Detection and inventory of saline seep using color infrared aerial photographs and video image analysis
by Daniel Simpson Long

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University

Abstract:
Saline seep is an important conservation problem affecting dryland agriculture in the northern Great plains of North America. Surveys on the location and acreage of saline seep are needed to assess economic losses and to develop strategies for reclamation. Survey needs have been met with varying success by such remote sensing techniques as photography, thermo-graphy, and satellite imaging. However, high costs, sensor resolution limits, and lack of ground reference data prevent a fully operational remote sensing system to survey saline seep.

Small-format photographs (1:32,000 scale) were taken to record saline seeps in a 200 square mile portion of the Sage creek watershed in Liberty County, Montana. Beginning, developing and mature seeps were visually identified and subsequently mapped and inventoried using a video image analyzer. Ground data on soils, crops and weeds were used to verify the interpretations.

Beginning, developing and mature seeps were detected on the 1:32,000 scale color infrared photographs. Optimal image date for recording seeps occurred when rank growth, darker color, and delayed crop maturity of beginning seeps appeared in fields that were otherwise nearly ripe and ready for harvest. Developing and mature seeps were visible on CIR imagery for most of the growing season. Electromagnetic and electrical conductivity measurements of salt content and depth distributions confirmed that extra water caused the heavy crop growth on beginning seeps. Developing seeps were areas where crops were reduced or eliminated due to high salinity. Mature seeps were areas with salt crusts, halophytic weeds and very high salinity. The inventory revealed 2.4 percent of total cropland was seep-affected. However, many individual farms were as much as 7 percent affected. Mapping accuracy was 85 percent for mature seeps and 76 percent for beginning seeps: Beginning, developing and mature seeps are mappable from small-scale CIR imagery. Crop expression of salinity is the key to detecting saline seeps. The 2 week period ending about 1 week before harvest is the best time for recording beginning seeps. Video image analysis is accurate and rapid for quantifying, compiling and sorting large amounts of map data. An operational survey is possible pending training programs and adaptation of interpretation guidelines to fit other areas.

DETECTION AND INVENTORY OF SALINE SEEP USING COLOR INFRARED AERIAL PHOTOGRAPHS AND VIDEO IMAGE ANALYSIS

by

Daniel Simpson Long

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APPROVAL

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Daniel Simpson Long

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date 15 Oct. 1986

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ABSTRACT

Saline seep is an important conservation problem affecting dryland agriculture in the northern Great Plains of North America. Surveys on the location and acreage of saline seep are needed to assess economic losses and to develop strategies for reclamation. Survey needs have been met with varying success by such remote sensing techniques as photography, thermo-graphy, and satellite imaging. However, high costs, sensor resolution limits, and lack of ground reference data prevent a fully operational remote sensing system to survey saline seep.

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INTRODUCTION

Saline seep is defined as: intermittent or continuous saline water discharge, at or near the soil surface downslope from recharge areas under dryland conditions, that reduces or eliminates crop growth in the affected area because of increased soluble salt concentration in the root zone (Brown et al., 1983). Once a saline seep has formed, reclamation is difficult due to abundant supply of water and soluble salts. Cropland loss from saline seep could be as much as 10 percent per year as reported for the Highwood Bench in Montana (Brown et al., 1980). This phenomenon is currently the most important problem affecting dryland agriculture in the northern Great Plains of North America (Vander Pluym, 1978).

The regional extent of saline seep is throughout the Canadian prairie provinces of Alberta, Saskatchewan and Manitoba, and the upper Missouri Basin states of Montana, Wyoming, North Dakota and South Dakota (Vander Pluym, 1978). Much of this region contains Cretaceous marine shales and Quaternary glacial till which are high in soluble salts (Miller, 1971; Schafer, 1982). The shales are impermeable and form a barrier against deep drainage resulting in perched water tables. Alternate crop-fallow, a widespread practice to promote water conservation, actually allows water in excess of field capacity to infiltrate beyond the soil profile to the water table. The movement of water through the profile leaches salts to the water table. Added inputs of both water and salts cause the water table to both build towards the soil surface and increase in salt content. When the water table approaches the soil surface, salts accumulate due to capillary rise and evaporative loss of water.

Quantitative information on the location and acreage of saline seeps are lacking and are urgently needed in order to address seep control needs, and to assess present and future economic losses. Saline seeps have been surveyed by both ground and aerial methods, however, there exists no operational and cost effective way to survey saline seep for large areas. Time and labor expenses are too high to allow survey by ground methods alone. In addition, ground surveys are not fast enough to extensively map many beginning and developing seeps before they lose distinctive appearance after crop harvest.

Remote sensing can improve saline seep surveys because map-like and synoptic views of large land areas are provided. The aerial imagery is a permanent record of the terrain which can be studied at later dates. Flexibility of remote sensing also allows for selection of periods when various saline seep areas are best expressed, thus, those saline seeps that at times lack distinctive appearance can be inventoried.

Saline seeps have been detected and mapped in recent years with varying success using several remote sensing techniques. These include: photography, thermography, and microwave and LANDSAT imaging. However, in spite of increases in theoretical and technological knowledge, no remote sensing system is currently being used to detect and inventory saline seeps on an operational basis. Reasons seem to include high cost, sensor resolution limitations, and lack of ground reference data.

The objective of this study was to develop a method for detecting and inventorying saline seeps using color infrared aerial photographs and video image processing. Different stages of saline seep development in cropland were termed "beginning", "developing", and "mature". Relationships between saline seep ground conditions and their respective photo-characteristics were determined. A method for mapping and inventorying saline seep is described herein in keeping with criteria used by the Soil Conservation Service in Montana for classifying saline seep.

LITERATURE REVIEW

Approaches to Remote Sensing of Saline Seep

Background

Numerous methods have been employed to remotely sense cropland salinity. The methods differ among the kinds of sensors and imagery used. Though each method is reasonably successful at detecting salinity, none to date is fully operational for mapping salinity over large areas. Remote sensing appears only partially successful due to lack of such ground data as concentration, and depth distribution of salts in beginning seeps. In addition, the most effective image collection dates have not been determined for capturing best expression of beginning seeps. Finally, methods of computer classification and compilation of digital data need to be further developed if amounts and distributions of dryland salinity are to be quantified over large geographical areas.

Methods Using Aircraft Imagery

Rust and Gerbig (1974) in Minnesota were among the first to use crops as indicators of soil salinity. Color infrared photographs (1:40,000 scale) recorded at a time of peak growth showed maximum visual differences in crop vigor that were attributed to different saline conditions. Fields were damage rated as having severe, moderate, slight or no yield reduction along the transects flown.

Small-scale (1:24,000 and 1:80,000) color infrared photographs were used by the Ecological Consulting Service (1974) of Helena, Montana to detect saline seeps on cropland near Ft. Benton, Montana. This consulting firm recognized the need to photograph during mid-season to record maximum crop differences expressed between the following soil conditions: unaffected, incipient, moderate, and highly saline. However, logistical problems limited imagery to late season image dates and incipient seeps were not detected. Nevertheless, moderate and highly saline areas were detectable and were mapped from the 1:24,000 scale imagery with 92 percent accuracy.

Fogarty et al. (1976) detected saline seeps in a regional study involving locations in Montana, North Dakota, and South Dakota. They recorded seeps via thermal and CIR imagery during mid-May, late July, late August, and early September. Salt crust, salinity indications by crops and weeds, and changes in cultural practices due to excessive wetness were the visual criteria used to detect seeps. They concluded that photo-interpreters can identify seeps of moderate and high salinity at 70 to 80 percent accuracy providing seep mechanisms, and soil and geological factors are understood. Incipient seeps were difficult to identify on both types of imagery.

Saline seeps were classified into 3 developmental stages termed incipient, intermediate, and mature based on visual characteristics seen in soils, crops, and weeds in a study by Dalsted et al. (1979). Intermediate, and mature stages of seep growth were identified and mapped in this North Dakota study to within 70 and 90 percent accuracy using thermal and CIR imagery, respectively. Incipient seeps were indicated by thermal imagery as areas of cooler temperatures in an otherwise warmer, drier field, however, these seeps were not revealed on CIR photographs.

Methods Using Satellite Imagery

May and Petersen (1976) determined the usefulness of multispectral LANDSAT-1 data to detect and map saline seeps in the Ft. Benton area of Montana. The LANDSAT data were analyzed using computer supervised and unsupervised techniques and classified according to signatures of salt crusts, crops, and weed halophytes. Evidently, only highly saline areas of salt crusts and weeds were mapped. Seeps less than 2 hectares were too small to be resolved by the LANDSAT scanner. They recommended that mapping capabilities of computer classified LANDSAT data be developed to operational status pending test of signature applicability in other areas.

Thompson et al. (1981) analyzed LANDSAT 2 digital data of salinized land using computer analysis techniques. Data were first classified by the computer into areas of low, moderate, and high salinity, and salt crust. Manual techniques were then used to transfer the classified data to base maps. They concluded that moderately to strongly saline areas can be mapped with greatest accuracy between May and mid-July when most contrast occurs between saline soils and such features as crops and moist bare soils.

In a later study, Thompson et al. (1984) extended their 1981 results to include mapping salinity in several dryland agricultural areas of southern Alberta. Their objective was to test operational feasibility of using LANDSAT data for regional survey of dryland salinity. The analysis process was found to be relatively simple and rapid with one complete LANDSAT scene (180 square km) being processed in less than 4 hours. Further interpretation and image transfer for production of base maps required additional time due to the manual tasks involved.

Using the techniques developed by Thompson (1981 and 1984) above, Sommerfeldt et al. (1984) mapped salinity over all of southern Alberta. Their objective was to accurately map saline areas and identify the salinity according to severity and type. Ground investigations revealed that the resulting maps were highly accurate for moderately and strongly saline areas, but less accurate for areas of low salinity. Inaccuracy was due to misidentifying saline areas, and not enough sensor resolution to map areas smaller than 2 hectares.

Ground Investigations of Saline Seep

Background

Ground investigations are important to remote sensing for verifying whether or not aerial interpretations are correct. Electroresistive and electromagnetic techniques have been used to map saline seep, determine depth distributions of salts, and ascertain the pedologic and geo-hydrologic factors of seep formation.

Mechanisms of seep formation are thoroughly described elsewhere and will not be covered here. For further information readers should review work by Worcester et al. (1975), Brown and Krall (1981), Halvorson and Black (1974), and Brown et al. (1983).

Visual Indications in Soils, Weeds, and Crops

Brown (1976) listed several indications of incipient saline seeps that can be visually observed from the ground in soils, crops, and weeds. Some of the indications include: 1) prolonged wetness following a substantial rain, 2) rank growth in small grains, 3) scattered salt crystals or localized soil cloddiness, 4) weed increases in certain locations after harvest, and 5) appearance of a dark colored soil surface due to dispersion of organic matter by sodium.

Incipient stage of saline seep growth was also described by Worcester et al. (1979) as being wet and having luxuriant crop growth. Advanced stages were indicated by salt-tolerant vegetation in intermediate seeps, and by white salt crust in mature seeps. In addition, the stages of seep development may exist alone or in combination with a mature seep at the center surrounded by zones having intermediate and incipient characteristics.

Weed Halophytes as Saline Indicators

Worcester and Seelig (1976) in North Dakota found the areal distributions of different plant species to vary with different levels of salinity. Kochia (*Kochia scoparia*) dominated at the highest salt concentrations and foxtail barley (*Hordeum jubatum*) dominated at the lower salt concentrations. They thought it possible that luxuriant growth displayed by pigeon grass (Setaria viridis) and green foxtail (Setaria lutescens) indicates the high moisture conditions of incipient seep. With progressive increases of salinity the next indicator plants will be foxtail barley followed by kochia. Continued salinization will lead eventually to the formation of a salt crust.

Evidence for plant-soil relationships in saline areas is presented by several authors. In Saskatchewan, halophytic vegetation occurred along salinity gradients increasing from low at the dry margin of depressions to high in wet saline centers in the following sequence: Agropyron spp., Hordeum jubatum, Distichlis stricta, Puccinellia airoides, Triglochin maritima, and Salicornia rubra (Dodd and Coupland, 1966). Salt gradients could be divided on the basis of visible changes from one homogeneous plant community to another. Ungar (1967) in northern Kansas and Ungar et al. (1969) in Nebraska revealed that not only are the distributions of halophytic plants controlled by salinity level, but also by competition among species for sites of low salinity such that some are restricted to the most highly saline.

Four-probe Resistivity Technique

The four-probe Wenner electrode configuration can be used to: 1) measure soil electrical conductivity (EC) by depth or within depth increments, 2) identify an encroaching saline seep, 3) map the extent of a saline seep, 4) estimate depth to water table and subsurface discontinuities, and 5) identify recharge areas (Rhoades and Halvorson, 1977).

Quantitative information on EC depth distribution for unaffected sites, and encroaching and developed seeps was acquired using the four-probe technique (Rhoades and Ingvalson, 1971; Halvorson and Rhoades, 1974). Each stage of seep development possessed a distinctive salt depth distribution curve that was the result of leaching, evaporative, and capillary interactions in the soil profile. Additionally, the technique demonstrated that soil profiles became salinized wherever a saline water table approaches to within 4 feet of the ground surface.

Halvorson and Rhoades (1976) used the four-probe technique to map surface and subsurface conditions in saline seep. Resulting maps showed discharge areas expanding in the direction of inflow paths, and their spatial relation to recharge areas. In addition, the maps showed salinity spreading beyond its visual indications at the ground surface.

Electromagnetic Conductivity Technique

Electromagnetic inductive techniques have been tested by Rhoades and Corwin (1981), Corwin and Rhoades (1982), and Corwin and Rhoades (1984) for determining soil salinity profiles using the Geonics Lt. model EM38 salinity meter. This instrument is efficient for making field measurements of salinity because it provides continuous readings without having to insert electrodes as is required with the four-probe technique. Salts can be measured in two depth increments depending on the meter's induction coil orientation; horizontal for shallow or near surface conditions and vertical for deep or sub-surface conditions. The EM38 is designed to effectively measure soil EC within the root zone or to about 1 meter deep.

Wollenhaupt et al. (1986) developed a simple method for converting EM38 readings into commonly used saturated paste extract electrical conductivity (ECe) values. Their method used equations by McNiell (1980) that describe the expected meter response to soil EC per unit of soil depth.

This technique has yet to see increased use in practical applications. Nevertheless, Cameron et al. (1981) used it to map several saline sites in Saskatchewan. The technique revealed that salinity was more extensive and more clearly mapped than otherwise was possible by visual methods. For complete description on the theory and operation of this technique, readers should consult McNeill (1980) and DeJong et al. (1979).

MATERIALS AND METHODS

Study Area Description

The Sage Creek Watershed is located in northern Liberty County, Montana. The Watershed is bordered by Canada to the north, the Sweet Grass Hills to the west, Hill County to the east, and Adobe Ridge to the south (Figure 1).

Precipitation varies across the Watershed with the greatest amount falling at higher elevations in the Sweet Grass Hills and the least amount falling at lower elevations. Average annual rainfall is about 10 inches (39 mm) most of which falls during the growing season (Montana Water Resources Board, 1969).

Soils in the Watershed are derived from Quaternary glacial till that overly various shale and sandstone formations of upper Cretaceous age (Ross et al., 1955; Gieseker, 1933). The geo-hydrologic conditions favorable for saline seep formation include high salt content in glacial till and poor internal drainage imposed by impermeable shales.

The Watershed encompasses 246,000 acres (384 square miles) of which 118,800 are dryland cropland (USDA, Soil Conservation Service, 1983). Alternate crop-fallow, a dryland water conservation practice, is widely used in the Watershed. It is one of the major causes of saline seep on dryland cropland in the northern Great Plains (Brown et al., 1983). Seep affected acres have increased in the Watershed from 765 acres 20 years ago to an estimated 5,200 acres in 1983 (USDA, Soil Conservation Service, 1983).

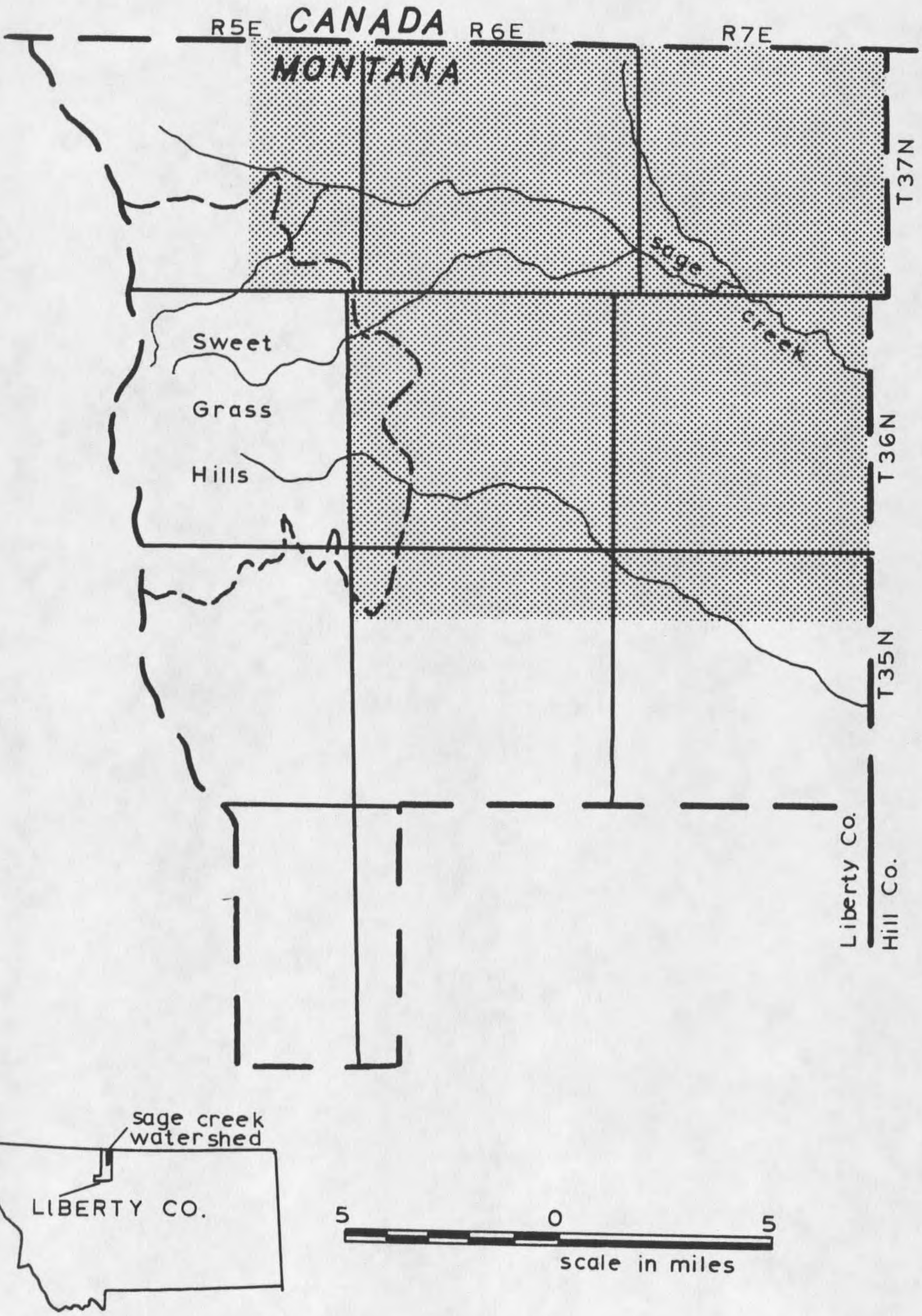

Figure 1. Area of photo-coverage (shaded) within the Sage Creek Watershed, Liberty County, Montana.

Aerial Photography

Small-scale Image Collection

Small-scale (1:32,000) color infrared (CIR) aerial photographs were acquired of a 200 square mile continuous portion of the Sage Creek Watershed (Figure 1). Photographs were recorded on Kodak Aerochrome 2443 CIR film using a Hasselblad EL-M 500, 70 mm format camera through a 50 mm lens and Wratten #15 filter.

Vertical photographs were obtained from an altitude of about 9,500 feet from a Cessna model 150 single engine high wing aircraft. Flight lines were oriented along east-west section lines in order to facilitate visual navigation and minimize drift against prevailing winds. Exposure intervals were timed such that approximately 30 percent overlap resulted between successive photographs. A lens setting of f/5.6 at 1/500 second was generally used for all exposures. Exposures were made between hours of 1000 and 1500 (MST) under clear sky conditions.

Imagery was acquired twice during 1984; on 13 July and 30 September to coincide with pre-harvest maturity differences in small grains and post-harvest weed conditions, respectively.

Large-Scale Image Collection

Large-scale (1:10,000) color infrared aerial photographs were taken of 19 of 22 reference areas in order to obtain detailed views of crops, weeds and soils, and for locating ground sampling points and transects. Numerical identification, legal description, and ground data collected for the 22 reference areas are listed in Table 1.

Table 1. Site Number, Legal Description, and Ground Data Collected for Reference Areas.

Site #	Legal Description	Ground Data a	b	c	d	Aerial Imagery e	f
1	SE1/4 NW1/4 S10-T37N-R5E					X	X
2	NW1/4 NE1/4 S10-T37N-R5E	X					X
3	SE1/4 SE1/4 S10-T37N-R5E	X	X	X		X	X
4	SE1/4 SE1/4 S10-T37N-R5E	X				X	X
5	NW1/4 SW1/4 S02-T37N-R5E	X			X	X	X
6	SW1/4 SW1/4 S11-T37N-R5E	X				X	X
7	SE1/4 NW1/4 S33-T37N-R6E					X	X
8	SE1/4 SE1/4 S02-T37N-R6E	X				X	X
9	SE1/4 NE1/4 S11-T37N-R7E	X	X			X	X
10	NW1/4 NE1/4 S11-T37N-R7E	X	X			X	X
11	NE1/4 NW1/4 S11-T37N-R7E	X			X		X
12	NE1/4 SW1/4 S03-T37N-R7E	X				X	X
13	NE1/4 NE1/4 S09-T37N-R7E	X				X	X
14	SW1/4 SE1/4 S10-T37N-R7E			X		X	X
15	NW1/4 NE1/4 S15-T37N-R7E	X			X	X	X
16	- - S12-T37N-R7E					X	X
17	SE1/4 SW1/4 S21-T36N-R6E		X			X	X
18	SW1/4 SE1/4 S21-T36N-R6E	X	X			X	X
19	NE1/4 SW1/4 S35-T36N-R6E	X	X		X	X	X
20	SW1/4 SE1/4 S35-T36N-R6E	X			X	X	X
21	- NW1/4 S15-T35N-R6E				X		
22	NE1/4 SW1/4 S13-T35N-R7E	X	X	X		X	X

a- EC Depth Distribution
b- EM Salinity Mapping
c- Halophyte Frequency and Cover
d- Crop Yield, Soil Water, and Soil Salinity
e- Large-scale (1:8,000), Multi-date
f- Small-scale (1:32,000)

Materials and methods for obtaining the large-scale imagery were essentially the same as described above for collecting the small-scale imagery with the following exceptions: 1) an 80 mm lens was used, 2) photographs were acquired from 6,500 feet altitude, and 3) ground coverage for each photograph was about 100 acres.

Imagery was acquired on 9 May, 6 June, 13 July, and 15 and 26 August, 1984 coinciding with emergence, tillering, and heading crop events, and post harvest conditions in weeds, respectively. A target calendar was developed to schedule the image dates (Table 2).

Table 2. Target Calendar For Growing Events in Spring and Fall Planted Small Grain and Various Weeds.

Target	May	June	July	August	September
Grain-fall	<----t----><---h---><--r-->harvest				
-spring	<---e---><---t---><----h----><---r--->harvest				
Weeds-*Kochia scoparia*				<-----peak--------->	
Salsola kali				<-----peak--------->	
Salicornia rubra				<-----peak--------->	
Hordeum jubatum				<-----peak--------->	

e= emerging
t= tillering
h= heading
r= ripening
peak= peak growth period for weeds

Camera Mount

A camera mount was designed for the Cessna 150 to carry a single Hasselblad 70 mm camera (Long, et al.). The mount was essentially a rectangular enclosure fastened over an opening cut into the right cabin door that allowed: 1) access to the imaging system without opening windows, 2) wide angle views of the ground with little airframe obstruction, 3) one-man flying and imaging operation, and 4) airframe modification without placing permanent camera ports in the aircraft hull.

Camera leveling and lens adjustment was made possible by a quick release bracket that allowed the camera base to be clamped instead of bolted. Leveling was achieved by turning the camera to the desired position and then tightening it down. Targeting was done by viewing the subject area beneath the aircraft as much as possible through the left window.

The camera could be easily removed from the mount for in-flight film reloading and lens adjustment. On small-scale image collection flights an observer attended to such duties while the pilot navigated. Both photography and flying activities were done as a one-man operation on large-scale image collection missions.

Ground Reference Data

Approach

Ground reference data were acquired on crop and weed response to salinity, and on amount and distribution of soil salts at the 22 reference areas. A listing of the type of ground data and reference site locations where each data type was taken is given in Table 1. The ground data were used to verify photo-expression of three developmental stages of saline seep termed: "beginning", "developing" and "mature".

Electromagnetic Field Salinity Measurements

Field soil salinity measurements were made using a Geonics Ltd. model EM38 electromagnetic conductivity meter. The meter electromagnetically induces current flow in the soil at a rate that is proportional to the amount of salt present.

Readings taken with the EM38 reflect the cumulative contribution of soil electrical conductivity above some depth. The depth monitored partly depends on how the meter is oriented with the soil surface. When held on its side (horizontal position) the meter measures to about 0.5 m whereas when held on its edge (vertical position) the meter measures to about 1 m. Figure 2 shows successive response curves for EM38 horizontal and vertical positions. About 44 and 15 percent of the reading comes from soil EC in the first 3 dm (1 foot) for the horizontal and vertical orientations, respectively. Hence, the horizontal position is more sensitive than the vertical orientation for measuring EC near the soil surface. In contrast, the vertical position is more sensitive than the horizontal position for measuring EC at deeper depths.

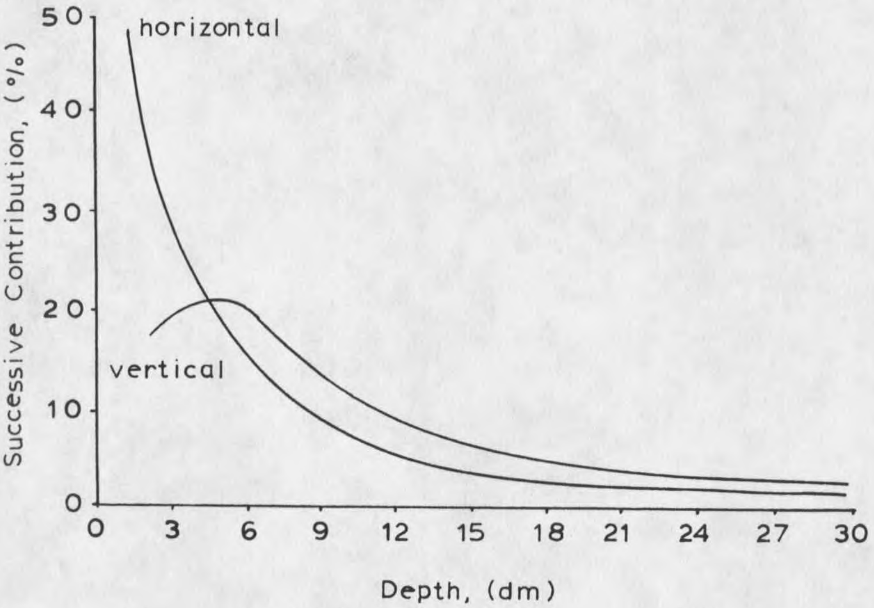

Figure 2. Successive Relative Contribution of Soil EC with Depth to the EM38 Reading (McNeill, 1980).

Electromagnetic (EM) readings were taken at regularly spaced points at grid intersections or along transects. Grid spacings ranged from 10 to 40 meters depending on the size of the area to be mapped. Seven reference sites ranging in size from about 10 to 40 acres were mapped using this instrument. Soil salinity was measured at numerous transects that were established in crop along salt gradients at 6 reference sites. The salinity data from gridded areas were displayed as contours on computer generated maps.

Deep Soil Sampling in Saline Seeps

Soil samples for salinity analysis were collected from soil pedons in order to determine the amount and distribution of salts in 20 beginning, 17 developing, and 3 mature seeps. Soil profiles were sampled to a depth of 5 feet (150 cm) in 12 inch (30 cm) increments using a 2.5 inch Giddings soil tube driven into the ground. Each 12 inch increment of soil was stored in sealable paper bags and oven dried to constant weight in preparation for chemical analysis.

Boundary areas of beginning, developing, and mature seeps were sampled in order to determine how these stages differed from each other in regard to salt content and distribution. Sampling occurred during early September, a time of little salt leaching from rain and high evaporative salt rise in soil profiles.

Analysis of Soil Samples

Soils were ovendried and ground to pass a 2 mm sieve as soon as they were brought from the field to the laboratory. Water content was gravimetrically determined by calculating the weight loss upon drying. Electrical conductivity (EC) and pH of saturation paste extracts were determined for field sampled soils using a conductivity bridge and pH meter, respectively.

Water soluble sodium (Na), magnesium (Mg), and calcium (Ca) were determined in the saturation extracts using a Perkin-Elmer ICP-4000 atomic absorption spectrophotometer. Sulfate ($SO4^{-2}$) was estimated by determining the amount of water soluble sulfur (S) in the saturation extract using the above method. Chloride (Cl^-) and nitrate ($NO3^-$) were determined using colormetric techniques.

Crop and Weed Transects

Transects were established between non-affected areas and seeps for determining crop and weed response along salinity gradients. Crops were sampled at places spaced 5 or 10 meter apart by removing 1 meter of row of the standing biomass. Soil water and salinity were also determined where crops were sampled by measuring soil weight loss upon oven drying and soil electrical conductivity with the EM38.

Weed zonation was determined by measuring cover along randomly established transects that were located across salinity gradients. Cover was determined using the 2 X 5 dm plot frame method by Daubenmire (1959). Weeds and native plants in saline seeps were identified for compilation of a species list.

Image Analysis Techniques

Image Interpretation

Each photograph, a 70 mm transparency, was viewed on a light table using stereo lenses and/or a Baush and Lomb binocular magnifier. Saline seeps were identified by learning to recognize their spectral, spatial, and temporal characteristics on imagery (ie. color, tone, pattern, texture, location, size, and shape) in the following ways:

1) Visual study of known seeps on imagery of different scales and dates.

2) Visiting seeps in the field with imagery in hand.

3) Registering imagery with mapped or plotted ground data.

4) Visual study of older aerial photographs showing native range before areas were plowed.

Visual appearance of soils, crops, and weeds on large scale imagery was compared to contour lines or point data marked on the computer generated contour maps. This was done by registering the large-scale imagery and the contour maps together at 1:660 scale using a slide projector. A photo-interpretation key was developed for identifying saline seeps on the small-scale transparencies.

Mapping of Saline Seep

After seeps were identified on each small-scale transparency, they were mapped onto 1:8,000 scale ASCS (Agricultural Stabilization and Conservation Service) field sheets. The transparencies were merged to the field sheets by using a slide projector mounted vertically to an adjustable copy stand. Variable scale and image distortion in the non-metric transparencies were corrected when registered with the metric field sheets.

Video Analysis

Map delineations (map polygons) of seeps were traced from the field sheets onto white paper so that delineations could be resolved by the video analyzer. A video image analyzer with the trade name

Measuronics System I Linear Measuring Set (LMS), was used to measure the delineated areas of different seeps and to compile the map polygon data.

Final Map Production

The video image analyzer was used to transfer the delineated map polygons to translucent mylar sheets fit onto 1:24,000 scale topographic maps of the area. For simplicity, the final mylar maps only showed locations and sizes of different seeps. These maps are filed with the U.S.D.A. Soil Conservation Service, Bozeman, Montana.

Inventory of Saline Seep

Classification Scheme

Saline seeps were classified according to systems proposed by Worcester et al. (1978) and USDA, Soil Conservation Service (1982). The classifications are identical except for the terms used to designate three developmental stages. These terms are, respectively, emerging, developing, and developed, and stage 1, stage 2, and stage 3. In the present study, the terms beginning, developing, and mature correspond with stage 1, stage 2, and stage 3 as defined in Table 3.

Table 3. Definitions of Saline Seep Conditions.

Map Unit Name	Definition
Stage 1	Beginning Seep- Area of luxuriously growing crop that may or may not neighbor stage 2 and stage 3 seeps. Areas of crop with both higher productivity and prolonged crop growth than rest of crop.
Stage 2	Developing Seep- Area of reduced or eliminated crop due to high salinity. Salt crust is absent and weeds may or not be present.
Stage 3	Mature Seep- Area of eliminated crop with numerous weeds and salt crust present. Includes a bare salty area in fallow.
Salinized Drainage	On Cropland- Consisting of fluves, and salinized runoff from range sites and seeped areas.
	On Rangeland- Fluves assumed to be affected if within 1/2 mile of cropland.
Complex	Consists of stage 1, 2 and 3 areas on cropland so intermixed that it is impractical to separate at 1:8,000 map scales. (Areas of complexes were delineated on maps but their areas were not included in the inventory of saline seep.)

Saline seeps were also inventoried according to the following depressional landforms: swale (Bates and Jackson, 1980), fluve (Peterson, 1981), pothole (Bates and Jackson, 1980), and hillslope (Hawley and Parsons, 1980). The above landforms are defined in Table 4 and are illustrated in Figures 3 through 5. In addition, salinized

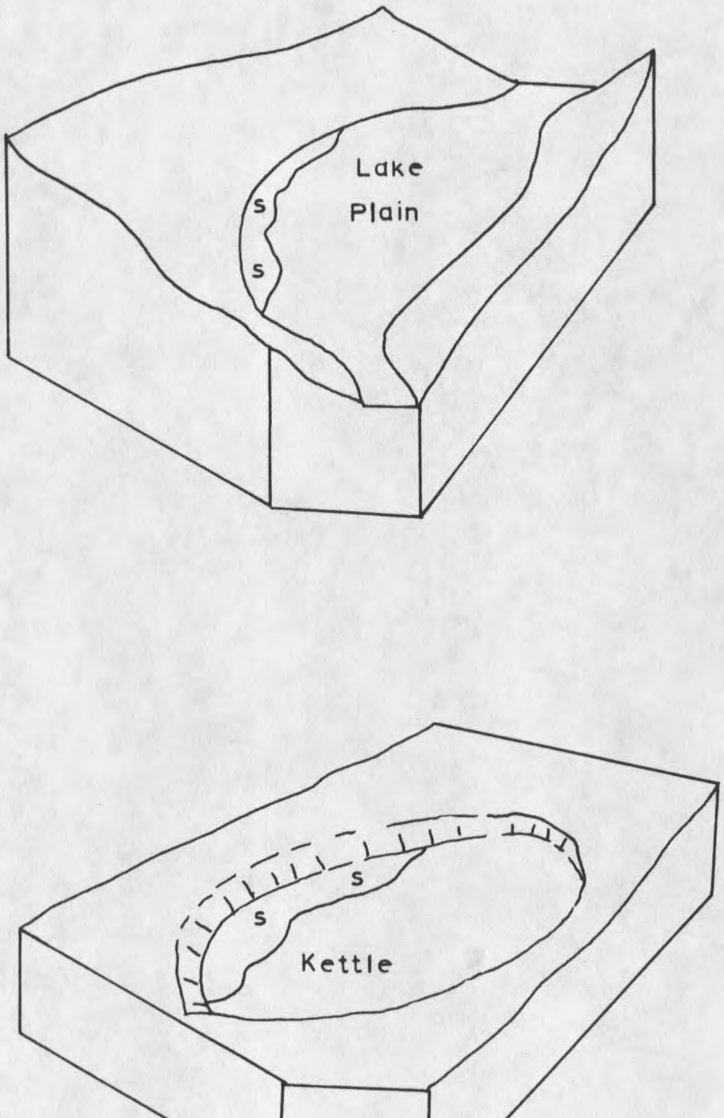

Figure 3. Pothole Landforms. These landforms consist of kettles and small lake plains. Salinity occurs along edges of these depressions (salinity at -S- above).

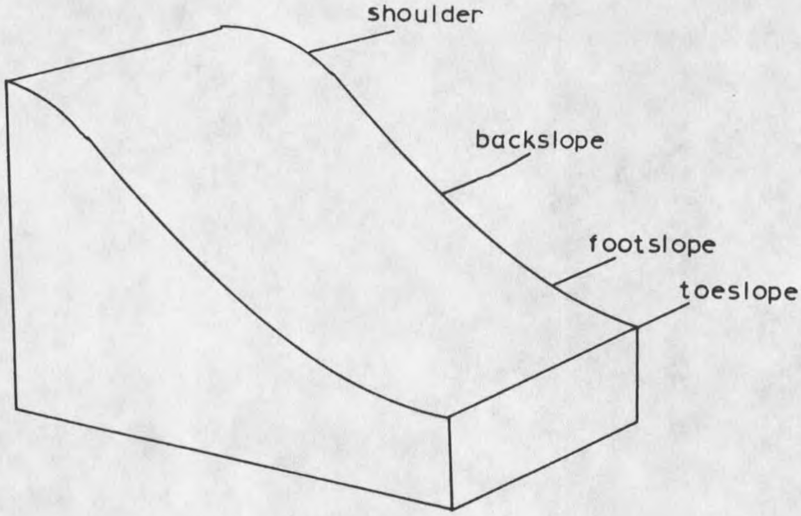

Figure 4. Hillslope Landform. Salinity can occur at shoulder backslope, footslope, and toeslope portions of hillslopes.

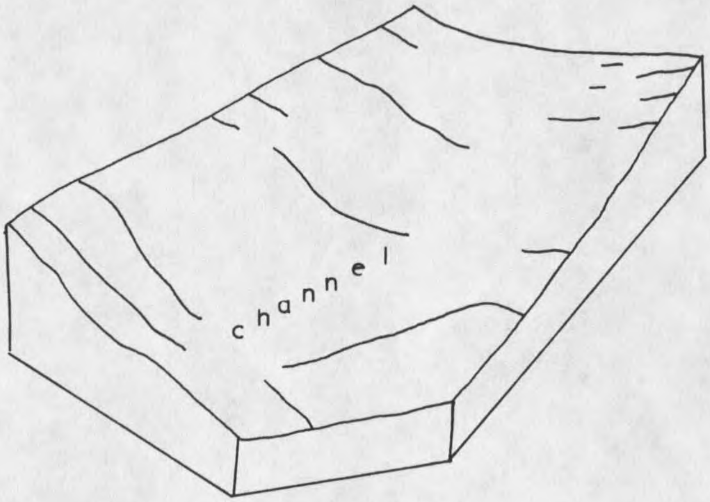

Figure 5. Fluve Landform. Salinization occurs in channel of various fluve landforms (i.e. valley, gully, rill, drainageway).

drainages both on cropland and within 1/4 mile of cropland were inventoried.

Table 4. Definitions of Landforms

Name	Definition
Pothole	Any pot shaped pit or hole (kettle) including small lake plains (>5 acres and <20 acres). Seep is positioned along margin of landform Kettle- Usually undrained, circular depression (5 acres) formed by melting of stranded ice block. (Hawley and Parsons, 1980) Lake plain- A floor of nearly level, fine textured, stratified, bottom sediments of an extinct lake. (Bates and Jackson, 1980)
Hillslope	Area of hill containing the saline seep that is comprised of shoulder, backslope, and footslope. Summit and toeslope are excluded
Fluve	A linear depression of any size (valley, gully, rill, drainageway). Seep is positioned on the channel of the fluve.
Swale	Non-linear, irregularly shaped and closed depressions on glacial till. Seep occur on swale bottoms where adjacent toeslopes meet.
Other	Saline area occupies impoundment made by road embankment or dam.

Inventory Techniques

Seeps were inventoried by compiling map polygon data according to geographic reference location and three specific attributes using the inventory sort program of the video image analyzer. The specific attributes included seep type, landform, and landowner. Inventory data were obtained for each of 200 land sections and were displayed in tabular form on hardcopy printout. In addition, these data were geographically displayed as a computer generated contour map.

RESULTS

Saline Seep Detection on CIR Photographs

Saline Seep Appearance

Saline seeps usually appeared as a combination of beginning, developing and mature stages rather than as single stages separated from each other. Mature seeps were surrounded by rings or partial rings of developing and beginning seeps.

Seeps were usually located in depressional areas such as swales, kettles, and fluves, or at the bottom of hillslopes. Features within saline seeps that could be identified on CIR photographs included 1) small grain crops, 2) various halophytes such as Suaeda depressa (seablite), Salicornia rubra (saltwort), Salsola kali (Russian thistle), Kochia scoparia (Kochia), Hordeum jubatum (foxtail barley), and Puccinellia nuttalliana (alkaligrass), 3) salt crust on soil, and 4) different cultural practices such as summer fallowing, weed spraying, and harvesting.

Grain Crops

Crops are absent from mature seeps due to high salt levels. Developing seeps are visible on CIR photographs during May as aqua colored areas absent of crop in fall planted fields. In contrast, spring planted wheat and barley either have not emerged or are not large enough to be seen on aerial imagery during May. Beginning seeps are not visible on CIR imagery at this time.

By June, developing seeps are conspicuous within both fall and spring planted grain crops. Beginning seeps are still not noticeable. During July, beginning seeps are evident because crops on these areas remain green and actively growing several weeks after crops on normal areas have matured and are yellow. Beginning seeps appear as dense red areas of crop on CIR photographs, whereas, the rest of crop appears straw colored (Figure 6). This appearance is nearly gone by late July and August when the crop has turned yellow and is ready for harvest.

Halophytic Weeds

Halophytes important to seep detection include Suaeda, Salicornia, Kochia, and Hordeum. These weeds are not visible on May imagery due to their small size, but become increasingly more visible as plants grow. During June, Suaeda and Salicornia are visible on CIR imagery as dull red areas forming irregular shapes within the bright white salt encrusted zone of mature seeps. Kochia, though not yet visible, is less salt tolerant than the above two weeds, and tends to increase in developing seeps. Hordeum, a perennial grass, is visible when it forms relatively dense stands in mature and developing seeps. This grass lacks a red signature on CIR photographs and remains aqua colored throughout the season. Weeds are not characteristic of beginning seeps because cultivation and herbicides tend to remove them.

By July, stands of Suaeda are at peak growth and have enlarged up to twice their June size in mature seeps. Kochia now appears within developing seeps as forming partial rings that encircle adjacent mature

Figure 6. Color Infrared Aerial Photograph of Seeped Cropland. Photograph is taken in mid-July (1:6,600 scale). Mature, developing, and beginning seep are marked at 3, 2, and 1 respectively. Mature seep at 3 are indicated by white colored salt crust with patches of dull red colored weeds. Aqua colored areas within 3 are such grasses as Hordeum jubatum, and Puccinellia nuttalliana. Lighter aqua colored areas marked at 2 are bare soils of developing seep. Beginning seep are the dense red crop areas marked at 1. Mottled appearance within areas marked at C are native salt-affected soils. Areas enclosed by dashed lines are kettles. Note position of seep along edges of the kettle landforms. The seep at 3A lies within a swale landform. Red and white colored strips are spring wheat and barley, respectively.

seeps. Shortly before or after harvest in early August, *Kochia* enters a period of rapid growth and increases considerably over its June size. Visible contrast between the red CIR signature of weeds in saline areas and the straw color of unaffected crop areas is maximal during this time, and is maintained until September after which weeds senescence. In late August *Suaeda* turns black and appears black, and *Salicornia* turns red and appears yellow on CIR imagery.

Soils

The only direct visual indication of salinity in soils is the presence or absence of a salt crust which is used to differentiate between developing and mature seeps. Beginning seeps have salt levels too low to impair crops and do not display bare areas of soil. A white salt crust is diagnostic of mature seeps and it is often located in a depression or on a toeslope. Well established mature seeps having thick salt crusts are showy throughout the year. However, rainfall leaches most of the salt beneath the soil surface in thinly encrusted mature seeps but reappears as the soil dries.

Developing seeps are surrounded by areas of crop or varying amounts of crop residue throughout the season. Under fallow, developing seeps may be devoid of crop residue in fields otherwise covered by residue. Ground observations reveal incipient development of a salt crust as indicated by the presence of individual salt crystals on the soil surface. These crystals are too few or small to be detected on CIR photographs.

Developing seeps appear as bare or thinly covered areas surrounded by thicker crops, crop stubble or crop residue. The soil itself appears aqua colored throughout the season on CIR photographs.

Ground Reference Data

Correlation of Imagery and Mapped Ground Reference Data

Visual outlines of unaffected soils, and beginning, developing, and mature seeps on July CIR imagery correlated with the position and shape of EM isolines plotted on ground maps. Figure 7 shows visual outlines of seeps together with ground mapped EM data.

EM38 Readings of Beginning, Developing and Mature Seep

Mean EM38 values for horizontal and vertical readings, and horizontal to vertical ratios are reported in Table 5 for 7 saline seep areas located within reference sites 3, 9, 10, 11, 17, 18, and 22, respectively. The reported data are means of several hundred EM38 horizontal and vertical readings taken from different site locations in unaffected soils, and beginning, developing, and mature seep.

Nearly all mean EM values and EM ratios from each site location differed significantly at the 5 percent level using one way analysis of variance. These data show that salinity increases in order from unaffected soils, beginning seeps, developing seeps, to mature seeps. In addition, the EM horizontal to vertical ratio increases in the same order.

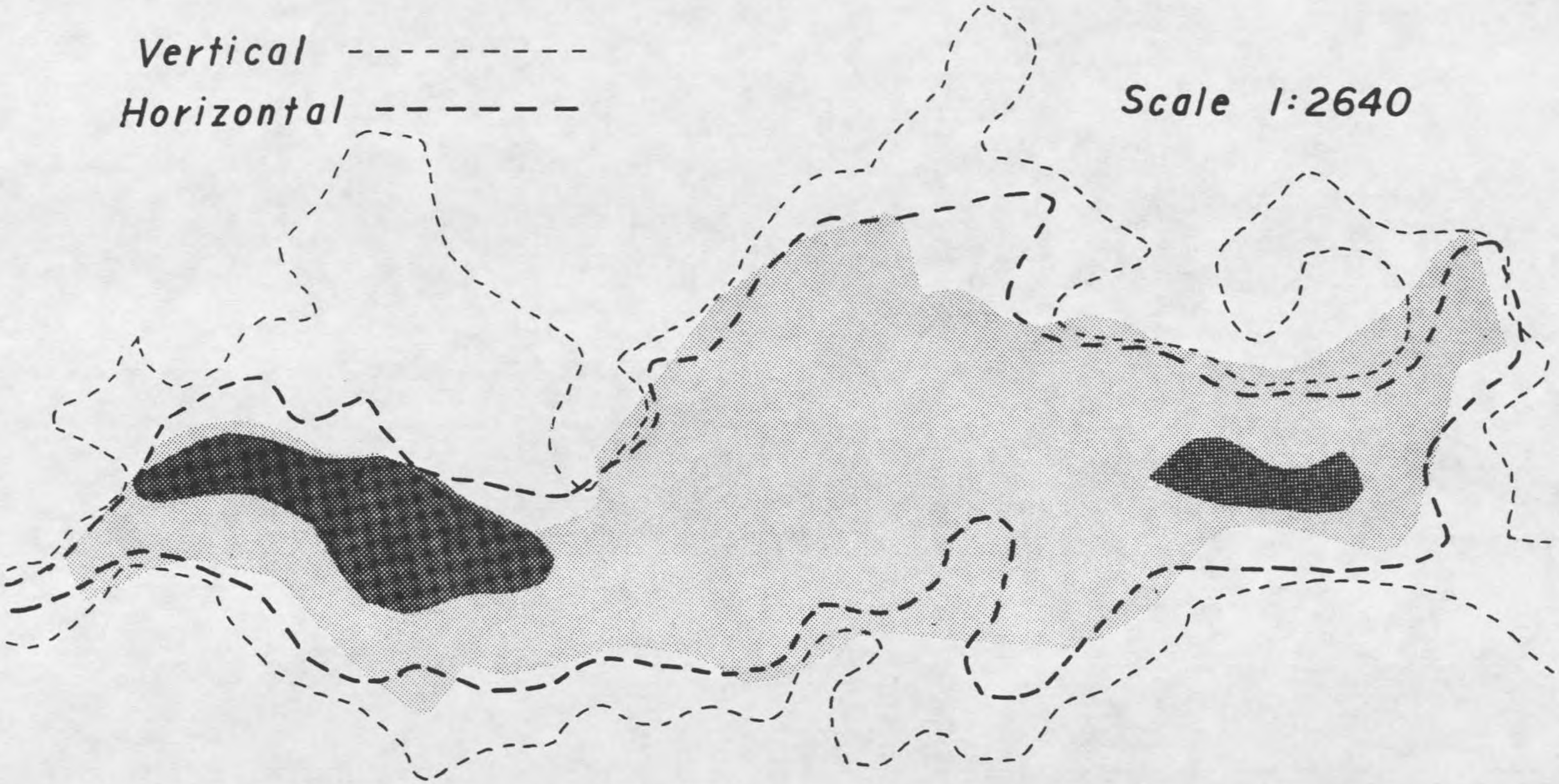

Figure 7. Mapped EM38 Isolines and Photo-visual Seep Boundaries. Location of mature seep (dark shaded area) in relation to horizontal and vertical EM38 readings, contoured at 150 mS/m. EM38 contours conform to shape of saline seep and indicate potential spread of salinity to new areas. Note agreement between shallow contour and border of developing seep. Generally, small grain yields decrease abruptly at shallow EM38 readings, greater than 150 mS/m.

Table 5. Mean Horizontal and Vertical EM Conductivity Readings and EM Ratios of Different Site Locations in Unaffected Soils, and Beginning, Developing, and Mature Seeps.

Location	Vertical (V)	Horizontal (H)	Ratio (H/V)
	-------------mS/m----------		
Site 3			
unaffected	42 A *	38 A	0.91 B
beginning	94 B	67 B	0.71 A
developing	218 C	189 C	0.86 B
mature	412 D	493 D	1.15 C
Site 9			
mature	366	327	0.89
Site 10			
beginning	164 A	118 A	0.71 A
developing	390 B	327 B	0.83 B
mature	513 C	492 C	0.95 C
Site 11			
developing	237 A	204 A	0.86 A
mature	323 B	327 B	1.01 B
Site 17			
developing	221 A	201 A	0.92 A
mature	332 B	306 B	0.92 A
Site 18			
unaffected	37 A	35 A	0.97 A
beginning	94 B	75 B	0.80 B
developing	121 C	102 C	0.86 C
Site 22			
unaffected	32 A	26 A	0.87 B
beginning	114 B	80 B	0.70 A
developing	199 C	168 C	0.84 B
mature	230 C	221 D	0.96 C

* Means in each reading position and ratio per site location denoted by the same letter are not significantly different at the 5% LSD level.

Variation of EM Readings of Salt Content in Unaffected Soils, and Beginning, Developing, and Mature Seeps

The wide ranges and large coefficient of variation (CV) reported in Table 6 below indicate that salt levels vary widely between saline seeps. Less variation is indicated for horizontal to vertical EM ratios.

Table 6. Number of Readings, Mean, Median, Range and Coefficient of Variation (CV) of EM38 Horizontal (H) and Vertical (V) Readings, and EM38 Ratio (H/V) in Unaffected Soils, and Beginning, Developing, and Mature Seeps.

EM Reading	# Readings	Mean	Median	Range	CV
		------------- mS/m	-------------	-------------	%
		Unaffected Soils			
H	41	31	34	14 - 54	33
V	41	33	40	14 - 65	39
H/V	41	0.94	0.94	0.73 - 1.15	15
		Beginning Seeps			
H	88	85	110	30 - 190	39
V	88	117	122	34 - 210	37
H/V	88	0.73	0.74	0.59 - 0.88	10
		Developing Seeps			
H	181	200	270	40 - 500	46
V	181	235	313	66 - 560	42
H/V	181	0.84	0.91	0.46 - 1.35	15
		Mature Seeps			
H	212	363	528	135 - 920	43
V	212	371	415	130 - 700	30
H/V	212	0.96	1.18	0.60 - 1.77	21

Comparison of EM Values Among All Seeps and Unaffected Soils

Pooled mean EM values of unaffected soils, and beginning, developing, and mature seeps were significantly different using one-way analysis of variance at the 5 percent level. These results are reported in Table 7.

Table 7. Comparison of Pooled EM Means For Unaffected Soils, and Beginning, Developing and Mature Seeps.

Condition	Horizontal	Vertical	Ratio (H/V)
	-------------mS/m----------		
Unaffected Soils	31 A *	33 A	0.94 A
Beginning Seeps	85 B	117 B	0.73 B
Developing Seeps	200 C	235 C	0.84 C
Mature Seeps	363 D	370 D	0.96 A

* Means of the horizontal and vertical readings, and their ratio for unaffected soils, and beginning, developing and mature seeps denoted by the same letter are not significantly different at the 5% LSD level.

Soil EC Depth Distributions

Mean ECe (saturation paste extract) depth distribution data collected from soil profiles in 17 beginning, 9 developing and 3 mature seeps are listed in Table 8. Though strong variation is indicated by large CV´s, the data reflects distinctive depth distributions for each seep type. Figure 8 shows progressive changes

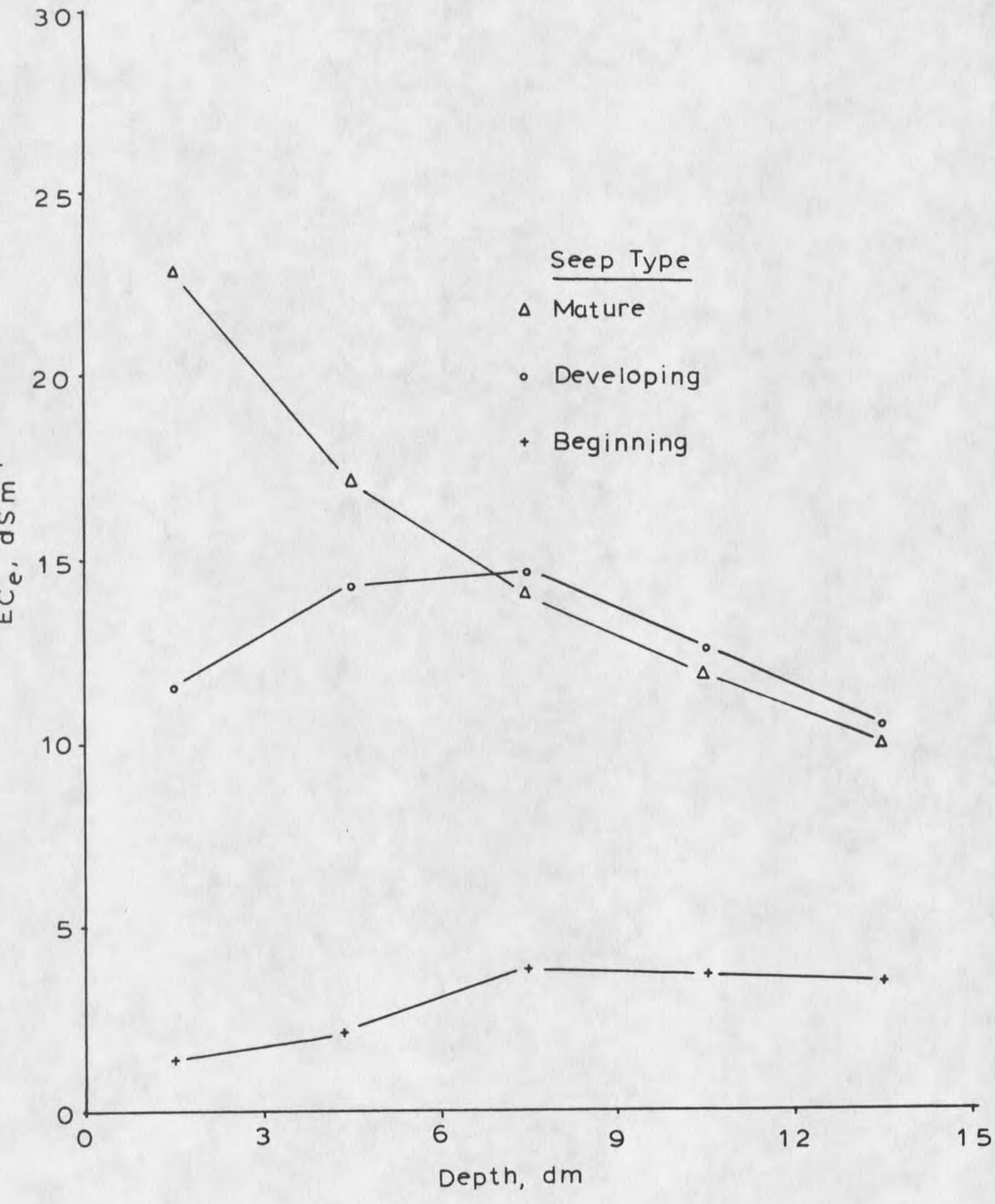

Figure 8. Mean ECe (saturation extract electrical conductivity) versus soil depth in mature, developing and beginning saline seep.

in content and depth distribution of salt among soil profiles in beginning, developing, and mature seeps. Beginning seeps concentrate salts in the lower half of the root zone in contrast to mature seeps that concentrate salts near the soil surface. Developing seeps are intermediate between the other two seep stages and have salts concentrated near the middle of the root zone.

Table 8. Number of Readings, Mean, Median, Range and Coefficient of Variation (CV) of Saturation Extract Electrical Conductivity in soil Profiles of Beginning, Developing and Mature Seeps.

Depth	Readings	Mean	Median	Range	C.V.
-cm-	#	--------------dS/m--------------			%
			Beginning Seeps		
0-30	17	1.47	2.30	0.30 - 4.3	114
30-60	17	2.11	4.20	0.39 - 8.0	99
60-90	17	3.92	5.91	0.41 - 11.4	71
90-120	17	3.67	4.25	0.59 - 7.9	70
120-150	16	3.65	4.20	0.61 - 7.8	58
			Developing Seeps		
0-30	9	11.5	10.8	0.86 - 20.8	67
30-60	9	14.3	13.0	3.7 - 22.3	50
60-90	9	14.7	15.0	5.3 - 24.8	43
90-120	8	12.6	14.0	1.9 - 26.0	60
120-150	6	10.5	10.3	1.8 - 18.7	64
			Mature Seeps		
0-30	3	22.8	23.3	18.6 - 28.0	21
30-60	3	17.2	17.1	15.1 - 19.1	12
60-90	3	14.0	14.0	12.2 - 15.8	13
90-120	3	11.9	12.0	11.6 - 12.3	3
120-150	1	10.0	10.0	0	0

Crop Response to Salinity

Small grains were luxurious in beginning seeps, severely diminished in developing seeps, and completely lacking from mature seeps. Often the boundary between developing and beginning seeps was marked by an abrupt increase in crop height and density. Mean crop and soil data (Table 9 and Figure 9) taken during July from along transects show no yield in mature seeps where salinity and soil water content are highest, low yields in developing seeps where salinity and soil water content are both high, and highest yields in beginning seeps where salinity is moderately low and soil water moderately high. Normal yield was associated with lowest salinity and least soil water.

Table 9. Mean Soil Water, Salinity (EM38), and Yield Data From Unaffected Areas, and Beginning, Developing and Mature Seep (Mid-July, 1984 Data).

Condition	1/Soil Water	2/ EM38	3/ Yield
	-%-	mS/m	g/m row
Unaffected Areas	4.4	47	93.6
Beginning Seeps	9.7	66	204.7
Developing Seeps	17.7	212	49.6
Mature Seeps	17.7	272	0

1/Soil water in 0 to 30 cm depth reported as percent weight loss upon oven drying.
2/Salinity, horizontal EM38 reading.
3/Yield reported as grams of oven dried standing biomass per meter of row. Rows were spaced 12 inches apart.

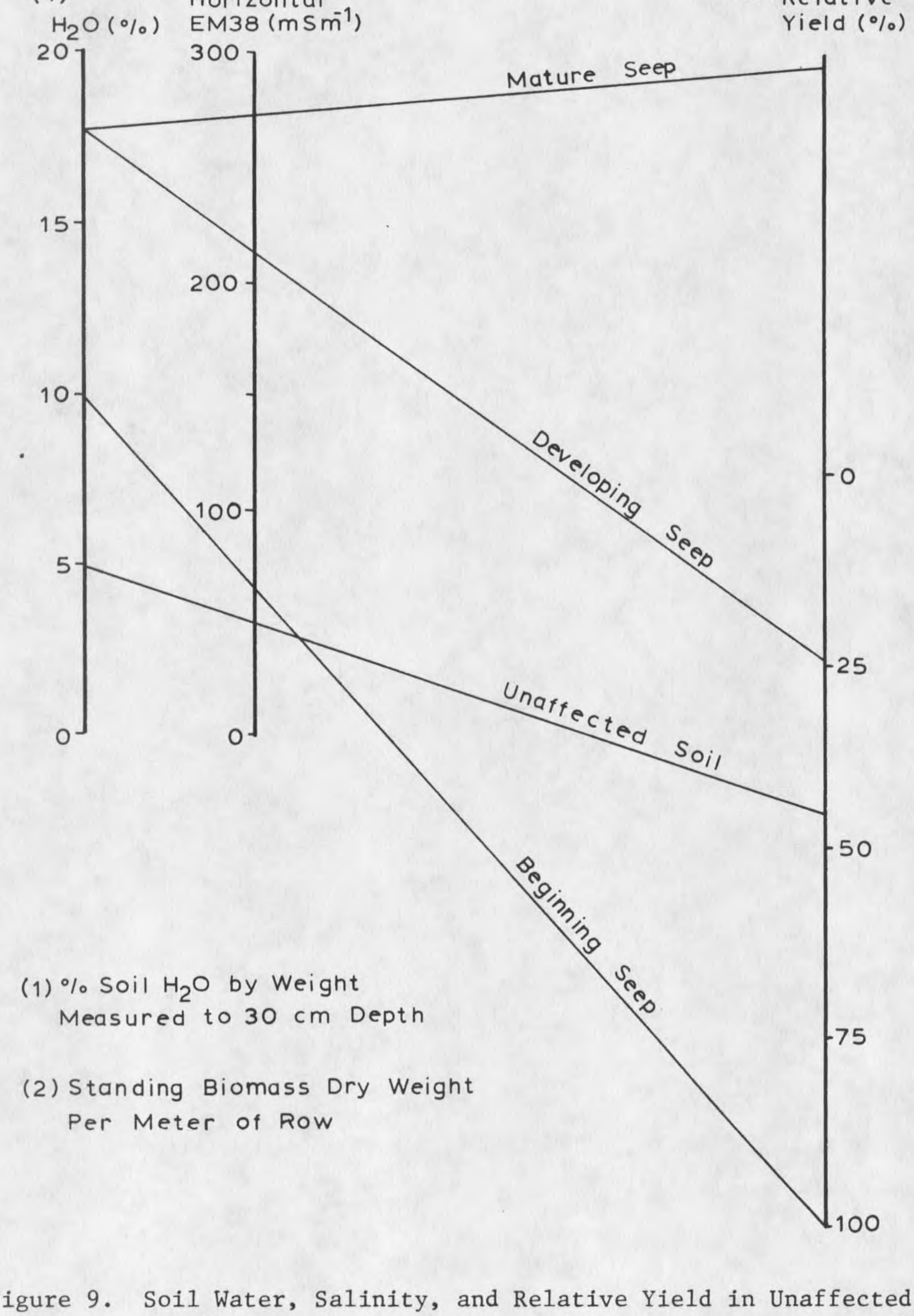

Figure 9. Soil Water, Salinity, and Relative Yield in Unaffected Soil, and Beginning, Developing, and Mature Seep. The graph predicts general trends for different seep and unaffected soils. No attempt has been made to account for management, small grain varieties, soils, climate that vary in time/space.

Halophytes

Table 10 presents means and ranges of EM (horizontal reading) and EC values associated with Suaeda, Salicornia, Kochia, Hordeum and Puccinellia determined for several seeps in the study area.

Table 10. Mean EM38 Reading (Horizontal) and Saturation Extract Electrical Conductivity (ECe) Data For Halophytes in Saline Seep.

Species	Obs.	Horizontal	Range	1/ECe	Range
	#	mS/m	mS/m	dS/m	dS/m
Salicornia rubra	16	610	720-480	48	57-37
Suaeda depressa	54	355	700-180	27	55-13
Puccinellia nut.	77	377	720-135	29	57- 9
Kochia scoparia	41	298	390-180	22	30-13
Hordeum jubatum	57	194	370- 80	14	28- 4

1/Approximate ECe (saturation extract) of the composite 1.2 m depth. Values were converted from mean horizontal EM38 readings using the relation ECe= -2.22 + 0.082H by Wollenhaupt et al. (1986) where H is the horizontal reading.

Photo-interpretation Key

Table 11 is the photo-interpretation key that was developed for identifying saline seeps. The key correlates visual characteristics and ground data of crop, weed, and soil conditions in beginning, developing, and mature saline seeps. The key is referenced for mid-July, the image date when all three seep stages are best expressed simultaneously.

Table 11. Photo Interpretation Key for Crops, Weeds and Soils in Beginning, Developing and Mature Seeps.

Beginning Seep

	Visual	Ground
Crop	Lush and luxuriant growth. Crop appears red colored in contrast to rest of crop, which has already turned.	Crop yields more than twice that of normal crop areas. Crop is between early and late heading stages.
Weed	Weeds are absent due to cultivation.	
Soil	Soil not visible due to crop cover.	Average EM38 horizontal and vertical readings of 85 and 117 mS/m respectively. Mean ratio of the two values is 0.73. Salts are low, increasing to a peak at shallow depth, then decreasing with further depth.

Developing Seep

	Visual	Ground
Crop	Reduced or eliminated crop, thin red areas on CIR. Irregular or semi-circular shaped patches, usually bordering mature seeps.	Crop yields reduced below normal and those in beginning seeps. Individual plants stunted and heads not filled.
Weed	Semi-circular rings or patches of annual weeds. <u>Kochia</u> visible as dark red patches.	Principle weed is <u>Kochia</u>. EM38 horizontal reading ranges from 180-390 mS/m.
Soil	Aqua colored areas of bare soil. Irregularly shaped or as partial rings bordering mature seeps.	Average EM38 horizontal and vertical readings 200-235 mS/m, respectively. Mean ratio of the above two values is 0.84. Salts are high, increasing to a peak at shallow depth, then decreasing with further depth.

Table 11. (Continued)

Mature Seep

	Visual	Ground
Crop	Crop is absent.	
Weed	Irregular patches of Suaeda and Salicornia. Weed patches are light pink to red.	Principle weeds are Suaeda and Salicornia. EM38 horizontal reading ranges from 180-720 mS/m.
Soil	Encrusted with white salt.	Average EM38 readings both about 363 mS/m. Mean ratio between horizontal and vertical readings is around 1.0. Salts are high, decreasing with depth.

Saline Seep Inventory

Compiled Inventory Data

Acreage data are itemized in Table 12 according to amount of beginning, developing and mature seeps, and salinized drainages within the study area. Detailed inventory data on the amount of saline seep within each land section are on file with the U.S.D.A. Soil Conservation Service, Bozeman, Montana.

Table 12. Area of Saline Seep in 74,000 Continuous Acres of Cropland in Sage Creek Watershed, Liberty County, Montana.

Seep Stage	Acres	Percent of Total
Beginning	542	0.7
Developing	666	0.9
Mature	595	0.8
Salinized Drainage	28	0.04
Total	1831	2.4

Geographic Distribution of Saline Seep

Total percent salinized cropland for each 640 acre section is summarized in Figure 10. Figure 10 indicates that seeps are distributed unequally among the sections comprising the study area. Seep affected cropland in the Watershed totals 2.4 percent, however, many 640 acre sections are 4 percent or more saline seep affected.

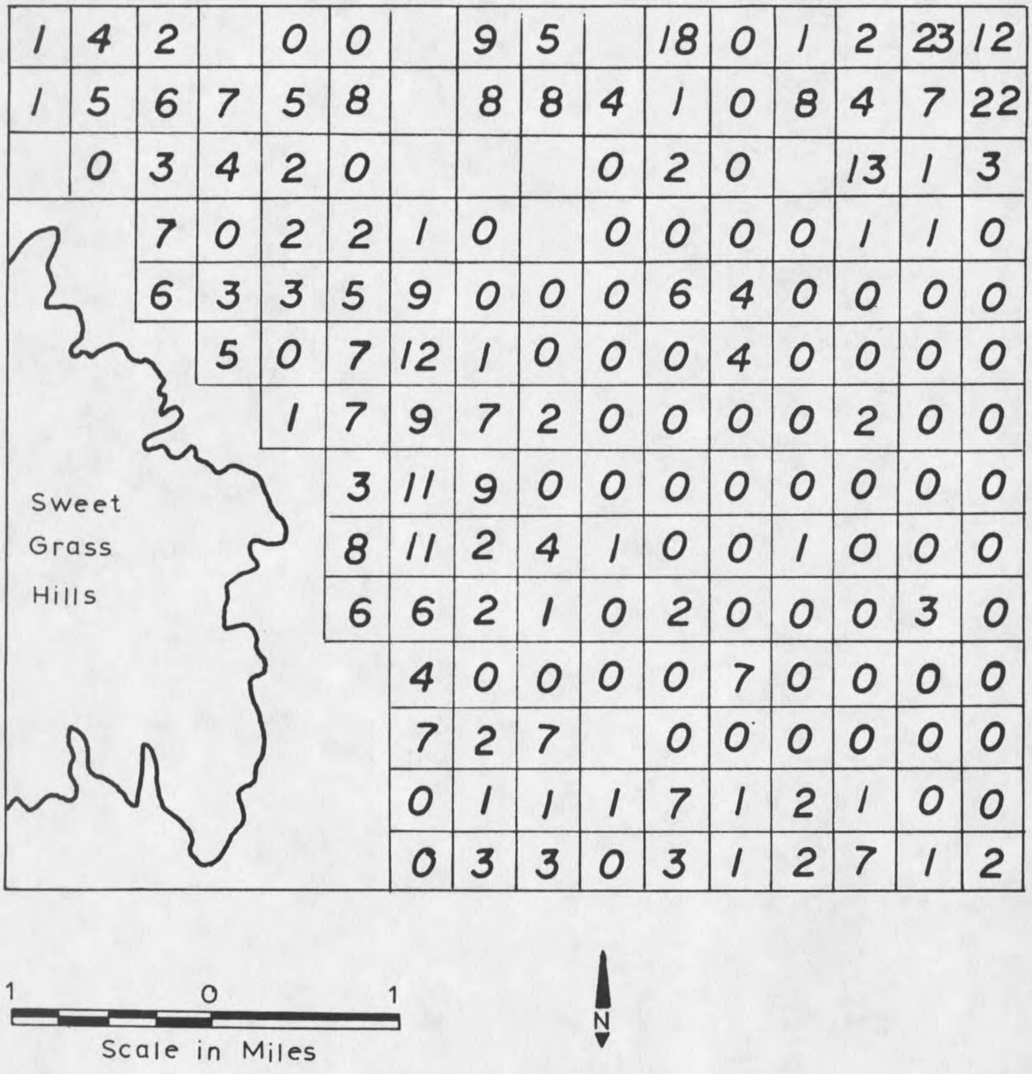

Figure 10. Cell Map of Percent Salinized Cropland.

DISCUSSION

Interpretation of Saline Seep

Interpretation

The interpretive process involves recognizing and identifying features on aerial imagery and evaluating their significance or relationship to other features. Usually interpretations rely on supporting data for achieving full understanding of the phenomena under study and are expressed in map or written form. Effective interpretation depends on the nature of the scene observed and on the training and aptitude of the observer (Rabben et al., 1960).

Factors Affecting Interpretation

The amount of visual contrast in a scene is determined by different spectral and spatial qualities characteristic of various features. These spectral and spatial qualities are manifested in photographs as tone, texture, pattern, location and size. Aerial photo-interpreters use these visual qualities to identify ground features and relate them to actual conditions on the ground.

Photo tone or color is probably the most important quality for interpreting saline seeps. Unaffected areas, and beginning, developing, and mature seeps were differentiated largely on the basis of color. The greatest visual contrast occurred in mid-July when maximum color differences in vegetation existed.

Vegetation was an important ground feature for interpreting saline seeps because vegetation reflects soil conditions. Two soil conditions that caused differences in crop maturity and morphology include:

1) A shallow water table can prolong crop growth causing green and rank growth in beginning seeps in contrast to yellow, shorter, mature crop in unaffected soils.

2) Crops in developing seeps have stunted growth, mature slowly and may not complete their life cycle in contrast to crops in beginning seeps and unaffected soils which develop fully and complete their life cycle.

Finally, visual contrast is dependent on proficient aerial photography including such factors as proper image date, film exposure, and scale. Saline seep detection is best when photography coincides with maximum differences in vegetation. Improper exposures result in poor contrast and resolution. Improper image scales present too much or not enough detail to be useful.

Factors Involving the Interpreter

Personnel with prior experience in seep diagnosis and management will have greatest potential as interpreters due to familiarity with geo-hydrologic, topographic and biologic processes related to seeps. Many farmers exhibit strong ability to recognize saline seeps on aerial photographs because of their intimate knowledge of seep locations and history on their land. This was why farmers were selected to assess the relative accuracy of this seep inventory.

Ground data were essential for learning relationships between visual and actual conditions of topography, crops, halophytes, and soils in saline seep. Field visits to seep verified whether or not interpretations were correct. Confidence was gained from correctly identifying numerous seep and other seep were then interpreted without need of being investigated on the ground.

Visual Indications of Salinity on Cropland

Beginning Seep

Green and rank growth in an otherwise yellow and maturing field of the same crop occurs where the water table contacts the root zone. Such crop characteristics are recognized in several studies to be the beginning stages of saline seep development (Dalsted et al, 1979; Sommerfeldt, 1985, personal communication; and Brown, 1976). Soils in these areas are wet but are not excessively saline thus causing prolonged and productive crop growth.

Work by Halvorson and Rhoades (1974) confirmed that water tables approached within 120 cm (4 feet) of the soil surface in emerging seep, but provided no evidence for water table influence on crop growth. The present study found prolonged crop growth and evidence for a shallow water table in most beginning seeps.

Weeds are usually not present in beginning seeps due to strong competition by crops, herbicide applications, and disturbance by cultivation. Wild oats (Avena fatua L.) is often present in the wetter field areas (Sharma and Vanden Born, 1978) and for this reason can indicate beginning seeps. However, because it tends not to form pure stands and has a similar phenology and morphology as small grains, it is not visible on CIR photographs. If patches are cut down as sometimes is done to control wild oats, the open areas are visible on aerial imagery, thus the wetter field areas and the possibility of beginning seep are indicated.

Developing and Mature Seeps

Some uncertainty occurs in the identification of developing seeps since there are other causes of poor crop growth rather than just high salinity. Crop areas that visually resemble developing seeps may be caused by extremely clayey soils, winter kill, insect damage, herbicide spill, water logged soils, etc. However, their location next to mature seeps is often enough evidence for correct identification because mature seeps are easily identified by virtue of the bright white salt crust conspicuously present at the surface.

Weeds undergo peak growth shortly before and after harvest and become highly visible in developing and mature seep on CIR photographs. Halophytic weeds such as Kochia and Salsola form pure or intermixed and dense stands that mark the transition between beginning and developing seeps. The boundary between developing and mature seeps is usually indicated by salt encrustation and an increase in such weeds as Suaeda or Salicornia. Weeds in developing and mature seeps are distinguished by bright red versus pink colors, respectively. Ground reference data on halophytic plant zonation along salinity gradients are discussed in a later section.

Interpreting Boundaries Between Different Seeps

Recognition of boundaries are based on natural demarcations existing between contrasting appearances of crops, weeds, and soils in different seeps. There is agreement between the natural demarcations and the contoured EM38 data mapped in Figure 6, hence, aerial photographs appear to be useful for mapping areas of high, moderate and low salinity. However, the contour maps reveal more specific information regarding where salinity has and may spread beyond its present visual boundaries. While less definitive, aerial photographs offer visual information on locations of general saline units that are more rapidly and accurately mapped than by ground methods alone.

Abrupt clear boundaries often appear between different saline seep stages, and between different saline seeps and unaffected soils but may also appear diffuse. Relative ease of delineating boundaries depends on how distinctive they are. Though the salinity change with distance is gradual between beginning and developing seeps, the crop responds with lush growth at a threshold point resulting in a clear boundary appearing on aerial imagery. Boundaries are distinctive between developing and mature seeps resulting from cultivation activities of plowing, seeding and weed control in the former but not the latter. In contrast, the boundaries can be sometimes diffuse between unaffected soils and beginning seeps.

Ground Reference Data

Salt Depth Distributions

Rhoades and Halvorson (1977) report diagnostic criteria for salt depth distribution in soil profiles of unaffected areas, and encroaching and developed seeps. These criteria along with terms and criteria developed by this study are correlated in Table 13.

Table 13. Depth Distribution Criteria Diagnostic of Unaffected Areas, Beginning, Developing and Mature Seep.

Saline Condition (1)	Saline Condition (2)	Salt Depth Distribution
Unaffected	Unaffected	Amount low, increasing with depth
Beginning	Encroaching	Amount low, increasing to a peak at a relatively shallow depth, then decreasing with further depth.
Developing	-------	Amount high, increasing to a peak at a relatively shallow depth, then decreasing with further depth.
Mature	Developed	Amount high, decreasing from a peak near the soil surface.

(1) Present study, 1986
(2) Halvorson and Rhoades, 1977

Each saline condition described above has a distinctive EC verses depth curve as plotted in Figure 11 (Halvorson and Rhoades, 1976) and as reported earlier in Figure 8. The depth distributions are determined by the degree to which leaching, capillarity, and evaporation act to move salts in the soil profile (Halvorson and Rhoades, 1977). Except for unaffected areas, salt is being added to some or all of the root zone by net upward flow of water from a shallow water table. This process is explained more in detail below.

Salts accumulate within the root zone due to reversal of leaching caused by capillary rise and evaporation wherever a saline water table approaches to within about 120 cm (4 feet) of the soil surface. Salts tend to concentrate at the interface between the downward and upward forces indicated where the curves for the different seep peak in Figure 11. The leaching depth will become gradually less with each incremental water table rise to depths above 4 feet due to corresponding increases in the strength of these upward forces.

Topography and Water Table Relations

Stereoscopic study of seep depicted on aerial photographs reveals topographic relationships between unaffected soils, and beginning, developing, and mature seeps. Mature seeps were usually located at the lowest landscape positions followed in order upslope by developing and beginning seeps. Unaffected areas are always found on

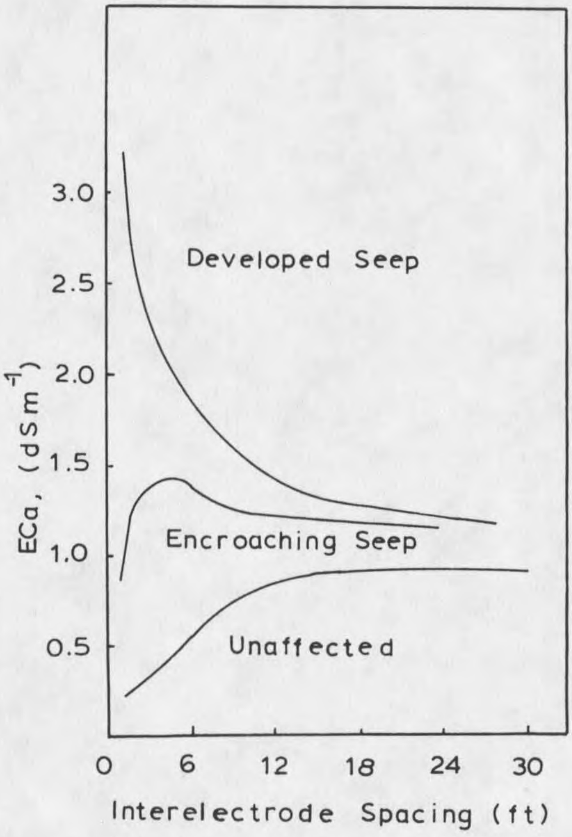

Figure 11. Relation between soil electrical conductivity, ECe, and interelectrode spacing for a developed seep, an encroaching seep, and an unaffected soil (Halvorson and Rhoades, 1976).

the highest terrain or farthest away from seep areas. In addition, beginning, developing, and mature seeps often border each other which is evidence for sharing a common water table.

Figure 12 shows a possible relation between water table height and topographic locations of beginning, developing, and mature seeps. The water table deepens relative to the ground surface in an upslope direction away from the bottom of the depression. The water table is initially shallowest in mature seeps, and gets progressively deeper in developing and beginning seeps.

Inverted salt depth distributions in mature seeps result from leaching being overcome by steady capillary rise and high evaporation from shallow water tables that are located in depressional areas. As the water table deepens upslope, evaporative and capillary potentials lessen and leaching increases within the profile. Initially, only the upper root zone is leached as indicated by the top of the curve for developing seeps. Further deepening of the water table allows leaching to greater depths as shown by the curve for beginning seeps. Unaffected areas have water tables that are too deep to influence the root zone and have, therefore, normal salt depth distribution curves.

Beginning seeps are located where the root zone and capillary fringe coincide. Water is available for the duration of the growing season so long as the capillary fringe remains within the root zone. Though water is readily available in developing seeps, salts are too high to allow crop growth. Crops in unaffected areas receive no benefit from the water table since it is too deep below the root zone.

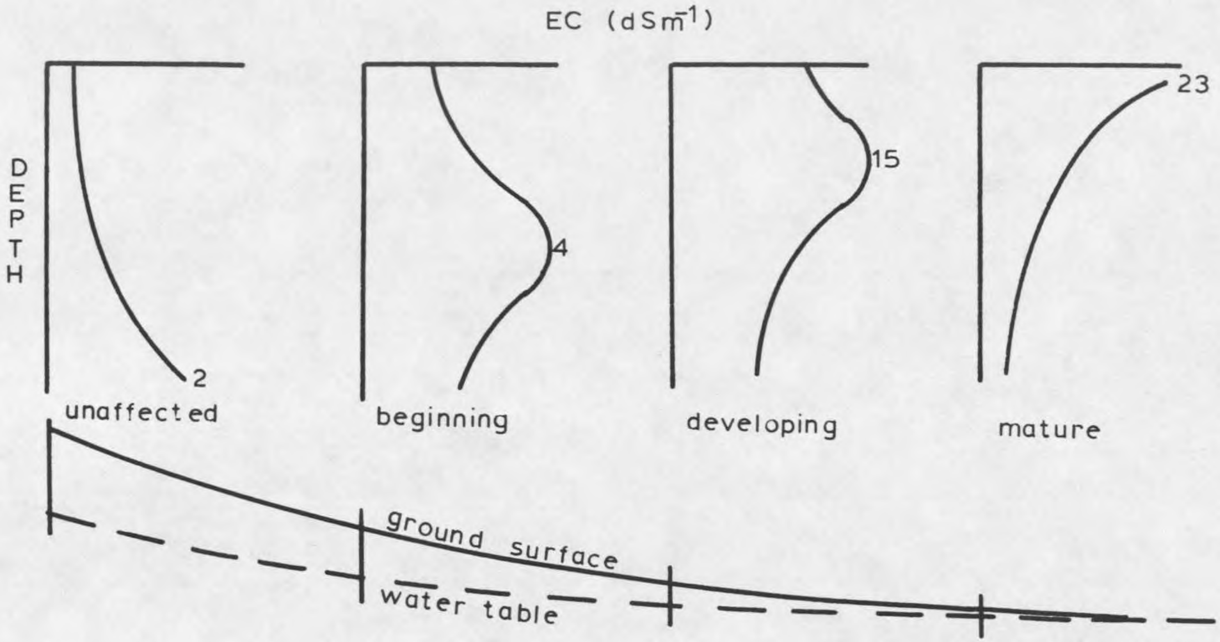

Figure 12. Relation Between Salt Depth Distribution and Depth of Water Table along a Slope. EC data are values representative of unaffected soils, and beginning, developing, and mature seep (soil profiles to 150 cm depth). The EC peak shifts downward and diminishes in magnitude as the water table deepens below the ground surface in an upslope direction away from mature seep to developing and beginning seep, and unaffected soils.

Figure 12 shows surface ECe (saturation extract) decreasing as depth to water table increases in order from mature to developing, and beginning seeps. Halvorson and Rhoades (1974) use surface measured bulk soil EC (ECa) greater than 0.5 dS/m (equal to 2.5 dS/m ECe, Rhoades and Halvorson, 1976) to identify glacial till-clay soils under the influence of saline water tables less than 4 feet (120 cm) deep. This agrees with the present study where surface ECe exceeded 2.5 dS/m in most beginning seep and in all developing, and mature seeps.

EC Depth Determinations Using EM Measurements

When EM38 readings increase in value in mature seeps, the ratio between horizontal and vertical readings tends to increase also. The ratio increases because salts increase progressively high in the soil profile from beginning seeps to developing and mature seeps. Since the EM38 horizontal position is more sensitive than the vertical position to salts at shallow depths, the horizontal reading will tend to approach the vertical reading as salts move higher in the profile. This agrees with Corwin and Rhoades (1982, 1984), who revealed that soils with most salt at the surface (inverted profiles) are indicated by horizontal EM readings that are greater than vertical readings. The opposite is true for soils with leached profiles where most salt is located low in the profile. However, their investigations did not consider the salt depth distributions that are intermediate between leached and inverted conditions where salts may peak in the middle of the profile as in beginning seeps.

McNiell (1980) described the EM38 response to soil EC for the horizontal and vertical positions using equations [1] and [2]below.

[1] Horizontal:

$$ECem = 0.44\ EC(0.0\text{-}0.3) + 0.20\ EC(0.3\text{-}0.6) + 0.10\ EC(0.6\text{-}0.9) + 0.06\ EC(0.9\text{-}1.2) + 0.03\ EC(1.2\text{-}1.5)$$

[2] Vertical:

$$ECem = 0.15\ EC(0.0\text{-}0.3) + 0.21\ EC(0.3\text{-}0.6) + 0.16\ EC(0.6\text{-}0.9) + 0.10\ EC(0.9\text{-}1.2) + 0.07\ EC(1.2\text{-}1.5)$$

Where ECem is the soil EC influencing the EM38 reading, EC is bulk soil EC (ECa), and decimal values are relative percent contribution to EM reading by soil at depth increments (listed within parentheses). Wollenhaupt et al. (1986) used these equations to convert EM38 readings into soil ECe values.

The present study calculated the expected EM38 response to soil ECa via equations [1] and [2] using methods similar to those used by Wollenhaupt et al. (1986). Actual mean ECe data listed in Table 9 were converted to ECa values using the following relation: ECe= 5.23ECa + 0.16 (Rhoades and Halvorson, 1976). Soil ECa are more convenient to use instead of ECe because the instrument is calibrated to read the former values. The data from Table 9 are characteristic of salt depth distributions in beginning, developing, and mature seep.

Horizontal and vertical EM38 values were calculated via equations [1] and [2]. Actual values (from Table 6) and calculated horizontal and vertical values, and their respective ratios are compared below in Table 14.

Table 14. Calculated and Actual EM38 Values and Ratios.

EM Reading	Horizontal	Vertical	Ratio
	mS/m	mS/m	
		Mature Seeps	
Actual	363	371	0.98
Calculated	363	304	1.19
		Developing Seeps	
Actual	200	235	0.86
Calculated	238	251	0.95
		Beginning Seeps	
Actual	85	117	0.73
Calculated	38	51	0.75

The calculated and actual EM values in Table 14 are generally comparable in trend and magnitude for each of the seep stages. All calculated and actual EM values increase from low values in beginning seeps to high values in mature seeps. Additionally, increases in EM values are accompanied by increases in horizontal/vertical ratios.

Actual ECa data from beginning, developing, and mature seeps used in equations [1] and [2] yielded EM ratios that are similar in trend and magnitude with actual EM ratios. Thus, the calculations verified that increases in EM ratios are commensurate with salts accumulating and moving higher in the soil profile.

These results imply that values and ratios yielded by horizontal and vertical readings may be useful for determining amounts and depth distributions of salt in saline seeps. Wollenhaupt et al. (1986) demonstrated this ability by using the EM38 to separate soil salinity profiles with salts concentrated near the ground surface from those with salts increasing with depth. Some practical uses of the EM38 could include verifying those areas displaying green and lush crop growth as being beginning seeps and determining the extent of below ground salinity not seen in crops and soils at the surface.

Halophytes as Saline Indicators

Local Survey of Halophytes

In Sage Creek, Salicornia, Suaeda, Puccinellia and Hordeum are the communities that inhabit saline seep. Each of these communities are distributed in the above order along gradients from high to low salt. Salicornia and Suaeda are shallow-rooted Cenopodiaceous annuals that invade the open habitats of barren salt flats (Ungar et al., 1969; Ungar, 1967). Puccinellia is a perennial bunchgrass that occupies more area and exists in less wet and less saline conditions than Salicornia (Dodd and Coupland, 1966). Hordeum is a pioneer species that tolerates moderate salinity and forms nearly pure stands over large areas where the more permanent grass cover has been destroyed (Dodd and Coupland, 1966).

Baidek et al. (1984) presented a survey of native and introduced plants found in disturbed saline sites in dryland cropland across the Canadian prairie provinces of Alberta, Saskachewan and Manitoba. In the south Alberta study area, near Sage Creek, Kochia, Salicornia, Suaeda calceoloformis (depressa), Sonchus arvensis, Distichlis, Hordeum, and Puccinellia were among the species with highest frequency occurring in 44, 55, 67, 11, 22, 33, and 40 percent of all sites, respectively.

In Sage Creek, Kochia, Suaeda, Hordeum, and Puccinellia also occurred with high frequency together or in part in nearly all seeps examined from the ground. Suaeda, an associate of the Salicornia community on undisturbed sites (Dodd et al., 1966), tended to replace Salicornia as a dominant in many seep. Salicornia and Sonchus occurred in only a few of the seep examined.

Importance for Air-photo Interpretation

Kochia, Suaeda, Salicornia, Puccinellia and Hordeum are important for saline seep detection because dense and large stands can be seen on small-scale (>1:24,000) aerial photographs. Except for Puccinellia and Hordeum which appear similar on CIR photographs, these plants have contrasting spectral signatures that allow species identification and subsequent interpretation of salinity levels.

The data in Table 11 compare with findings by Ungar (1966) and Ungar et al. (1969) relative to species distribution with salt concentration. Salicornia and Suaeda both occupy the zone of highest salt followed in order by Kochia and Hordeum. A wide range of salt tolerance is due to capability by halophytes to grow in moderate conditions, but interspecific competition restricts them to more extreme environments (Ungar et al, 1969). Therefore, it is more appropriate to use halophytes as indicators of general salinity ranges rather than indicators of specific salinity at point locations.

Other halophytes such as Chenopodium spp., Atriplex spp. and Disticlis stricta did not form dense enough stands to be seen on small-scale photographs. A partial list of both halophytic and non-halophytic plant species identified in this study is given in Appendix C.

Ancillary Interpretive Information

Old Photographs

Aerial photographs from 1940 to 1957 show more uncultivated land than at present. Much of this land is now cultivated and 1984 photographs show saline seeps that were not present in the earlier imagery. Therefore, saline seep is a phenomenon that accelerated after cultivation.

The older photographs show depressional landforms such as kettles, small lake beds, drainages and swales. Extensive native salt affected soils (expressed as barren areas sometimes called pan spots or buffalo wallow) are also visible and are most pronounced within or near depressional landforms. These features are usually visible in crops on current photographs in spite of being plowed. Present-day saline seeps may also indicate their locations.

Saline seeps tend to exist at locations that were previously native salt affected soils. This tendency is verified by ground investigations and older photographs that predate most cultivation. However, it is doubtful that circumstances surrounding the genesis of native salt affected soils are the same ones responsible for saline seep. There exists considerable controversy over whether or not these soils form in the presence of a water table. Apparently, they can form in the absence of one (Munn et al, 1982). Nevertheless, many of these native salt-affected soils in the watershed are becoming salinized as indicated by salt crusts that have formed since cultivation began. Some seeps that were difficult to see on CIR photographs were verified by studying older photographs that show kettles, lake beds and native salt-affected soils. After enough older photographs were used in this way, confidence in interpreting the CIR photographs increased to where they were used exclusively.

Efficiency of Inventory

Video Image Analysis

Recent developments in video and computer technology have led to new ways of extracting information from remotely sensed imagery. A device that uses an interactive microcomputer and a closed circuit television system is called a video image analyzer. Video image analyzers are faster and more accurate than manual techniques for inventory data compilation, image to map data transfer, and image analysis (Harrison, 1985).

Video technology has the advantage of converting photographs, maps, etc. to computer compatible digital format. Operation revolves around vidicon TV cameras converting image tones in original imagery to analog electronic signals. These signals in turn are converted to digital values that vary in proportion to signal strength.

The video image analyzer used in this study was the Measuronics System I Linear Measuring Set. This instrument consists of: 1) two vidicon TV cameras independently mounted to lighted copy stands, 2) TV monitor, 3) video cassette recorder, 4) linear measuring set, and 5) interactive microcomputer subsystem. The linear measuring set and the microcomputer interact and provide control over the following functions: image processing, storing and retrieving data, synchronizing TV cameras, data processing, and analog to digital signal conversion.

Application

The video image analyzer is capable of: 1) registering different maps and/or photographs for image transfer or map updating, 2) measuring spatial features on maps of images, and 3) compiling spatial data by different classification attributes. Various images are introduced to the system by viewing them on lighted tables with TV cameras.

Spatial features are measured when areas on original imagery are density sliced or when polygons on maps are digitized. Density slicing electronically selects for a gray tone within a range of tones that makes up an image scene. By selecting for a narrow range of tones only specific features on imagery may be digitized for measurement. Map polygons may also be measured by simply digitizing the delineations marked on maps.

The computer subsystem allows sorting of map units by the specific attributes assigned when they were delineated. Data is displayed in tabular form on the video screen or hardcopy printout, and may be stored on magnetic disk. Another useful function of the video image analyzer is magnification of original imagery via TV zoom lenses to working scales for data transfer, map updating and final map production. Listed below are image processing functions that are accomplished either manually or automatically using the computer:

1) Image registration and overlay for map unit transfer from interpretive maps to base maps.
2) Image processing involving line and point editing, border thinning, area fill, and digitizing.
3) Scale calibration.
4) Area measurement.
5) Inventory sort involving compilation of map units by specific attributes in tabular form.
6) Hardcopy printout and disk storage of images and numerical data.

Interpretation and Image Transfer Techniques

Successful remote sensing depends on effective interpretation, transfer and analysis of imagery before accurate map and inventory products are achieved. Speed and accuracy of mapping saline seep depends not only on mental and visual acuity, but also on manual skills at operating equipment used for viewing, transferring and measuring features on imagery. Equipment used to do these tasks must be easy to operate, and capable of resolving and rendering original imagery.

A separate instrument is usually required for each of the above three tasks. Stereoscopic and non-stereoscopic lenses allow interpretive views for making mapping decisions. Projection devices such as sketch masters and zoom transfer scopes enlarge or reduce the original imagery for registry with a base map of different scale. Once the two images are merged, data can be transferred from one and mapped onto the other. Planimeters and dot grids are analytical tools for measuring areas of map units.

Computer-video techniques are faster and more automated that the traditional methods described above. Their image processing capability permits registry of different images for data transfer, and measurement and compilation of mapping units for various inventory purposes.

Efficiency of Interpretation and Image Transfer Techniques

Since seeps were too small to be mapped directly on the 1:32,000 scale original imagery, the imagery had to be projected to larger scale. However, detail in the original image was lost when enlarged by a projector causing difficulty at interpreting the resulting scene. Instead, visual study had to be repeated several times until mapping units were correctly identified and accurately delineated. Though accuracy was maintained, the time required for interpretation and transfer was excessive.

Digitizing CIR transparencies for making measurements is difficult using the Measuronics System I due to poor resolution and contrast in the resulting video image. This problem was circumvented by digitizing the map units drawn on white paper that were transferred from CIR transparencies. This is a time consuming step but is necessary in order to resolve delineated map units to be measured.

The image analyzer more rapidly and accurately measures mapping units and compiles inventory data than manual techniques using planimeters or dot grids. A further advantage is production of final 1:24,000 scale maps. The image analyzer is able to register large-scale and small-scale maps with ease and accuracy.

Accuracy of Inventory

Accuracy Assessment

Several farmers assessed the relative accuracy of the saline seep inventory by reviewing maps of their land. The sample represented 28 land sections distributed among 14 widely located farms having varying amounts of seeped land. The farmers were asked to evaluate the delineations of beginning and mature seeps. For simplicity, developing seeps were grouped together with mature seeps. Based on personal discussions, farmers were aware of their land and the seep phenomenon.

The land owners indicated map inaccuracies by marking the seeps incorrectly identified (errors of commission) or missed (errors of omission). Hence, the total beginning and mature seeps listed in Appendix F reflect the original quantity mapped plus land owner map corrections.

Of 177 total beginning seeps, 136 were assessed to be correctly identified for 77 percent. Commission and omission errors amounted to 15 and 14 percent, respectively. Of 92 mature seeps, 78 were assessed to be correctly identified for 85 percent. Errors of commission and omission were 9 and 5 percent, respectively.

The equation (Snedecor and Cochran, 1980)

$$p = p + \{1.96 \quad p\, q/n\}$$

was used to determine the 95 percent two tailed confidence limits about the above agreement statistics. The inventory agrees with 95 percent certainty to within 77 +6.2% and 85 +7.3% of the farmer assessment for beginning and mature seeps, respectively.

Errors of Omission

Omission errors involving missed seeps occurred when phenological differences did not appear in crops due to improper image dates. Fewer mature seeps were missed than beginning seeps (5 percent verses 14 percent) because the former are conspicuous during most of the growing season whereas the latter are readily seen only during part of the growing season.

Omission errors are due to photographic and scene factors that reduce contrast such that the interpreter cannot distinguish between seep features and their background. Poor contrast arises from different ground features having similar spectral reflectances, and over and under-exposure of film. Field areas appear spectrally different at times when phenological variation exists within a crop and do not appear different when crops are uniform. For this reason more beginning seeps can be identified shortly before harvest than at any time before or after this period. Saline seeps were difficult to identify on over-exposed photographs.

Errors of Commission

Commission errors result from interpretations that misidentify features resembling saline seeps. Features that resemble beginning seeps include prolonged green crop areas in clay soils occupying swale depressions and kettles. This appearance may be caused by cloddy soils that delay or reduce seedling establishment. Seedlings that are delayed from growing normally until later in the season tend to mature later than the rest of the crop. Greeness is promoted by a greater supply of soil water for individuals when stand densities are reduced and competition is lessened.

Where soil conditions caused delay in crop maturity, the visual appearance resembled developing seeps. Misinterpretations of mature seep were the result of white tones caused by glazed, dry surfaces of clayey lake beds and channel bottoms. Other false appearances of mature seep were caused by shallow soils on calcareous ridgetops.

Geographic Information Capabilities

Map Data Base

An advantage of sub-dividing the watershed and measuring resulting smaller land units is ability to assign positional data to each unit. The present study used one land section (640 acres) as the sub-divided unit because this amount of area was covered by each photograph and is a basic land unit of the U.S. Land Grid System. Use of the Land Grid System is convenient because the east-west and north-south coordinate lines are usually visible as roads or field edges on aerial photographs.

Figure 13 is a computer drawn contour map of Figure 10. Both figures are the inventory data geographically displayed in map form. Figure 13 shows that most saline seeps are concentrated in zones bordering the Sweet Grass Hills to the east and on the northern drainage divide in Canada. Relatively little saline seep occurs in the central part of the watershed.

Displaying inventory data in geographic form is useful for showing cause and effect relationships between different factors. The following geo-hydrologic, topographic and agricultural factors could participate in causing saline seeps to concentrate in these zones:

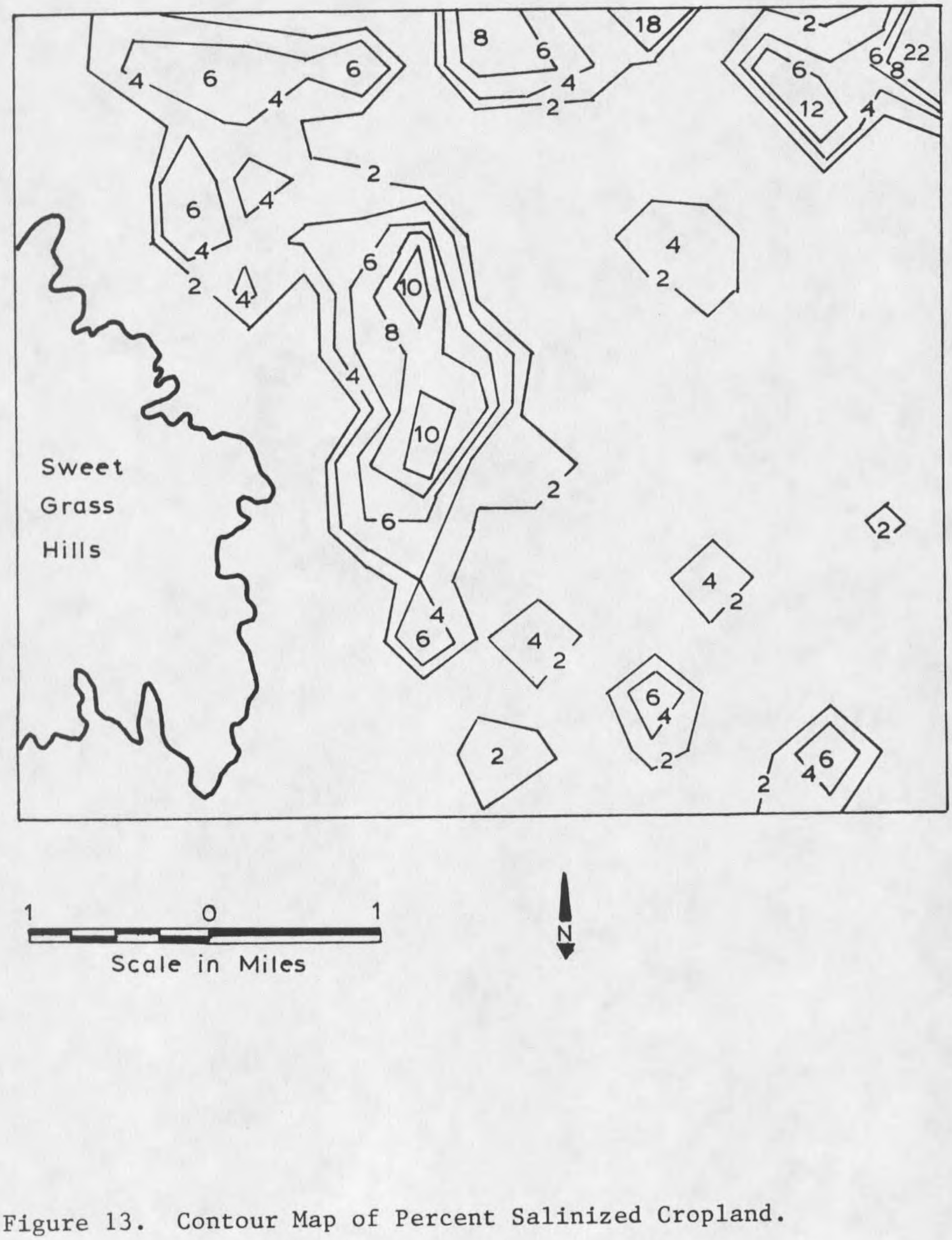

Figure 13. Contour Map of Percent Salinized Cropland.

1) The Sweet Grass Hills contribute large amounts of runoff to a ground water table in glacial till at lower elevations.
2) Many water catching landforms (ie., kettles, lakebeds) exist within these zones.
3) Presence of crop-fallow agriculture.

Descriptive Attributes

Table 15 is an example of spatial data measured from one of many land sections that were inventoried in the watershed. The inventory data are tabulated according to descriptive attributes (ie., landscape position, landowner, stage of development) that are in turn keyed to the location of each land section.

Table 15. Tabulated Inventory Data for SECTION 33 T37N R6E.

Saline Seep Inventory — Total Acres of Cropland = 600

Area in Acres	Number of Units	Type	Landscape Position	Land Owner
.75	1	SLNZD DRNG-C	FLUVE	N/A
8.7	3	SLNZD DRNG	FLUVE	N/A
8.6	2	STAGE 1	FLUVE	GRAMMER
1.3	1	STAGE 1	FLUVE	SAGE CR CLNY
1.3	1	STAGE 1	POTHOLE	GRAMMER
13.3	1	STAGE 3	POTHOLE	GRAMMER
31.4	1	STAGE 1	FLUVE	GRAMMER
.16	1	STAGE 2	FLUVE	GRAMMER
2.6	1	STAGE 3	FLUVE	GRAMMER
.65	2	STAGE 3	SWALE	GRAMMER
.42	1	STAGE 2	SWALE	GRAMMER
14.1	1	STAGE 1	SWALE	GRAMMER
83.3	16			

Descriptive attributes allow useful ways to organize and display inventory data. For example, the attributes enabled determining the frequency distributions of beginning, developing, and mature saline seep acreage relative to different landforms as shown in Figure 14.

Fluve saline seeps are more numerous and are smaller in average size than pothole saline seeps. The greater quantity of fluve seeps than pothole seeps is probably due to differences in the amounts of these landforms present. The larger size of pothole seeps may relate to available ground surface area. Pothole landforms are wide and round whereas fluve landforms are narrow and linear, therefore, pothole landforms potentially afford greater surface area for seeps to form on.

Additionally, Figure 14 reveals the potential for salinity in fluve seeps to become more severe as indicated by greater amounts of beginning and developing seeps than mature seeps. In contrast, less potential exists for pothole seeps to become more severe because there are fewer beginning and developing seeps than there are mature seeps.

Aerial Photography

Small Camera System

Small cameras (small-format, 35 mm and 70 mm) are inexpensive compared to large cameras (large-format, 9 X 9 inch) due to relatively lower costs for cameras, film and accessories. Small cameras are more practical than large cameras when recording small target areas such as

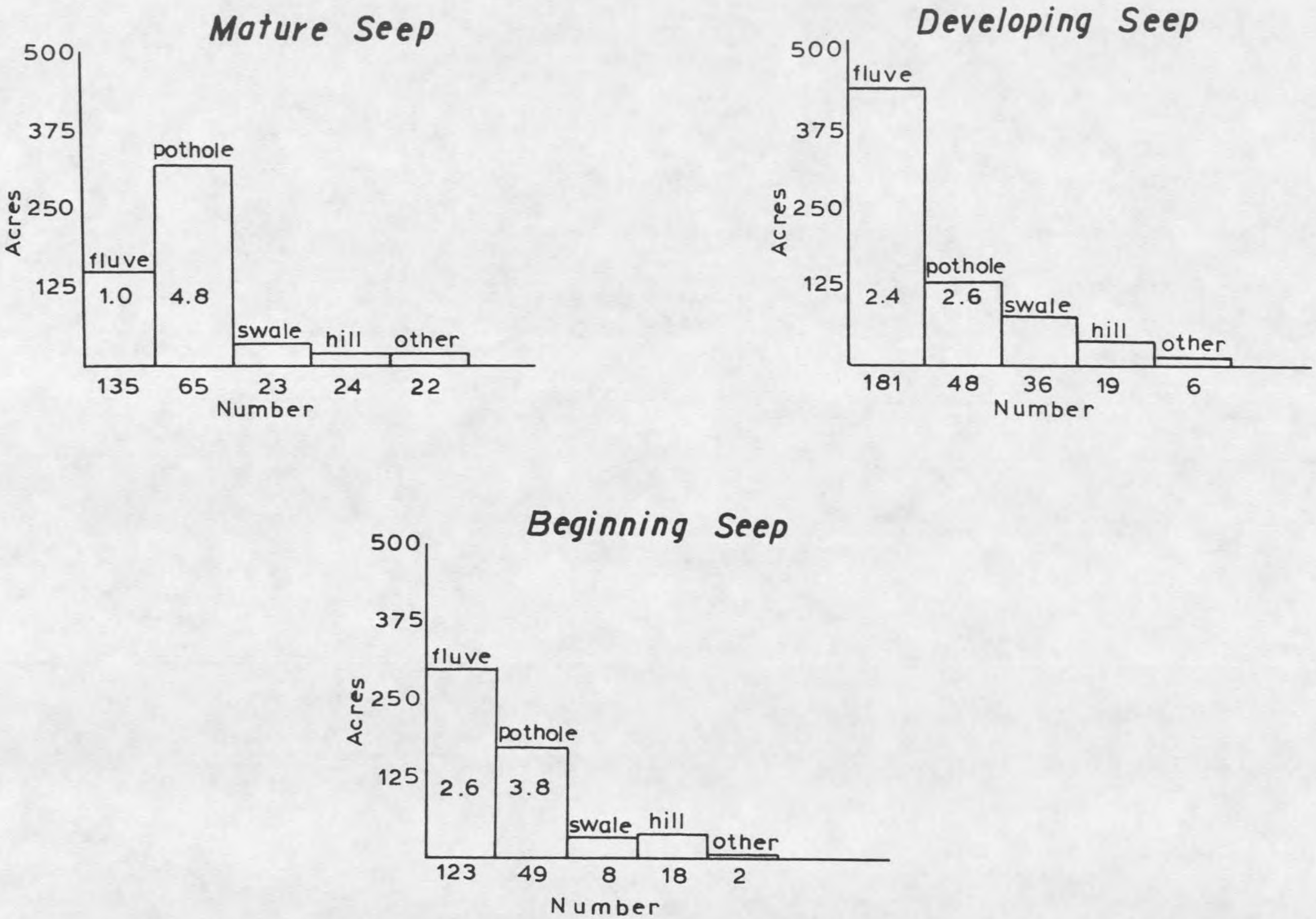

Figure 14. Saline Seep Fredquency and Acreage Among Landforms. Values within bars are average size (acres) for fluve and pothole seep.

experimental plots and sampling units. In addition, small-format photography is a cost effective approach to determine the feasibility of using large cameras that cover large geographic areas on an operational basis.

Aircraft

A further advantage of small camera systems is light weight, small size, and portability that permits use of small aircraft as remote sensing platforms. Such aircraft as Cessna models 150, 172 and 182 are small and consequently cost less to operate than larger aircraft that are required to carry heavy large-format camera systems.

The Cessna 150 used in this study normally is the least expensive of the above three aircraft. However, its limited climb capability makes it difficult to achieve and maintain high altitudes necessary for recording small-scales. Fuel consumption can be up to 30 percent for climb leaving little for conducting missions over large target areas. In this study, two trips were required to photograph all 200 square miles of the target area in one day from 10,000 feet altitude above mean sea level. Under flying conditions of high altitudes and long missions, Cessna models 172 and 182 are more suitable because of greater climb and speed performance. The higher operating costs of these aircraft will tend to be offset by shortened mission times.

Flight Lines

Maintaining extended flight lines by manual flying was difficult even when section lines or other linear ground features were followed.

Manual flying resulted in gaps and duplicate coverage between photographs of adjacent flight lines. If greater flying efficiency was possible, film resources could have been extended to include more photo-coverage of the watershed.

Recent advances in electronic micro-circuitry has allowed installation of economical LORAN (Long Range Navigation) equipment in light single engine aircraft. This equipment provides an accurate readout of aircraft position in reference to the ground such that a pilot can promptly make directional corrections. The navigation problems associated with intercepting and maintaining flight lines are alleviated, thus, small camera coverage of relatively large land areas is achieved without wasting film.

Imaging

Color infrared film was exposed under clear sky conditions between 1000 and 1500 hours (MST) through a 50 mm lens at an exposure setting of f/5.6 and 1/500 second. Transparencies tended to be properly exposed at this setting between 0930 and 1130 (MST). After that time period exposures tended to be 1/2 to 1 f/stop over exposed depending on scene reflectance. Nevertheless, the slight over exposure did not detract from their usefulness.

The 30 percent overlap achieved between most successive transparencies is helpful for insuring complete coverage and for providing at least some stereo coverage. Complete stereo coverage is most useful for interpretive purposes but more film is required.

Commonly available small-scale black and white ASCS photographs may be used to interpret topography in lieu of incomplete stereo coverage on small-format transparencies especially where economy is essential. An intervalometer, an automatic device for exposing imagery at precisely timed intervals, is recommended to maintain a predetermined amount of overlap relative to aircraft ground speed.

Operational System

Status of LANDSAT

The method developed by Sommerfeldt et al. (1984) is capable of mapping areas of salinity using LANDSAT data interpreted via manual and automatic techniques. Their method is limited by sensor resolution but is reasonably accurate (75%) and rapid for reconnaissance (Sommerfeldt, 1985, personal communication). Evidently, various remote sensing programs are still in the research and developmental stages of collecting interpretive ground data, and improving system reliability and sensor resolution. Until these items are improved, present remote sensing methods can not be beneficial in terms of cost and performance (Watkins, 1982).

Operational Requirements

Benton (1982) lists the requirements of a successful operational system as follows. Though stated in regard to satellite systems, these requirements will pertain to airborne systems also. The system must: 1) be driven by and tailored to user needs, 2) provide continuity of data, 3) be reliable, 4) provide timely data, 5) be consistent, 6) be stable over time, and 7) be amenable to change. The above criteria are adapted by the present study in relation to saline seep survey as follows:

1) System successfully meets users operational needs in terms of quality data (ie. resolution, image dates, etc.).
2) Remotely sensed data must still be obtainable for future inventory and monitoring surveys.
3) System equipment is reliable and easy to operate. In addition, inventory procedures are simple.
4) Timely data must be provided in order to meet current decisions and projected deadlines.
5) Remotely sensed data must consistently relate to ground reference data. Provisions must exist to account for anomalous signatures.
6) Remote sensing and image interpretation procedures must follow established guidelines in order to maintain consistency between users who survey different areas.
7) Remote sensing and image interpretation procedures need to be amenable to procedural and technological improvements.

Evaluating and Selecting Imagery

The most important requirement of remote sensing for inventorying saline seeps is obtaining high quality imagery. Imagery must record all stages of saline seep at once and must resolve the smallest seep. Various kinds of satellite and aircraft imagery differ in image quality depending on such factors as resolution, ground coverage, and system reliability. Advantages and disadvantages of satellite and aircraft imagery are evaluated by the present study in Table 16 below.

Table 16. Relative Performance Characteristics of Aircraft and Satellite Systems.

CHARACTERISTIC	SATELLITE	AIRCRAFT		
		Large Format		Small Format
Source	LANDSAT MSS	NHAP ASCS	contract	contract
Coverage	very large	medium	medium	small
Scale	very small	small	small	small
Resolution	low	high	high	high
Delivery	slow	fast	fast	fast
Reliability	lowest	low	high	high
Cost	lowest	low	high	high

Table 16 indicates that LANDSAT imagery is least expensive, however, relatively low resolution limits its use to reconnaissance of large areas (Sommerfeldt, 1985). More detailed saline seep inventories are possible with development of a proposed 10 meter resolution system, but future sensor improvements are slow in coming and will be more expensive than present LANDSAT imagery (Watkins,1982).

Commercially available large-format CIR and color NHAP (National High Altitude Photography) and ASCS aerial photographs have high resolution and are inexpensive at about $2 per square mile. However, image dates are often incorrect and are not reliable for detecting saline seeps. Nevertheless, such imagery should be useful for surveys wherever areas have been photographed are the proper time.

Costs of commercial photography would have been about $10 per square mile for the present study area of 200 square miles. Large-format systems would not have cost appreciably more than small-format systems. Small-camera systems are not more economical than large-camera systems if relatively large areas are photographed because more flight lines are required. Though contract photography is more expensive than all other imagery, it offers the greatest capability for attaining image dates needed for detecting saline seep. This ability is due to short notice scheduling for recording at specific times when salinity is best expressed in crops. The specified image dates will also coincide with time when crop differences reflect soil variability within fields, thus, contract photographs could serve purposes other than just saline seep inventories.

Large and small format systems each offer separate advantages depending on the size of the area to be photographed and the associated equipment costs. Generally, small-format photographs cost less to obtain than large-format photographs if target areas are relatively small and missions are short. They are also less expensive due to small capital investment in equipment and lower operating costs. However, a large-format system will record large areas faster than small-format systems because more ground is covered per photograph. This may be important for acquiring photo-coverage over large regions if required to be completed in one season.

Normal color film and color video may present further cost savings approaches. Regular color film will render enough contrast between saline and non-saline areas to permit its use. Regular Ektachrome films may be practical to use if bought in bulk quantity, are less expensive than CIR film, and can be processed locally thus shortening turn-around times. Low equipment costs and "real time" image data are characteristics of color video imagery that may prove advantageous for saline seep inventories. A chief disadvantage of video is relatively poor resolution, however, most seeps are probably large enough to be resolvable.

Acquiring Imagery

The most important objective for remote sensing of saline seep is to obtain imagery when saline seeps are best expressed in crops. However, no single image date will be best for whole regions since type of crop and growth stage will vary in response to management and regional climatic differences. It follows that large regional areas will need to be partitioned into smaller areas which can be surveyed on image dates that best coincide with local expression of salinity in crops.

Selecting the best image date requires monitoring stages of crop growth from the ground within each area in order to determine the best time of saline seep expression. The Montana Agricultural Potentials System (MAPS), a geographic information system, could be used to approximate dates of crop maturity in various areas for scheduling remote sensing. Because beginning seeps show best for about two weeks before harvest, there probably would not be enough time to acquire imagery of a large region if using a single small-format camera in a single year. The best imagery can be obtained by small cameras gradually over several growing seasons or by large cameras in relatively little time because of large ground coverage.

Interpreting and Analyzing Imagery

The photo-interpretation key in Table 11 that correlates image and ground characteristics is a list of guide-lines that different observers can use as a common basis for interpretations. This will help insure consistent interpretations among observers. The key is in keeping with inventory guidelines established by the SCS for saline seep inventory.

The key will be applicable to other locations as indicated by various remote sensing studies that report similar visual characteristics of saline seep on CIR imagery for much of the northern Great Plains (Fogarty et al., 1976; Worcester et al., 1979; May and

Peterson, 1974; Cameron et al., 1981; and Sommerfeldt et al., 1984). Nevertheless, some management, geo-hydrologic, climatic, and pedologic factors will not be described for areas outside of Sage Creek. The present interpretation criteria should be expanded as new criteria not previously described are discovered.

Simple and efficient manual methods are available for viewing imagery and transferring map information. Stereo lenses and non-stereo magnifiers are readily available and are inexpensive. A projection device for enlarging small-scale imagery for registering with ASCS field sheets can be fabricated at low cost (Meyer and Grumstrup, 1978), as was done by the present study. An instrument that can be used for both interpreting and mapping is a Bausch and Lomb zoom transferscope. Thompson et al. (1981) used this instrument for interpreting original imagery and transferring data directly onto base maps in one step. Though costly, this instrument can save time.

Computer technology for measuring and compiling large amounts of map polygon data will be essential for an operational survey of any kind. For this reason, video image analyzers will be important for conducting specific tasks such as: 1) merging imagery and base maps for information transfer and final map production, 2) digitizing and quantifying features from various aerial imagery, and 3) sorting inventory data by different attributes.

Harrison (1984) evaluated video image processing techniques for compiling map data from aerial photographs. His equipment and procedures were similar to those exercised in this study. He concluded that video image processing is less time and labor intensive, and more accurate than traditional map measurement techniques. This conclusion supported adoption of the technique for map data quantification and compilation in resource inventories. Benefits included ability to use economical small-format videographs and photographs, and reduction in field efforts of surveying land. Costs for equipment and training are initially high but are compensated by reduced laboratory and field labor costs.

The positive evaluation given video image analyzing by Harrison is consistent with experience in this study. The Measuronics System I LMS was invaluable for quantifying and compiling hundreds of mapping units and for preparing final maps. In addition, this system enabled sorting of essentially four attributes (ie. location, seep type, landscape position, and landowner) that otherwise could not have been done using manual techniques alone. The system requires little training time due to its user friendliness and simple configuration.

An operative system for surveying saline seep is possible if imagery is properly acquired over large areas and users of the technology are trained in methods of image interpretation. The next step towards operational survey of saline seep is a training program for teaching photo-interpretation skills, ground survey techniques using the EM38, and techniques in image transfer and video image analysis. These skills and techniques will need to be tested on a trail basis within an area larger than Sage Creek in order to determine their practicality in an operational setting.

SUMMARY

This is a summary of the author's understanding of saline seeps and their delineation on aerial photography. It is based upon previous work and his own. Saline seeps are best identified on the ground with equipment, e.g. EM 38. Their extent, acreage, spacial distribution, etc. is best determined with aerial photos.

Saline seeps in the Sage Creek Watershed of Liberty County, Montana were inventoried from 70mm format, 1:32,000 scale, color infrared aerial photographs. Saline seep were classified into three developmental stages: beginning, developing and mature. These stages often appeared in combination rather than in single stages separate from each other. For example, mature seep were surrounded by rings or partial rings of developing and beginning seeps.

Vegetation differences reflected saline seep stages. Saline seep detection was best when aerial photography coincided with maximum differences in vegetation. In this study, optimal image date for recording seep occurred when rank growth, darker color, and delayed crop maturity of beginning seeps appear in fields that are otherwise nearly ripe and ready for harvest. Developing and mature seeps were visible on color infrared (CIR) imagery for most of the growing season.

Features within saline seep that can be identified on CIR photographs include: 1) small grain crops, 2) various halophytic weeds, 3) salt crusts on soil surface, and 4) different cultural practices such as tillage patterns, weed control, and harvesting.

By mid-July, beginning seeps showed on CIR photographs as dense red areas due to their luxurious grain crop and delayed maturity. Crops on unaffected areas were mature and appeared straw-colored on CIR photographs. By late July and August this difference was nearly gone when all of the crop was mature.

Developing seeps appeared aqua-colored on CIR photographs due to a high percentage of exposed bare soil. Crops were absent from developing and mature seeps due to high salt levels. Several salt-tolerant weeds (halophytes) were visible on CIR photographs as dull red, irregularly shaped areas within the bright white salt-encrusted areas of mature seeps. Mature seeps were often located in a depression or a toeslope position and were easily identified by the bright white salt crust at the soil surface. Crops were absent due to high salt levels.

Electromagnetic and electrical conductivity measurements of salt content and depth distributions helped to confirm visual interpretations. EM38 data maps, along with aerial imagery, revealed specific information regarding where salinity was and may spread beyond present visual boundaries.

Ground measurements confirmed that beginning seeps produce crop yields twice that of unaffected crop areas, and mature later than unaffected areas. High yield resulted from low salt and intermediate water content. Salts in beginning seeps were relatively low in amount, increased to a peak at shallow depth from the surface, then decreased with further depth. Crop yields were reduced or eliminated in developing seeps because of high salt in spite of high soil water content. Salt level was high at the surface, increased to a peak at shallow depth, then decreased with further depth. Crops were absent in mature seeps due to salt levels that were very high at the ground surface and decreased with further depth.

Halophytic weeds were good indicators of saline seep stages. Kochia, Suaeda, Salicornia, and Hordeum each tolerated different levels of salinity and had different spectral signatures on CIR photographs that allowed interpretation of salinity levels. However, it was appropriate to use halophytes as indicators of general salinity ranges rather than as indicators of specific salinity at point locations.

The video image analyzer (Measuronics System I, LMS) allowed registration of different maps and photographs for image transfer, areal measurements of saline seep, and compilation of spatial data by descriptive attributes. The descriptive attributes, such as seep type and landscape position were keyed to geographic locations that allowed useful methods to organize and display data with tables and maps.

The following procedures were developed for detecting and inventorying saline seeps using CIR aerial photographic and video-image analysis:

1. Acquiring imagery during a 2 or 3 week period ending about 1 week before harvest,

2. Using the photo interpretation key (Table 11) (to guide interpretations and to maintain consistent interpretations),
3. Mapping images of saline seeps on large-scale base maps after projected from small-scale aerial transparencies, and
4. Using a video image analyzing device for rapid and accurate measurement of map polygons, and for sorting and compiling large amounts of inventory data.

The following were recommendations for further developing an operational system for detecting and inventorying saline seeps:

1. A training program for teaching photo-interpretation skills and video image analysis,
2. Use of a large-format camera system for covering large areas rapidly. However, small-cameras can gradually cover large areas over several growing seasons, and
3. Test skills and developed methods within an area larger than Sage Creek, in order to determine operational practicality.

CONCLUSIONS

Beginning, developing, and mature saline seeps can be mapped using CIR aerial photographs. Seeps smaller than 1 acre are discernable on 1:32,000 scale transparencies.

Beginning seeps support crops that are more productive, greener, and slower to mature than yellow, more mature crops in unaffected areas. The prolonged and luxuriant crop growth is due to a lasting supply of water supplied from a water table proximal to the root zone. The best time for recording beginning seeps is during a two week period, lasting until about one week before harvest. Remote sensing of developing and mature seeps are not time dependent because they are visible during most of the growing season.

Electromagnetic and EC determinations of salt/depth relations confirm that salts accumulate within the soil profiles of beginning, developing and mature seep due to upward flow of water from a saline water table. The EM38 electromagnetic conductivity meter is an invaluable tool for saline seep diagnosis. This tool efficiently allows field measurements of salt concentrations and depth distributions in saline seeps.

Weed halophytes are useful indicators of developing and mature saline seeps. The different tolerances to salinity displayed by various weeds can generally serve as an index to site conditions. *Suaeda depressa*, *Kochia scoparia*, and *Hordeum jubatum* are the most useful weeds for remote sensing of saline seep in the Sage Creek watershed. Old photographs are useful for interpreting saline seeps because they show native saline soils, kettles, lakebeds, and other depressional landforms that otherwise may not be seen on current photographs because of plowing.

Video image analysis offers an accurate and rapid way to measure, compile, and sort large amounts of map polygon data. The technology is useful for registering images and maps for data transfer and final map preparation. Because of a lack of resolution and contrast in the video image, the Measuronics System I is not effective for directly measuring original imagery. However, this problem can be circumvented by using manual image transfer techniques.

The interpretation and mapping techniques were accurate at 77 and 85 percent for beginning and mature seeps, respectively. The procedures described can be operational if: 1) training programs are implemented, and 2) procedures are locally adapted to account for different geohydrologic, pedologic, climatic, and management conditions at other locations.

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APPENDICES

APPENDIX A

CHEMICAL DATA FROM SOIL PROFILES IN BEGINNING, DEVELOPING AND MATURE SEEPS

Table 17. Chemical Data From Soil Profiles in Beginning, Developing and Mature Seeps at Reference Sites.

Beginning Seep

Site No.	Depth	Ca	Mg	Na	SO_4^{-2}	Cl^-	NO_3^-	ECe	pH
	--cm--	ppm						dS/m	
12	0-30	93.0	28.0	172.0	39.9	62.8	31.6	1.23	7.27
	30-60	281.0	97.6	173.1	189.9	16.8	76.0	2.16	7.47
	60-90	509.5	278.8	415.7	477.0	10.7	113.9	5.20	8.08
	90-120	153.0	139.0	874.9	424.3	20.1	17.8	5.30	8.15
	120-150	81.0	51.75	672.2	207.9	23.4	4.4	3.90	8.32
13	0-30	70.5	34.7	102.6	12.7	18.4	4.4	0.66	6.70
	30-60	162.5	67.4	327.8	119.4	16.9	0	1.91	7.28
	60-90	95.5	110.1	1107.2	609.0	32.9	0	5.30	8.05
	90-120	15.0	18.5	530.1	181.9	72.6	8.8	3.40	8.50
	120-150	---	---	---	---	---	---	---	---
11	0-30	71.0	11.1	55.5	7.7	30.0	17.8	0.38	6.76
	30-60	80.5	20.2	48.9	9.0	34.9	17.8	0.39	6.84
	60-90	332.0	85.4	182.0	104.2	25.2	86.5	2.14	7.25
	90-120	182.5	49.3	258.6	120.0	28.5	50.8	1.77	7.59
	120-150	104.0	40.8	97.2	36.6	33.9	0	1.93	7.64
11	0-30	60.5	11.9	83.8	9.9	30.0	22.4	0.36	5.20
	30-60	83.5	29.7	198.1	9.3	36.3	13.3	7.60	6.24
	60-90	50.0	15.4	95.3	7.2	22.3	8.8	0.41	7.37
	90-120	40.0	3.2	259.6	13.5	28.6	13.3	0.76	7.92
	120-150	69.5	27.7	1210.9	66.4	103.0	17.8	5.20	8.35
10	0-30	39.5	16.8	175.0	11.8	31.0	17.8	0.65	6.70
	30-60	66.0	21.3	209.1	51.3	44.0	17.8	0.87	6.75
	60-90	494.5	220.3	369.9	476.5	18.9	13.3	4.80	6.90
	90-120	550.5	312.3	1254.5	13.9	19.9	17.8	7.90	7.14
	120-150	338.0	199.7	1498.5	735.9	49.4	22.4	7.80	7.25
10	0-30	49.0	14.1	381.5	49.0	71.4	22.4	1.28	7.44
	30-60	239.5	290.2	1342.5	935.8	43.0	22.4	8.00	7.94
	60-90	354.5	538.1	1823.5	1662.0	32.0	17.8	11.40	8.22
	90-120	49.0	130.7	881.9	571.0	42.0	13.3	5.30	8.15
	120-150	13.0	30.0	698.5	213.3	75.9	13.3	3.60	8.35

Table 17. (Continued)

Site No.	Depth	Ca	Mg	Na	SO_4^{-2}	Cl^-	NO_3^-	ECe	pH
		Beginning Seep							
	--cm--	ppm						dS/m	
8	0-30	89.5	10.3	137.2	4.7	235.3	4.4	0.73	6.80
	30-60	568.0	131.0	77.1	100.9	788.5	20.6	2.90	7.19
	60-90	435.0	210.9	331.4	285.5	94.2	27.9	3.90	7.69
	90-120	139.5	109.9	138.1	131.8	33.4	2.2	3.00	7.90
	120-150	171.0	95.7	10.2	124.1	611.5	0	2.04	7.57
8	0-30	649.0	167.3	183.8	435.5	120.0	4.4	3.30	7.17
	30-60	588.5	245.3	314.5	563.8	51.6	4.4	5.10	6.96
	60-90	620.5	168.6	175.0	436.5	36.8	2.2	4.20	7.35
	90-120	666.5	129.1	35.1	289.4	53.0	2.2	3.50	7.45
	120-150	621.0	193.1	298.3	317.3	35.5	2.2	3.70	7.51
9	0-30	175.5	28.0	91.7	5.9	24.3	8.9	0.90	6.95
	30-60	153.0	16.3	30.0	7.8	20.5	0	0.48	6.92
	60-90	100.0	25.6	143.0	16.6	25.8	15.8	1.07	7.42
	90-120	72.5	15.7	101.9	10.9	31.5	6.6	0.99	7.56
	120-150	100.0	20.5	91.7	16.0	28.2	8.9	1.00	7.35
9	0-30	53.0	23.8	99.6	4.9	48.7	6.6	0.89	6.85
	30-60	44.5	14.5	141.8	14.3	29.4	0	0.70	6.75
	60-90	117.5	33.6	30.0	46.8	26.5	2.2	1.10	7.22
	90-120	95.0	26.4	120.2	25.4	45.1	0	0.79	7.42
	120-150	119.5	29.9	99.1	15.3	74.5	6.6	0.82	7.46
9	0-30	94.0	21.8	89.0	6.0	27.5	6.6	0.86	6.89
	30-60	73.5	24.9	124.4	10.7	13.8	4.4	0.70	7.37
	60-90	379.5	124.8	169.7	208.5	32.0	4.4	2.37	7.46
	90-120	484.5	121.1	178.4	207.1	22.9	0	2.80	9.35
	120-150	682.5	152.1	388.8	156.7	31.5	4.4	3.90	7.45
10	0-30	601.0	177.5	24.0	374.2	155.9	8.9	4.30	7.20
	30-60	481.0	250.8	227.2	625.0	50.55	11.2	4.70	7.13
	60-90	47.0	277.2	283.5	615.0	27.0	11.2	4.80	7.55
	90-120	510.0	280.5	260.7	583.9	21.7	2.2	4.90	7.75
	120-150	246.5	147.6	202.3	335.2	27.0	4.4	3.70	7.81
19	0-30	209.0	41.4	22.1	21.9	79.5	48.6	1.55	7.35
	30-60	246.0	52.5	29.5	110.7	31.3	28.9	1.37	6.90
	60-90	668.5	149.3	165.0	161.1	34.1	54.2	3.80	7.36
	90-120	259.0	65.6	96.7	136.6	27.9	20.6	1.80	7.37
	120-150	360.5	119.5	152.3	171.6	41.9	23.0	2.37	7.35

Table 17. (Continued)

Site No.	Depth	Ca	Mg	Na	SO_4^{-2}	Cl^-	NO_3^-	ECe	pH
					Beginning Seep				
	--cm--	ppm						dS/m	
6	0-30	39.5	19.1	21.6	17.0	26.5	18.2	0.30	6.40
	30-60	97.0	30.5	23.2	17.0	67.5	13.5	0.49	6.25
	60-90	873.5	341.9	105.7	321.8	16.3	15.8	3.30	7.15
	90-120	825.5	570.5	289.4	497.3	8.6	8.9	4.40	7.58
	120-150	627.0	813.0	412.6	643.0	10.1	11.2	5.60	7.76
6	0-30	148.0	40.4	31.2	20.8	149.1	8.9	0.69	5.59
	30-60	563.0	197.4	65.6	192.7	40.4	11.2	2.16	6.60
	60-90	931.0	357.1	110.6	568.2	47.6	4.4	4.00	7.24
	90-120	826.5	510.0	689.6	683.2	8.2	4.4	5.60	7.63
	120-150	554.5	614.7	977.5	561.9	52.9	4.4	6.00	7.83
4	0-30	75.0	19.0	20.4	22.3	45.7	8.9	0.39	6.35
	30-60	88.5	24.8	8.3	9.2	59.2	8.9	0.44	7.00
	60-90	113.5	62.0	20.8	8.1	39.4	6.6	0.79	7.57
	90-120	33.0	62.4	39.4	18.0	73.6	35.4	0.59	7.88
	120-150	44.0	59.2	67.9	13.5	67.8	4.4	0.61	8.05
2	0-30	176.0	21.5	1199.9	414.2	110.6	23.0	6.50	7.39
	30-60	189.5	145.6	328.9	277.3	86.1	11.2	2.80	7.75
	60-90	693.5	658.3	1146.3	739.4	66.9	11.2	8.10	7.89
	90-120	615.0	849.9	2110.1	964.0	71.6	15.8	9.70	7.85
	120-150	117.5	265.4	1621.7	963.0	64.0	15.8	6.20	8.00

Table 17. (Continued)

Developing Seep

Site No.	Depth	Ca	Mg	Na	SO_4^{-2}	Cl^-	NO_3^-	ECe	pH
	--cm--	ppm						dS/m	
12	0-30	437.5	385.2	5820.0	973.5	47.6	0	18.70	8.02
	30-60	43.5	111.8	3469.5	1218.0	38.5	0	12.20	8.81
	60-90	73.0	382.5	7801.0	1634.0	41.9	36.4	24.80	8.83
	90-120	460.0	811.9	8796.0	2708.5	28.7	8.8	26.00	8.48
	120-150	401.0	504.4	5590.0	4375.5	15.4	0	18.70	8.24
13	0-30	44.5	18.1	228.3	51.9	27.7	22.4	0.87	6.42
	30-60	169.0	96.7	466.0	206.6	36.8	8.8	3.70	7.50
	60-90	354.5	258.1	1425.3	582.0	29.1	4.4	7.40	8.07
	90-120	20.0	11.2	185.3	65.7	42.1	0	1.93	8.81
	120-150	49.5	10.9	246.3	55.5	42.9	0	1.84	8.53
11	0-30	58.0	12.7	242.4	7.50	32.0	22.4	0.86	6.66
	30-60	101.5	88.1	602.0	384.0	41.1	31.6	4.10	7.19
	60-90	117.5	332.5	2517.0	1687.5	62.9	55.7	11.50	8.27
	90-120	70.5	124.4	1922.9	727.0	78.4	70.9	8.00	8.39
	120-150	37.5	38.7	1080.2	307.5	70.6	31.6	4.70	8.51
10	0-30	344.5	126.6	466.9	335.8	42.1	36.4	4.40	6.98
	30-60	175.5	436.1	2278.0	1297.5	50.3	27.0	12.20	8.10
	60-90	97.5	415.9	3281.0	1646.5	52.6	31.6	13.60	8.35
	90-120	319.5	570.9	4372.0	2416.5	34.4	31.6	17.50	8.32
	120-150	327.5	478.3	4761.5	1962.5	35.8	27.0	17.20	8.25
6	0-30	482.0	1066.7	5286.0	2966.0	83.3	331.9	20.80	7.90
	30-60	456.5	951.5	5706.0	2856.0	82.4	270.2	22.30	8.12
	60-90	454.0	653.4	5231.5	1541.0	84.7	199.7	19.40	8.15
	90-120	---	---	---	1117.0	52.4	80.6	---	---
	120-150	---	---	---	---	---	---	---	---
4	0-30	897.5	1961.5	5013.5	3555.0	150.6	11.2	17.50	6.92
	30-60	1014.0	2752.0	5045.5	2695.5	103.9	6.6	21.10	7.90
	60-90	981.0	2870.1	5773.0	3323.0	63.5	4.4	20.20	8.04
	90-120	845.5	1631.3	3871.0	1942.5	47.1	11.2	14.20	8.09
	120-150	532.5	746.6	2309.5	704.7	71.7	6.6	9.10	7.83
4	0-30	1984.5	867.2	3181.0	1038.5	525.0	1027.9	16.30	5.95
	30-60	1471.7	100.5	5809.0	2146.5	100.5	134.3	18.60	7.77
	60-90	510.0	1009.1	4771.5	1816.0	82.6	97.3	17.50	8.24
	90-120	238.5	626.7	5267.0	451.9	49.5	220.2	16.50	8.42
	120-150	147.5	250.5	3687.0	326.1	98.1	62.7	11.70	8.31

Table 17. (Continued)

Developing Seep

Site No.	Depth	Ca	Mg	Na	SO_4^{-2}	Cl^-	NO_3^-	ECe	pH
	--cm--	ppm						dS/m	
5	0-30	705.0	765.5	3912.0	1133.0	104.4	40.6	13.70	7.10
	30-60	724.0	1124.5	7470.0	2184.5	69.3	2.2	21.80	8.09
	60-90	568.0	413.7	3567.5	1532.0	82.7	0	13.00	7.81
	90-120	602.0	393.2	3220.0	1705.0	41.7	0	11.00	7.99
	120-150	---	---	---	---	---	---	---	---
5	0-30	645.0	561.2	2950.5	1012.0	77.5	2.2	10.40	7.74
	30-60	614.0	638.5	3671.5	2138.5	39.9	0	12.60	8.16
	60-90	48.5	70.9	1355.8	---	---	0	5.20	8.62
	90-120	50.0	65.1	1548.7	586.2	181.3	0	5.70	8.42
	120-150	---	---	---	---	---	---	---	---

Mature Seep

Site No.	Depth	Ca	Mg	Na	SO_4^{-2}	Cl^-	NO_3^-	ECe	pH
	--cm--	ppm						dS/m	
13	0-30	457.0	790.8	5248.5	1982.5	34.4	137.2	18.60	7.89
	30-60	422.0	453.9	5038.0	1714.5	29.1	17.8	15.10	8.34
	60-90	408.5	372.0	4525.0	731.0	30.6	17.8	15.80	8.38
	90-120	453.0	141.8	2811.0	1117.5	18.9	0	11.60	8.23
	120-150	---	---	---	---	---	---	---	---
10	0-30	424.0	1175.8	465.5	2714.0	390.0	2.2	21.90	8.04
	30-60	266.5	1125.8	370.1	1699.5	171.8	2.2	19.10	8.27
	60-90	167.0	20.1	259.1	1150.5	110.2	2.2	14.00	8.26
	90-120	134.5	428.4	242.6	1027.0	120.8	0	11.48	8.22
	120-150	125.0	323.6	168.9	649.0	93.9	6.6	10.00	8.24
4	0-30	703.0	2425.0	9096.5	3788.5	365.5	1027.9	28.00	6.10
	30-60	624.0	818.1	5709.0	2123.5	83.7	220.2	17.30	7.84
	60-90	148.0	273.5	4528.5	984.0	148.1	220.2	12.20	8.44
	90-120	367.0	285.0	4199.0	---	---	57.0	12.30	8.35
	120-150	---	---	---	---	---	---	---	---

Table 18. Corresponding Horizontal and Vertical EM38 Readings for Unaffected Soil, and Beginning, Developing and Mature Seeps at Reference Sites.

Reference Site 3, Developing Seep

No.	Horizontal	Vertical
	mS/m	
1	115	130
2	280	300
3	200	205
4	150	200
5	150	200
6	120	175
7	64	110
8	95	140
9	65	115
10	65	140
11	65	100
12	175	190

Note: No grid coordinate locations are given with these values.

Table 18. (Continued)

Reference Site 3, Mature Seep

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
1	270	320	25	700	515
2	210	290	26	720	430
3	295	295	27	690	500
4	350	380	28	810	600
5	300	320	29	685	490
6	260	300	30	225	260
7	300	340	31	470	410
8	450	430	32	550	470
9	490	410	33	790	540
10	520	430	34	480	400
11	500	360	35	470	380
12	420	380	36	225	220
13	390	370	37	430	390
14	490	420	38	550	435
15	490	490	39	470	440
16	820	520	40	350	320
17	820	530	41	440	380
18	720	520	42	590	490
19	870	570	43	360	320
20	330	340	44	420	370
21	390	310	45	430	380
22	260	250	46	310	300
23	200	250	47	460	340
24	435	405	48	340	320
			49	240	250
			50	410	390
			51	290	300
			52	480	320
			53	380	360
			54	320	350
			55	230	220

Table 18. (Continued)

Reference Site 9, Beginning Seep

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
1	42	47	14	70	87
2	45	55	15	71	84
3	46	58	16	73	86
4	59	75	17	76	86
5	64	84	18	62	83
6	125	150	19	61	72
7	76	96	20	65	88
8	110	135	21	62	76
9	77	105	22	70	81
10	140	175	23	89	115
11	66	98	24	70	83
12	140	185	25	72	88
13	58	72			

Reference Site 9, Developing Seep

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
1	90	100	11	82	92
2	105	110	12	86	100
3	88	105	13	82	96
4	94	110	14	130	170
5	125	145	15	155	199
6	90	120	16	140	175
7	96	130	17	105	135
8	120	115	18	91	120
9	105	100	19	96	125
10	90	84	20	110	150

Table 18. (Continued)

Reference Site 9, Unaffected Soils

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
1	33	30	12	38	42
2	31	30	13	35	36
3	31	31	14	32	32
4	32	34	15	26	26
5	39	43	16	29	27
6	42	50	17	32	30
7	44	50	18	38	40
8	28	25	19	44	56
9	31	28	20	40	46
10	35	34	21	30	30
11	34	37	22	30	29

Table 18. (Continued)

Reference Site 10, Beginning Seep

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
1	180	250	24	82	120
2	62	98	25	55	86
3	135	175	26	57	82
4	140	162	27	55	82
5	84	112	28	91	135
6	96	130	29	68	98
7	130	165	30	71	100
8	110	155	31	98	150
9	69	105	32	65	100
10	71	120	33	102	132
11	61	97	34	81	110
12	74	110	35	62	90
13	115	155	36	64	92
14	98	148	37	82	110
15	75	110	38	78	100
16	38	59	39	50	79
17	57	85	40	38	56
18	72	105	41	36	49
19	90	140	42	30	34
20	89	150	43	36	54
21	56	88	44	78	105
22	58	90	45	90	120
23	77	120	46	86	120

Reference Site 10, Developing Seep

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
1	120	165	7	190	205
2	160	195	8	105	115
3	230	265	9	98	120
4	110	160	10	210	245
5	255	285	11	130	140
6	145	185	12	130	150

Table 18. (Continued)

Reference Site 10, Mature Seep

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	----------mS/m---------			----------mS/m---------	
1	265	265	5	280	290
2	235	250	6	230	240
3	160	160	7	170	185
4	210	220			

Reference Site 10, Unaffected Soil

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	----------mS/m---------			----------mS/m---------	
1	23	22	18	38	46
2	31	32	19	44	62
3	47	54	20	13	13
4	37	46	21	31	43
5	24	33	22	30	42
6	14	16	23	22	20
7	54	65	24	22	27
8	20	14	25	29	42
9	33	34	26	25	36
10	18	19	27	24	30
11	21	23	28	36	59
12	15	13	29	52	72
13	12	15	30	31	39
14	17	21	31	30	45
15	14	18	32	65	80
16	21	27	33	60	87
17	16	21			

Table 18. (Continued)

Reference Site 17, Developing Seep

No.	Horizontal	Vertical
	mS/m	
1	235	315
2	340	400
3	360	450
4	380	400

Reference Site 17, Mature Seep

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
1	310	390	15	350	370
2	160	240	16	280	390
3	310	370	17	400	450
4	380	400	18	390	420
5	340	390	19	380	400
6	430	450	20	305	350
7	350	380	21	265	300
8	360	390	22	350	390
9	305	315	23	205	290
10	250	305	24	240	305
11	270	340	25	210	315
12	360	400	26	310	315
13	305	370	27	300	305
14	270	330	28	380	400

Table 18. (Continued)

Reference Site 18, Beginning Seep

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
1	130	180	10	115	165
2	130	180	11	125	180
3	190	200	12	120	175
4	140	190	13	90	130
5	155	210	14	110	170
6	80	120	15	145	220
7	120	155	16	70	100
8	90	140	17	85	110
9	105	150			

Reference Site 18, Developing Seep

No..	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
1	305	340	13	480	480
2	460	460	14	400	520
3	430	500	15	380	480
4	390	460	16	370	470
5	500	370	17	220	320
6	460	500	18	180	250
7	310	320	19	260	340
8	320	440	20	220	280
9	400	500	21	240	260
10	580	560	22	160	240
11	480	480	23	160	240
12	460	520			

Table 18. (Continued)

Reference Site 18, Mature Seep

No.	Horizontal	Vertical
	mS/m	
1	220	290
2	145	230
3	165	250
4	235	285
5	380	470
6	420	420
7	420	460
8	420	430
9	315	410
10	190	270
11	170	275
12	225	310
13	215	300
14	380	440
15	195	280
16	150	250
17	240	345
18	265	360
19	220	300
20	440	540
21	590	620
22	360	500
23	510	480
24	400	320
25	560	660
26	700	600
27	460	480
28	700	700
29	650	640
30	520	540
31	520	540
32	385	460
33	480	540
34	440	520
35	430	500
36	380	460
32	400	480
38	380	480
39	220	320
40	275	370
41	260	360
42	250	330
43	300	390
44	440	400
45	680	650
46	780	660
47	380	400
48	540	590
49	460	490
50	430	520
51	510	480
52	690	600
53	270	290

Table 18. (Continued)

Reference Site 19, Developing Seep

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
1	100	160	36	205	260
2	215	265	37	220	250
3	175	245	38	130	130
4	130	170	39	145	150
5	190	240	40	175	245
6	255	310	41	130	135
7	140	200	42	205	240
8	180	210	43	230	265
9	93	120	44	245	250
10	230	280	45	190	250
11	170	185	46	225	250
12	150	185	47	200	230
13	180	190	48	230	250
14	170	215	49	215	240
15	190	245	50	240	260
16	195	250	51	260	295
17	215	250	52	265	285
18	190	190	53	200	215
19	195	215	54	240	265
20	195	170	55	205	245
21	120	170	56	93	150
22	90	130	57	180	245
23	87	120	58	160	200
24	170	265	59	170	175
25	170	250	60	190	240
26	240	290	61	240	255
27	235	270	62	200	250
28	200	230	63	215	175
29	250	240	64	260	300
30	200	200	65	235	260
31	215	225	66	255	280
32	155	185	67	180	230
33	125	180	68	160	175
34	140	200	69	150	215
35	165	205	70	290	300

Table 18. (Continued)

Reference Site 19, Developing Seep

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
1	265	300	10	250	250
2	260	275	11	205	215
3	280	265	12	230	265
4	250	295	13	185	215
5	190	205	14	240	310
6	170	190	15	280	340
7	230	260	16	175	245
8	150	200	17	210	225
9	125	175			

Reference Site 19, Mature Seep

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
1	340	320	9	350	350
2	310	330	10	320	360
3	390	400	11	570	460
4	260	265	12	275	260
5	380	390	13	270	270
6	340	330	14	270	260
7	340	360	15	265	250
8	385	330			

Table 18. (Continued)

Reference Site 22, Developing Seep

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
1	275	300	13	285	300
2	250	310	14	280	310
3	200	275	15	225	230
4	135	190	16	140	180
5	80	125	17	94	142
6	125	170	18	200	205
7	40	66	19	230	240
8	130	170	20	205	240
9	155	200	21	310	315
10	205	220	22	260	210
11	160	220	23	230	255
12	130	155			

Reference Site 22, Mature Seep

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
1	175	310	36	250	275
2	180	250	37	165	225
3	290	330	38	245	320
4	330	270	39	260	320
5	280	350	40	255	290
6	330	370	41	300	340
7	330	400	42	340	340
8	440	480	43	200	200
9	375	420	44	170	150
10	400	475	45	155	150
11	185	255	46	105	130
12	293	340	47	200	320
13	485	480	48	240	270
14	410	420	49	135	143
15	400	400	50	320	330
16	490	550	51	400	400
17	430	430	52	155	210
18	440	465	53	205	270

Table 18. (Continued)

Reference Site 22, Mature Seep (Continued)

No.	Horizontal	Vertical	No.	Horizontal	Vertical
	mS/m			mS/m	
19	280	320	54	190	245
20	450	425	55	155	175
21	390	430	56	160	185
22	380	380	57		
23	450	500	58		
24	360	430	59		
25	330	400	60		
26	390	400			
27	430	480			
28	410	400			
29	170	190			
30	245	200			
31	245	175			
32	170	200			
33	340	305			
34					
35					

Table 19. Some Native and Non-native Plant Species Occupying Saline Habitats in Sage Creek Watershed, Liberty County, Montana.

I. Poaceae

1. *Poa juncifolia* (POJU)	alkali bluegrass
2. *Festuca arundinacea* (FEAR)	tall fescue
3. *Bromus tectorum* (BRTE)	cheat grass
4. *Poa pratensis* (POPR)	kentucky bluegrass
5. *Agropyron cristatum* (AGCR)	crested wheatgrass
6. *Hordeum jubatum* (HOJU)	foxtail barley
7. *Puccinellia nuttalliana* (PUNU)	alkali grass
8. *Distichlis stricta* (DIST)	inland salt grass

II. Chenopodiaceae

1. *Kochia scoparia* (KOSC)	kochia
2. *Sarcobatus vermiculatus* (SAVE)	greasewood
3. *Suaeda depressa* (SUDE)	seablite
4. *Salsola kali* (SAKA)	Russian thistle
5. *Salicornia rubra* (SARU)	saltwort
6. *Atriplex spp.* (AT)	saltbush
7. *Chenopodium spp.* (CH)	lamb´s quarters

III. Brassicaceae

1. *Thlaspi arvense* (THAR)	field pennycress
2. *Descurainia pinnata* (DEPI)	tansy mustard
3. *Camelina microcarpa* (CAMI)	falseflax

IV. Asteraceae

1. *Taraxacum spp.* (TA)	dandelion
2. *Artemisia frigida* (ARFR)	fringed sagewort
3. *Artemisia ludoviciana* (ARLU)	prairie sage
4. *Achillea millefolium* (ACMI)	yarrow
5. *Cirsium spp.* (CI)	thistle
6. *Dyssodia papposa* (DYPA)	fetid marigold
7. *Sonchus ugliosus* (SOUG)	perrenial sowthistle

V. Onagraceae

1. *Epilobium watsonii* (EPWA)	willow herb

VI. Juncaginaceae

1. *Triglochin spp.* (TR)	arrow grass

Table 20. EM38 Salinity Readings and Vegetation Cover Classes, Measured Along Salinity Gradients.

Reference Site #14, Transect 1

Distance	Horizontal	Vertical	BS*	KOSC*	HOJU	SUDE	SOUG	PUNU
---m----	--------mS/m-------							
1	310	330	4	2		+		
2	310	350	2	3		2		
3	350	315	4	2		2		
4	350	310	3	1		4		
5	310	360	3	3		+		
6	360	380	4	2		+		
7	410	370	4			2		
8	405	340	2		+	5		
9	315	370	2		3	1		
10	350	350	3		1	3		
11	330	300	2		4	1		
12	340	330	1		+	5		
13	330	340	1		1	5		
14	350	290	2		+	4		
15	320	320	2		3	2		+
16	270	300	1	1	4	1		+
17	250	280	1	4	3	1		
18	250	270	1	5	2	+		
19	250	270	1	1	2	3		
20	270	240	1		+	5		
21	230	230	1		+	5		
22	220	260	1		1	5		
23	200	250	1		2	2		
24	200	230	1		4	2		
25	190	235	0		4	2		
26	180	210	0		5	1		1
27	170	200	0		6			
28	160	200	0		6			
29	160	200	0		6			
30	150	195	1		5			

* BS = Bare Soil; Refer to Appendix C for Plant Species Codes.

Table 20. (Continued)

Reference Site #14, Transect 1 (Continued)

Distance	Horizontal	Vertical	BS*	KOSC*	HOJU	SUDE	SOUG	PUNU
---m----	--------mS/m-------							
31	150	170	0		6			
32	145	160	1		5		+	
33	130	155	0		6		+	
34	120	130	0		5		1	
35	100	130	0		4		2	
36	92	125	0		3		3	
37	85	110	1		3		3	
38	86	120	1		2		4	
39	80	98	1		1		5	
40	82	98	1		1		5	
41	76	95	2		1		4	
42	76	92	1		+		5	
43	78	92	1				5	
44	88	98	2		1		4	
45	110	110	2		2		3	
46	105	115	2		1		4	
47	115	115	2		2		4	
48	105	115	2		1		4	

Table 20. (Continued)

Reference Site #14, Transect 2

Distance	Horizontal	Vertical	BS*	KOSC*	HOJU	SUDE	SOUG	CH
---m----	--------mS/m-------							
1	280	265	3	1	2	3		
2	260	275	3	2	2	1		
3	280	265	2	3	+	2		
4	300	320	3	2	+	3		
5	370	300	5			1		
6	390	320	5			1		
7	370	340	5		+	1		
8	370	370	4		1	2		
9	380	340	4		+	2		
10	360	340	2		+	4		
11	360	405	2		+	4		
12	425	300	2			5		
13	470	380	4			2		
14	440	370	5			1		
15	390	370	1	1		5		
16	320	340		1	2	+		1
17	260	320		4	2		+	+
18	230	270		2	4		+	
19	225	265			6			
20	220	260			5			1
21	210	260			6			
22	210	265			6			
23	205	260			6			
24	200	255			6			
25	220	265			5			
26	220	270	1					

Table 20. (Continued)

Reference Site 14, Transect 3

Distance	Horizontal	Vertical	BS*	KOSC*	HOJU	SUPE	PUNU	CH
---m----	--------mS/m-------							
1	370	280	1			5		
2	390	370	1			5		
3	350	270	5		+	1		
4	390	370	3		+	3		
5	425	340	6		+	+		
6	420	320	5			1		
7	380	420	2		+	1		
8	380	290	3			3		
9	420	400	2			4		
10	400	380	5			1		
11	430	370	6					
12	420	360	3			3		
13	370	340	3			3	1	
14	300	320	1	2	1		4	
15	230	280	1	2	4			
16	200	260	1		4			2
17	190	250	1	1	4			
18	185	220	1	1	5			
19	180	225	1	5				1
20	180	235	2		4			1
21	175	230	0		5			1
22	185	250	1		5			
23	195	250	1		5			1
24	180	245	1		5			
25	190	255	1		5			

Table 20. (Continued)

Reference Site 18, Transect 1

Distance	Horizontal	Vertical	BS*	KOSC*	HOJU	SARU	PUNU	SUDE
---m----	--------mS/m-------							
1	640	---	4	3		1	3	
2	620	---	3	2		3	2	
3	560	---	3	1		3	4	
4	570	---	4	2		3		1
5	580	---	4	1		2		
6	600	---	3	1		1	+	
7	620	---	4	1		2	+	
8	650	---	4	1		+	2	
9	680	---	3	1		1	2	
10	720	---	4	1		1	1	
11	720	---	4	+		1	1	
12	700	---	2			1	3	1
13	680	---	5	+		2	+	1
14	640	---	5	1		1	+	
15	600	---	3	+		2	3	+
16	540	---	3	+		1	4	+
17	500	---	4			2	2	
18	480	---	4	+		3	2	1
19	390	---	4	1			1	+
20	370	---	3	+	+	+	3	
21	370	---	2	+	1		3	
22	380	---	2	1	2		3	
23	340	---	2	+	3			
24	280	---	2		3		3	
25	280	---	3		3			
26	270	---	2		4			
27	220	---	2		4			
28	170	---	4	+	2			
29	165	---	2		3			
30	145	---	2		1			
31	145	---	2		1			
32	135	---	1		+			
33	110	---	1	+	2			
34								
35								
36								

Table 20. (Continued)

Reference Site 18, Transect 2

Distance	Horizontal	Vertical	BS*	KOSC*	HOJU	PUNU	AT
---m----	--------mS/m-------						
1	360	440	3	3			
2	380	420	4	2			
3	380	410	4	2			
4	385	410	4	2			
5	370	420	5	2			
6	370	390	5	2			
7	350	400	3	3			
8	350	390	3	3		1	
9	360	410	3	3			
10	330	390	3	3		+	
11	350	400	3	3		+	
12	320	380	3	2		2	
13	380	390	4	1		2	+
14	340	360	3	+		3	+
15	310	360	3		3		1
16	255	350	3		3	+	1
17	235	320	2		3	+	1
18	235	300	2		2	+	1
19	225	270	2		3	+	2
20	205	270	1		3	2	1
21	185	250	3		2	+	+
22	165	240	3		2	+	
23	140	225	2		2	3	

Table 20. (Continued)

Reference Site 22, Transect 1

Distance	Horizontal	Vertical	BS*	KOSC*	HOJU	SUDE	PUNU	CH
---m----	--------mS/m-------							
1	640	600	6					
2	600	570	6					
3	610	610	5			1		
4	640	600	5			1		
5	650	570	6					
6	610	580	6					
7	550	560	5				1	
8	530	570	3				3	
9	510	560	5				2	
10	500	550	4				2	
11	490	540	3	2			3	
12	480	540	1	5			1	
13	470	540	3	3			2	
14	460	550	3	3			+	
15	480	545	2	3		1	+	
16	470	520	3	3			+	
17	460	500	2	2			3	
18	440	490	2			3	2	
19	400	470	1			+	3	2
20	400	470	3			2	2	
21	420	420	1				4	1
22	370	440	1				4	
23	320	400	1				4	
24	270	360	1				4	
25	265	340	1				4	
26	270	360	0				6	
27	260	360	1				5	
28	270	380	2				4	
29	310	390	2				4	
30	340	370	1				5	

Table 20. (Continued)

Reference Site 22, Transect 2

Distance	Horizontal	Vertical	BS*	KOSC*	HOJU	PUNU	AGCR
---m----	--------mS/m-------						
1	650	580	6				
2	610	680	6				
3	610	600	6				
4	660	570	6				
5	540	570	6				
6	610	540	6				
7	550	520	6				
8	500	500	6				
9	440	460	3	3			
10	420	470	3	4			
11	400	460	2	3		+	
12	380	450	1	5			
13	400	480	3	3		+	
14	450	480	3	1		3	
15	470	470	3	+	2	2	
16	460	460	5		1	1	
17	420	420	4		1	2	
18	380	420	4			2	
19	360	400	6				
20	320	390	2		3		
21	300	380	2		2	3	
22	310	380	3			3	
23	340	400	2		+	4	
24	340	420	4			3	
25	380	460	3			4	
26	380	420	2			4	
27	250	420	4		2	2	
28	330	420	2			4	
29	320	400	2		1	3	
30	320	390	1		2	4	
31	320	390	2			4	
32	320	380	1		2	3	
33	260	350	2		1	4	
34	260	360	1		2	4	
35	250	300	1		1	4	
36	250	310	0		1	5	
37	210	270	1			4	
38	180	260	3		2	2	

Table 20. (Continued)

Reference Site 22, Transect 2 (Continued)

Distance	Horizontal	Vertical	BS*	KOSC*	HOJU	PUNU	AGCR
---m----	--------mS/m-------						
39	180	250	1		1	4	
40	160	240	1		1	4	
41	150	230	1		1	4	
42	135	220	2		2	4	
43	150	230	1			2	
44	150	240	2			3	
45	165	250	1				5
46	170	250	2				4
47	185	260	1			1	3
48	180	240	3			3	2
49	170	230	2				4
50	170	240	3				3

Table 21. Crop Yield, Soil Water, 2:1 Saturation Paste Electrical Conductivity (ECe) and EM38 Readings (EM) in Unaffected Soils, and Beginning, Developing, and Mature Seeps.

Beginning Seep

Reference Site No.	Yield g/m of row	Soil Water (wt) 1	Soil Water (wt) 2	ECe 1	ECe 2	EM Horiz	EM Vert
		-----%----		---dS/m---		----mS/m----	
21	190.4	9.1	10.1	7.6	5.6	42	66
21	165.5	8.0	6.5	1.4	4.4	26	43
21	166.8	7.1	4.8	0.7	1.2	22	33
21	147.9	12.3	12.1	1.3	2.0	75	110
21	134.7	11.8	14.2	4.3	17.5	145	185
21	231.8	10.2	10.0	1.8	5.2	105	150
5	296.7	15.7	14.2	0.5	0.7	60	84
5	250.2	17.4	14.7	0.6	0.7	58	78
5	238.4	11.4	10.9	1.1	1.3	68	83
5	333.2	11.3	10.4	---	0.9	78	120
5	265.8	19.9	10.0	0.3	0.7	65	83
15	317.4	4.0	6.7	0.4	0.4	24	29
15	248.2	3.5	4.8	0.4	0.4	43	66
19	141.0	---	---	---	---	40	80
19	116.2	6.3	6.3	2.1	5.7	60	100
19	94.7	---	---	---	---	110	190
19	87.3	10.1	10.1	1.5	6.6	140	230
20	153.7	9.8	21.0	4.2	19.6	98	155
11	324.7	5.7	6.8	0.4	0.6	25	28
11	246.8	9.2	10.5	---	3.7	55	85
11	323.4	6.6	8.3	---	1.5	44	68
11	254.6	7.2	7.8	4.0	4.9	---	---
11	106.8	7.6	8.2	---	1.0	---	---
11	76.3	6.7	7.8	1.2	3.4	---	---

1 - 0-30 cm Depth Increment
2 - 30-60 cm Depth Increment

Table 21. (Continued)

Developing Seep

Reference Site No.	Yield g/m of row	Soil Water (wt) 1	Soil Water (wt) 2	ECe 1	ECe 2	EM Horiz	EM Vert
		-----%----		---dS/m---		----mS/m----	
5	61.9	15.6	18.6	14.9	17.1	200	240
5	42.5	23.4	20.5	28.2	20.5	250	360
5	19.8	26.4	21.5	---	18.9	350	350
5	57.4	23.2	21.2	26.8	23.7	380	380
5	98.5	23.1	23.9	30.9	27.6	280	350
21	103.9	11.6	18.1	4.4	16.5	150	220
21	52.5	16.7	22.8	14.5	19.0	270	305
21	64.1	10.4	8.2	14.3	12.7	90	94
21	1.5	9.7	7.0	10.4	10.0	105	140
15	50.7	15.5	14.6	12.4	15.6	200	230
19	42.5	12.5	12.5	0.8	16.6	70	140
19	9.8	16.8	16.8	13.6	15.3	180	200
20	77.8	15.3	22.3	17.1	23.8	125	220
20	21.8	21.3	20.5	25.5	25.4	280	320
11	39.5	21.7	20.1	20.9	13.9	260	275

Mature Seep

Reference Site No.	Yield g/m of row	Soil Water (wt) 1	Soil Water (wt) 2	ECe 1	ECe 2	EM Horiz	EM Vert
		-----%-----		---dS/m---		----mS/m----	
21	0	15.2	10.4	23.1	17.5	340	460
21	0.4	19.2	15.0	14.0	12.4	195	210
21	0.2	13.2	14.8	14.7	9.9	185	190
15	0	19.3	19.1	12.9	14.5	300	330
15	0	16.2	---	7.2	---	150	175
19	0	---	---	---	---	290	320
19	0	21.8	21.8	17.2	14.4	310	380
20	0.3	22.4	20.2	26.4	16.6	350	370
20	0	18.8	17.1	17.2	16.6	380	360
11	0	18.0	19.0	13.2	15.1	220	225

Table 21. (Continued)

Unaffected Soils

Reference Site No.	Yield g/m of row	Soil Water (wt) 1	2	ECe 1	2	EM Horiz	Vert
		-----%-----		---dS/m---		----mS/m----	
21	77.1	5.3	7.4	0.8	7.1	115	190
21	90.0	2.3	2.7	0.5	0.6	20	34
21	78.8	4.6	2.8	0.9	0.6	19	30
21	76.5	6.1	---	0.5	---	18	29
15	59.4	3.7	4.0	0.4	0.4	13	19
15	45.2	2.4	---	0.5	---	18	23
19	104.7	5.1	5.1	---	0.8	60	100
11	207.1	4.2	5.3	0.2	0.2	38	60
11	80.4	6.0	5.0	0.9	2.8	70	94
11	117.1	4.9	3.0	---	0.4	100	160

Table 22. Accuracy Assessment Data

Legal Description		Beg*	Agree*	Miss*	Incor	Mat*	Agree	Miss	Incor
S11	T37N,R5E	6	6	0	0	6	6	0	0
S12	T37N,R5E	7	5	1	1	4	2	0	2
S23	T36N,R7E	2	2	0	0	3	3	0	0
S13	T36N,R6E	1	1	0	0	2	1	1	0
S 3	T36N,R6E	16	15	1	0	8	8	0	0
S17	T36N,R6E	14	14	0	0	3	3	0	0
S33	T37N,R6E	8	8	0	0	4	4	0	0
S28	T37N,R6E	5	5	0	0	1	1	0	0
S16	T36N,R6E	10	10	0	0	3	3	0	0
S21	T36N,R6E	3	3	0	0	6	6	0	0
S10	T37N,R7E	12	9	0	3	3	3	0	0
S 1	T37N,R7E	4	1	0	3	1	0	0	1
S15	T36N,R6E	6	0	4	2	2	0	1	1
S14	T36N,R6E	7	4	2	1	1	1	0	0
S30	T37N,R7E	2	2	0	0	1	0	0	1
S29	T37N,R7E	5	1	1	3	1	0	0	1
S 8	T36N,R6E	6	0	6	0	0	0	0	0
S13	T37N,R5E	5	5	0	0	5	5	0	0
S29	T37N,R6E	15	12	2	1	4	4	0	0
S10	T37N,R5E	14	11	3	0	8	8	0	0
S 9	T37N,R5E	7	4	3	0	4	4	0	0
S32	T37N,R6E	5	4	1	0	2	2	0	0
S 6	T36N,R6E	1	0	1	0	3	0	3	0
S20	T36N,R6E	2	2	0	0	1	1	0	0
S29	T36N,R7E	1	1	0	0	3	2	0	1
S23	T36N,R6E	3	3	0	0	2	0	0	2
S 9	T36N,R6E	7	5	1	1	4	4	0	0
S33	T36N,R6E	3	3	0	0	7	7	0	0
TOTAL		177	136	26	25	92	78	5	9

* Beg. = Total No. of Beginning Seeps
Mat. = Total No. of Mature Seeps
Agree = No. of seep identified to be in agreement with farmers
Miss = No of seeps missed
Incor = No. of seeps incorrectly identified

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