Journal of Coastal Research	5	1	83-91	Charlottesville, Virginia	Winter 1989

Spatial Analysis of Coastal Land Loss by Soil Type

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ABSTRACT

HILL, J.M. and TURNIPSEED, P., 1988. Spatial analysis of coastal land loss by soil type. *Journal of Coastal Research*, 5(1), 83-91. Charlottesville (Virginia). ISSN 0749-0208.

A geographic information system (GIS) was developed to quantify and illustrate the conversion of wetlands to open water in the Cameron-Creole Watershed Management Area in southwestern Louisiana. An accelerating trend of land loss was identified for the period between 1933 and 1975. A land loss of 75 km^2 was recorded. The land losses are associated with a complex combination of natural and man-made causes. After the land loss for a given period was established, the GIS was used to merge soil type data with the land loss data to establish the influence of soil type on land loss. Certain soil associations were shown to suffer disproportionate losses of land. Finally, a computerized proximity model was developed to examine possible methodologies for analyzing and predicting the spatial distribution of land loss. With further development, such models may become important tools in determining best management practices (BMP) for wetlands.

ADDITIONAL INDEX WORDS: *Coastal zone management, erosion, GIS, geographical information systems, proximity models, wetlands.*

INTRODUCTION

Wetland conversion to open water is a serious problem in coastal Louisiana. Losses of 102 km^2/yr in the Mississippi River Deltaic Plain (GAGLIANO, *et al.*, 1981) have degraded fisheries and increased the exposure of inland areas to natural hazards such as hurricanes. Natural causal factors, including subsidence, sea level rise and erosion-deposition imbalance have been blamed for much for this loss. Man-made factors, such as impoundments, canals and spoil banks, have accelerated this loss in many areas (GOSSELINK, *et al.*, 1978; SCAIFE, *et al.*, 1983).

Much research has assessed change in the coastal wetlands of Louisiana. SCAIFE, *et al.* (1983) and DEEGAN, *et al.* (1984) used photointerpreted data generated by GAGLIANO, *et al.* (1981) to establish positive correlations between coastal land loss in the deltaic plain and canal surface area. The correlation was related to deltaic substrate, distance to the coast, and the availability of new sediments. Loss rates were found to be highest where canal densities were high in recently abandoned deltas near the coast and lowest where canal density was low in older deltas farther from the coast. Aerial photography, as well as other remotely sensed data have been used to map wetlands. Historical aerial photographs have stored information about ecological processes and man-induced environmental impacts that we desired to monitor only during recent times. Little is known about the spatial patterns of marsh loss to other geophysical parameters, such as proximity to levees, rivers and soil types.

The objectives of this study were to document wetland conversion in the Cameron-Creole Watershed Management Area, investigate the association of wetland conversion with soil type, and to develop a methodology for modeling critical proximity relationships. A computerized spatial data base was developed to determine the amount, rate and location of wetland change over time. Land loss data was merged with a soil data base to determine the relation

87041 received 28 September, 1987; accepted in revision 31 May 1988.

between soil type and marsh degradation. The channel data developed in the land loss study was used as a base for a proximity model.

STUDY AREA

The Cameron-Creole Watershed Management Area is located in the Chenier Plain of southwestern Louisiana (Figure 1). The study area is bounded on the south by the Gulf of Mexico and the Mermentau River, on the west by Calcasieu Lake, on the north by the Intracoastal Waterway, and on the east by Little Chenier Canal, Little Chenier Ridge and the Creole Canal. The study area is typical of the Chenier Plain. It consists of recent sediments of the Mississippi River Deltaic Plain. Cheniers, ridge-like swales parallel to the Gulf of Mexico, provide the only natural topographic relief in the marshes. Marshes cover 41,667 ha out of a total of 49,800 ha in the study area. Sabine National Wildlife Refuge is located in the west central section. Man-made modifications of the study area include two roads, LA 82 and LA 27, the towns of Cameron, Oak Grove and Creole on the Gulf Coast Cheniers, and numerous canals and spoil banks.

Salinity levels in Calcasieu Lake and adjacent marshes began to increase in 1941 with completion of the Calcasieu Ship Channel. This increase in salinity corresponded with extensive loss of marsh to open water (GOSSELINK,

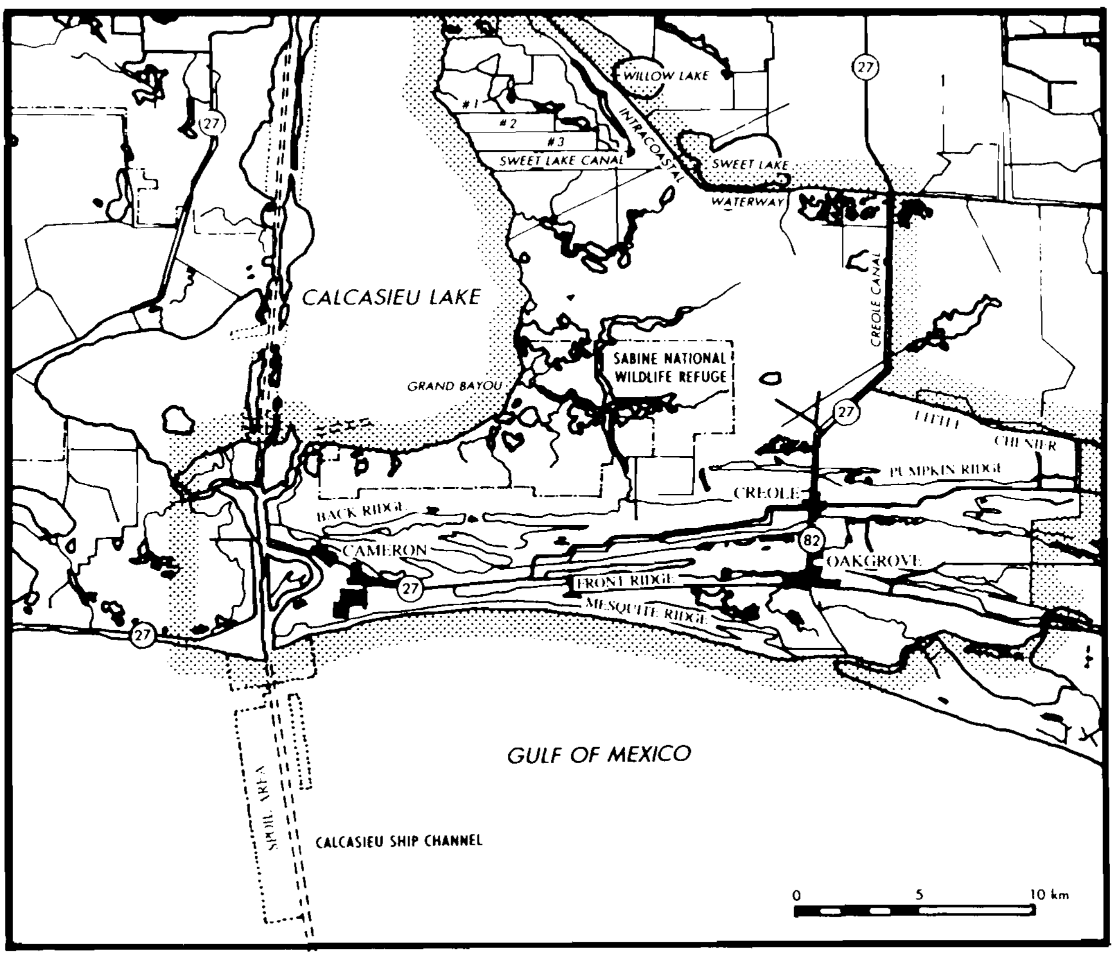

Figure 1. Location of the Cameron-Creole Watershed Management Area, Cameron Parish, Louisiana.

et al., 1979). Levee construction in the study area has resulted in decreased sediment deposition, obstruction of sheet flow, and impoundment of marshes. The dredging of canals has allowed further intrusion of saltwater into the marsh. Increased salinity has been found to cause plant die-off which further reduces substrate stability and increases erosion (O'NEIL, 1949; KOLB and VAN LOPIK, 1958; ADAMS, *et al.*, 1978; CRAIG, *et al.*, 1979). The U.S. Department of Agriculture Soil Conservation Service (SCS) began construction of a series of water control structures in 1970. A major goal was reduction of saltwater movement into the marsh between the cheniers and the Intracoastal Waterway.

MATERIALS AND METHODS

Photointerpretations of historic aerial photographs, satellite imagery and soil type maps were combined using a computer-based Geographic Information System (GIS). Data sets were converted to a common computer format and compared. An Interdata 8/32 minicomputer, a Talos digitizing system, a Comtal image processing system and various output peripherals were used to process 111 million data cells. A proximity model was developed for studies of the relation between land loss and proximity to channels. Modular program overlays of the Earth Resources Laboratory Applications Software (ELAS), developed by the National Aeronautics and Space Administration (NASA, 1980), were used to manipulate the data.

Aerial Photography

Three data sets were acquired for this project. The first data set was preimpact aerial photography of the study area, photographed in May and June, 1933. This photography included both 7-by-9 inch black-and-white prints at a scale of approximately 1:18,000 and photogrammetrically uncontrolled, black-and-white panchromatic mosaics in 7.5 minute quadrangle format. The second set was 11-by-11 inch black-and-white aerial prints photographed 29 January, 1953, at a scale of 1:15,840. This data set showed the study area approximately 12 years after construction of the ship channel. The third data set consisted of 1975 U.S. Geological Survey (USGS) 7.5' orthophoto quadrangle sheets. These maps were used as a base to which all other information was registered. High-altitude photographs were used to reference and validate the third data set. These photographs were 9-by-9 inch color infrared transparencies photographed by NASA in October 1978 at a scale of 1:65,000.

Any photointerpreted data set is biased by the interpreter, the classification scheme, the quality of data, the mapping methodology, and the mapping unit. Rarely do individual classifications compare well with others even of the same geographic area. Use of orthophoto quadrangle sheets provided not only a ready source of current information of the study area (*i.e.*, water, marsh, land use, roads, levees, channels, *etc.*), but also provided an adequate rectified image (base map) of the study area. The aerial photographs provided spaced data sets over 42 years.

SCS Soil and Channel Maps

The Soil Conservation Service (SCS), provided preliminary maps of the Soil Survey of Cameron Parish, Louisiana. This information was drawn on frosted mylar overlain on 1:24,000 USGS orthophoto quadrangle sheets. Digital input of soil types to the GIS allowed for the spatial and temporal analysis of the change of wetland to open water by individual soil type. The Soil Survey also contained water channels labeled according to their influence on the influx of saltwater into the study area. SCS field personnel provided qualitative ratings of the influx as heavy or moderate for each data set. This classification emphasized the relative influx of saltwater and the presence of the channels. No actual construction dates were readily obtainable for canals, pirogue (boat) trails, *etc.*, in the project area. Therefore, water channels were input as they appeared on the three dates photographed.

Photointerpretation and GIS Information

The photointerpretation and mapping of land-water boundaries in the study area followed several steps. First, frosted mylar was overlain on the 1975 USGS orthophoto quadrangle basemaps. A Jena Sketchmaster was used to transfer the land and water boundaries to the mylar overlay by optically superimposing and scaling the photographs. A minimum mapping unit of 2 ha was used, except for areas of small linear features such as canals and levees. The 1933 photography contained some sun spots (sun glint on water) which actually helped to accentuate land and water boundaries. Where image quality was questionable, sets of historical photography were referenced one set to another for boundary clarification.

The spatial resolution of a GIS is governed by varying the size of the grid cell (pixel). Several grid cell sizes were examined for this project in order to preserve the required mapped data while at the same time minimizing computer storage requirements and processing time. Three grid resolutions were selected for evaluation based on compatibility with possible sources of data base updates, such as satellite imagery. The sizes examined were:

(1) 10 meter grid cell - represents a resolution similar to that found on 7.5' (1:24,000) USGS quadrangle sheets;
(2) 25 meter grid cell - represents a resolution similar to Landsat Thematic Mapper data (30 m);
(3) 50 meter grid cell - represents a resolution equivalent to Landsat Multispectral Scanner data (60-by-80 m).

A 10-by-10 meter grid cell size was selected. It best captured relevant mapped data such as contiguous narrow channels and canals in the area. All channels below 10 m width were mapped as 10 m.

A modified version of ELAS was used to construct, display and analyze all spatial information. The ELAS software was designed to process digital image and map data in a grid cell format and develop multi-channel overlays referenced to a map coordinate system. The base maps were gridded to 1,000 meter blocks based on the Universal Transverse Mercator (UTM) mapping system. The digitizing software, developed by the U.S. Army Corps of Engineers, Waterways Experiment Station (WES) limited input of matrix grids to 200-by-200 cell blocks. Land and water boundary maps were digitized manually into a polygonal system of x-y values. Each map was then converted from vector to raster (grid cell) format and merged to form a larger map.

Proximity Model

One of the objectives of this study was to develop a methodology for modeling critical proximity relationships. Of particular interest was the nearness of eroded areas to channels introducing saltwater into the watershed from 1933 to 1975. Positive correlations have been made between canal construction and erosion due to saltwater intrusion (GOSSELINK, *et al.*, 1979). A portion of the study area in the Sabine Refuge was selected for proximity modeling because it contains both natural and man-made water channels and land loss. This test data set contained soil types, water channels, and land loss for all three dates. Water channel data were extracted from the historic land-water data sets. Channel data were distinguished by assigning it a count value of one, while other information was assigned a value of zero.

The ELAS/DIST module was used to compute distance from the center of each pixel classed as water channel to the center of the nearest pixel classed as land. The resultant image contained the channel data and contour distances ranging from 0 to 255 increments. Distance images were created for all three image dates in this manner. The Programmable Calculator (ELAS/PCAL) overlay was then utilized to arithmetically blend each temporal distance image with its corresponding land loss image.

Table 1. *Historic land and water areas during 1933, 1953 and 1975 in the Cameron-Creole Watershed Management Area, Cameron Parish, Louisiana.*

Class	1933		1953		1975	
	ha	%	ha	%	ha	%
Land	47,870.35	96.00	47,440.00	95.18	41,384.91	83.23
Water	1,993.60	4.00	2,400.69	4.82	8,339.61	16.77
Total*	49,863.98	100.00	49,840.68	100.00	49,724.51	100.00

*Error due to the manual interpretation and georeference process caused some variation (less than .0028%) in study area sizes.

Table 2. *Change (△) in land and water areas between 1933 and 1975 in the Cameron-Creole Watershed Management Area, Cameron Parish, Louisiana.*

Class	Δ 1933–53 ha	Δ 1933–53 %	Δ 1953–75 ha	Δ 1953–75 %
Unchanged Land	46,596.10	93.76	40,809.50	82.26
Unchanged Water	1,279.66	2.57	1,930.64	3.89
New Land	715.32	1.44	463.83	0.93
New Water	1,106.50	2.32	6,407.98	12.92
Total	49,697.58	100.00	49,611.94	100.00

RESULTS AND DISCUSSION

Digital analysis of land and water boundary changes over time demonstrated conclusively that extensive loss of marsh to open water occurred in the Cameron-Creole study area from 1933 to 1975. Furthermore, the loss of land was unevenly distributed among different soil types.

Table 3. *Water and soil types in the Cameron-Creole Watershed Management Area, USDA/SCS Cameron Parish (Louisiana) Soil Survey.*

Class	Symbol	Area in 1933* ha	Area in 1933* % of Total
Water	—	1,993.63	4.00
Beach	BEACH	200.37	0.41
Allemands muck	AE	5,061.61	10.32
Aquents, frequently flooded	AN	848.75	1.73
Arat mucky silt loam	AR	neg.**	neg.
Clovelly muck	CO	6,319.52	12.89
Creole clay	CR	11,538.54	23.53
Creole clay, saline	CR (SALT)	614.18	1.25
Ged clay	GB	438.22	0.89
Gentilly mucky clay	GC	650.03	1.33
Hackberry loamy fine sand	Hb	492.28	1.00
Hackberry—Mermentau complex gently undulating	Hm	3,911.96	7.98
Larose mucky clay	LE	814.84	1.66
Leton silt loam	Lt	58.25	0.12
Mermentau clay	ME	3,918.85	7.86
Midland silty clay loam	Mn	neg.	neg.
Morey silt loam	Mr	541.80	1.10
Mowata-Vidrine silt loams	Mt	969.29	1.98
Peveto fine sand, 1-3% slopes	Pe	242.73	0.50
Scatlake clay	SC	9,038.56	18.43
Scatlake clay, saline	SC (SALT)	1,353.11	2.76
Udifluvents, 1-20% slopes	UD	832.12	1.70

*1933 Land-water conditions overlayed with soil types. No change in soil distribution is assumed for duration of study.

**Negligible areas, less than 25 ha or .05% of total.

Historic Land Change

Historic land-water data bases were merged to detect temporal changes. The change detection analysis reveals land converted to water and vice versa. The area and percentage of each class are summarized for historic conditions and for the change analysis in Tables 1 and 2.

Water that changed to land in these analyses can be attributed mostly to rainwater present (in low lying areas) in an earlier year that was not present in the latter year. According to the Soil Conservation Service, some gains in land area can be attributed to farmers who leveed and pumped some areas and filled in others. Minor unavoidable alteration in the manual digitization procedure resulted in both new water and new land that cannot be ascribed to actual changes in the study area.

During the first 20 year period (1933–53), only 11.06 km^2 of land was converted to water, while during the 22 year period from 1953 to 1975, 64.10 km^2 of marsh degraded to open water. This would indicate that either a time delay factor or that the causal mechanisms of marsh degradation in the study area had accelerated from 1953 to 1975.

Land Loss to Open Water by Soil Type

Soil type information was merged with all three historic data sets of land and water boundaries (Figure 2). These figures are condensed in order to show the entire study area at once. Every seventh pixel is shown. Historic conditions and changes are summarized in Tables 3 and 4. Soil types were assumed not to have changed significantly during the study period. The four soil types that lost the most wetland to open water over the entire study area and the percent of area lost of each respective type are:

(1) Allemands muck (AE) - 20.49 percent
(2) Scatlake clay (SC) - 25.18 percent
(3) Creole clay (CR) - 4.75 percent
(4) Clovelly muck (CO) - 33.31 percent

Different combinations of marsh loss processes affect different parts of the study area. Some of these processes are evident in portions of the

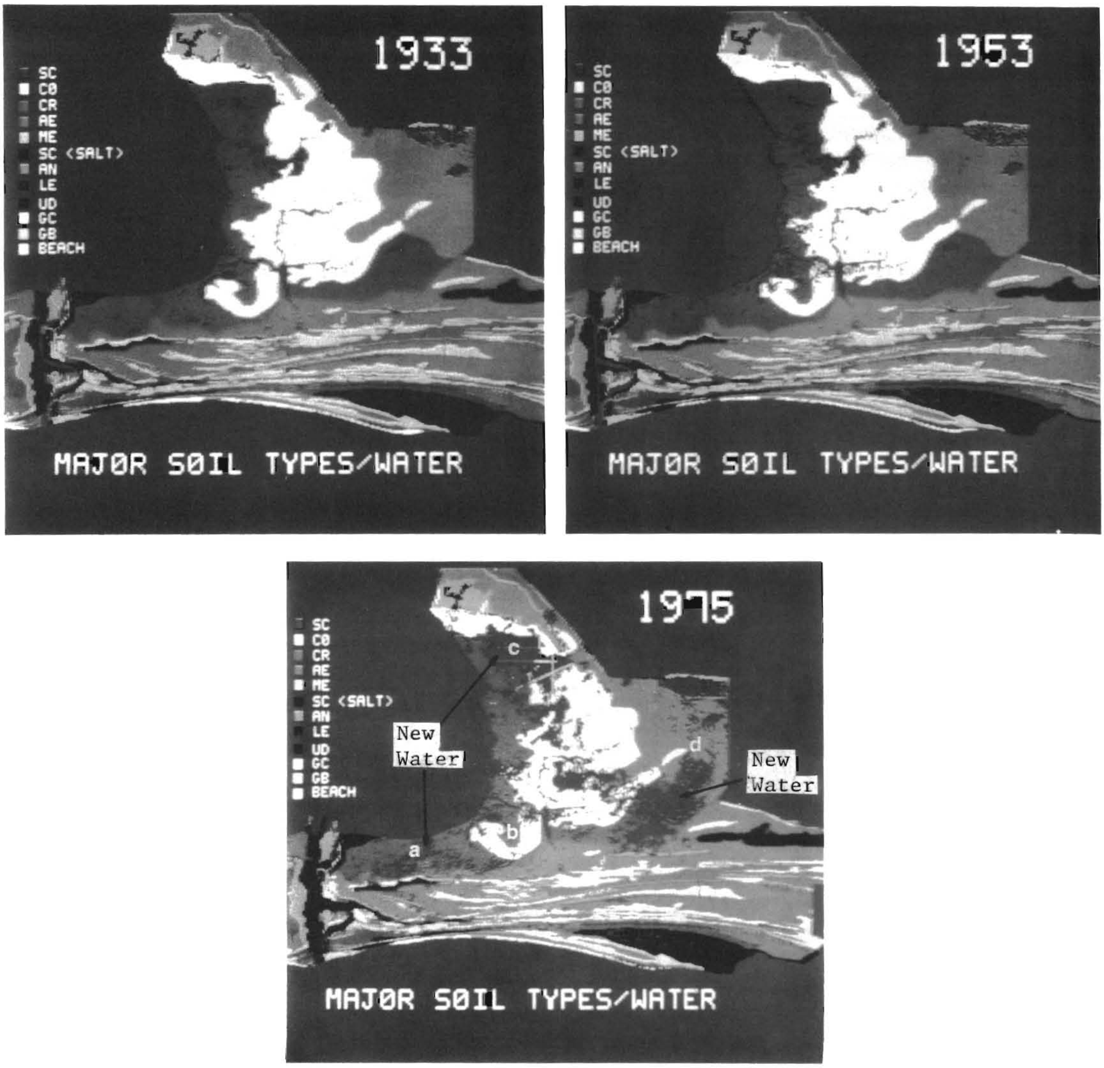

Figure 2. Soil types with 1933, 1953, and 1975 water in the Cameron-Creole Watershed Management Area, Louisiana.

study area, designated A, B, C and D in Figure 2 (1975).

Scatlake (SC) and Creole (CR) clays are the predominant soil types lost to open water in Area A. DELAUNE, *et al.* (1983) estimated coastal submergence in the area to be 1.2 cm/yr, and the rate of accretion to be 0.8 cm/yr, which results in a 0.4 cm/yr deficit since 1954. This seems to indicate that subsidence is the dominant causal mechanism of marsh loss in this portion of the watershed.

Scatlake clay (SC) and Clovelly muck (CO) are the soil types in Area B. The Clovelly muck deteriorated over the 42 year period, while the Scatlake clay remained relatively stable. This loss could be explained by a faster subsidence rate of the muck versus the clay, or possibly rapid oxidation of the highly organic muck. Also, the physical and chemical properties of clay may make it more resistant to erosion by wave action. Furthermore, the clay may protect roots from saltwater more effectively than the muck.

A closeup view of Area B (Figure 3) shows a

Table 4. *Change (△) in water and soil type areas between 1933 and 1975 in the Cameron-Creole Watershed Management Area, Cameron Parish, Louisiana.*

Symbol	Δ 1933–53		Δ 1953–75		Δ 1933–75	
	ha	% of Total	ha	% of Total	ha	% of Total
Water	407.06	0.82	5,938.92	11.92	6,345.98	12.74
BEACH	− 37.36	− 0.08	− 51.22	− 0.10	− 88.58	− 0.18
AE	32.24	0.06	− 1,069.25	− 2.15	− 1,037.01	− 2.08
AN	− 1.90	0.00	3.53	0.01	1.63	0.00
AR	neg.	neg.	neg.	neg.	neg.	neg.
CO	− 218.07	− 0.44	− 1,886.95	− 3.79	− 2,105.02	− 4.23
CR	− 54.89	− 0.11	− 492.73	− 0.99	− 547.62	− 1.10
CR (SALT)	12.24	0.02	− 25.92	− 0.05	− 13.68	− 0.03
GB	32.69	0.07	− 76.47	− 0.15	− 43.78	− 0.09
GC	15.82	0.03	− 125.94	− 0.25	− 110.12	− 0.22
Hb	− 3.08	− 0.01	1.14	0.00	− 1.94	0.00
Hm	− 24.41	− 0.05	4.36	0.01	− 20.05	− 0.04
LE	− 1.54	0.00	− 19.78	− 0.04	− 21.32	− 0.04
Lt	0.00	0.00	0.00	0.00	0.00	0.00
ME	− 15.98	− 0.03	− 5.73	− 0.01	− 21.71	− 0.04
Mn	neg.	neg.	neg.	neg.	neg.	neg.
Mr	6.51	0.01	− 17.20	− 0.03	− 10.69	− 0.02
Mt	1.56	0.00	− 5.28	− 0.01	− 3.72	− 0.01
Pe	0.07	0.00	0.02	0.00	0.09	0.02
SC	− 23.15	− 0.05	− 2,252.68	− 4.52	− 2,275.83	− 4.58
SC (SALT)	− 78.38	− 0.16	− 3.58	− 0.01	− 81.96	− 0.16
UD	− 78.06	− 0.16	− 13.04	− 0.03	− 91.10	− 0.18

pattern of marsh degradation within the bounds of the Clovelly muck. Deterioration starts at the upper ends of the bow shaped formation nearest sources of intruding saltwater. In succeeding years, the deterioration progresses to the center area farthest from sources of saltwater.

Area C is also predominantly Scatlake clay (SC) with a small portion of Clovelly muck (CO). In the early 1930's, agricultural development was initiated. The area was leveed and drained for crop production and later reflooded. The oxidation and compaction of exposed organic material, because of this development, may explain the extensive loss seen here. It appears that when leveed and dried out, both Scatlake clay and Clovelly muck degrade at nearly the same rate.

The predominant soils in Area D are Allemands muck (AE), Scatlake clay (SC), and Creole clay (CR). All three soils exhibit extensive loss to open water. This area may be deteriorating because of subsidence, extraction of oil and gas, natural subsidence, and partial impoundment of the area by Louisiana State Highway 27, which altered the local hydrology.

Proximity Model Results

Proximity models were generated for 1933, 1953 and 1975. Through time, land loss near channels increased. This in itself is not conclusive evidence linking land loss to channel proximity and, therefore, saltwater intrusion, since the construction of new canals occurred throughout the study area for the time period studied. The results do indicate that much more marsh was exposed to the potential of saltwater intrusion as canal construction increased. In some instances, water bodies enlarged near channels that had been present the entire 42 years. In other instances, there appeared to be a degradation of solid marshes starting with the development of scattered small ponds which later coalesced into one large body.

CONCLUSIONS

A spatial computerized data base was constructed for discrimination of the location of patterns and rates of loss of land to open water for the Cameron-Creole Watershed Management Area, Louisiana. The maps created in this

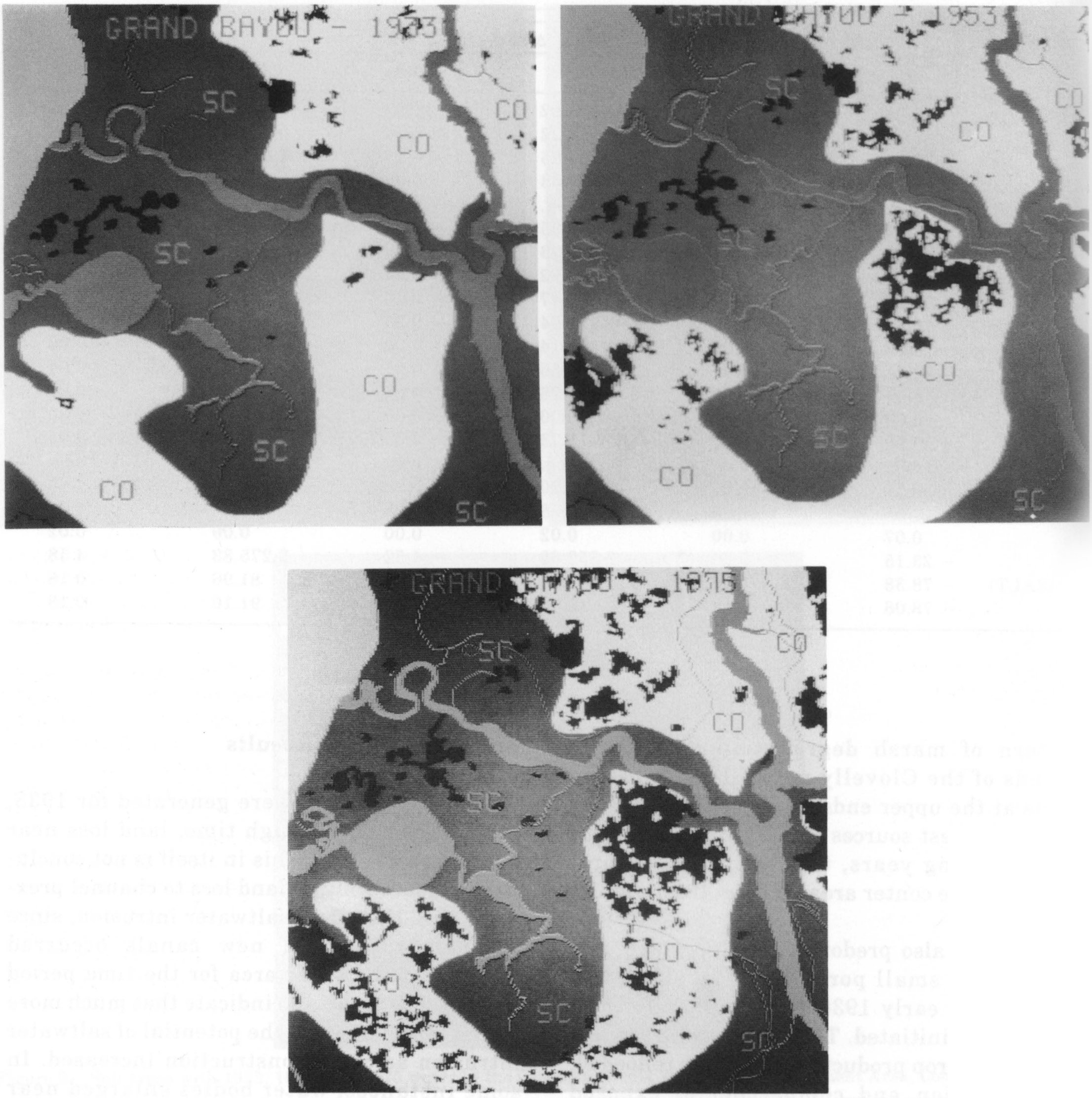

Figure 3. Land loss patterns by soil types with 1933, 1953, and 1975 water near Grand Bayou, Cameron-Creole Watershed Management Area.

research closely approximate the resolution and accuracy of USGS 1:24,000 quadrangle sheets. More than 75 km^2 of land loss was recorded as a result of this study. Fifteen percent of the wetland in the study area was converted to open water during the 42 year period.

Results of this study establish trends of land loss by soil type. No attempt was made to link salinity definitively to this land loss. Marsh on some soils has been lost at a much faster rate than on other soil types in the study area. Scatlake and Creole clays eroded more than other soil types in the watershed. High rates of land loss were also observed in impounded areas. A proximity analysis was used to spatially associate water channels and marsh deterioration. This analysis demonstrated that land loss increased near channels rather than away from channels, but increased channel construction during the 42 years greatly limits this conclusion. In conclusion, land loss in the Cameron-Creole Watershed was mapped over a 42 year period and found to be occurring at an accelerating rate. This land loss was tied to channel proximity, impoundment, and soil types.

The methodology of this study could be used to examine spatial relationships between land loss and levees and impoundments. A logical extension of this research is the development of predictive models of land loss under various proposed management schemes. Both overall schemes, such as the salt-water intrusion control levee under construction, and site specific development proposals, such as pipeline routes, could be modeled. Such models could be invaluable aids for determining best management practices (BMP) for coastal wetlands.

ACKNOWLEDGEMENTS

Funding for this project was provided by the Soil Conservation Service, U.S. Department of Agriculture. Technical editing by M.A. Fincher is appreciated.

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