United States Department of Agriculture

NRCS

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Subject: Soils – Geophysical Investigations **Date:** 2 July 2014

To: Joyce Swartzendruber
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Purpose:
The development, control, and reclamation of saline seeps are major concerns of management in the Northern Great Plains. This field study was conducted to evaluate the use of different electromagnetic induction (EMI) meters to identify and characterize saline seeps and recharge areas in an area of dryland farming. Each meter provides different depths of observation and resolution.

Participants:
Kelli Coleman, Soil Conservation Technician, USDA-NRCS, Conrad, MT
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Heidi Fleury, Pathways Student, USDA-NRCS, Shelby, MT
Pat Hensleigh, State Agronomist, USDA-NRCS, Bozeman, MT
Holly Taylor, Soil Conservationist, USDA-NRCS, Fort Benton, MT
Joyce Trevithick, Area Agronomist, USDA-NRCS, Great Falls MT

Activities:
All activities were completed on 16 June 2014.

Summary:

1. This study was greatly shortened by the untimely hospitalization of Jim Doolittle in Great Falls and his discharge with instructions to return immediately home for further care. It is a deep disappointment that this study could not be completed. Hopefully, the National Soil Survey Center will be able to support a return visit by Jim Doolittle to Great Falls, Montana, this fall to complete this comparative study of the effectiveness of different EMI meters to identify saline seeps and recharge areas in the Northern Great Plains..

2. An EM31 meter (Geonics serial number: 9315002; USDA-NRCS: AG0002518477) and a 25-ft cable with 10-pin connector (EM31 meter to field computer) have been loaned by the National Soil Survey Center to Patrick Hensleigh and the Montana State Office Staff for their use and further evaluation. If this meter is found useful, it will be transferred to the Montana State NRCS Office.

3. At two sites in Cascade County, apparent conductivity (EC_a) maps identified the probable locations of recharge and discharge areas. Areas with low EC_a were associated with recharge areas. Areas with high EC_a were associated with discharge, salt accumulation and saline seeps.

Limited ground-truth soil observations and cores are required to confirm these interpretations and provide measures of the salinity levels associated with these identified areas,

4. Apparent conductivity maps provide a rational approach for planning the management of saline seeps. Time-lapse EC_a surveys can be used to evaluate the extent of saline seeps and document the speed and extent of reclamation processes.

5. An Excel worksheet containing all geo-referenced EMI data that were collected at the Cascade County sites with the EM31 meter have been forwarded to Patrick Hensleigh.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to work with members of your fine staff and be of assistance to you.

JONATHAN W. HEMPEL
Director
National Soil Survey Center

cc:
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Technical Report on EMI Saline Seep Study, Cascade County, Montana
16 June 2014.

Jim Doolittle

The development, control, and reclamation of saline seeps are major concerns of management in the Northern Great Plains. This study explores the use of different electromagnetic induction (EMI) meters and the resulting, measured apparent conductivity (EC_a) data to identify recharge and discharge areas associated with saline seeps. In an abbreviated study, a mobile EMI platform (see Figure 1) was used to survey about 94-acres, which is under the Conservation Reserve Program (CRP), in Cascade County.

Figure 1. A mobile EMI survey was conducted across 94-acres of CRP with an EM31 meter (arrow) in Cascade County, Montana.

Background:

Changes in land use and periods of higher precipitation in the Northern Great Plains have contributed to the development of saline seeps. A recent phenomenon is the increase in the number of saline. In 1987, Daniels (1987) described saline seeps as areas of saline soils that have formed in non-irrigated areas within the last 30 to 40 years. Brown et al. (1982) noted that saline seeps "can be differentiated from other saline soil conditions by their recent and local origin, saturated root zone profile, shallow water table, and sensitivity to precipitation and cropping systems". Saline seeps are areas of groundwater discharge. They develop when excess water that is not absorbed by plants moves downwards in soil profiles from upslope, recharge areas and eventually reappears at the surface in downslope, discharge areas. As the excess water moves through the soil, it dissolves mineral salts. On lower-lying slope positions, the water discharges on the surface, where it evaporates, concentrates, and leaves the salts behind as a white crust. Because of the increased soluble salt concentration, crop growth in the saline seeps is reduced or excluded (Brown et al., 1982).

For control and reclamation of saline seeps, both the discharge and recharge areas need to be identified and located. As noted by Brown et al. (1982), most remedial measures for controlling saline seeps are applied to recharge areas, which are located on nearby, higher-lying areas.

Electromagnetic induction (EMI) has been used to detect groundwater recharge and discharge areas, and chart the distribution of soluble salts across landscapes (Williams and Baker, 1982; Cook et al., 1989a, 1989b, 1992; William and Arunin, 1990; Richardson and Williams, 1994; and Cook and Williams, 1998). The apparent conductivity (EC_a) measured by EMI sensors is principally affected by the soluble salt, clay, and water contents of soils (McNeill, 1980). However, in areas of saline soils, variations in soluble salt content is the principal factor affecting EC_a (William and Baker, 1982). Williams and Baker (1982) and Williams (1983) concluded that, in saline soils, salinity can account for 65–70% of the EMI response.

The distribution of saline seeps is largely controlled by surface geology, above-normal periods of precipitation, and farming practices that encourage water to move beyond the root zone. Recharge and discharge areas are often underlain by geologic and soil materials of low hydraulic conductivity such as shale, dense till, or clay. These relatively impermeable layers restrict the downward movement of water and compel it to flow laterally along the restricting layer into lower-lying slope positions. Saline seeps develop wherever the saline groundwater comes within about 1.5 m of the surface (Daniels, 1987). Typically, discharge areas will expand laterally and downslope with limited upslope extension (Brown et al., 1982). Because of upward leaching and evaporative processes, salts are concentrated near the soil surface in discharge areas (Richardson and Williams, 1994). The higher concentration of soluble salts in surface layers results in high EC_a and *inverted salt profiles* (EC_a is highest in surface layers and decreases with increasing depth). In general, discharge areas have higher EC_a than recharge areas.

Recharge areas are always at higher elevations and generally within 600 to 2,000 feet of discharge areas (Brown et al., 1982). In addition, the recharge area is generally located directly upslope or at an angle across the slope from the discharge area (Brown et al., 1982). Recharge areas are characterized by the downward leaching and concentration of salts at greater soil depths. As a consequence, EC_a is low in surface layers and increases with increasing depth (*regular salt profile*). The low soluble salt and water contents of recharge areas are associated with low EC_a (Mankin and Karthikeyan, 2002).

Study Area:
The study sites are located in Sections 28, 33, and 34, Township 21 N, and Range 3 E. The southeast corner (47.5318 N, 111.3420 W) of the study areas is located about 3.75 miles northwest of the center of Great Falls, Montana, on the Chamberlain farm. Figure 2 is a soil map of the survey sites (1 & 2) from the Web Soil Survey[1]. As evident on this map, the study area drains towards Watson Coulee to the east (blue line on right side of map). Soil map units delineated within these sites include: Assinniboine fine sandy loam, 4 to 8 percent slopes (16); Dooley sandy loam, 8 to 15 percent slopes (55); Ethridge-Kobar silty clay loams, 2 to 8 percent slopes (68); Evanston loam, 2 to 4 percent slopes (69); Tally loam, 2 to 8 percent slopes (189); Tanna clay loam, 0 to 2 percent slopes (191); and Yawdim-Rentsac-Cabbart complex, 15 to 50 percent slopes (231). The names and symbols for these map units are listed in Table 1.

The very deep, well drained Assinniboine, Dooley, Ethridge, and Evanston soils formed in reworked glacial lake deposits (Glacial Lake Great Falls) and/or alluvium on lower-lying stream terraces. Kobar (fine, montmorillonitic Borollic Camborthid) is an inactive soil series. The very deep, well drained Tally soils formed in material derived from eolian deposits or alluvium on stream terraces and hills. The more sloping, higher-lying, upland portions of the study areas are composed of Cabbart, Rentsac, Tanna, and Yawdim soils. The moderately deep, well drained Tanna soils and the shallow, well drained Cabbart,

[1] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed [06/25/2014].

Rentsac, and Yawdim soils formed in colluvium or residuum weathered from Cretaceous-age calcareous siltstone, sandstone, and shale. The taxonomic classifications of these soils are listed in Table 2.

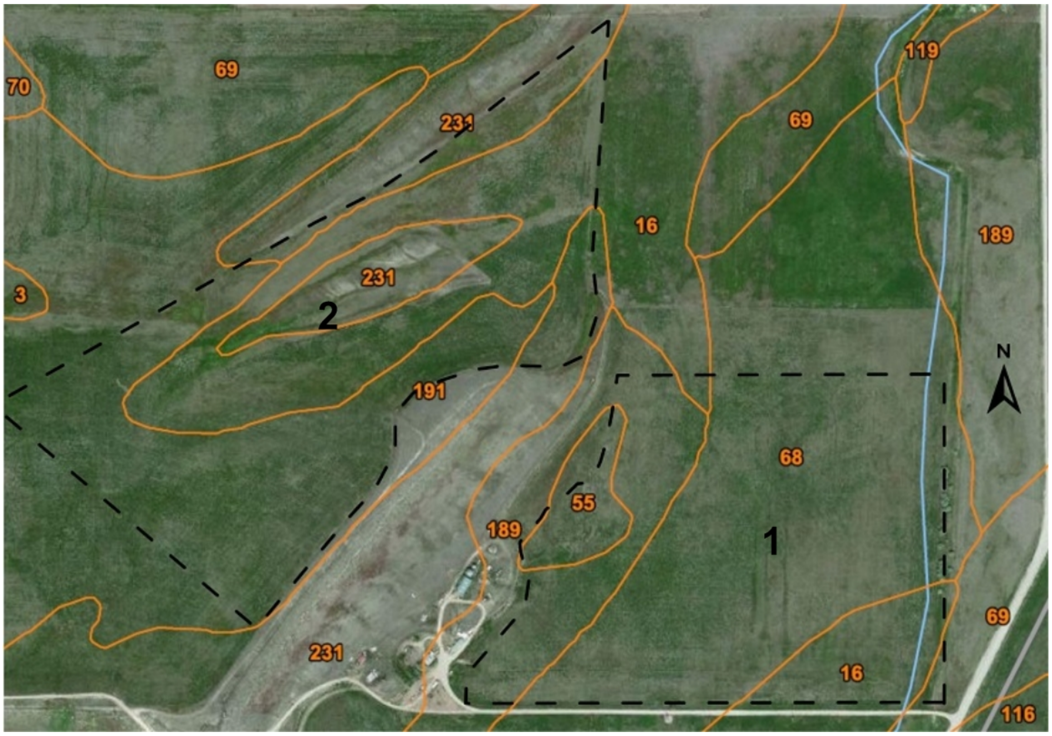

Figure 2. This soil map shows the locations of the two saline seep study sites (1 & 2) in Cascade County. Montana.

Table 1. Soil map units delineated within the study sites in Cascade County.

Map Unit Symbol	Map Unit Name
16	Assinniboine fine sandy loam, 4 to 8 percent slopes
55	Dooley sandy loam, 8 to 15 percent slopes
68	Ethridge-Kobar silty clay loams, 2 to 8 percent slopes
69	Evanston loam, 2 to 4 percent slopes
189	Tally loam, 2 to 8 percent slopes
191	Tanna clay loam, 0 to 2 percent slopes
231	Yawdim-Rentsac-Cabbart complex, 15 to 50 percent slopes

Table 2. Soil taxonomic classifications of the soils identified within the study.

Soil Series	TAXONOMIC CLASS
Assinniboine	Fine-loamy, mixed, superactive, frigid Aridic Argiustolls
Cabbart	Loamy, mixed, superactive, calcareous, frigid, shallow Aridic Ustorthents
Dooley	Fine-loamy, mixed, superactive, frigid Typic Argiustolls
Ethridge	Fine, smectitic, frigid Torrertic Argiustolls
Evanston	Fine-loamy, mixed, superactive, frigid Aridic Argiustolls
Rentsac	Loamy-skeletal, mixed, superactive, frigid Lithic Calciustepts
Tally	Coarse-loamy, mixed, superactive, frigid Typic Haplustolls
Tanna	Fine, smectitic, frigid Aridic Argiustolls
Yawdim	Clayey, smectitic, calcareous, frigid, shallow Aridic Ustorthents

No mention of saline seeps is made for these soils and map units. Saline or wet spot symbols, if used to mark these areas on the original soil maps have been removed from modern digitized soil survey maps. The complex hydrology and morphology of soils in saline seeps is unrecorded.

Equipment:
The EM38 and EM31 meters were used in this study. These meters are manufactured by Geonics Limited (Mississauga, Ontario)[2]. These meters are portable and require only one person to operate. No ground contact is required with these meters. The EM38 meter weighs about 3 kg (6.6 lbs.), and operates at a frequency of 14,600 Hz. It has effective penetration depths of about 0 to 0.75 and 0 to 1.5 m in the horizontal (HDO) and vertical dipole (VDO) orientations, respectively (Geonics Limited, 1998). This meter was pulled in a sled behind a utility vehicle at speeds of about 3 to 5 m/hr.

The EM31 meter weighs about 12.4 kg (27.3 lbs.), has a 3.66 m intercoil spacing, and operates at a frequency of 9,810 Hz. When placed on the soil surface, the EM31 meter has effective penetration depths of about 0 to 3.0 and 0 to 6.0 meters in the HDO and VDO, respectively (McNeill, 1980). McNeill (1980) has described the principles of operation for the EM31 meter. This meter was pulled in a sled behind a utility vehicle in the VDO at speeds of about 3 to 5 m/hr (Figure 1).

A Pathfinder ProXT GPS receiver (Trimble, Sunnyvale, CA) was used to georeferenced EMI data collected with the EM31 meter.[2] Position data were recorded at a rate of one reading per second.

The Geonics DAS70 Data Acquisition System was used with the EMI meters to record and store both EC_a and GPS data. The acquisition system consists of an EMI meter, GPS receiver, and either an Archer or Allegro CX field computer (Juniper Systems, Logan, Utah).[2] The RTmap31 software program developed by Geomar Software Inc. (Mississauga, Ontario) was used with the EM31 meter and the Allegro CX field computer to record, store, and process EC_a and GPS data.[2] The recorded EC_a data were not corrected to a standard temperature of 75^o F.

To help summarize the results of the EMI surveys, SURFER for Windows (version 10.0), developed by Golden Software, Inc. (Golden, CO), was used to construct the simulations shown in this report.[2] Grids of EC_a data were created using kriging methods with an octant search.

Results:
The measurements recorded with the EM38 meter were surprising low with a large number of negative values. In addition, the EM38 meter did not record measurements for a large portion of Study Site 1, and in Study Site 2, intermittent noise or "*spikes*" affected the quality of the measurements. There was also a noticeable drift to lower EC_a values as the EM38 survey progressed. The data are therefore considered defective, and will not be discussed further in this report.

Site 1:
A detailed survey was conducted across Chamberlain's fields 9 and 10 (about 55-acre) using a mobile platform with an EM31 meter (operated in the VDO) towed in a plastic sled. Data were recorded at a rate of two measurements per second. Based on 9190 EC_a measurements, for the nominal depth of investigation (0 to 6 m), EC_a averaged 39 mS/m and ranged from about 8 to 86 mS/m across this study site. One-half of the recorded measurements were between about 31 and 46 mS/m.

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[2] Trade names are used to provide specific information. Their mention does not constitute endorsement by USDA-NRCS.

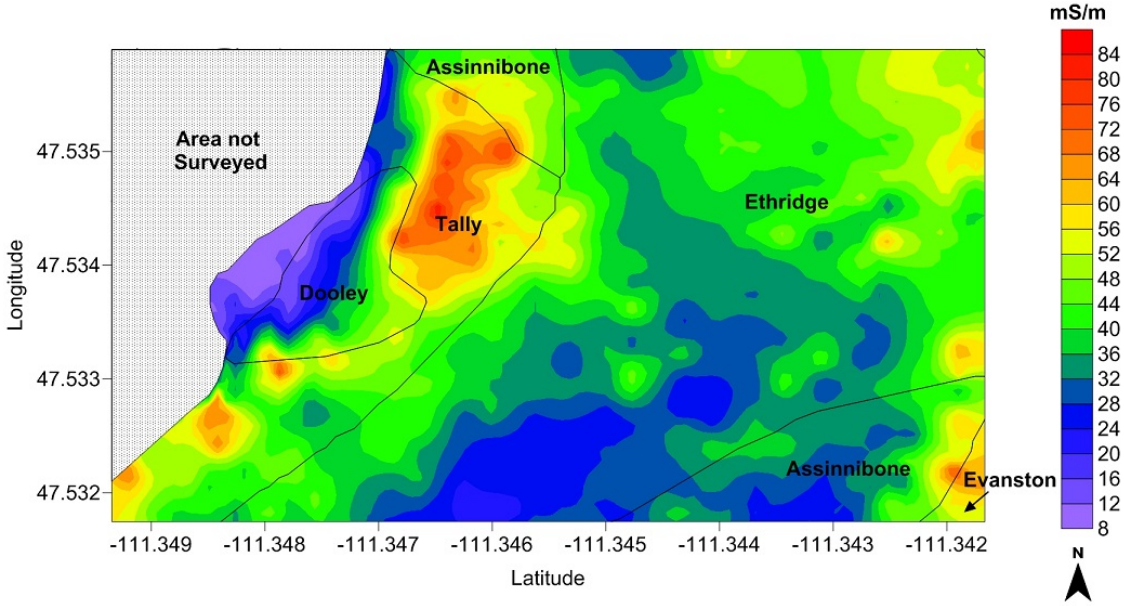

Figure 3. A 2D simulation of EC_a measured with the EM31 meter across Study Site 1.

Figure 3, is a two-dimensional (2D) plot of the EC_a data collected with the EM31 meter at Study Site 1. This plot is based on the 9190 EC_a measurements collected with the EM31 meter. In Figure 3, areas of higher EC_a (> 56 mS/m) were associated principally with areas of higher salt concentrations. These areas are arranged in two discontinuous, linear-trending, discontinuous patterns: one along the more sloping area of Tally soils in the western portion of the site, and the other in areas of Assinniboine, Ethridge and Evanston soils that are located near Watson Coulee in the eastern portion of the site. In the western portion of this site, the higher-lying area of Dooley and Tally soils with lower EC_a (< 28 mS/m) are believed to represent a potential recharge area.

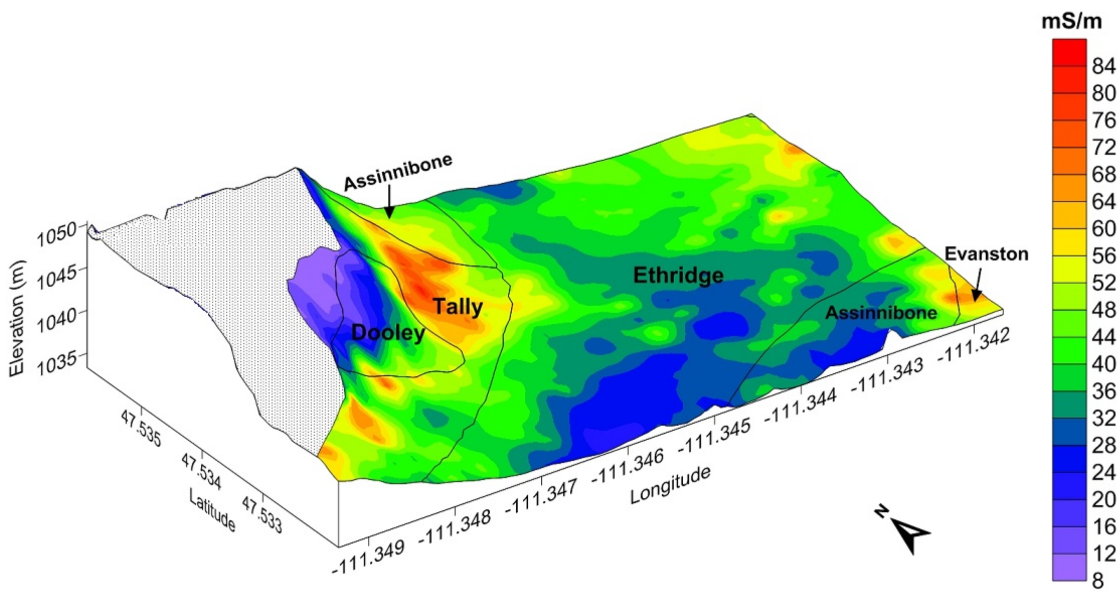

Figure 4. A 3D simulation of EC_a measured with an EM31 meter across Study Site 1. Elevation data used in this simulation were obtained by GPS.

Figure 4 is a three-dimensional (3D) image of the EC_a data collected with the EM31 meter at Study Site 1. The elevation data used to construct the underlying wireframe image were collected with the Trimble

Pathfinder ProXT GPS receiver. The overlying contour plot of EC_a data is the same as shown in Figure 3. Several discontinuous areas of higher EC_a (>56 mS/m) are evident within the more sloping delineation of Tally loam, 2 to 8 percent slopes. In this 3D image, the relative locations of potential recharge and discharge areas on the more sloping, upland area in the western portion of the study site are evident. The areas of higher EC_a along the more sloping areas of Talley soils are believed to represent saline seeps. These areas are discontinuous and vary in size, suggesting a complex hydrology that fosters preferential flow of excess water and variable concentrations of soluble salts.

Site 2:
A second, detailed survey was conducted across Chamberlain's fields 6 and 18 (about 25-acre) using the same mobile platform with an EM31 meter (operated in the VDO) towed in a plastic sled. Compare with Study Site 1, Study Site 2 is located on a higher-lying upland area and has greater relief. The study site is divided by a deep, dry coulee or draws that trend in a downslope direction from west to east. This draw is mostly mapped as Yawdim-Rentsac-Cabbart complex, 15 to 50 percent slopes (231).

Data were recorded at a rate of two measurements per second. Based on 3970 EC_a measurements, for the nominal depth of investigation (0 to 6 m), EC_a averaged 31 mS/m and ranged from about -26 to 129 mS/m across this study site. One-half of the measurements were between about 12.4 and 43 mS/m. Compared with the EC_a data from Study Site 1, measurements were generally lower and more variable across Study Site 2. Negative readings recorded within Study Site 2 were attributed to metallic artifacts scattered across the site. The overall lower EC_a at Site 2 is attributed to higher-lying, drier, and shallower to bedrock soils compared to the soils at Study Site 1.

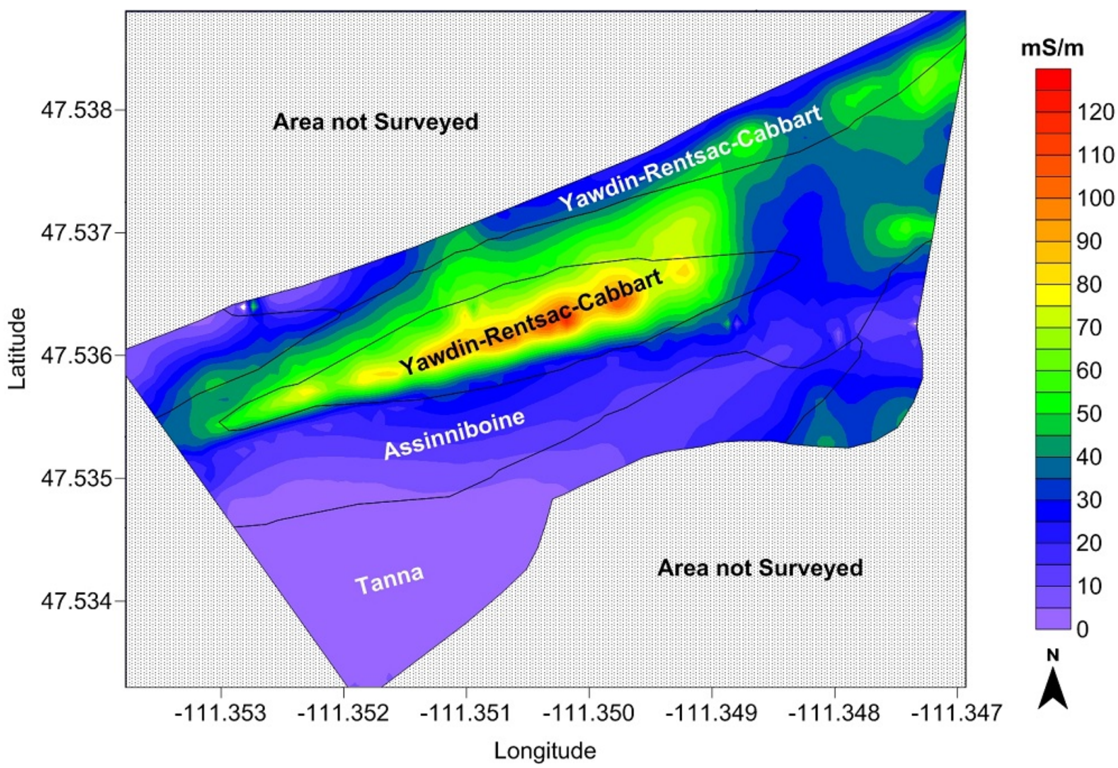

Figure 5. A 2D simulation of ECa measured with the EM31 meter across Study Site 2.

Figure 5, is a 2D plot of the EC_a data collected with the EM31 meter at Study Site 2. This plot is based on the 3970 EC_a measurements collected with the EM31 meter. In Figure 5, areas of higher EC_a (> 50 mS/m) are principally associated with south-facing, 15 to 50 percent slopes to a dry coulee that is composed of shallow, well drained Yawdim, Rentsac, and Cabbart soils. A traverse was run along the centerline of the coulee. Along this line, soils of increased wetness were observed. The higher moisture content of these soils could, in part, account for the higher EC_a measured along this traverse line.

Figure 6 is a 3D image of the EC_a data collected with the EM31 meter at Study Site 2. Once again, the elevation data used to construct the underlying wireframe image were approximated using a Trimble Pathfinder ProXT GPS receiver. The overlying contour plot of EC_a data is the same as shown in Figure 5. Low EC_a and presumably low soluble salt storage occurred in the upland hills with a noticeable increase on the flanking south-facing side slope areas, where soil materials are mainly composed of colluvium underlain by weathered bedrock material at relatively shallow, but varying depth. The north-facing slopes to this dry coulee have significantly lower EC_a compared to the south-facing slopes. This suggest that seepage may occur along lithologic boundaries which dip towards the south. Along the bottom of the coulee, soils are presumed to have higher moisture and soluble salt contents. Here the conductivity is higher than in other parts of this study site.

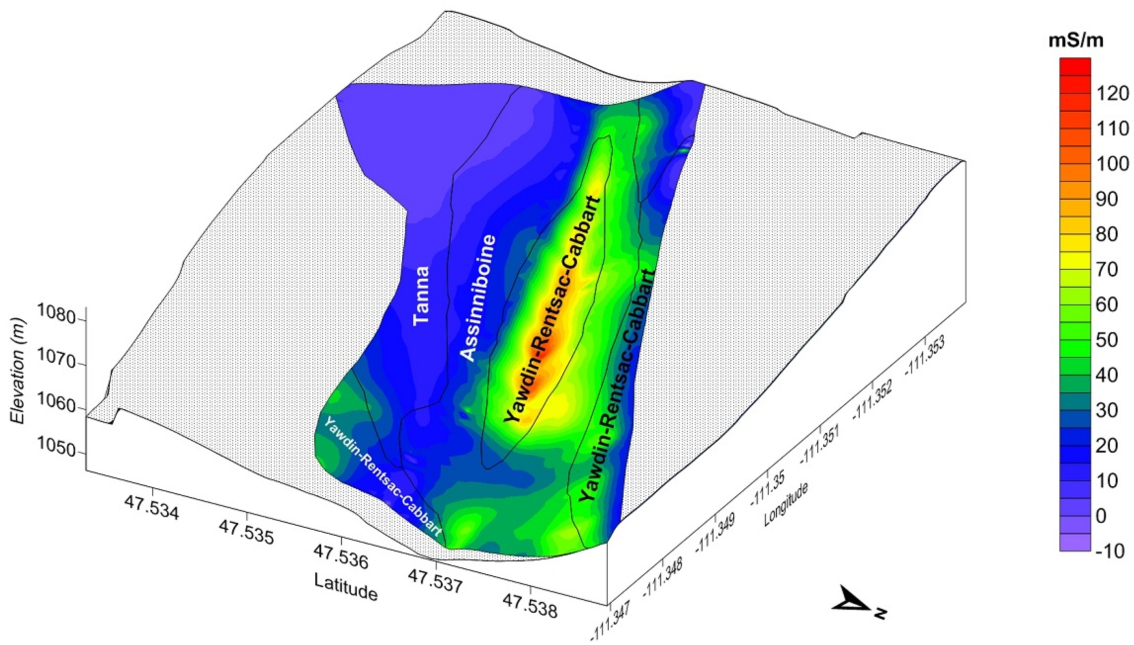

Figure 6. This 3D simulation shows the spatial distribution of EC_a for the upper 0 to 6 m of the soil across the Site 2 in Cascade County. Elevation data used in this simulation were obtained by GPS.

Apparent conductivity maps are valuable tools to management as they show the locations of not only established, but emergent saline seeps and the connectivity among them. Areas with low EC_a represent areas of vertical recharge. Here, infiltrating water leach soluble salts deeper in soil profiles. On the other hand, areas with high EC_a are associated with discharge and salt accumulation.

The interpretation of EMI data is site-specific. Best interpretations occur where subsurface layers are well understood (thru soil core and borehole information) and continuous, and the groundwater occurs in a single water-bearing layer (Parks et al., 2011). The two study sites in Cascade County offered great challenges to EMI surveys and the assessment of recharge and discharge areas. These sites were challenging due to the known lateral and vertical variations in soil properties, and the presumed segmented and discontinuous nature of soil, stratigraphic, and lithologic layers, which fosters a discontinuous hydrodynamic communication among groundwater surfaces and also variations in soluble salt concentrations. The hydropedological- and stratigraphic complexity of these sites, makes interpretation of EMI data more difficult to interpret and predict. However, the spatial EMI data does provide insight into the hydro-stratigraphic complexity of these sites.

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