0 - 60 cm. depth
SALINITY LEVEL
ECa
LOW
0-0.66 mmhos/cm
MEDIUM
0.66-1.33
HIGH
1.33-2.00
VERY HIGH
2.00+
OBSERVATIONS BY
Doug Cameron
Martin Oosterveld
Gord Parker
Don Read
MAP BY
Dave Mc Gee
SURVEYED OCTOBER 31 – NOVEMBER 2, 1977
E 1/2 NE 1/4 3 14 26 W2
FEET
200
400
METERS
50
25
0
100

FIGURE 1

prepared. A soil survey had previously been completed. At each grid point resistance readings were taken using 'a' spacings of 30, 60, 90, and 120 cm. Soil temperature readings were taken at depths of 3-4 cm and a temperature correction factor was determined from the average soil temperature during the survey. The field work was carried out between October 31 and November 2, 1977, with air temepratures ranging from about 0 to 10^{0}C and soil temperatures from 6.5 to 9.0^{0}C.

Results

Temperature corrected values of EC_a were plotted for all depths and lines of equal conductance were drawn. Only those depths of specific interest will be presented in this report. For the purposes of crop response, classes of soil salinity were defined based on saturated extract electrical conductivity (EC_e) as in Table 1.

Table 1. Salinity classes based on saturated extract conductivity of the top 60 cm of soil.

Salinity class	EC_e mmhos/cm
Low salinity	0-4
Medium salinity	4-8
High salinity	8-12
Very high salinity	12+

For this report these salinity levels were assumed to apply to a depth of 60 cm although it is realized that this standard is rather arbitrary and should be more clearly defined. A calibration between EC_a and EC_e was attempted in the field, but this portion of our observations was not successful. A value of $EC_e = 6.EC_a$ was estimated from the literature (Rhoades and Halvorson, 1977) based on the textural groups observed in the field. The salinity summary map (see Figure 1) indicates a rapid increase in salinity in the sidehill seep from low to very high salinity. The largest portion of the problem area falls into the very high salinity category which is consistent with the appearance of the crop. It also indicates that the problem has existed for a number of years.

The directions of groundwater flow were determined from EC_x values in the 90 to 120 cm depth increment. This map (see Figure 2) indicates that several stages of salinity exist on the site. The first outcropping is a sidehill seep. The groundwater flow cannot be completely evaporated from the sidehill seep and some of the water flows into the next stage downslope. The water which leaves the sidehill seep contains much more salt than that feeding the seep since it is in contact with the salt left from previous evaporation. On this site there is a chain of such salinity cells with the most saline one being the last one in the sequence. The sidehill seep in the southwest corner of the map spills over into at least three subsequent evaporation areas of increasing salinity.

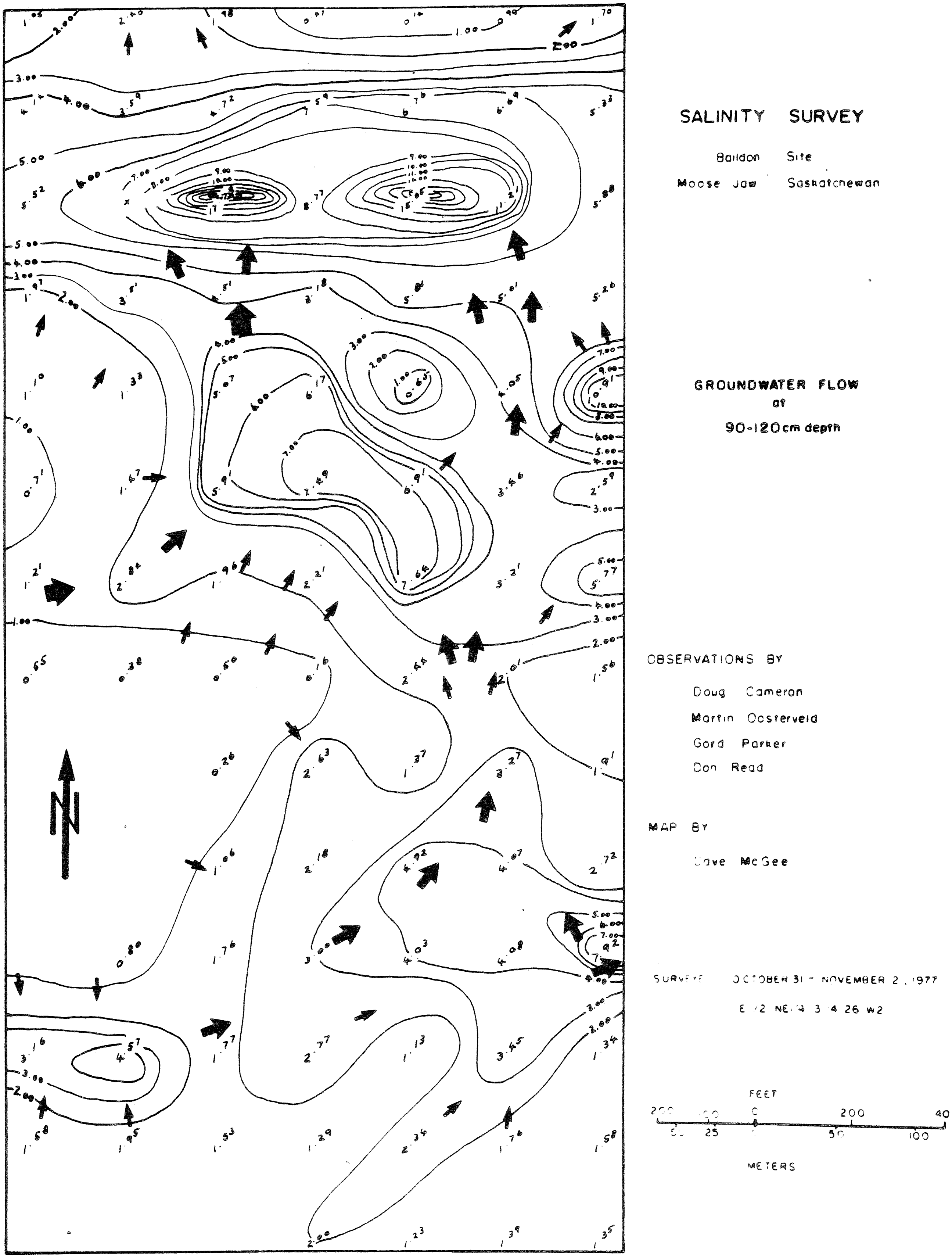
SALINITY SURVEY
Baildon Site
Moose Jaw Saskatchewan
GROUNDWATER FLOW at 90-120cm depth
OBSERVATIONS BY
Doug Cameron
Martin Oosterveld
Gord Parker
Don Read
MAP BY
Dave McGee
SURVEY OCTOBER 31 - NOVEMBER 2, 1977
E 1/2 NE 1/4 3 4 26 W2
FEET
200 100 0 200 400
50 25 0 50 100
METERS

FIGURE 2

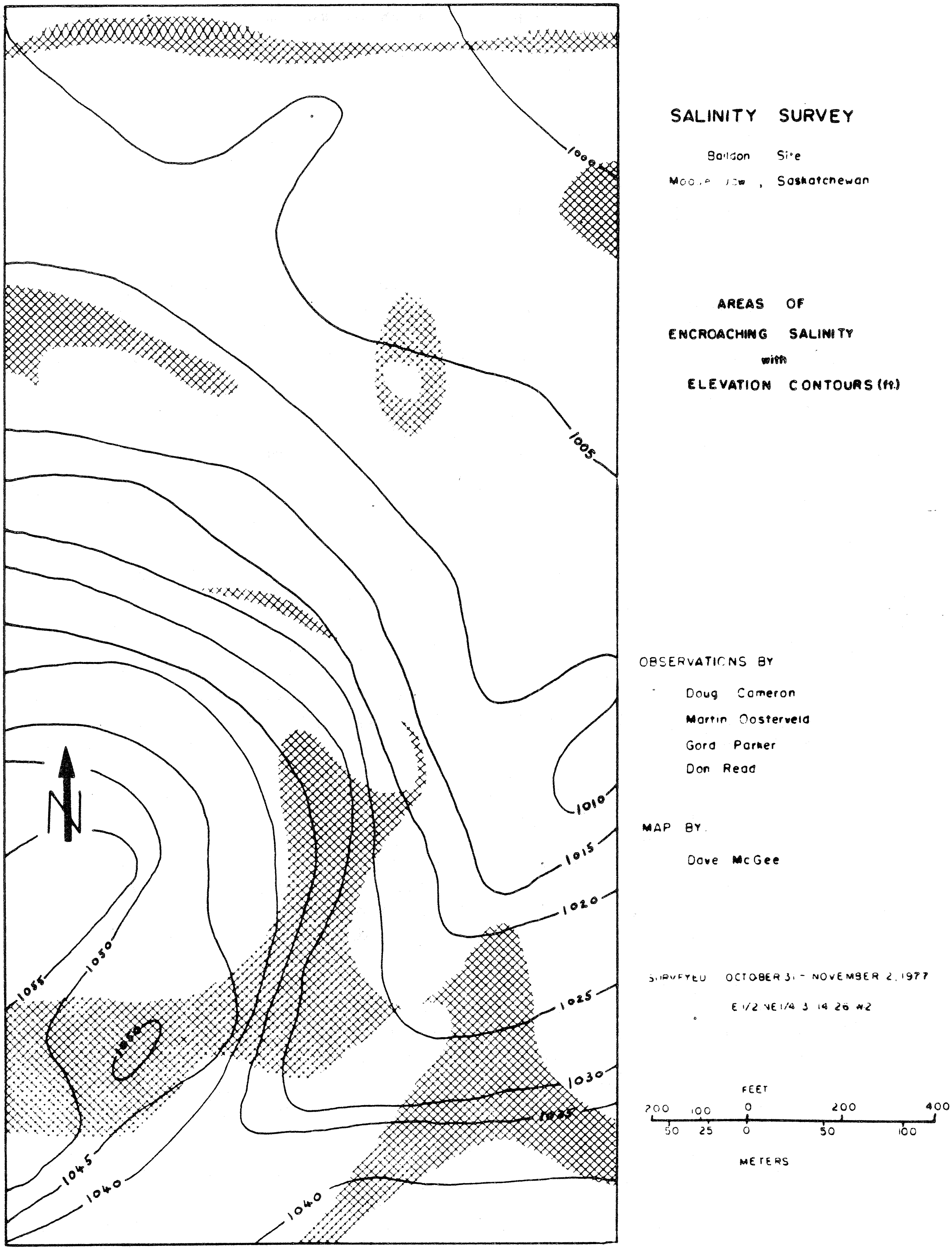
SALINITY SURVEY
Baildon Site
Moose Jaw, Saskatchewan
AREAS OF
ENCROACHING SALINITY
with
ELEVATION CONTOURS (ft)
OBSERVATIONS BY
Doug Cameron
Martin Oosterveld
Gord Parker
Don Read
MAP BY
Dave McGee
SURVEYED OCTOBER 31 - NOVEMBER 2, 1977
E 1/2 NE 1/4 3 14 26 W2
FEET
200 100 0 200 400
50 25 0 50 100
METERS
N
1000
1005
1010
1015
1020
1025
1030
1035
1040
1040
1045
1050
1055
1060

FIGURE 3

From Figure 2 and the depth profiles of EC_a an area was outlined where salinity is likely to encroach if present management is continued. As is evident from the shading in Figure 3 some further expansion may be anticipated in an upslope direction. A sidehill seep will likely develop on both sides of a slight valley running in a southwesterly direction near the south end of the map and some further encroachment may be anticipated into the less saline areas on the flat land at the bottom of the slope. Movement of groundwater at the 90-120 cm depth into the adjacent property to the north is apparent and some expansion of salinity in that direction may be anticipated.

Shallow drilling in an upslope direction from the sidehill seep indicated a saturated sand layer which terminates near the saline outcropping. The upslope extent of this permeable layer could not be mapped since the drill available could not penetrate to the required depth and deep readings of EC_a could not be interpreted with confidence. The more permeable material is overlain by saline till making it difficult to detect the water bearing layer from changes in EC_a readings. The water table did appear as a distinct break in the EC_a readings plotted against depth. When this break was extended to an upland slough to the west of the mapped area it indicated that the water table in this slough was some 6 m (20 ft) above the level of the water table at the sidehill seep. Although the hydraulic connection was not verified conclusively there appears little doubt that this slough is a very important source of recharge for the sidehill seep.

The water feeding the sidehill seep had an electrical conductivity of about 1.5 mmhos/cm which is not particularly saline. This would indicate that the water has not been in contact with a saline medium for a prolonged period. The quality adds credence to the possibility that much of the water could come from concentrated recharge from the upland slough.

The good quality of the water at that location also raises the possibility of intercepting some of it by using a vegetative interceptor strip. The only limitations to this method are the steepness of the slope and the layering of the soil near the outcropping. The plant roots will have to penetrate the till layer to gain access to the water bearing layers. Because of the steep slope even deep rooted plants will only be able to reach the water table for an upslope distance of about 30 m.

In order to stop further accumulation of salt in the discharge area either recharge will have to be cut off at the source or subsurface drainage will have to be installed in the discharge area. At the present time cutting off recharge at the source appears to be a more attractive solution. Draining the upland recharge slough and increasing crop water use in the higher land should go a long way in reducing the amount of recharge.

A time delay must be anticipated in reclaiming the saline area. If the discharge can be cut off by preventing recharge and intercepting water just above the sidehill seep, a decrease in salinity will start at the upslope end and work through the various stages in the flow system. Discharge to the last stages of the flow system will not be cut off until excess water from all upslope stages has been removed. Since these last stages are also the most saline, the leaching of salt will take longer before the soil is returned to a productive state. The EC_e values in the top 60 cm range in concentration up to 40 mmhos/cm and must be reduced to at least 1/5 of its present level before medium tolerance crops can be considered. The present surface salinity is high enough in the very saline areas to inhibit establishment of even the most salt tolerant varieties of forages. Establishment of a crop will have to be done in stages as reclamation progresses.

Further Research with the Four-probe Method

For the particular site, a calibration should be established between EC_e and EC_a. As well the mapping should be expanded to include the entire problem area. When this is completed an estimate of the volume of inflow can be made based on a coefficient times the difference between potential evaporation and precipitation.

Some further work will have to be done in understanding the anticipated accuracy of quantitative maps. There are usually significant textural changes both with depth and location in a given problem field. Perhaps several calibrations for each site will need to be prepared. The temperature correction factor will also require some further study since a 10^0C error in temperature will result in a 28% discrepancy in the corrected conductivity reading. Early spring, late fall, and intensive heating periods in the summer can easily cause a 10^0C gradient from the soil surface to the 120 cm depth.

Interpretations which depend on relative values, such as directions of groundwater flow, can be treated with reasonable confidence, since the differences are usually large in comparison with variations due to temperature and texture. This also applies to sequential values in time since textural variations will be constant for a specific site.

Summary

The four-probe method of mapping saline areas has been shown to be very useful for obtaining a detailed map of saline areas with an acceptable amount of effort. The technique is particularly useful for interpretations depending on relative values such as directions of groundwater flow and areas where salinity is encroaching. Some additional investigations will be required to understand the limitations of the techniques for applications where accurate maps of saturated extract electrical conductivity are required.

References

RHOADES, J. D. and HALVORSON, A. D. 1977. Electrical conductivity methods for delineating saline seeps and measuring salinity in Northern Great Plains soils. ARS W-42, U.S. Salinity Laboratory, Riverside, California. 45 pp.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. U.S.D.A. Handb. 60. 160 pp.