DETECTING CANAL SEEPAGE USING THE ELECTROMAGNETIC INDUCTION METHOD

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SUMMARY

Many water districts in California are faced with important water losses and reduced irrigation efficiency due to canal seepage. Thus, it is necessary to identify tools that can help detect potential leakages along canals in an effort to conserve irrigation water. The goal of this study was to apply the electromagnetic induction (EM) technology to detect potential seepage in a section of canal located at the Lost Hills Water District, CA. A mobile system comprising of an EM-31 sensor, GPS, and soil sampler, was developed to conduct the survey. Potential canal seepage was assessed when the canal was open (August) and then closed (October). Data calibration was performed following soil sampling at 0-8 ft. Contour maps indicated that soil water content was lowest near the surface (0-3 ft) with values ranging from 20-30%. For all depths, water content was greater in the canal mid-section. After the canal had been closed in October, water content remained high in the mid-eastern segment of the canal. Greater water content could be indicative of potential seepage along that part of the canal. Percent soil clay content increased with depth and ranged from 10-50%. The overall results of such study can be useful in improving water management and conservation strategies along irrigation canals.

INTRODUCTION

Seepage from irrigation canals is a serious water management problem in California's San Joaquin Valley (SJV) since more than 600 million cubic meters of water are being lost every year. Seepage reduces irrigation efficiency and its water may contain toxic substances harmful to soils and groundwaters. Additionally, water shortage is becoming a very important problem for California agriculture. Is it is forecasted that, by 2020, California's population will increase to 47.5 million people and the state will experience water shortages of 2.4 million acre-feet in average years and 6.2 million acre-feet in drought years. These shortages will inevitably result in water reallocation to urban and industrial sectors, thereby posing a significant threat to the agriculture industry. Thus, it is important to identify tools that can help detect potential leakages along canals thereby conserving irrigation water and sustaining crop productivity in the region.

The electromagnetic (EM) induction technology has become a very useful and cost-effective tool to monitor and diagnose soil properties over large areas, because it allows for rapid, aboveground measurements with very limited soil sampling (Hendrickx et al., 1992). However, while the EM technique has been commonly utilized for salinity assessment, its use for seepage investigations is just developing. The principle of the EM technology is as follows: the EM instrument transmitter coil induces an electromagnetic field in the ground, which in turn creates a secondary magnetic field that is measured by the receiver coil. The ratio of both fields provides a measure of the depth-weighted apparent electrical conductivity (EC) in a volume of soil below both coils (McNeill, 1980). Since EC of a soil is a function of its water content, salt content, and texture, use of the EM technique can be very valuable for canal seepage assessment. Recently, researchers in Australia found that EM was useful in detecting canal seepages (Akbar et al., 2000). If the EM technology can effectively be used as a non-invasive mean of measuring soil water content and detecting potential canal seepage, significant water savings should be possible throughout irrigated agriculture in California. Therefore, the objective of this study was to use the EM technology to assess potential seepage along an irrigation canal of Central California.

MATERIALS AND METHODS

The canal seepage surveys were conducted at the Lost Hills Water District in the San Joaquin Valley, Kern County, CA. An unlined section of a canal, about 4000 ft long, was selected for the study. The surveys were performed in August 2001 when the canal was open and susceptible to seepage, and in October 2001 after the canal had been closed. The soil along the canal was clay loam with increasing clay content with depth.

A Mobile Conductivity Assessment (MCA) system was developed at the Center for Irrigation Technology to conduct the canal surveys. The MCA system comprised four basic components mounted on a truck: (1) an electromagnetic (EM) induction sensor, (2) a global positioning system (GPS) receiver, (3) a computer, and (4) a hydraulic soil sampler (Figure 1.). The EM sensor was placed in a plastic carrier-sled attached about 10 ft behind the truck to avoid any interference due to metallic objects. The EM and GPS instruments were connected via digital interfaces to an on-board computer that simultaneously recorded the EM readings along with their geographical locations.

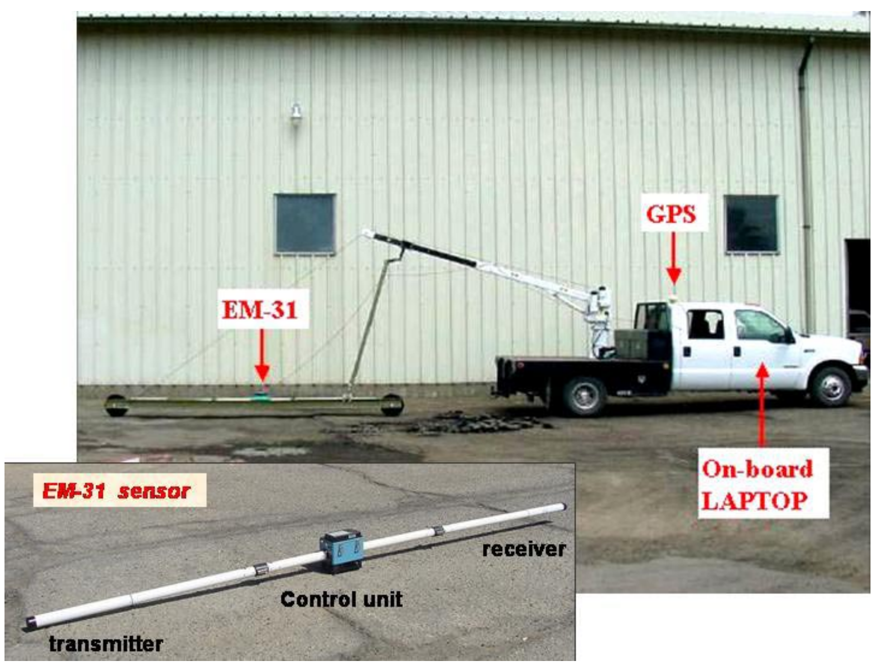

Figure 1. Mobile conductivity assessment (MCA) system used in the canal seepage surveys.

In this study, the EM-31 meter (Geonics Limited, Ontario, Canada) was used to measure soil electrical conductivity and indirectly soil moisture down to 8 ft. The EM-31 operates at a frequency of 9.8 kHz and consists of a transmitter coil and a receiver coil with a control unit in the center. The instrument has a fixed inter-coil spacing of 12 ft, which allows observation measurements down to 10 and 20 ft in the horizontal (meter parallel to the surface) and vertical (meter perpendicular to the surface) dipole modes, respectively.

The EM and GPS data were collected from four traverses parallel to the water flow on each side of the canal. The surveys were conducted at a speed of about 4 mph, with readings taken every 5 seconds. Calibration of the EM data was obtained through soil sampling. For each survey, an optimal sampling plan was generated using the statistical package ESAP (Lesch et al., 1999). This sampling plan consisted of six locations that characterized the spatial distribution of the EM readings along the canal. At these six sites, soil samples were collected in 3-ft increments to a depth of 8 ft using the hydraulic soil sampler. Soil water content, electrical conductivity (EC), and texture were determined on these samples, following standard analytical methods (Rhoades, 1996; Klute, 1986). Estimates of each measured parameter were then obtained for the entire survey area using the statistical software. Contour maps showing the distribution of the three parameters were generated with the ArcView GIS software (Environmental System Research Institute, 1996).

RESULTS AND DISCUSSION

Contour maps showing the distribution of soil moisture, EC, and clay content along the canal at different profile depths in August 2001 are presented in Figure 2. Soil water content was lowest near the surface (0-3 ft) with values ranging from 20 to 30%. The maps also showed that water content increased with depth. The 6-8 ft profile had the highest moisture levels (up to 48 cm^3 cm^{-3}) due to the presence of water table at those depths. In the 3-6 ft soil profile, water content ranged from 20 to 40% with greater percentages found in the mid-section and north-east segment of the canal. Higher soil water content could be indicative of potential seepage. Water loss in those sections of the canal was also observed by the Water District.

In August, soil EC ranged from 0.5 to 9 dS/m throughout the profile. The lowest values (<4 dS/m) were observed at higher depths (6-8 ft). Soil EC was greater in the mid and north sections of the canal at the 3-6 ft depth, with highest values always found on the eastern side of the canal. This pattern was similar to that noted on the soil water content maps.

Results also indicated that percent clay content increased with soil depth and ranged from 11 to 53%. This is indicative of coarser-textured soil and lower water holding capacity at the surface. Throughout the soil profile, higher clay contents (40-53 %) were observed in the mid-section of the canal. However, lower clay percentages (20-30%) were found in the middle-eastern side of the canal at 3-6 ft depth. At that location, soil water content and EC were particularly high, which could suggest potential seepage.

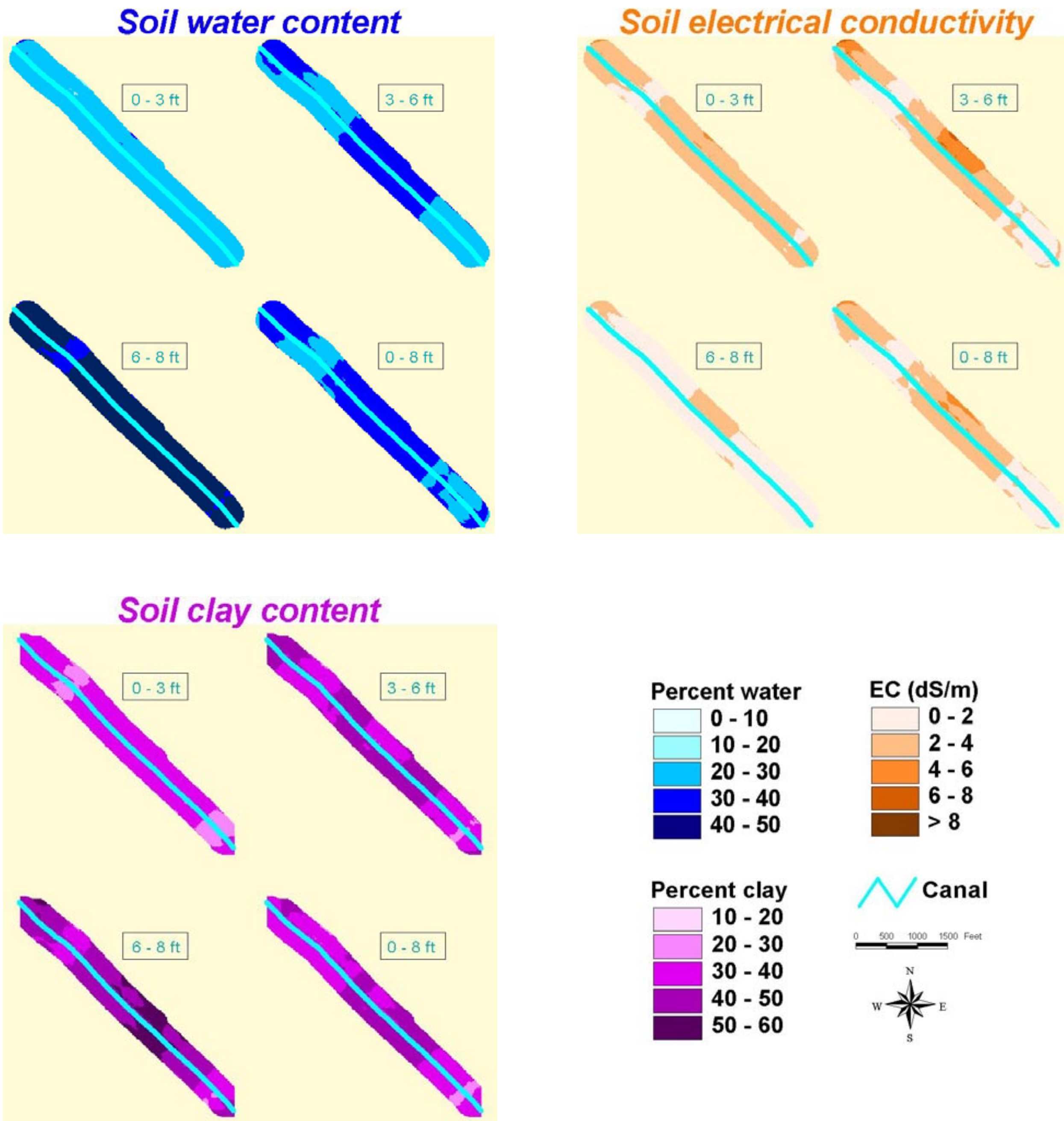

Figure 2. Distribution of soil water content, electrical conductivity, and clay content along the irrigation canal at different depths in August 2001.

Changes in soil water content and EC observed in Octob8er 2001 after the canal had been closed are shown in Figure 3. The maps indicated that water contents were very uniform and low (20-30%) at the soil surface (0-3 ft). Moisture spatial distribution and percentages were comparable to those observed in August, suggesting that seepage is unlikely near the soil surface. In October, low soil water contents were also found at the 3-6 ft depth, except in the mid-eastern section of the canal where values up to 40% were noted. This indicated that water percentages did not decrease in that section after the canal had been closed and could confirm the possibility of seepage at that location and depth. Water content decreased through the 6-9 ft profile in October, although it remained highest than the upper depths due to the presence of water table. Average soil EC increased after closing the canal.

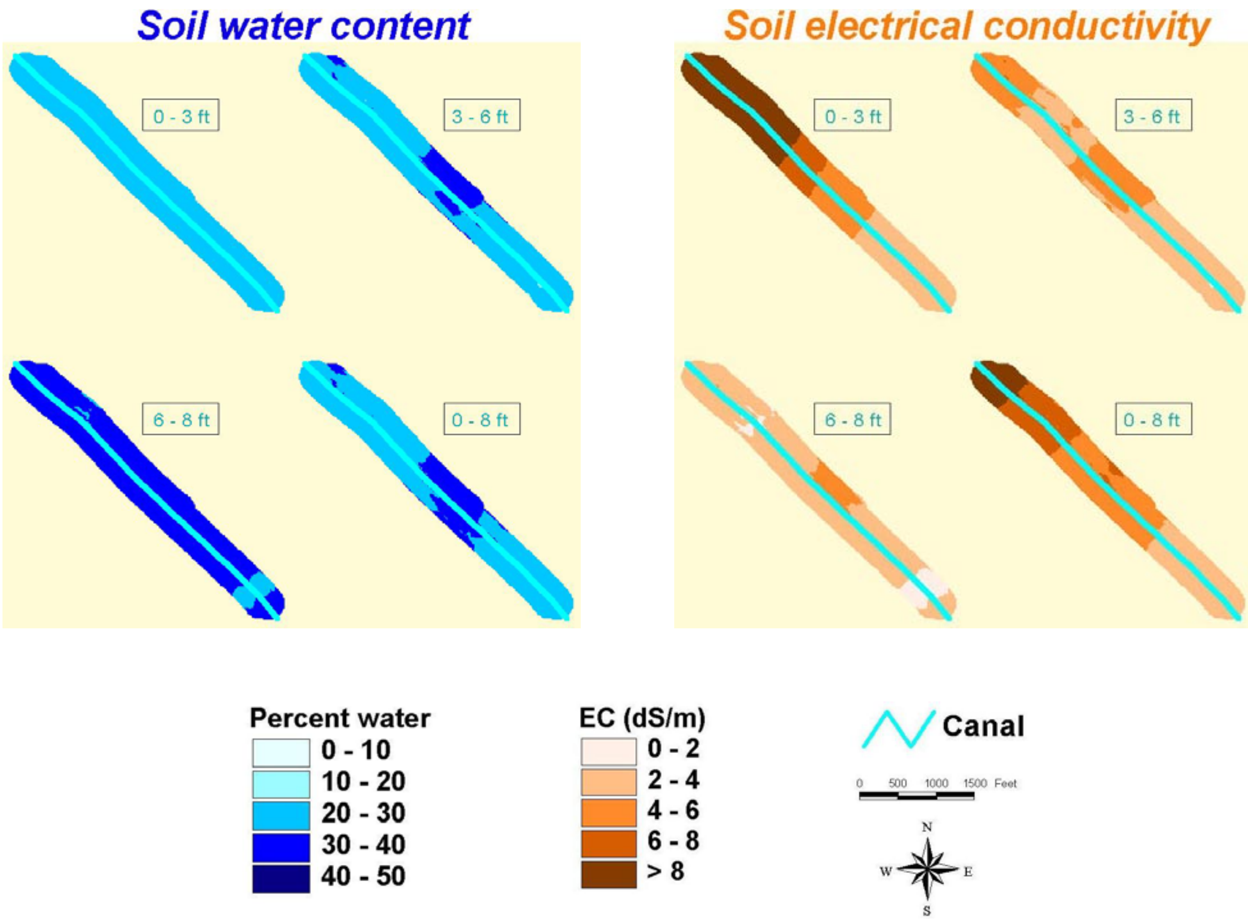

Figure 3. Distribution of soil water content and electrical conductivity along the irrigation canal at different depths in October 2001.

CONCLUSIONS

The purpose of the study was to use the EM technology to detect potential seepage along an irrigation canal of Central California. The surveys demonstrate that the EM technique has great potential for quick evaluation of soil water content over large areas and is a cost-effective alternative to extensive sampling. The overall results of such study and the contour maps indicate that canal seepage assessment using the EM technique can be useful in improving water management and conservation strategies along the irrigation canals. Data obtained from the canal surveys can also aid in financial decision making by providing information on the extent of possible canal seepage and need of canal lining.

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