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The Use of Computer-Assisted Mapping Techniques to Delineate Potential Areas of Salinity Development in Soils

I. A Conceptual Introduction

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II. Field Verification of the Threshold Model Approach

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ABSTRACT

I. A Conceptual Introduction

Several interacting factors are generally associated with the development of soil salinity on irrigated lands of the arid Southwest. Notable examples include physical edaphology (clay content and soil permeability), depth to the perched water table, salinity of the perched groundwater, and irrigation efficiency. By creating map overlays of these properties and noting the areas of intersection of specific levels or thresholds of these properties, areas can be delineated that demonstrate varying propensities for salt accumulation in the soil profile.

Utilizing an automated geographic information system (GIS), a conceptual approach to delineating areas with similar propensities for the development of soil salinity on irrigated arid-zone soils is presented. The computer mapping strategies provide an efficient and accurate means of organizing, compiling, analyzing, and displaying complex interrelated data bases that are associated with soil salinization. A map can easily be made from the data to aid in land and irrigation management decision making. The automated GIS operates on a microcomputer with enhanced graphics capabilities and requires only 32K of usable memory. The automated GIS is capable of performing mapping tasks generally reserved for larger and more expensive computer systems. The mapping system's polygonal spatial data base maximizes spatial accuracy and produces maps that are aesthetically pleasing and easy to interpret.

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II. Field Verification of the Threshold Model Approach

INTRODUCTION

THE 1980S HAVE BROUGHT an explosion in the use of automated cartography and geographic information systems (GISs) as tools to display complex spatial data, thereby making its interpretation easier. The overlaying of spatial data began as early as the 1960s. The first systems used a grid cell (raster) structure because it offered easy spatial analysis. However, recent developments in computer hardware and automated cartography software have resulted in the development of automated GISs that offer spatial analysis capabilities, but are structured on the basis of vectors that form polygons. Vector systems provide a good representation of the phenomenological data structure, a compact data structure, accurate graphics, and a capacity to retrieve, update, and generalize the graphics and attributes (Burrough 1986).

In Part I we described an automated GIS for a 32K microcomputer that utilizes a vector data structure, has many of the current automated cartographic software features, and has limited polygon overlaying capabilities. This automated GIS was used to introduce the concept that the potential for a soil to develop salinity can be determined by overlaying various soil properties and conditions believed to result in the salinization of irrigated, arid-zone soils. The computer model, referred to here as the "threshold model," proposed that areas of high salinization potential could be delineated based on the presence of threshold levels of four soil properties or conditions:

1. Leaching fraction ≤ 0.10
2. Soil permeability ≤ 0.5 cm/hr and clay content > 40 percent
3. Groundwater electrical conductivity > 4 dS/m
4. Depth to groundwater < 1 m

The threshold levels were not selected arbitrarily, but were based upon generally acknowledged threshold levels of properties or conditions that should give rise to high salinity in the soil profile of arid-zone soils (Bohn, McNeal, and O'Connor 1979; Holmes 1971; Quirk 1971; U.S. Salinity Laboratory 1954). Once a composite overlay has been made of all four coverages, areas of high salinization potential appear as polygons representing the intersection of all four factors.

The purpose of this paper is to verify the concepts presented in Part I for the delineation of high salinization potential on irrigated soils by comparing predicted salinization potentials to actual field salinity data, using the microcomputer-based GIS. The threshold model will be validated against field measurements of salinity that have been categorized as low, medium, and high salinity.

PROCEDURE

The threshold model was verified using data from a roughly 160-square-mile study area in the Wellton-Mohawk Irrigation District east of Yuma, Arizona (fig. 1a). For display purposes, however, only the center section of the Wellton-Mohawk Irrigation District will appear in subsequent figures in order to magnify the visual detail (fig. 1b). The Wellton-Mohawk site offered several advantages as a study site. First, a comparatively comprehensive set of data existed for irrigation amounts, cropping history, soil

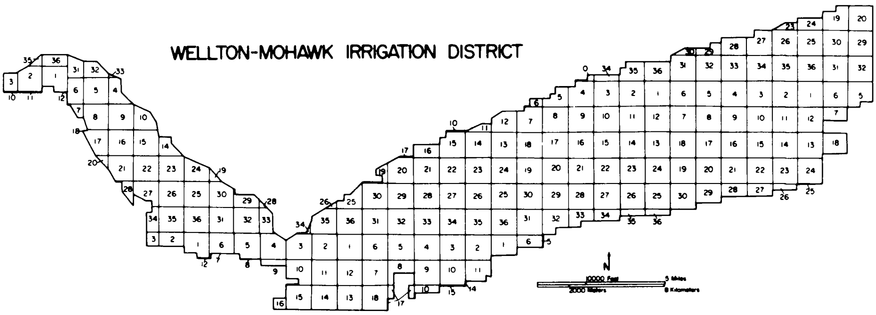

Fig. 1a. Wellton-Mohawk Irrigation District section and boundary lines.

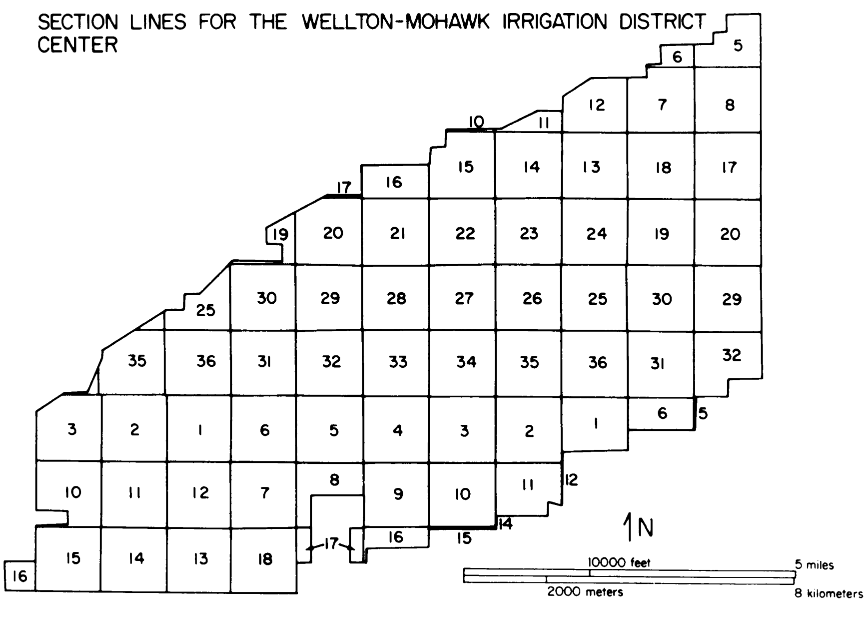

Fig. 1b. Section and boundary lines for the center module of the Wellton-Mohawk Irrigation District study area.

type, groundwater levels, and groundwater quality. Second, a broad range of salinities was known to exist within the site. Third, a salinity traverse conducted by the University of Arizona in November 1973 could serve as a ground truth measure of salinity to which the forecast salinization potentials could be compared for verification.

The 5-year period preceding the 1973 salinity traverse was an ideal period from which to draw the data necessary to verify the threshold model approach. From 1968 to 1973, the interactions of the processes believed to influence salinity development in the soil profile of an irrigated, arid-zone soil were not perturbed by external factors, such as unusual weather patterns or flood conditions. In 1973, however, flood conditions did exist, and resulted in a sharp rise in the water table as seen in the increase in the number of acres having a water table depth of less than 1.22 m, 1.83 m, and 2.44 m or 4, 6, and 8 feet, respectively (fig. 2). Since the influence of flood conditions on the salinity traverse measurements was unknown, representative preflood and postflood data were compiled and were used with the threshold model to test its validity. The overlay maps for leaching fraction, preflood and postflood electrical conductivity of the groundwater, preflood and postflood depth to the groundwater, and soil type are illustrated in figures 3-6, respectively.

Prior to digitizing, the overlay coverages had to be preprocessed. For instance: The leaching fraction had to be determined for each quarter section of cropped land, the depth-averaged soil permeability had to be calculated for each soil type, a representative contour map had to be selected for the depth to the groundwater, and a representative groundwater quality map had to be selected with the total dissolved solids converted to an associated electrical conductivity.

Leaching fraction is a measure of irrigation management efficiency and is represented by the fraction of irrigation water that passes through the root zone and becomes drainage water. As the leaching fraction approaches unity, the more water passes through the root zone and the more closely the soil solution salinity approaches that of the irrigation water. The leaching fraction was determined for each quarter section of the Wellton-Mohawk study area on the basis of historical data provided by the Wellton-Mohawk Irrigation District. The historical data included the amounts of irrigation water applied, estimated amounts of consumptive water use for each crop, and the cropping history. However, a complete set of this information was only available for the period from 1970 to 1972. The calculated 3-year leaching fraction was assumed to approximate the leaching fraction for the 5-year study period. A time-weighted average leaching fraction was calculated using equation 1:

$$LF = f_1 \frac{D_{iw_1} - D_{cu_1}}{D_{iw_1}} + f_2 \frac{D_{iw_2} - D_{cu_2}}{D_{iw_2}} + \ldots + f_n \frac{D_{iw_n} - D_{cu_n}}{D_{iw_n}} \quad [1]$$

where $f_1, f_2, \ldots f_n$ = fraction of the total time a crop, n, was present for a given quarter section

n = number of different crops

D_{iw_n} = amount of irrigation water applied to crop n

D_{cu_n} = consumptive water use for crop n

D_{dw_n} = amount of drainage water for crop n

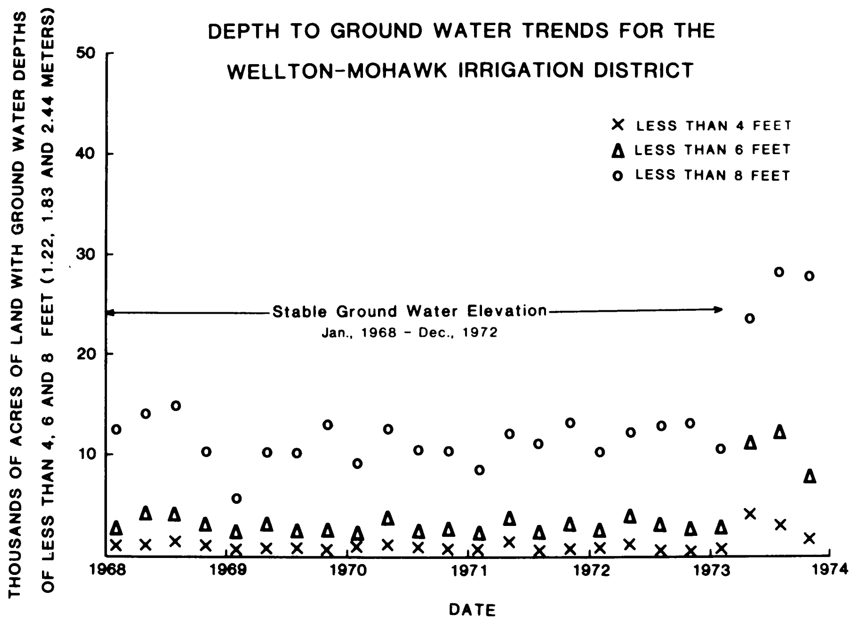

Fig. 2. Groundwater elevation trends from January 1968 to December 1972.

The time-weighted average leaching fractions determined for each quarter section of the center module of the Wellton-Mohawk study area are shown in figure 3.

Representative preflood and postflood groundwater quality (figs. 4a and 4b, respectively) and depth to the groundwater contour maps were selected (figs. 5a and 5b, respectively). The representative contour maps were selected from quarterly data taken by the Wellton-Mohawk Irrigation District from 1968 to 1973. The postflood contour maps were selected from data collected in 1973, since flood conditions existed at that time. From 1968 to 1972, groundwater quality as measured by total dissolved solids (TDS) and groundwater depths were relatively stable. Consequently, the selection of representative preflood contour maps was taken for the final quarter of this stable period. The postflood contour maps were selected from quarterly data taken from the peak of the flood, the time when the water table was the shallowest. Equation 2 was used to convert the groundwater quality data (TDS) to groundwater electrical conductivity:

$$EC = \frac{TDS}{640} \qquad [2]$$

where EC = electrical conductivity (dS/m)
TDS = total dissolved solids (PPM)

For spatial analysis reasons, the area between contour boundary lines was assigned a single attribute value for its soil property or condition. The value was determined by averaging the values of the contour lines defining the polygon.

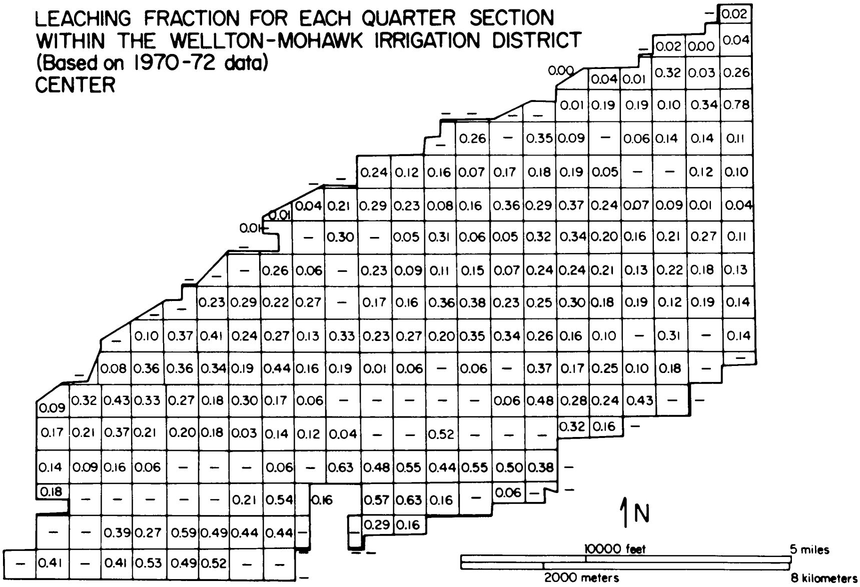

Fig. 3. Leaching fraction for each quarter section of the module of the Wellton-Mohawk study area.

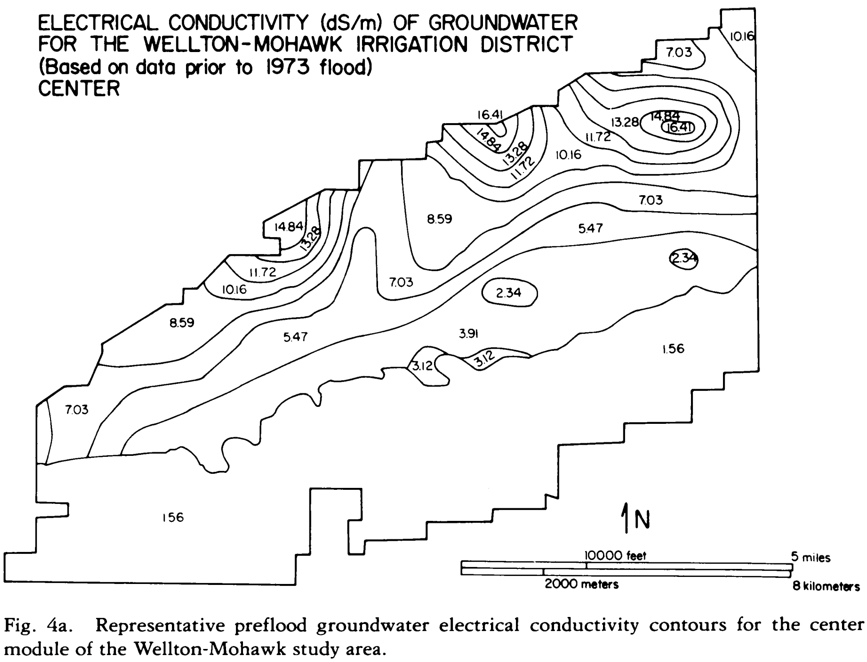

Fig. 4a. Representative preflood groundwater electrical conductivity contours for the center module of the Wellton-Mohawk study area.

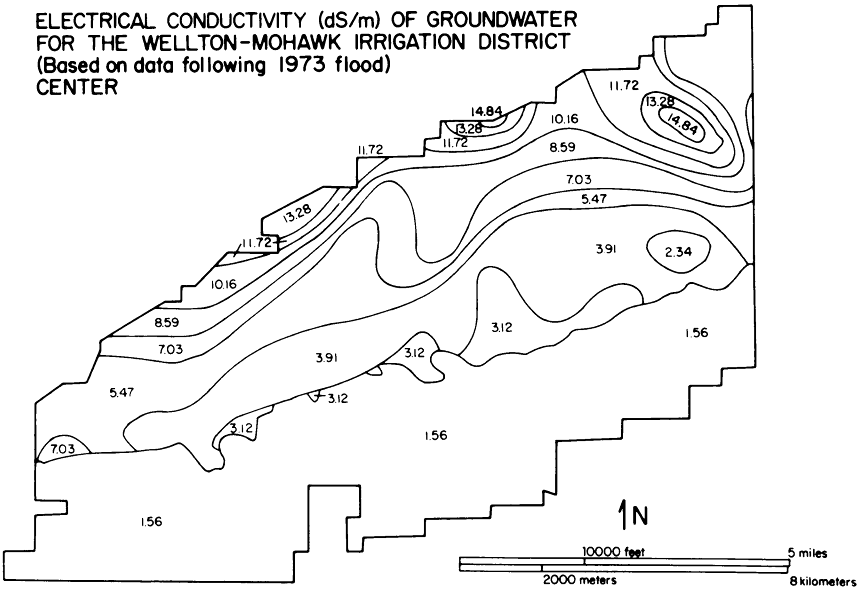

Fig. 4b. Representative postflood groundwater electrical conductivity contours for the center module of the Wellton-Mohawk study area.

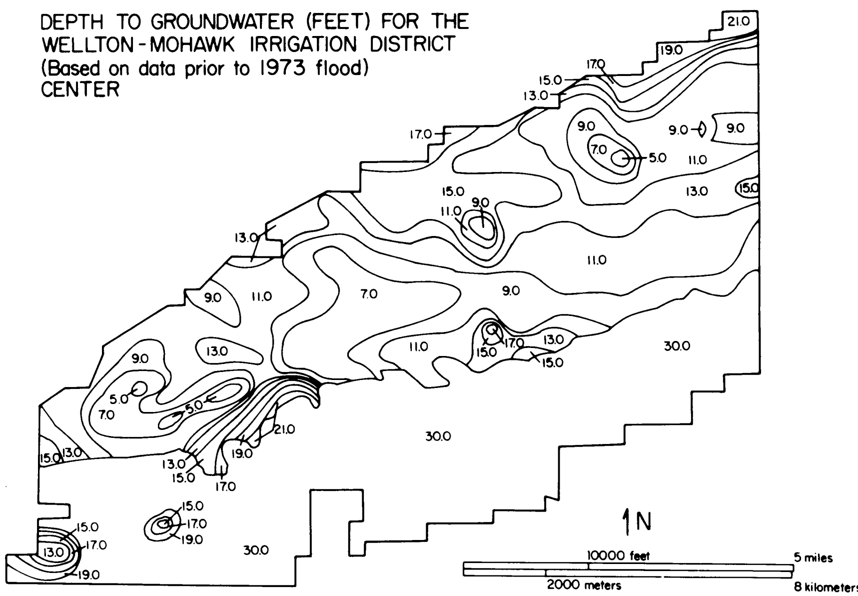

Fig. 5a. Representative preflood depth to groundwater contours for the center module of the Wellton-Mohawk study area.

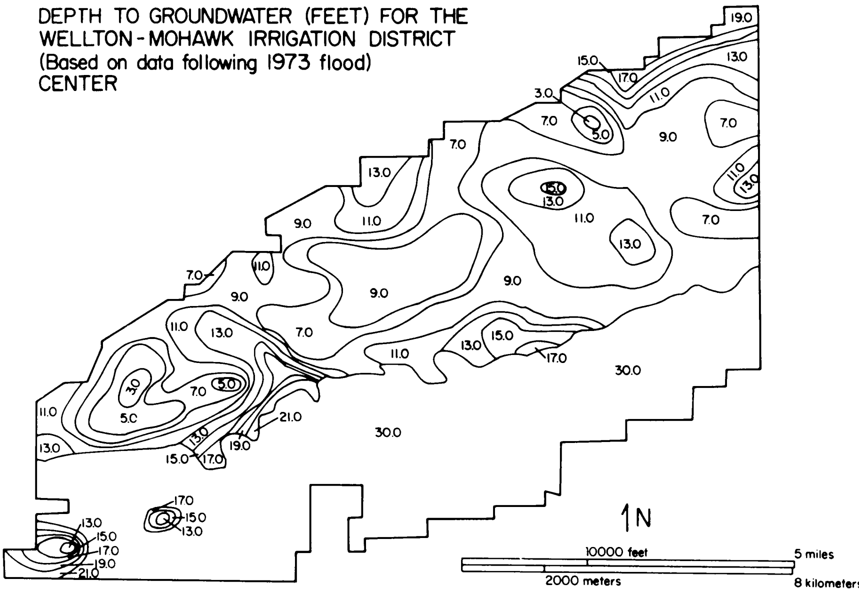

Fig. 5b. Representative postflood depth to groundwater contours for the center module of the Wellton-Mohawk study area.

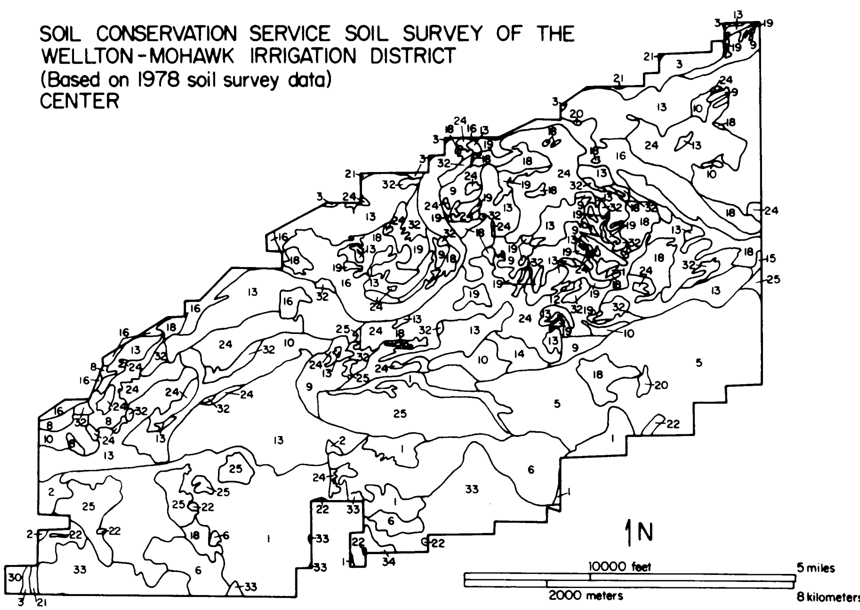

Fig. 6. Soil Conservation Service soil type map for the center module of the Wellton-Mohawk study area.

A USDA Soil Conservation Service map of soil type for the study area (fig. 6) provided a means of estimating the soil permeability. A depth-averaged soil permeability was calculated over the depth of 0 to 61 cm (0 to 24 inches) for each soil type, using the soil permeability information from the Soil Conservation Service Soil Survey of the Yuma-Wellton Area (1980). The soil type numbers and the associated depth-averaged soil permeabilities appear in table 1.

The four overlay maps were digitized and edited as described in Part I. Check plots of each overlay were generated from the graphics system and meticulously scrutinized for errors. Preflood and postflood final composite overlay maps were generated from the polygon overlay analysis routine.

TABLE 1. SOIL TYPE CODE AND ASSOCIATED SOIL PERMEABILITY FOR THE WELLTON-MOHAWK STUDY AREA

Soil type code	Soil name	Depth-averaged soil permeability
		cm/hr
1	Antho sandy loam	10.2
2	Antho fine sandy loam	10.2
3	Carrizo very gravelly sand	50.8
4	Cherioni-Rock outcrop complex	3.3
5	Dateland loamy fine sand	12.4
6	Dateland fine sandy loam	10.2
7	Gachado very gravelly loam	0.5
8	Gadsden clay	0.3
9	Gilman loam	3.3
10	Glenbar silty clay loam	1.0
11	Harqua-Tremant complex	2.0
12	Holtsville clay	3.0
13	Indio silt loam	3.3
14	Indio silt loam, saline	3.3
15	Indio silt loam, strongly saline	3.3
16	Indio-Lagunita-Ripley complex	15.5
17	Kofa clay	0.3
18	Lagunita loamy sand	33.0
19	Lagunita silt loam	3.3
20	Laposa-Rock outcrop complex	3.3
21	Ligurta-Crystobal complex	8.6
22	Pits, borrow	0.3
23	Pits, gravel	0.3
24	Ripley silt loam	3.3
25	Rositas sand	33.0
26	Rositas-Ligurta complex	23.1
27	Salorthids	0.3
28	Superstition sand	31.2
29	Superstition complex	28.7
30	Torriorthents-Torrifluvents complex	10.2
31	Tremant-Rositas complex	15.2
32	Vint loamy fine sand	10.2
33	Wellton loamy sand	10.2
34	Wellton-Dateland-Rositas complex	14.5

The salinity traverse data consisted of electrical conductivity measurements and chemical analyses of anions and cations for a 1:1 soil-to-water extract. An initial screening of the traverse data showed a reasonable agreement between the sum of the anions, the sum of the cations, and the measured electrical conductivity. If an obvious discrepancy existed for cross-checked data at a sample point, then that point was excluded from the verification data set. A total of 66 reliable sample points from the traverse study fell within the boundary of the Wellton-Mohawk study area. These 66 observations formulated the verification data set.

The salinity traverse data were categorized into low, medium, and high salinity categories using criteria presented in Agricultural Handbook No. 60 (U.S. Salinity Laboratory 1954). The U.S. Salinity Laboratory electrical conductivity criteria and their corresponding equivalent salt concentrations for a saturation extract and a 1:1 soil-to-water extract (assuming the presence of predominantly chloride salts) are presented:

		Salt concentration (meq/l)	
Salinity category	EC_e (dS/m)	Saturation extract	1:1 extract
Low	0–2.0	0–20.0	0– 7.5
Medium	2.0–4.0	20.0–45.0	7.5–16.9
High	>4.0	>45.0	>16.9

The salt concentration for the 1:1 extract was determined from the salt concentration of the saturation extract, assuming a representative porosity of 0.5 cm^3 per cm^3, a representative bulk density of 1.33 g per cm^3, and a water density of 1.0 g per cm^3.

The final composite overlays that delineated areas of low, medium, and high salinization potentials were verified by comparing the forecast salinization potentials from the threshold model to the salinity categories of the measured data. This was based on the assumption that the processes leading to salinization over the 5-year study period reached a steady state, so the measured salinity of the root zone (0 to 61 cm) reflected the salinization potential for the existing soil properties and conditions at that sample site.

DESCRIPTION OF THE THRESHOLD MODEL

The original concept of the threshold model as introduced in Part I proposes that the presence of threshold levels of certain soil properties or conditions that are believed to be involved in the salinization process will determine the salinization potential. For instance, a high salinization potential would exist for a location with all of the threshold properties or conditions, while a medium salinization potential would have any three of the four critical properties or conditions, and a low potential would have any two.

For verification purposes, the threshold criteria were adjusted slightly in order to be more specific to the chosen study area, based on professional judgment and discussions with Soil Conservation Service personnel and Wellton-Mohawk Irrigation District staff. Table 2 lists the final criteria used to determine salinization potential. For

TABLE 2. THRESHOLD MODEL CRITERIA FOR THE WELLTON-MOHAWK STUDY AREA

Threshold category	Water quality (EC)	Groundwater depth	Leaching fraction	Permeability
	dS/m	*m*		*cm/hr*
Low	<2.0	>3.05	>0.30	>10.16
High	>4.0	<1.83	<0.15	<1.27

TABLE 3. MODEL 1 CRITERIA FOR THE ASSIGNMENT OF NORMALIZING VALUES TO THE SOIL PROPERTIES AND CONDITIONS CAUSING SALINIZATION

Permeability	Leaching fraction	Depth to groundwater	Groundwater EC	Assigned value
cm/hr		*m*	*dS/m*	
>25.4	>0.40	>4.57	<1.0	2
10.2-25.4	0.30-0.40	3.05-4.57	1.0-2.0	4
1.3-10.1	0.16-0.29	1.83-3.04	2.1-4.0	6
0.6- 1.2	0.05-0.15	1.22-1.82	4.1-5.0	8
<0.6	<0.05	<1.22	>5.0	10

the Wellton-Mohawk study site, it was decided that either three or all four high threshold categories were necessary for the assignment of a high salinization potential, except in cases where no leaching fraction was available. In such cases, the remaining three high threshold criteria were necessary. Similarly, a medium salinization potential required the presence of one or two of the threshold levels, and a low potential consisted of all remaining areas.

A modification the threshold model was also formulated and verified. For the purposes of simplification and of easily differentiating from subsequent salinization potential models, the modified threshold model will be referred to as "Model 1."

In Model 1 each property or condition measurement is assigned a value according to the criteria in table 3. Conceptually it is assumed that each of the four soil properties and conditions acts in an additive way to cause the development of salinity in the soil profile. The threshold model approach presupposes that the properties and conditions leading to salinity development are weighted equally. To reflect this in a modeling format, each salinization development property or condition must be normalized; consequently, the assigned values act as a quantitative means of measuring the relative significance of each soil property or condition in relation to each of the others on an equal-weight basis. These assigned values are summed, and the final summation value is classified as a low, medium, or high salinization potential (table 4). The purpose of developing Model 1 was to find a more quantitative means of assessing salinization potential while maintaining an overall format compatible with the polygon overlaying capabilities of the automated GIS described in Part I.

Technically, the application of arithmetic operations to ordinal level data, such as in Model 1, is inappropriate. However, if it is assumed that the assigned values are not ordinal data, but rather, represent interval data, then the application of arithmetic

TABLE 4. MODEL 1 SALINIZATION POTENTIAL CRITERIA

Salinization potential	Final summation values	
	With leaching fraction	Without leaching fraction
Low	0–23	0–17
Medium	24–31	18–23
High	32–40	24–30

operators is permissible. This assumption, though of some questionable validity, is necessary to overcome the inherent vagaries and complexities of the data due to the spatial variability of heterogeneous real-world properties that could not be characterized sufficiently to determine customary statistical parameters such as a median or mean value. Rather, characterization was based on intervals, since accumulating sufficient measurements to do otherwise would have been prohibitive in time, labor and cost. Furthermore, the intent was to utilize data that were readily available through existing sources in order to demonstrate the utility and practicality of the approach.

DISCUSSION OF RESULTS

Verification of the original threshold model proposed in Part I, using a set of threshold criteria tailored more specifically to the Wellton-Mohawk study area (table 2), resulted in extremely poor, discouraging results for both preflood and postflood data sets (table 5). Out of the 66 verification sample sites from the 1973 salinity traverse, only 39 percent of the forecast salinization potentials matched the corresponding salinity category of the ground truth field measurements from the preflood data. Even worse results were found with the postflood data, where only 30 percent of the sites were correctly forecast. The inadequacy of the threshold model as a predictive tool appears to stem from its inaccuracy in predicting low and, especially, high salinization potentials. This suggests either that the threshold model criteria of table 2 are not applicable or that the threshold model does not sufficiently simulate the interactions of the factors leading to salinization by giving the factors equal weight in relation to one another.

The discouraging verification results for the threshold model prompted the formulation of the modified version, Model 1. Model 1 attempted to deal with the complexities of the interacting factors leading to salinity development by applying a slightly more detailed classification and normalization process to the four salinization factors. However, Model 1 still retained the basic features of the threshold model which weighted each factor equally and required thresholds to elicit a response. Model 1 also allowed for summing of the various thresholds or levels.

Model 1 noticeably improved the ability to forecast the salinization potential, but still fell far short of reliability (table 5). Only 58 percent of the salinization potential forecasts were correct using the preflood data. Once again, the postflood data did not result in better predictions, indicating that the flood conditions existing at the time of the salinity traverse probably had not influenced or altered salinity levels substantially at the sample locations. The general tendency for both the threshold model and Model

TABLE 5. THE THRESHOLD MODEL AND MODEL 1 VALIDATION DATA FOR THE WELLTON–MOHAWK STUDY AREA

	Measured data		Predicted data			
			Threshold model		Model 1	
Site	Salt concentration	Salinity category	preflood	postflood	preflood	postflood
	meq/l					
1	6.63	Low	Low	Low	Low	Medium
2	15.70	Medium	Low	Medium	Medium	Medium
3	3.01	Low	Low	Medium	Medium	High
4	9.86	Medium	Low	Low	Medium	Medium
6	5.73	Low	Medium	Medium	Medium	Medium
7	3.26	Low	Medium	Medium	Medium	Medium
8	10.88	Medium	Low	Low	Medium	Medium
9	8.47	Medium	Low	Low	Low	Low
10	5.70	Low	Low	Medium	Medium	Medium
11	4.95	Low	Low	Medium	Low	Low
12	3.80	Low	Medium	Medium	Medium	Medium
13	21.06	High	Medium	Medium	Medium	Medium
14	11.91	Medium	High	High	Medium	High
15	16.87	Medium	Low	Medium	Low	Low
16	3.14	Low	Medium	Medium	Low	Low
17	9.62	Medium	Medium	Medium	Medium	Medium
18	4.14	Low	Medium	Medium	Medium	Medium
19	3.44	Low	Medium	Medium	Low	Medium
20	2.84	Low	Medium	Medium	Medium	Medium
21	5.77	Low	Medium	Medium	Medium	Medium
22	3.83	Low	Medium	Medium	Medium	Medium
23	10.66	Medium	Low	Low	Low	Low
24	5.80	Low	Medium	Medium	Low	Low
25	10.38	Medium	Medium	Medium	Medium	Medium
26	3.25	Low	Medium	Medium	Medium	Medium
28	4.70	Low	Medium	Medium	Low	Low
29	4.42	Low	Low	Low	Low	Low
30	3.69	Low	Low	Low	Medium	Medium
31	8.81	Medium	Low	Medium	Medium	Medium
32	5.98	Low	Medium	Medium	Medium	Medium
33	19.64	High	Medium	Medium	Medium	Medium
34	37.49	High	Medium	Medium	Medium	Medium
35	5.22	Low	Medium	Medium	Low	Medium
36	37.33	High	Medium	Medium	Medium	Medium
37	13.42	Medium	Medium	Medium	Medium	High
38	4.29	Low	Low	Low	Low	Low
39	3.32	Low	Low	Low	Low	Low
40	5.02	Low	Medium	Medium	Medium	Medium
41	8.73	Medium	Medium	Medium	Medium	Medium
42	7.49	Low	Low	Medium	Low	Medium
43	10.41	Medium	Medium	Medium	Medium	Medium
44	3.46	Low	Medium	Medium	Medium	Medium
45	5.60	Low	Medium	Medium	Medium	Medium
46	3.35	Low	Low	Medium	Low	Low
47	24.44	High	Medium	Medium	Medium	Medium

Continued on next page

Table 5—Continued

	Measured data		Predicted data			
			Threshold model		Model 1	
Site	Salt concentration	Salinity category	preflood	postflood	preflood	postflood
	meq/l					
48	10.56	Medium	Medium	Medium	Medium	High
49	2.36	Low	Low	Medium	Low	Medium
50	15.73	Medium	Medium	Medium	Medium	Medium
51	38.89	High	Medium	Medium	Medium	Medium
52	9.59	Medium	Medium	High	Medium	High
53	15.82	Medium	Medium	Medium	Medium	Medium
54	5.70	Low	Medium	Medium	Low	Low
55	3.51	Low	Low	Medium	Low	Low
56	3.11	Low	Low	Medium	Low	Low
57	3.81	Low	Medium	Medium	Low	Medium
58	15.45	Medium	Medium	Medium	Medium	Medium
59	5.81	Low	Medium	Medium	Low	Medium
60	33.89	High	Medium	High	Medium	Medium
61	10.38	Medium	Medium	High	Medium	High
62	18.46	High	Medium	Medium	Medium	Medium
74	3.27	Low	Low	Low	Low	Low
75	3.54	Low	Medium	Medium	Low	Low
77	4.38	Low	Medium	Medium	Low	Low
78	5.78	Low	Medium	Medium	Medium	Medium
81	11.72	Medium	Medium	Medium	Medium	Medium
82	2.82	Low	Medium	Medium	Medium	High
Fraction of salinization potentials correctly forecast			0.39	0.30	0.58	0.39
Total number of observations: 66*						

*The salinity traverse consisted of 82 sample sites of which only the above 66 listed sites were actually within the study site boundary.

1, when using the postflood data, was to overestimate the salinization potential. The prediction of a salinization potential higher than the measured potential resulted from the existence of shallower water tables at the time of flooding.

Figures 7a and 7b show the final maps produced for the center module of the Wellton-Mohawk study area using the preflood and postflood data for Model 1. Both maps show a relatively sharp demarcation between a low salinization potential in the southern half and a medium salinization potential in the northern half. The medium salinization potential is interspersed with islands of low potentials and occasional pockets of high potentials. More high salinization potential areas resulted from the postflood data because of substantially higher groundwater elevations. The preflood data yielded more accurate predictions.

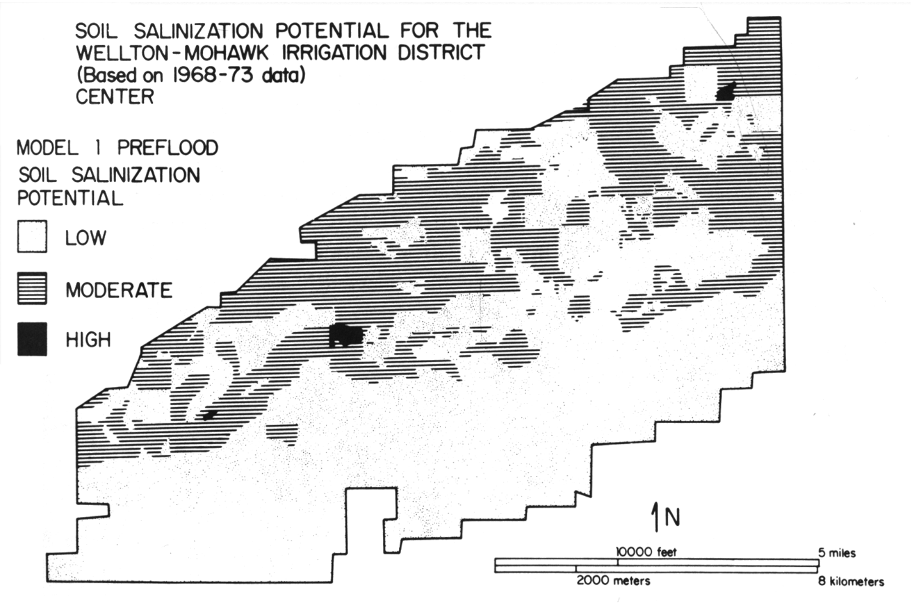

Fig. 7a. Soil salinization potential map generated from Model 1 for the center module of the Wellton-Mohawk study area using preflood data.

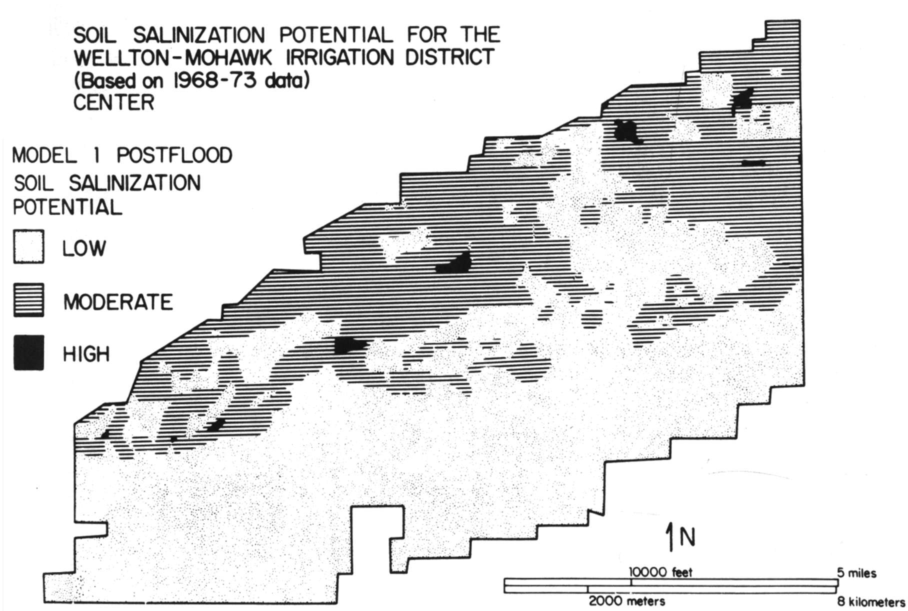

Fig. 7b. Soil salinization potential map generated from Model 1 for the center module of the Wellton-Mohawk study area using postflood data.

CONCLUSIONS

The fact that, at best, only 58 percent of the verification sites could be forecast correctly using the modified threshold approach indicates that the complexities of the interacting processes causing salinity to develop in the soil profile of irrigated, arid-zone land are not accurately characterized by the simplicity of the threshold approach. The limited though encouraging success of Model 1 could relate to the use of an ordinal value to describe interval data. Possibly, a midpoint value within the interval rather than an assigned value could have been used. It is likely that the various factors causing salinity development differ in their relative significance to the overall salinization process. A subsequent paper (Corwin, Sorensen, and Rhoades 1988) evaluates the degree to which the ability to forecast salinization potential can be improved by weighting the significance of each soil property or condition contributing to salinity development in the soil profile.

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II. Field Verification of the Threshold Model Approach

A study area within the Wellton-Mohawk Irrigation District, which lies east of Yuma, Arizona, was used to verify the threshold model proposed in Part I. Verification results showed that the threshold model could not reliably predict salinization potential; consequently, a modified threshold model, Model 1, was formulated. Model 1 was capable of predicting nearly 60 percent of the salinization potentials correctly, a significant improvement over the original threshold model. Nevertheless, Model 1 fell short of being considered a reliable forecasting tool.

It is postulated that the interactions between the factors believed to give rise to salinity development at the study site were too complex to characterize with the simple threshold model approach. Rather, a means of weighting the significance of the individual factors in the overall salinization process may be necessary.

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