CONTROLS ON SOIL SALINITY IN THE RIO GRANDE FLOODPLAIN, BOSQUE DEL APACHE, NATIONAL WILDLIFE REFUGE, NEW MEXICO

by

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ABSTRACT

The prediction of soil salinity in the Rio Grande Floodplain is difficult because of the variability of salinity levels over distances of just a few meters. The salinity levels within the soils of this study area are a result of the interaction between groundwater depth, floodplain stratigraphy (soil texture), landforms, and vegetation.

Thirty-nine observation wells were installed along four, one mile-long transects perpendicular to and just west of the Rio Grande within the Bosque del Apache, National Wildlife Refuge. Soil samples were taken during drilling, and analyzed for salinity levels and soil texture. Soil texture was determined in the lab, and paleotopography was identified from aerial photographs. Since the beginning of the Middle Rio Grande Project in 1948 and the closure of flood-control dams in the 1960s and 1970s, the river has been constricted to one stabilized channel. However, previous near river landforms such as abandoned channels, can be clearly seen from both historical (1938) and current (1996) aerial photographs. Each near-channel landform has its own characteristic stratigraphy. These stratigraphic units have textures which range from coarse gravely-sand to fine grained clay. There is a relationship between paleolandforms, stratigraphy, and salinity levels. The highest salinity or electroconductivity (EC) levels were recorded within or at the top of a clay layer in all soil profiles of this study. The lowest EC was recorded within profiles that contain only sand. The pattern of EC determined from soil samples are consistent with electromagnetic induction (EM) surveys conducted along the same transect area. Groundwater levels fluctuate seasonally, and may affect salinity concentrations on a short-term basis. Vegetation is primarily saltcedar (*Tamarix chinensis*), a phreatophyte that might be contributing to salt levels within the groundwater as well as the top soil.

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INTRODUCTION

Areas of riparian vegetation in the Bosque del Apache National Wildlife Refuge (N.W.R.) and its associated cropland, provide habitat for a diverse wildlife community that includes nesting and migratory birds (Johnson, 1988). However, since the invasion of saltcedar within the last 50 years, this sensitive ecosystem is in danger of becoming a hostile environment to the varied species of wildlife it once sustained. As a result, biologists have begun a concerted effort to replace salt cedar with the natural vegetation along the Rio Grande River corridor. There are two major concerns about the invasion of salt cedar; 1) salt cedar uses more water than natural vegetation and 2) the salt cedar concentrates salt in its leaves which fall to the ground as well as around its extensive root system (Welder, 1988 and McQueen et al. 1972). After removal of saltcedar along the Pecos river, a marked increase in groundwater storage was seen. Water use and soil salinity are of major importance to the control and revegetation programs of the Bosque del Apache N.W.R. management. Newly planted cottonwood seedlings in particular, and cottonwood and willows in general, are very sensitive to high (above 50 mS/m) soil salinity levels (Hendrickx et al., 1997). The success rates of revegetation projects are dependent on having a better understanding of the processes that affect soil salinity.

The various controls on soil salinity and their association to soil salinity levels along the Bosque floodplain are the focus of this study. Previous research on soil salinity and its effect on revegetation potential, in particular a survey done by Hendrickx et al. (1997) along the Rio Grande between Las Cruces and El Paso, concluded that salt accumulation resulted from capillary rise of groundwater. The factors affecting capillary rise were soil type, depth to water table, seepage flux form nearby areas (distance from a water body), vegetation, and salinity of the groundwater. Arid environments with high evapotranspiration rates overlying a shallow saline groundwater table (less than 6 m), will result in a greater potential for salt deposition as the water moves upward to the surface and evaporates. Because coarse textured soils offer more resistance to upward water flow than do finer textured soils (Jury, 1991), clay becomes more significant in the salinization of soils than sand. Different geomorphic surfaces (topography) contain their own characteristic stratigraphy, which in this study area ranges from gravels, sand and sandy loam to silt and fine grained clays.

For this study, five variables were chosen because of their measurable and suspected influence on soil salinity concentrations. These controls are; **depth to groundwater** to determine if leaching or capillary rise is affecting salinity, **soil texture** to determine if there is a correlation between stratigraphy and soil salinity concentration, **topography** (using aerial photographs) for any correlation between stratigraphy and paleo-landforms, **vegetation (saltcedar)** and how much it contributes to salt concentration, and **distance from the Rio Grande** which may be related to or affect depth to groundwater. After analysis and interpretation, these controls may be used to predict soil salinity concentrations throughout the Rio Grande floodplain and assist in future revegetation projects.

STUDY AREA DESCRIPTION

Location and Topography

The Bosque del Apache N.W.R. is part of the Rio Grande floodplain (within the Rio Grande Rift valley) and lies twenty miles south of Socorro, New Mexico, at an elevation of 4520 ft. (**Fig. 1**). To the west are the Magdelena Mountains and to the east the Jornado del Muerto Basin. The Rio Grande is a broad and shallow river that until the 1940s, underwent active channel migration with meandering subchannels frequently altered by flooding (Graff, 1994). Since the commencement of various water management projects and ending with the closure of flood-control dams in the 1960s and 1970s, the main channel location has become stable with little or no migration or avulsion occurring. The study area is now a broad sandy floodplain consisting of abandoned river channels and near-channel landforms such as point bars, scroll bars, and levees. The study area lies along the south border of the refuge, approximately one-half mile west of the Rio Grande and adjacent to the low-flow channel (**Fig. 2**).

Climate

The climate is semi-arid to arid with an average precipitation of about 6-8 in. (150-200mm) (Johnson, 1988). Most of the precipitation is in the form of rain which falls during a summer monsoon period (July through September). More than 70 percent of the annual average precipitation is received during the warmest 6 months. Snowfall is generally rare, amounts usually light, and only remains on the ground for a short time. Mean annual temperature is 59 degrees Fahrenheit with an annual average of 111 days that temperatures reach 90 degrees Fahrenheit or more. Average annual evaporation from a class A pan is estimated to be about 100 inches, with 70 percent of the annual evaporation occurring from May through October. Winds are predominantly from the north in winter and the south in summer. (Johnson, 1988).

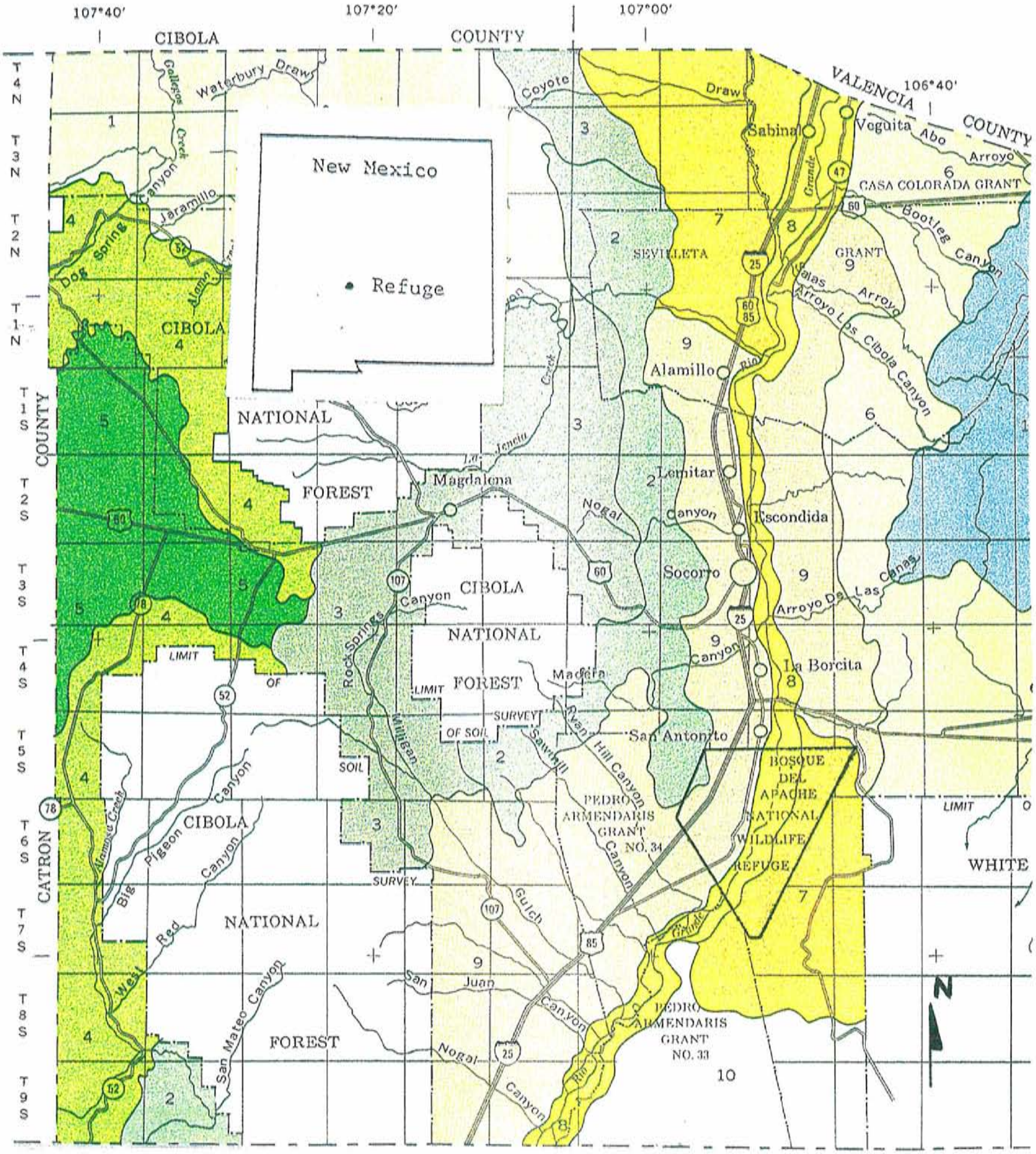


FIG. 1 - Study Area - Bosque del Apache

FIG. 2 Current (1996) aerial potograph of floodplain study area, showing transects in black. Rio Grande running right to left in lower right corner. (Bosque del Apache, N.W.R., New Mexico).

Vegetation

Since the invasion of saltcedar (*Tamarix chinesis*) beginning in the early 1900's, dense junglelike growths have overtaken the once dominant indigenous vegetation of cottonwoods (*Populous fremontii*), black willow (*Salix nigra*) and coyote willow (*Salix exigua*). Native riparian stands of cottonwood and willow which have rich canopy structures that are able to support nesting cavities, harbor greater avian species diversities along the Lower Middle Grande Valley than saltcedar monocultures with little foliage diversity (Taylor, 1997). Mammals, such as raccoons (*Procyon lotor*), badgers (*Taxidea taxus*), beaver (*Castor canadensis*) and porcupine (*Erethizon dorsatum*) prefer native habitat. Within the Bosque, saltcedar monocultures have had the lowest species diversities and abundance of reptiles and amphibians (Taylor, 1997). Willows also contribute to erosion control by stabilizing the soil on the banks of streams and gullies (Robinson, 1958).

Saltcedar, native to the Mediterranean region, was part of an international seed-exchange program initiated back in 1852 in southern California as an ornamental plant (Graf, 1994). By 1900 however, the plant had escaped cultivation and grew along sand bars and channel margins of the major rivers in the Sonoran Desert (Graf, 1994). Then, between 1900 and 1940 it spread throughout the Southwest, becoming widely established throughout the Rio Grande valley by 1935. In the late 1920's the planting of saltcedar for bank protection or erosion control was also undertaken, in particular along the Rio Puerco, a tributary to the Rio Grande (Everitt, 1980). Unfortunately, because of its prodigious production of airborne seeds, long germination period, extensive taproot system (aggressive phreatophyte) and rapid growth (especially on newly stabilized sandy or silty surfaces), it has largely replaced the natural vegetation in the floodplains of the middle Rio Grande. Also, because of its hardiness , density of growth, and resistance to herbicides, it its generally regarded as a pest (Everitt, 1980). Saltcedar has been termed a "facultative phreatophyte" (Everitt, 1980) which distinguishes it from other groundwater plants such as cottonwood and willow, termed "obligate phreatophytes". This means saltcedar may draw moisture from the saturated zones below the water table but may also survive indefinitely in the absence of saturated soil. Cottonwood and willow on the other hand, require uninterrupted access to saturated soil for survival (Everitt, 1980).

The cost of controlling saltcedar at the Bosque del Apache has averaged as high as $1,025.00 per hectare, and as high as $1,450.00 for revegetation (Taylor, 1997). Considering the magnitude of such programs, the success of these initiatives is an economic as well as an ecologic necessity.

The four transects set up for this study all lie within a dense growth of saltcedar along firebreaks that have been plowed clear of vegetation. Understory growth is also sparse along the firebreaks and is mainly alkali sakaton (*sporabolous*) known as wheat grass (Oldham, 1997).

<u>Soils</u>

Floodplain soils consist of stratigraphic layers of sand, loam, silt and clay, with a very weak pedogenic overprint. Pedogenic processes in this environment are reflected in the leaching of salts from the surface horizons, and weak development of A horizons. These soils have been identified as the Anthony-Gila complex with 0 to 2 percent slopes (Johnson, 1988). They are classified as coarse-loamy, mixed (calcareous) thermic Typic Torrifluvents that are well drained moderately permeable soils formed in recent alluvium (Johnson, 1988). The abandoned channels consist of unstable, sandy, silty, clayey, or gravelly sediment that was frequently, until very recently, flooded and reworked.

METHODS

Field

Thirty-nine observation wells were installed along four, one mile-long transects (running east to west) within a four square mile area. The wells were located approximately 161 m apart from each other along the transect. The four transects and their designations are; South Border – **SB**, Firebreak South – **FBS**, Firebreak North – **FBN**, and levee E – **E**. An auger truck with a 12.7 cm diameter auger was used to drill the well holes for insertion of a 5.1 cm. diameter PVC pipe. The well pipe was screened (0.051 cm slot size) along its lower 1.5 m.

During drilling, soil samples were taken approximately every 50 cm or when a change in soil texture was observed. Drilling was stopped when the water table was reached and the soil came up completely saturated. A 6 m PVC pipe was cut to approximately 1m above the surface when possible and the hole back-filled with soil from the drilled hole.

Water levels (depth to groundwater) were recorded at time of installation and measured at intervals over a one-year period. Due to a fluctuating water table and drier than normal conditions during the summer of 1995 and 1996, many wells became dry. However, those wells located furthest east along the transects, closest to the low-flow channel, retained water year round. All thirty-nine wells have since been developed by graduate students investigating soil and water salinity, and appear stable (Beekma, 1997).

Laboratory

Soil salinity was determined for each sample from the thirty-nine wells. Salinity or electroconductivity (EC) was measured in units of deciSiemens/cm (dS/cm). Soil textures were determined and recorded to make a stratigraphic column of each well. Average EC for each column was calculated by multiplying individual layer EC by its thickness and dividing by the total column depth. Average texture for each column was calculated the same way using the assigned texture value for each individual layer .

The direction of water flux was determined by measuring the chloride levels of samples from four stratigraphic columns along the south border. Evaluations of moisture flux from chloride data in desert soils indicates that moisture fluxes in the vadose zone are inversely proportional to chloride concentrations in the soil water (Scanlon, 1991). This analysis can indicate whether groundwater or precipitation has the greater affect on soil salinity within these representative stratigraphic columns.

Identification of eleven map units was made from analysis of aerial photographs taken from 1938-1996. The different geomorphic surfaces depicted in these photos were used to differentiate 11 maps units containing different landforms.

Chloride Analysis

Thirty-three samples (from stratigraphic columns SB-7, 8, 9,10,) were oven dried (at 40°C) to determine moisture content. 40 ml of distilled water was added to approximately 14g of soil. Samples were shaken (on shaker table) for approximately 5 hr. and then centrifuged for 30 min., or until soil water showed no suspended particles.

Samples were then measured for chloride in the soil water by inserting probes from a Sargent pH Model LS Meter. Readings were made in parts per million (ppm). Amount of chloride in the soil water was determined using the following formula:

$$\text{Cl in soil water} = (\text{ppm})\ (\text{wet-weight(g)} / \text{dry-weight(g)} \bullet \text{moisture content(\%)})$$

<u>Electroconductivity (EC)</u>

50 mL of distilled water were added to 10g of soil, and samples were shaken for a minimum of 30 minutes then wet-sieved in a Buchner funnel until the filter paper was completely dry. EC in soil water was measured using a Yellow Springs Instruments - Model 31 Conductivity Bridge.

After well installation, an EM38 survey along each transect was done by New Mexico Tech hydrology graduate students. A Geonics Ltd. EM38 measures ground conductivity in mS/m and can be taken at walking speed. The EM penetrates to approximately 1.5 m (Hendrickx et al., 1997).

<u>Texture</u>

Textures for each moist soil sample were determined by hand (descriptions after Birkeland et al., 1991). A texture type was assigned a number on a scale of 0 - 10 for use in statistical analysis. Textures ranged from coarse-grained (0 = gravel) to finest grained (10 = clay), see **Table 1** below.

Table 1 - Soil Texture With Assigned Values

Texture	Value
Gravel/coarse sand - G	0
Sand - S	1
Loamy Sand - LS	2
Sandy Loam - SL	3
Loam - L	4
Silty Loam - SiL	5
Silty Clay Loam - SiCL	6
Clay Loam - CL	7
Silty Clay - SiC	8
Sandy Clay - SC	9
Clay - C	10

Map Units

An aerial photograph (taken September 1996) of the study area was divided into separate map units based solely on the physical differences seen from this and earlier aerial photographs (taken in 1938 and 1987). Stratigraphic sections from each of the four transects were then grouped together according to their location within each map unit.

Statistical Analysis

Statistical relationships were developed for the variables, depth to the groundwater table (GW), distance from the river (DIS), soil texture (TEXT), and geomorphological map unit (MU), and soil salinity (EC). The data from an electromagnetic induction (EM38) survey taken by students along the four transects, was also included in this regression analysis for comparison. EM38 readings, although in different units than EC, can reflect trends in salinity concentrations within a stratigraphic column. All EC and EM38 data were run with their original values as well as log-transformed values.

RESULTS

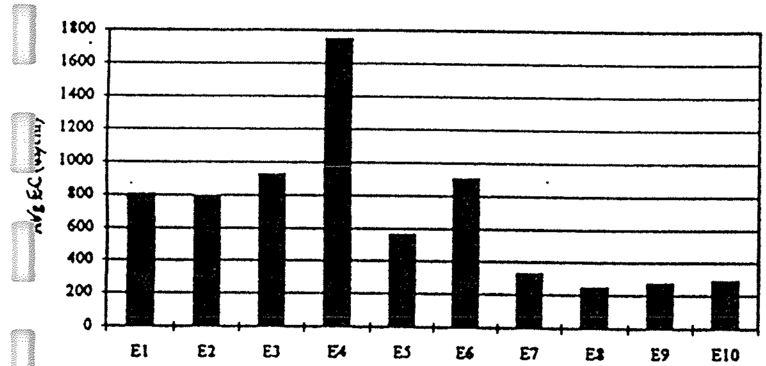
Descriptive data for each stratigraphic section is given in **Appendix I.**, and **Figure 3** shows average salinity data for each transect.

Controls on Soil Salinity

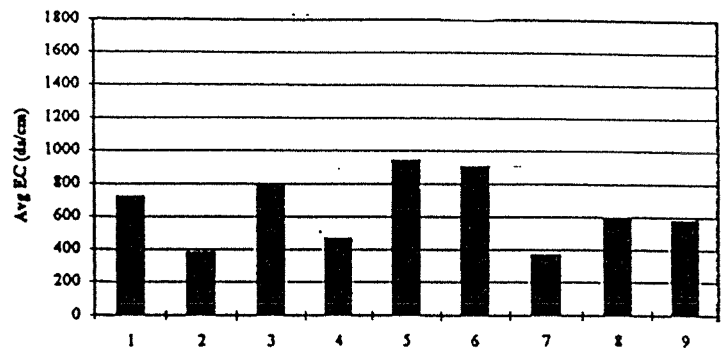
Texture

A strong relationship was observed between soil texture and salinity concentration. This relationship will be further supported by later statistical analysis. EC measurements vary greatly between clay and sandy soil textures. High EC values are always found within clay layers of a stratigraphic column, except for FBS10 with an EC of 2900 dS/cm in a silty-loam texture. The highest EC values (1900-3500 dS/cm), are in units with silty-clay and clay textures (**Table 2**). The highest EC value of 3150 dS/cm (FBS-7) is in a pure clay (**Fig. 4a**). All of the lowest EC values (≤ 150 dS/cm) were measured within sandy units (**Table 2**). The lowest values (72 dS/cm) are within those sections containing no clay layers at all (**Fig. 4b**).

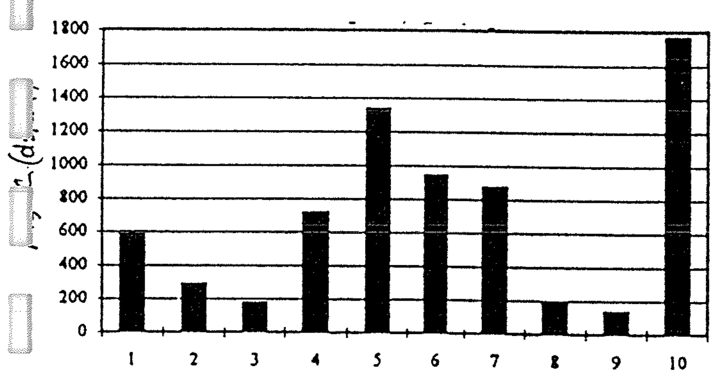
FIG. 3



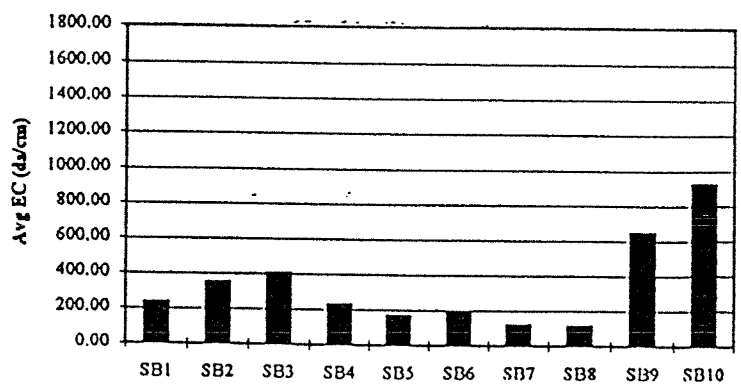
Average EC for Transect E - East to West



Average EC for Transect FBN - West to East



Average EC for Transect FBS - West to East



Average EC for Transect SB - East to West (The low ECs seen in SB4 through SB8, are all located within an abandoned channel of the Rio Grande.)

Table 2. <u>**EC and Texture data for each stratigraphic column by transect.**</u> Highest and Lowest EC shown with the type of soil texture where it was measured. (Highlighted) The very highest reading was taken from a pure clay (10) sample in FBS7 and the lowest EC was taken from a sand (1) layer within SB7.

SITE	Soil Map Units	HIGHEST EC SOIL TEXT	HIGHEST EC (ds/cm)	LOWEST EC SOIL TEXT	LOWEST EC (ds/cm)	AVG EC (ds/cm)	AVG TEXT
E1	B9	10	1900	10	310	801.48	6
E2	B9	4	1500	2	345	791.76	3
E3	B9	6	2000	3	320	923.94	3
E4	B9	8	2800	8	630	1746.57	7
E5	B9	5	1000	8	270	562.36	4
E6	B9	10	2450	0	220	903.30	3
E7	B8	2	440	2	200	324.88	2
E8	B8	1	340	1	185	242.86	2
E9	B8	1	390	5	210	268.29	3
E10	B8	2	410	1	190	286.00	3
FBN1	B7	8	2300	4	215	719.56	5
FBN2	B7	10	690	4	190	378.67	6
FBN3	B10	8	2650	3	155	797.00	5
FBN4	B10	6	1300	1	110	463.88	3
FBN5	B10	6	2250	1	120	938.42	5
FBN6	B10	10	2300	1	100	900.00	5
FBN7	B10	6	690	1	140	366.82	5
FBN8	B11	6	1150	2	160	591.33	5
FBN9	B11	9	950	3	135	579.50	8
FBS1	B4	3	1000	1	160	598.71	3
FBS2	B2	2	940	1	255	286.09	1
FBS3	B2	3	335	2	135	176.83	2
FBS4	B5	8	2700	1	310	714.75	1
FBS5	B5	10	2500	1	480	1335.94	4
FBS6	B5	7	2700	2	465	945.10	2
FBS7	B5	10	3150	8	290	873.21	3
FBS8	B6	5	430	1	110	193.78	2
FBS9	B6	3	180	1	105	133.88	2
FBS10	B10	5	2900	10	700	1767.50	6
SB1	B3	10	370	3	150	235.15	3
SB2	B3	5	660	10	210	353.16	6
SB3	B3	3	1800	3	195	405.97	3
SB4	B2	2	380	1	114	230.50	2
SB5	B2	2	200	1	145	167.50	1
SB6	B2	4	260	1	155	192.33	1
SB7	B2	2	170	1	72	119.02	1
SB8	B2	0	195	2	72	114.42	1
SB9	B1	10	1400	1	150	643.33	4
SB10	B1	10	1900	0	245	925.56	3

FIG. 4a

Graph showing how EC increases with the increase in soil texture value. The highest EC for this column, was measured in a clay (text=10) from the middle of the column. However, the lowest EC of this column is also within a clay (text=10), but this clay layer is subject to the fluctuating water table.

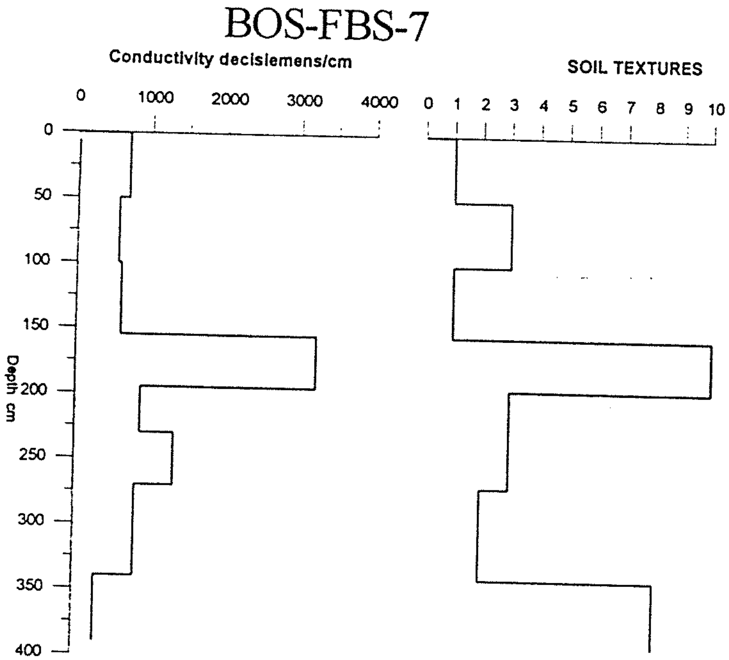
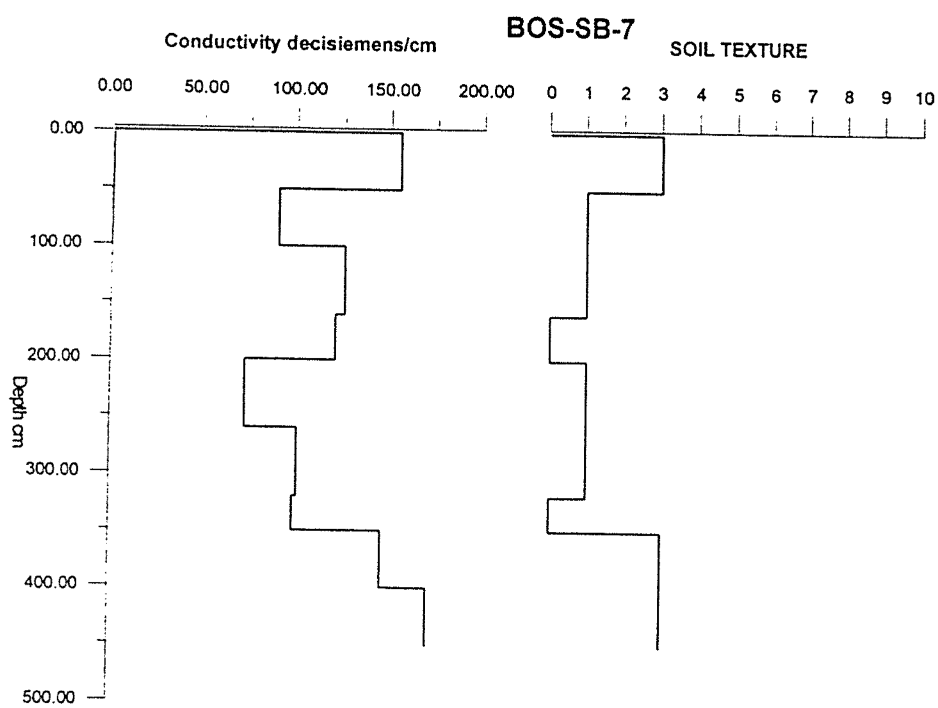


FIG. 4b

Stratigraphic column showing the lowest EC measure within the study area, from the South Border transect that is part of a clearly identified abandoned river channel. These abandoned channels of the Rio Grande are made up entirely of coarse-grained material such as sand (text=1) or gravel (text=0), and contain no clay.



Depth to Groundwater

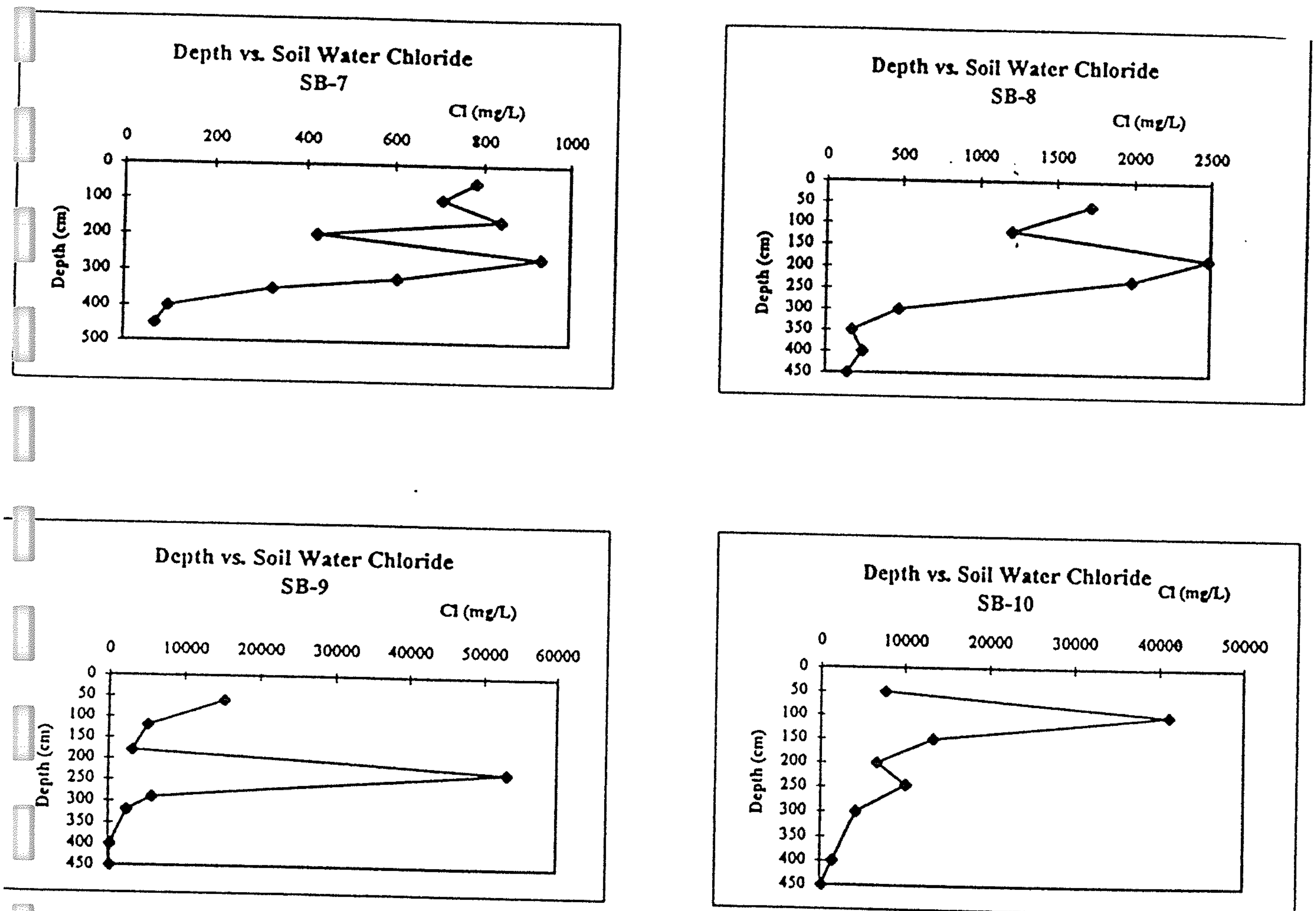
In five of the six stratigraphic sections in which the highest measured EC values were recorded, the groundwater is deeper than 400 cm. The greatest depth to groundwater was 600 cm (FBS3), and least was 250 cm (FBN7), with an average depth to groundwater for all sections of 396 cm.

The location of a texture within a stratigraphic section could influence the EC value. The highest EC values measured from wells E1, E6, FBN3, FBS7, FBS10, SB10, are all from samples taken from the middle of the section. The lowest EC in these sections was from the bottom of each stratigraphic unit.. Fifteen of the lowest measured ECs are found within soil samples taken from the bottom of a section. Soil textures from these sections ranged from gravel/coarse-sand to pure clay.

Chloride Analysis/Moisture Flux

Chloride concentration in soil water will increase to its peak value as the moisture flux increases (Scanlon, 1991). The chloride profiles on all four south border stratigraphic sections show a bulge in the middle of the section (approximately 250 cm), except for SB10, where the chloride peak is closer to the surface at 100 cm (**Fig. 5**). SB9 and SB10 have much higher levels of chloride than SB7 and SB8. Two peaks are seen in SB7, and minor secondary peaks in SB8, SB10. SB9 contains the highest chloride measurement of 5823 mg/L at a depth of 250-300 cm (within clay). The lowest reading, of 69.74 mg/L is recorded in SB7 at the base of the stratigraphic section. The groundwater level is at approximately 450 cm for each stratigraphic section, and all show a dramatic drop off from their peak chloride measurement (between 100-300cm) to a point just above or within the water table (**Fig. 5**). Just as is seen with section salinity levels.

FIG. 5
Depth versus Soil Water Chloride.
Four stratigraphic sections from the South Border showing a classic "chloride bulge". Higher readings in the two sections(SB-9 and SB-10) that contain clay. Note drop off below the chloride peak, decrease (as in EC) to minimal reading where soil is within the water table.



Map Units

The Rio Grande can be described as both a braided and a mixed-load, meandering river that can transport fine, suspended sediment as well as significant bedload. Along the transect area, the river occupies a meander belt, which is a zone of active and recently abandoned channels and their adjacent overbank environments. Overbank sedimentation is most rapid close to an active channel, leading to the growth of an alluvial ridge above the surrounding floodplain (Reading, 1996). This unstable situation is periodically relieved during a flood, when the channel bank is breached (avulsion) and a new channel course is established on the lowest part of the floodplain. Within this type of river, point bars develop on the sides of the meander bends and will accrete laterally. Due to helical flow and where a range of grain sizes is present, a systematic reduction of grain size upslope develops. Scroll bars, elongate ridges of sand, develop as well. Chutes can appear on large point bars to accommodate high discharge which diverts flow across the point bar. During falling water stages, the chutes are abandoned and become draped with fine-grained sediment. Clay plugs eventually fill abandoned channels which later resist erosion and help stabilize meander belts (Reading, 1996).

Eleven map units were identified from aerial photographs (**Fig. 6**). Units B2 and B6, are abandoned channels of the Rio Grande that contain units made up entirely of sand, and coarse bedload gravels and share very low average EC values (**Table 3**). Map units B1, B4 and B7, are old point bars (lateral accretion of coarser to finer grains) or levee and levee splays (vertical accretion of coarser to finer grains), and all contain clay along with similar average ECs. Unit B11 is possibly a channel levee or clay plug, has only two profiles within it, but both have high amounts of clay throughout each section (**Table 3**). B9 and B10 show both similar average texture and ECs, these areas are most likely old scroll bars. Unit B5 may contain scroll bars as well or possibly an area of overbank fines. Finally, B3 and B8 represent two paleo-landforms difficult to describe, B8 because of overprinting by more recent landforms and B3 because of vegetative cover. B8 has characteristics of both abandoned channel and inter-channel topography. B3 may be comparable to B11 (which has been described as a channel levee) because both share similar physical characteristics and similar average ECs within a range of 100 to 300 dS/cm. But, without further investigation, units B3 and B8 cannot with any certainty be grouped with any other map unit (**Table 3**).

Statistical Analysis

Note: Significance levels for the following data will be symbolized as: "ns" - not significant, "*" - significant at 0.10 level, "**" - significant at 0.05 level, and "***"- significant at 0.01 level.

Statistical Distributions

One important assumption for regression analysis and analysis of variance techniques is that the data have a normal distribution. Therefore, the statistical distribution of the EM38, EC, and ECAV data was checked by visual inspection. Histograms are presented for the original data and their logarithms (**Fig.** 7). When it became clear that taking the log-transform of the original values improves the normality of the distributions, this method was used throughout the proceeding analysis.

FIG. 6

Map of study area, with map units shown. Transects are in black, Rio Grande bordering map unit area on right. Aerial photograph taken Sept. 1996, with more recent abandoned channel (B6) clearly visible. See text for description of map units.

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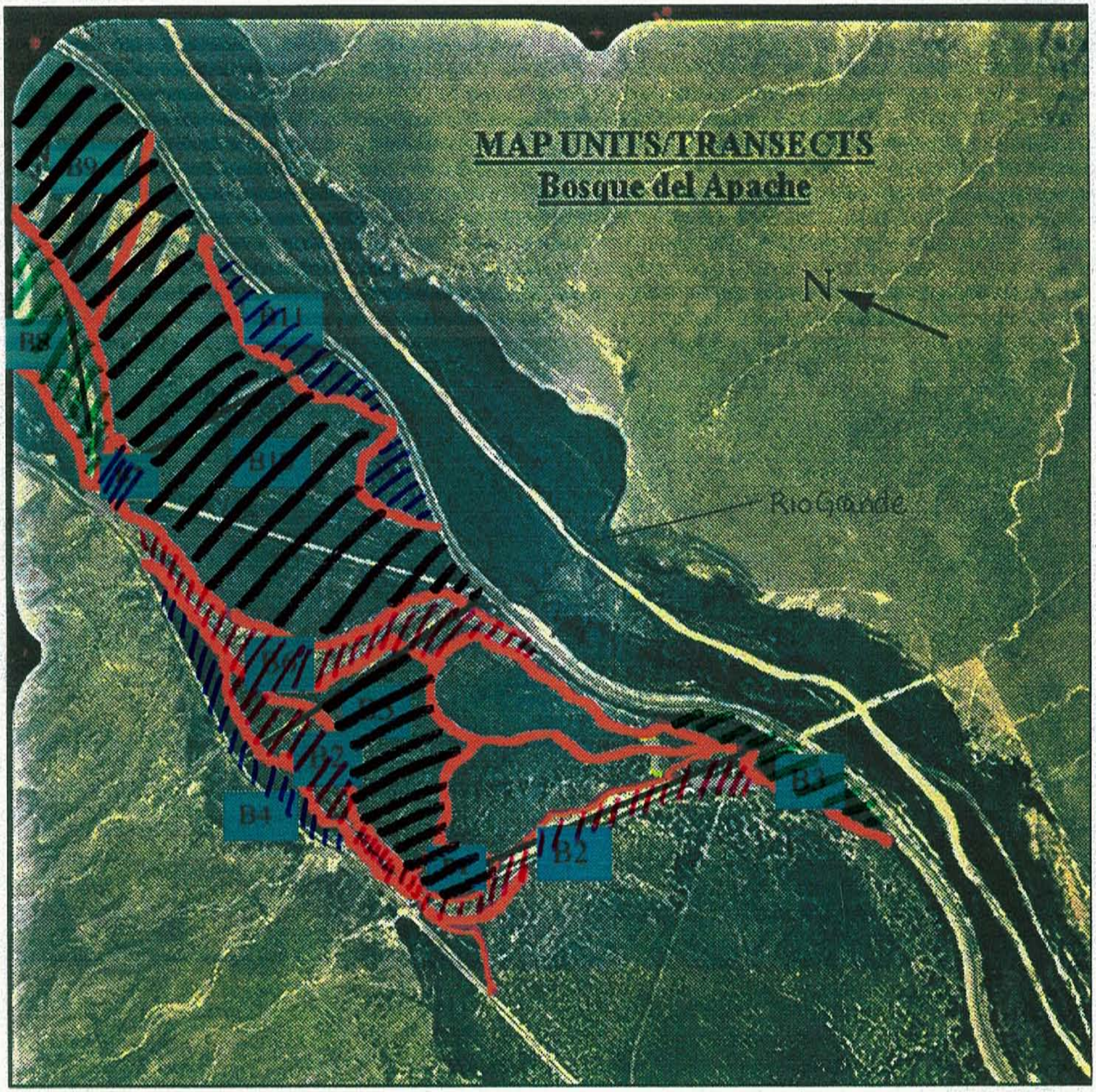


FIG. 6a (overlay)
Duncan Grouping of LEC means vs. Map Units
A-black, B-blue, C-green D-red
(See pg. 28)

Table 3. Map Units
Stratigraphic Section data correlated by Map Unit designation.

Landform by Map Unit desig.	Strat. Section	AVG EC (ds/cm)	AVG TEXT		Landform by Map Unit desig.	Strat. Section	AVG EC (ds/cm)	AVG TEXT
B1	SB9	643.33	4		**B7**	FBN1	719.56	5
B1	SB10	925.56	3		**B7**	FBN2	378.67	6
B2	FBS2	286.09	1		**B8**	E7	324.88	2
B2	FBS3	176.83	2		**B8**	E8	242.86	2
B2	SB4	230.50	2		**B8**	E9	268.29	3
B2	SB5	167.50	1		**B8**	E10	286.00	3
B2	SB6	192.33	1					
B2	SB7	119.02	1		**B9**	E1	801.48	6
B2	SB8	114.42	1		**B9**	E2	791.76	3
					B9	E3	923.94	3
B3	SB1	235.15	3		**B9**	E4	1746.57	7
B3	SB2	353.16	6		**B9**	E5	562.36	4
B3	SB3	405.97	3		**B9**	E6	903.30	3
B4	FBS1	598.71	3		**B10**	FBN3	797.00	5
					B10	FBN4	463.88	3
B5	FBS4	714.75	1		**B10**	FBN5	938.42	5
B5	FBS5	1335.94	4		**B10**	FBN6	900.00	5
B5	FBS6	945.10	2		**B10**	FBN7	366.82	5
B5	FBS7	873.21	3		**B10**	FBS10	1767.50	6
B6	FBS8	193.78	2		**B11**	FBN8	591.33	5
B6	FBS9	133.88	2		**B11**	FBN9	579.50	8

FIG. 7
Histograms data for EM38, EC, and ECAV showing normal distribution

Original Measurements

```
Variable=EM38
                    Histogram                         #
 190+***                                              7
    .
    .
 130+***                                              7
    .******                                          16
    .*****                                           15
  70+*******                                         21
    .************                                    34
    .******************************                  89
  10+************************************           107
    ----+----+----+----+----+----+----+-
    * may represent up to 3 counts
```

```
Variable=EC
                    Histogram                                #
3250+*                                                       1
    .**                                                      7
    .***                                                    10
1750+****                                                   15
    .*****                                                  18
    .****************                                       62
 250+**********************************************        183
    ----+----+----+----+----+----+----+----+----+-
    * may represent up to 4 counts
```

```
Variable=ECAV
                    Histogram                        #
1700+*******                                        14
    .
    .*****                                           9
    .
 900+******************************                 59
    .********************                           40
    .**********************                         44
    .**************************************         76
 100+***************************                    54
    ----+----+----+----+----+----+----+---
    * may represent up to 2 counts
```

Log of Measurements

```
Variable=LEM38
                    Histogram                        #
5.25+****                                            7
    .*******************                            38
    .***********                                    21
    .****************************                   56
    .**********************************             67
    .*******************************                62
    .*******************                            37
1.75+****                                            8
    ----+----+----+----+----+----+----+
    * may represent up to 2 counts
```

```
Variable=LEC
                    Histogram                        #
8.25+*                                               1
    .************                                   24
    .**********                                     20
    .*******************                            38
6.25+**************************                     51
    .**********************************             67
    .******************************                 59
    .***************                                30
4.25+***                                             6
    ----+----+----+----+----+----+----+
    * may represent up to 2 counts
```

```
Variable=LECAV
                    Histogram                                #
7.25+************                                           23
    .**********************************************         91
    .**************************                             52
    .***************************                            53
    .***************************                            53
4.75+************                                           24
    ----+----+----+----+----+----+----+----+----+-
    * may represent up to 2 counts
```

Relationship between ECAV (for a stratigraphic section) and EM38

The EM38 is an instrument to non-invasively measure the average electrical conductivity of a soil profile without taking soil samples. To evaluate its performance in the Bosque del Apache, the relationship between the ECAV and EM38 was explored. Statistical regression analysis yielded the following expression:

$$ECAV = 274.03^{***} + 7.642^{***}\ EM38$$

with $F=307^{***}$ and $R^2=0.51$. This indicated that the EM38 readings explain 51% of the variability in the ECAV data. Because ECAV are based on samples with a small volume, their inherent variability will be larger than the variability of the EM38 readings that are based on a large volume. In general, measurements taken with an EM38 are a good representation of the ECAV values found in a particular stratigraphic section.

Effect of the Groundwater Table Depth on Soil Salinity

Deep groundwater tables where the water is highly saline, will not contribute to soil salinity since the capillary rise is not able to reach the soil surface or root zone of the vegetation. Shallower groundwater tables can cause soil salinity because a steady upward capillary flux will deposit salts in the top layer of the soil. If no adequate leaching is maintained and in conjunction with an areas high evaporation rate, a saline soil will result (Jury et al., 1991). In this study, the following relationship between GW and EM38 was found:

$$EM38 = 95.9^{***} - 0.13^{***}\ GW\ (cm)$$

with $F=27.4^{***}$ and $R^2=0.09$. This analysis indicates that with a 100 cm rise or fall of the water table, only a 10% increase or decrease of EM salinity values will occur. Although we know groundwater depth has a notable effect on the processes that control soil salinity, its effect is dependent on other salinity controlling factors such as soil texture. Because of the high variability of soil textures within and between stratigraphic units, no significant effect was found (statistically) between ECAV and GW which can be explained by the higher intrinsic variability of the ECAV values. Therefore, these statistical values are not presented.

Effect of Distance from the River

The distance from the river and the groundwater table depth are weakly correlated because the depth to groundwater generally becomes greater with increasing distance from the river.

$$\mathrm{GW\ (cm)} = 241.63^{***} + 0.103^{***}\ \mathrm{DIS\ (m)}$$

with $F=159.6^{***}$ and $R^2=0.35$. Therefore, it is not surprising that a significant relationship was found between EC as measured by EM38 and distance:

$$\mathrm{EM38} = 96.91^{***} - 0.037^{***}\ \mathrm{DIS\ (m)}$$

with $F=74.3^{***}$ and $R^2=0.20$. A significant relationship also existed with ECAV:

$$\mathrm{ECAV} = 825.69^{***} - 0.159^{***}\ \mathrm{DIS\ (m)}$$

with $F=9.8^{***}$ and $R^2=0.03$. As before, the great intrinsic variability of the ECAV leads to a much lower R^2. These models show a higher significance between salinity and distance (DIS) than between salinity and groundwater. However, this result can be modified by the geographic location of the study area. Historically, soil textures tend to become finer grained with increasing distance from the river. But, because the transects for this study were laid out east to west from the river, and abandoned channels containing sand and gravel border the western edge of the study area, the stratigraphic units nearest the river consequently end up containing the finer grained soil textures.

Effect of Geomorphic Map Unit

Significant relationships have been found between salinity and map units. Approximately 83% of the variability of the logarithm of ECAV (**Table 4**) can be explained by the map units and approximately 79% of the variability of the logarithm of the EM38 data (**Table 5**). A comparison of the means of the log ECAV (LECAV) for each of the eleven map units, suggests that only four major geomorphological groups can be distinguished (**Table 6**). These four groupings (A-D) do share similar geomorphic characteristics between map units, such as group "D" comprising of only the abandoned channel map units B6 and B2 (**Fig. 6a overlay**). However, the relationship between LEC means can only be identified statistically at this time.

Table 4. General Linear Model Procedure (ANOVA) for the dependent variable Log EC average.

Dependent Variable: LECAV

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	131.9041503	13.1904150	136.15	0.0001
Error	285	27.6110456	0.0968809		
Corrected Total	295	159.5151958			

R-Square	C.V.	Root MSE	LECAV Mean
0.826906	5.082907	0.311257	6.12360075

Table 5. General Linear Model Procedure (ANOVA) for the dependent variable Log EM38.

Dependent Variable: LEM38

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	152.3763273	15.2376327	106.31	0.0001
Error	285	40.8490057	0.1433298		
Corrected Total	295	193.2253330			

R-Square	C.V.	Root MSE	LEM38 Mean
0.788594	11.24946	0.378589	3.36539889

Table 6. **ANOVA model (Duncan grouping) of LEC means versus Map Units.** The eleven map units were separated into four groups. All groupings (like map units) include similar salinities, but base on a more precise statistical analysis. .

Duncan Grouping	Mean	N	MAP
A	6.850	34	B5
A			
A	6.783	46	B9
A			
A	6.649	16	B1
A			
A	6.635	40	B10
B	6.395	8	B4
B			
B	6.371	13	B11
B			
B	6.258	16	B7
C	5.743	27	B3
C			
C	5.641	26	B8
D	5.160	57	B2
D			
D	5.068	13	B6

Effect of Soil Texture

Because the physical and chemical properties of a soil horizon depend to a large extent on its texure, a statistical test for correlations between texture and salinity was made. **Table 7** reveals a significant effect of soil texture on LEC that explains approximately 36% of the variablility in LEC. The comparison of the LEC means in **Table 8** shows a clear trend between the amount of clay in a sample and its salinity. The more clay, the higher the salinity. An exception is texture '9' that is a sandy clay.

Table 7. ANOVA model (SAS) run for LEC against Soil Texture. $R^2 = 35.7\%$, which means the variability in salinity within the study area can be explained (up to 36%) by the effect of soil texture.

Dependent Variable: LEC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	82.44993170	8.24499317	15.80	0.0001
Error	285	148.74260778	0.52190389		
Corrected Total	295	231.19253948			

R-Square	C.V.	Root MSE	LEC Mean
0.356629	12.04504	0.722429	5.99773134

Table 8. Comparison of LEC means (Duncan Grouping). This table also shows the effect of soil texture (clay vs. sand). Higher clay content results in higher salinity. Exception is texture 9, which is a sandy-clay and may be coarser in some layers than observed from actual samples.

Duncan Grouping		Mean	N	TEXT
	A	6.895	6	7
	A	6.854	22	10
	A	6.812	21	8
B	A	6.501	22	6
B	A	6.473	24	5
B	C	6.095	28	4
B	C	6.035	30	3
B	C	5.973	6	9
D	C	5.647	66	2
D		5.404	62	1
D		5.165	9	0

DISCUSSION

The goal of this study was to determine if it is possible to predict the soil salinity from the physical characteristics of floodplain landforms. Results have shown through lab analyses, graphically and statistically, that a solid correlation exists between two of the five variables and average EC. The variables are texture and map unit. The other three variables, especially groundwater depth, may influence soil salinity but statistical analysis has failed to show strong correlations with EC. Despite the above statistical analysis, and since the five variables are related to each other, and therefore to soil salinity, they will all be discussed below.

EC vs. Soil Texture

Clay and any stratigraphic layer containing a clay texture has the highest EC values. This is reflected in increasing EC levels with an increase in finer grained texture (**Figs. 4a,b,8**). A sand unit by itself, or within a profile containing clay textures, will usually have the lowest EC value. Exceptions are related to the depth to groundwater of the stratigraphic section, more than the texture type involved. Although soil layers containing clay textures show a range of EC values from less than 500 dS/cm to more than 3000 dS/cm, gravel/coarse-sand and sand never measure above 900 dS/cm. Sandy and loamy textures appear to have lower salinity concentrations than clay, regardless of their position in the profile. Whereas clay textures measure their highest EC when located in the middle of the profile and their lowest EC when located at the bottom (within or subject to a rise in the water table) (**Fig. 4a**).

It is unclear what process is responsible for clay exhibiting higher EC (salinity) readings. For many coarse-textured soils (including gravel), the drainage rate falls to an insignificant level within a few days after the infiltration of precipitation after redistribution has ceased. Finer textured soils do not show this abrupt decrease in drainage rate (Jury et al., 1991). The ability of clay to hold more water, longer, than sand could be significant. Saline water with a longer residence time in a soil can precipitate out more salt (Jury, et al., 1991). Whether water movement is down from the surface or up through capillary rise, higher salt retention may be a consequence of either process.

The low statistical correlation (R^2=0.36) between texture and salinity is not indicative of what is really going on because of other relationships. The high statistical correlation between map unit and salinity indicates that the type of soil texture associated with a specific landform is a major factor in the salinization of a soil column. The ANOVA statistical program used was run with both soil texture and Duncan groupings (A - D). Results explained 63% of the salinity variability of the samples. Another factor influencing soil texture correlation may be the effect of a fluctuating groundwater table on the salinity. To determine if the position of a texture unit within a stratigraphic section has an influence on ECAV, the soil samples were divided into two groups, group One comprised of samples from the top layer (surface to 50 cm above the groundwater table) of the column, and group Two comprised samples from the first 50 cm above the groundwater table. Group One soil texture now explains 54% of the salinity variability while group Two explains only 35% (**Appendix II**). The fluctuating groundwater table may leach out salts in soils within its direct influence, so that differences in soil texture become less relevant than the leaching action of the groundwater.

EC vs. Groundwater

Moisture migrates through soils as a liquid or as a vapor in response to energy gradients. In any (liquid) hydraulic system, flow occurs whenever a pressure difference is not compensated by a positional (elevation) difference. When soil water pressure is equal to the height above the water table, equilibrium exists and no flow occurs. Differences between the water pressure in a soil and its height above a water table represent either excess moisture that is on its way to the water table or deficiencies in soil moisture induced by evapotranspiration processes. Thermal gradients as well, are capable of moving moisture through soils, and there are indications that most of the moisture moved by thermal gradients migrates in the vapor phase. Moisture moves in the direction of decreasing temperature. In the top 40 - 60 cm of a stratigraphic column, movement would be downward during the day and upward during the night. Below 40 - 60 cm, movement in response to thermal gradients would be downward during the summer and upward during the winter. However, temperature has little influence on capillary-held water. (McQueen et al., 1972)

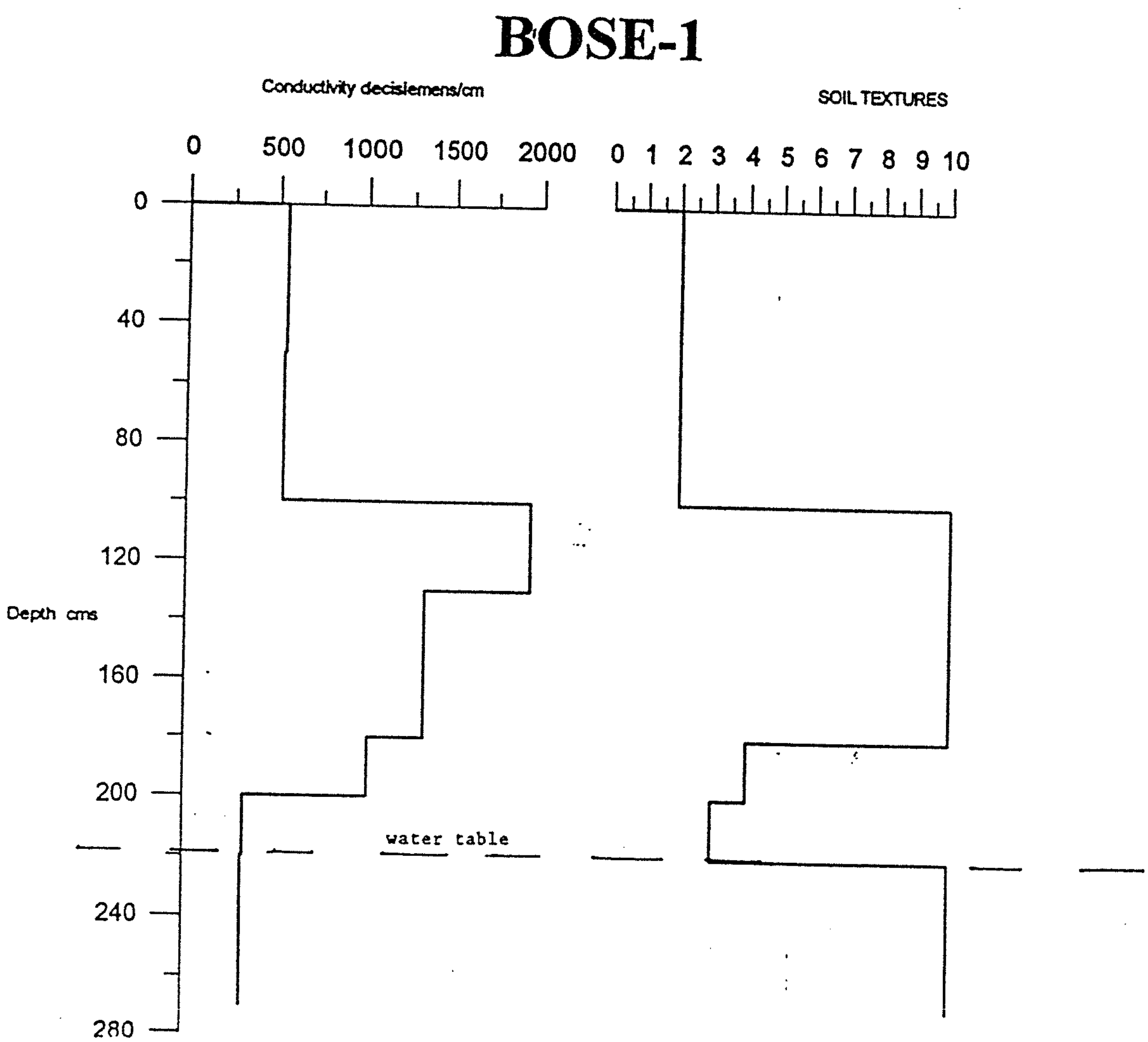
McQueen et al., (1972) lists several processes that may indicate a chemical imprint produced by migrating moisture. Soluble salt concentrations may be greater at or near the soil surface than at depth owing to either of two processes: capillary supplied evaporation, or guttation (process by which a plant will exude salt solutions which are deposited on the soil surface). Where the water table is near the surface, evaporation of water supplied from the saturated zone by capillary rise will leave a deposit of salts near the surface. Saltcedar in particular is known to guttate (McQueen, et al., 1972). Also, where moisture movement is dominated by the vapor phase, salts are left behind because their concentration soon exceeds solubility levels and they precipitate out. The result is an increase in salts in the direction of water movement.

Water level measurements taken from the wells in the study area show that the water table fluctuates seasonally with climate (Beekma, 1997). Major precipitation events and flooding may cause temporary changes in the water table. The EC data for this study were subject to the water table levels at the time the wells were drilled. Since then, other workers have taken EM38 readings along each of the transects, when the water table was at different levels. EM measurements, although taken in mS/m and not dS/cm, reflect the same high and low trends as EC measurements. The EM38 readings revealed a dramatic drop in conductivity in the transect sections containing high levels of clay, this may have been due to the flooding in May of 1996 of an adjacent irrigation channel that runs parallel to the four transects. In particular, map unit B3 (South Border), an area where clay is found in all three stratigraphic sections, reflected the biggest change in EM readings over the same period of the previous year (Beekma, 1997). These independent results support the data that EC levels drop dramatically in a clay layer when it is in direct contact with the water table (**Fig. 8**). It also suggests, that flooding or flushing of these soils will effectively leach salinity and lower conductivity levels.

Non-clay or sandy textured layers do not seem to be affected by water table proximity. Unlike clay layers where the lowest EC values are always within units in the bottom one-third of a stratigraphic section, sandy or loamy textures can have their lowest EC readings anywhere in a stratigraphic section (**Fig. 4b**). However, a clay layer at 150 cm in FBS-7 (**Fig. 4a**) has the highest EC reading, of any section, yet the lowest EC reading of any section, is also in this same section but taken from a clay layer located within the water table (**Fig. 4a**).

FIG. 8

Stratigraphic column showing possible affect of depth to groundwater. Same texture of clay (10), reading highest and lowest EC in the profile. High reading from middle of profile, furthest away from up or down moisture flux. Lowest reading from within the water table or subject to water table fluctuation.



Moisture Flux

The drop-off of chloride beneath the peak is an indication of a fluctuating water table, where the rise and fall of the capillary fringe in response to water table fluctuation will dissolve some chloride from the lower part of the section (Stone, 1992). The two peaks seen in SB7 may also be due to temporal changes in the water balance. Continual displacement of older soil water with younger recharge would create a pattern such as this. The intervals of more concentrated chloride record episodes of greater evapotranspirative loss of water from the soil (Phillips, 1994). The rise and fall of the water table creating an upward moisture flux along with the smaller water flux down from the surface during precipitation events, is what is keeping the chloride bulge within the mid to upper layers of the section. This same moisture flux process may also be responsible for a similar effect seen in salinity concentrations of the stratigraphic sections.

<u>Stratigraphy and Landforms</u>

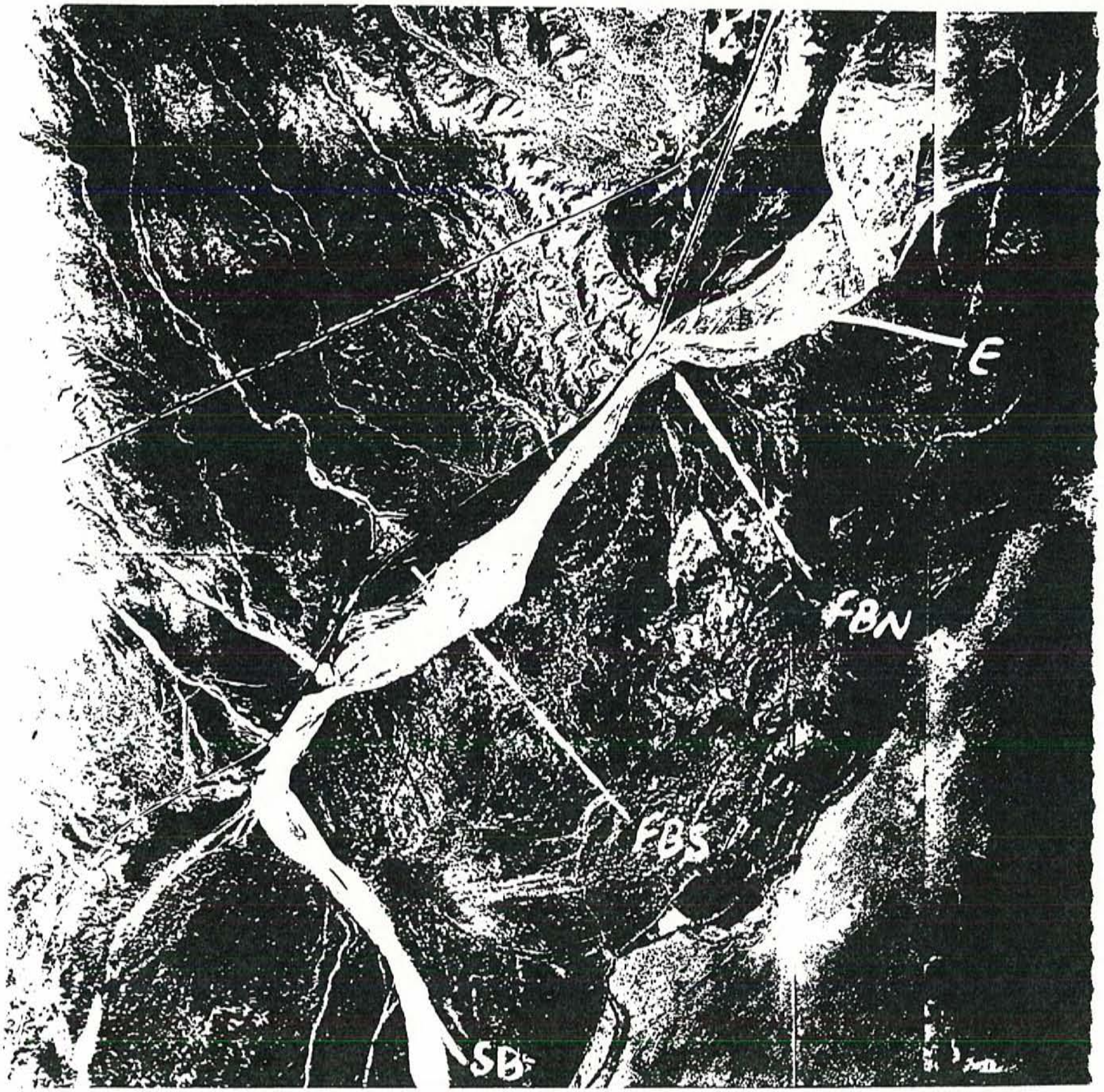
The stratigraphy of the floodplain was formed by the migrations and overbank flooding of the Rio Grande. Rivers such as the Rio Grande that carry a high proportion of suspended load, and that flow on low gradients, deposit fine-grained sediment both on the floodplain and, sometimes within the channels. The channels are mainly floored by sand which migrates as repetitive bedforms, possibly superimposed on alternating side bars. The rapid sedimentation that usually occurs in these systems means that channel floor, levees and floodplain areas all accrete vertically. This will give rise to elongate and often sinuous shoestring sandbodies (Reading, 1996).

All of the map units identified from the aerial photographs consist of a specific near river landform. The most obvious are the abandoned river channels (paleo-channels) that were active as recently as thirty years ago. The paleo-channel map units, B2 and B6, have similar profile stratigraphy made up of layers of gravel, sand and loam (**Table 3**), and in retrospect, could probably be referred to as one unit as designated in the Duncan grouping as unit "D" (**Fig. 6, Fig. 6 overlay**). In contrast, map units B1 and B7 that appear to have been point bars, contain thick (over 100 cm) clay layers and higher than average EC levels, but do not appear to be statistically similar in the Duncan analysis. Map units B10 and B11 are considered statistically different, but both contain stratigraphic units with high amounts of clay and are probably old scroll bars or channel levees. Unit B10, an inter-channel (floodplain) area containing overbank fines, has the highest overall average EC (1767.50 dS/cm) calculated in section FBS10 (**Table 3**).

The remaining map units, B3, B4, B5, B8, and B9 are a little harder to assign a corresponding landform. B8 does show considerable paleo-channel activity according to a 1938 aerial photograph. All but two sections E9 and E10, have textures in the sand to silty-loam range. These two exceptions contain silty-clay-loam and clay loam, suggesting they may either be a separate unit or more possibly part of B7 or B10, but this cannot be determined because of the lack of visual detail in the area or perhaps the overprinting of another more recent landform. Duncan grouping analysis has paired it with map unit B3 (unit "C), but there is no visual basis for this association. B5 has a range of soil textures, and displays the highest average EC values as a map unit, as well as the highest individual EC value within a stratigraphic section (3150.00 dS/cm). This map unit is highly vegetated (saltcedar) both in current and in fifty-year old aerial photographs, which means it has been an inter-channel area from before the earliest photograph was taken. Scroll bars are visible within the lower half of this unit, but definite landform identification is not possible. In the Duncan grouping, B5 does make up part of the largest statistical unit "A", which includes B9 and B10. All three of these map units display similar geomorphic and geographic characteristics. Unit B9 sections display both similar average textures and average EC values and is also highly vegetative and appears to be part of the inter-channel flood plain, at least since the 1938 photograph **(Fig. 6, 9)**. Finally, there is B4, the most inconclusive, as it represents only one section (FBS1) and has no outstanding texture or EC values. This unit lies adjacent to B2, a distinct paleo-channel, and may at one time have been part of B2 as can be seen in the 1938 photograph **(Fig. 9)**, but more recent photographs show a physical difference (separation) from B2 **(Fig. 6)**. B4 has been grouped statistically with B11 and B7, but as with B3, have no distinctive geomorphic feature that can be readily identified from aerial photographs.

FIG. 9

1938 aerial photograph clearly showing the previous location of the Rio Grande and what is now an abandoned channel running along the western edge of the study area. Associated point bars and scroll-bars are also visible. Location of current transects are shown in white.



(1938)

E
FBN - Firebreak North
FBS - Firebreak South
SB - South Border

CONCLUSIONS

The salinity along the Rio Grande Floodplain in the Bosque del Apache N. W. R. varies over short distances (5-10 m). Soil texture displays the greatest control on soil salinity, with high EC levels found in clay, and considerably lower EC levels in sand. Soil texture varies with characteristic near river landforms. Depth to groundwater effects the EC levels of soils with clay textures. Where clays are within or affected by the rise and fall of the water table, they display dramatically lower EC values than clay layers further away from the water table within the same stratigraphic section.

Approximately 83 percent of the variability in Log EC averages that are seen within this study area can be explained by characteristic landforms that were separated into eleven map units. Almost 79 percent can be explained when using Log EM38 data. Furthermore, statistical comparison of the LEC means resulted in only four map groups. A; an inter-channel floodplain area, B; river levees, C; indeterminate due overprinting, possibly abandoned channels, chute cut-offs or river levee, D; abandoned channels. Floodplain landforms, although complex, can be identified from aerial photographs. Individual landforms have developed through distinctive processes which produce a characteristic stratigraphy. This study has shown that it is possible to stratify a soil landscape and group homogeneous soil units by identifying floodplain landforms from aerial photographs. By taking non-invasive conductivity measurements with an EM38, an accurate salinity map can be produced.

FUTURE WORK

1. Determine the effect of removal of saltcedar from the study area, now that base-line data is available. Conductivity readings should be taken before and after flooding of the area.
2. Produce soil stratigraphic columns of the map units not yet labeled or described, that lie between transects SB and FBS.

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REFERENCES

Birkeland, P. W., Machette, M. N., Haller, K. M. (1991), Soils As A Tool For Applied Quaternary Geology. *Utah Geological and Mineral Survey*, Miscellaneous Publication 91-3, April 1991.

Chapin, Charles (ed.) (1983), *Socorro Region II*. New Mexico Geological Society, Thirty-Fourth Annual Field Conference, October 13-15, 1983.

Beekma, Jelle (1997), Personal Communication. Graduate Student , Hydrology, NMT.

Culler, R. C., Hansen, R. L., Myrick, R. M., Turner, R. M., Kipple, F. P. (1982). Evapotranspiration Before and After Clearing Phreatophytes, Gila River Flood Plain, Graham County, Arizona. Geological Survey Professional Paper 655-P

Earickson, Robert J., Harlin, John M. (1994), *Geographic Measurement and Quantitative Analysis*: Macmillan College Publishing Co., New York, p. 212.

Everitt, Benjamin L. (1980). Ecology of Saltcedar – A Plea for Research, *Environmental Geology* 3, 77-84.

Graff, William (1994). Riparian Vegetation, *Plutonium and the Rio Grande*. New York, Chapter 6.

Hendrickx, Jan M. H., Beekman, Jelle, Koch, Russ, Graciela Rodriguez, Marin (1997), Salinity Survey For Revegetation Potential Along The Rio Grande In The Paso Del Norte Region. A Report to the El Paso Field Division of the U.S. Bureau of Reclamation.

Hendrickx, Jan (1997). Personal Communication. Assoc. Professor, Hydrology, NMT.

REFERENCES

Johnson, William R. (1988), *Soil Survey of Socorro County Area, New Mexico*. United States Department of Agriculture, Soil Conservation Service.

Jury, William A., Gardner, Wilford R., Gardner, Walter H. (1991). *Soil Physics*, Fifth Edition. John Wiley & Sons, Inc. New York.

McQueen, I. S., Miller, R. F. (1972). Soil-Moisture and Energy Relationships Associated With Riparian Vegetation Near San Carlos, Arizona. Gila River Phreatophyte Project, Geological Survey Professional Paper 655-E.

Oldham, Mike (1997). Personal Communication. U.S. Fish and Wildlife Biologist, Bosque del Apache, N.W.R. , New Mexico.

Phillips, Fred (1994). Environmental Tracers for Water Movement in Desert Soils of the American Southwest, in *Soil Science Society of America Journal*, Vol 58, no 1

Reading, H. G. (ed.) (1996). *Sedimentary Environments: Processes, Facies and Stratigraphy*. Oxford. Chapter 3.

Robinson, T. W. (1958). Phreatophytes, Geological Survey Water-Supply Paper 1423.

Scanlon, Bridget R. (1991). Evaluation of moisture flux from chloride data in desert soils, in *Journal of Hydrology*, 128: 137-156.

Stone, W. J. (1992). Paleohydrologic implications of some deep soilwater chloride profiles Murray Basin, South Australia, in *Journal of Hydrology*, 132:201-223.

Taylor, John P., McDaniel, Kirk C. (1997). Restoration of Saltcedar Infested Floodplains, *Weed Science*, In Press.

REFERENCES

Taylor, John P. (1997), Personal Communication. U.S. Fish and Wildlife Biologist, Bosque del Apache, N.W.R.

Welder, G. E. (1988). Hydrologic Effects of Phreatophyte Control, Acme-Artesia Reach of the Pecos River, New Mexico, 1967-82. U.S. Geological Survey, Water-Resources Investigations Report 87-4148.

APPENDIX I
Selected Data

SITE	Soil Map Units	TOP 1/3 SOIL TEXT	MIDDLE 1/3 SOIL TEXT	BOTTOM 1/3 SOIL TEXT	HIGHEST EC LOCATION	HIGHEST EC SOIL TEXT	HIGHEST EC (ds/cm)	LOWEST EC LOCATION	LOWEST EC SOIL TEXT	LOWEST EC (ds/cm)	AVG EC (ds/cm)	AVG TEXT	EM 38 VERT. (ms/m)	DEPTH TO GW (CM)	Highest EC dist from GW	Lowest EC dist fromGw	CLAY 1M THICK. (CM)	CLAY 2M THICK. (CM)	CLAY 3M THICK. (CM)
E1	B9	2	10	10	2	10	1900	3	10	310.	801.48	6	96.3	270	140	0	0	70	40
E2	B9	2	6	4	1	4	1500	3	2	345	791.76	3	104	340	210	40	0	0	80
E3	B9	3	2	4	1	6	2000	2	3	320	923.94	3	110.8	330	230	70	0	50	0
E4	B9	6	7	8	1	8	2800	3	8	630	1746.57	7	184.7	350	300	0	50	60	100
E5	B9	5	5	6	1	5	1000	3	8	270	562.36	4	98.3	360	260	50	0	40	20
E6	B9	4	6	0	2	10	2450	3	0	220	903.30	3	60	518	248	148	0	0	40
E7	B8	3	1	2	3	2	440	1	2	200	324.88	2	20.6	400	0	300	0	0	0
E8	B8	1	1	1	3	1	340	1	1	185	242.86	2	18.3	350	0	150	0	0	0
E9	B8	5	3	2	3	1	390	1	5	210	268.29	3	19.2	410	130	270	0	0	40
E10	B8	6	3	2	3	2	410	2	1	190	286.00	3	18.2	450	0	160	100	20	0
FBN1	B7	5	5	7	3	8	2300	1	4	215	719.56	5	25.4	450	50	400	0	0	20
FBN2	B7	5	6	9	3	10	690	1	4	190	378.67	6	27.7	.450	150	270	60	0	20
FBN3	B10	6	7	1	2	8	2650	3	3	155	797.00	5	24.7	450	150	100	0	80	100
FBN4	B10	6	1	2	1	6	1300	2	1	110	463.88	3	36.6	400	300	170	100	20	0
FBN5	B10	5	7	2	1	6	2250	3	1	120	938.42	5	66.6	380	280	0	20	100	50
FBN6	B10	8	7	2	1	10	2300	3	1	100	900.00	5	63.8	380	330	0	100	100	40
FBN7	B10	5	3	6	1	6	690	3	1	140	366.82	5	41.1	250	330	0	20	80	40
FBN8	B11	6	7	4	1	6	1150	3	2	160	591.33	5	34	300	190	50	100	100	30
FBN9	B11	7	9	6	3	9	950	2	3	135	579.50	8	33	330	50	0	100	40	100
FBS1	B4	3	5	1	1	3	1000	3	1	160	598.71	3	12.2	350	250	0	0	0	30
FBS2	B2	1	1	1	1	2	940	2	1	255	286.09	1	13.9	550	500	320	0	0	0
FBS3	B2	2	2	0	1	3	335	2	2	135	176.83	2	10.7	600	530	150	0	0	0
FBS4	B5	5	2	1	1	8	2700	3	1	310	714.75	1	18.7	590	460	270	0	30	0
FBS5	B5	2	3	10	3	10	2500	1	1	480	1335.94	4	39.4	400	50	220	0	0	40
FBS6	B5	2	7	1	3	7	2700	1	2	465	945.10	2	27.9	340	190	0	0	0	70
FBS7	B5	2	4	4	2	10	3150	3	8	290	873.21	3	46.9	390	195	0	0	10	0
FBS8	B6	4	1	1	1	5	430	2	1	110	193.78	2	11.3	450	350	90	0	0	0
FBS9	B6	2	2	1	1	3	180	3	1	105	133.88	2	9.7	400	330	0	0	0	0
FBS10	B10	5	4	8	2	5	2900	3	10	700	1767.50	6	124.3	400	180	0	0	0	0
SB1	B3	3	4	7	3	10	370	1	3	150	235.15	3	41.1	330	50	230	0	50	30
SB2	B3	5	3	9	1	5	660	3	10	210	359.16	6	43	380	260	50	50	0	20
SB3	B3	3	2	5	2	3	1800	3	3	195	405.97	3	9.6	310	180	0	0	0	40
SB4	B2	2	3	1	1	2	380	3	1	114	230.50	2	6.4	350	300	0	0	0	0
SB5	B2	2	1	1	1	2	200	2	1	145	167.50	1	12.8	320	210	150	0	0	0
SB6	B2	3	1	1	1	4	260	3	1	155	192.33	1	10.8	320	270	200	0	0	0
SB7	B2	1	1	2	3	2	170	2	1	72	119.02	1	14.5	450	0	190	0	0	0
SB8	B2	2	2	1	3	0	195	1	2	72	114.42	1	26.6	450	0	390	0	0	0
SB9	B1	7	7	2	1	10	1400	3	1	150	643.33	4	20.9	450	220	0	100	30	40
SB10	B1	5	5	1	1	10	1900	3	0	245	925.56	3	22.6	450	205	0	0	40	45

LOCATION VALUES:
1=TOP, 2=BOTTOM
3=MIDDLE OF PROFILE

TEXTURE VALUES:
0=GRAVEL, 1=S, 2=LS, 3=SL, 4=L, 5=Sil, 6=SiCL, 7=CL, 8=SiC, 9=SC, 10=C

APPENDIX II

Group One and Group Two
Text analysis above and within the
water table.

------------------------------- WATEF=BELOW -------------------------------

General Linear Models Procedure

Dependent Variable: EC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	34134016.87	3413401.69	11.71	0.0001
Error	215	62678406.36	291527.47		
Corrected Total	225	96812423.23			

R-Square	C.V.	Root MSE	EC Mean
0.352579	79.68187	539.9328	677.610619

------------------------------- WATEF=ABOVE -------------------------------

General Linear Models Procedure

Dependent Variable: EC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	8100513.400	1012564.175	9.09	0.0001
Error	61	6796268.371	111414.236		
Corrected Total	69	14896781.771			

R-Square	C.V.	Root MSE	EC Mean
0.543776	86.17371	333.7877	387.342857