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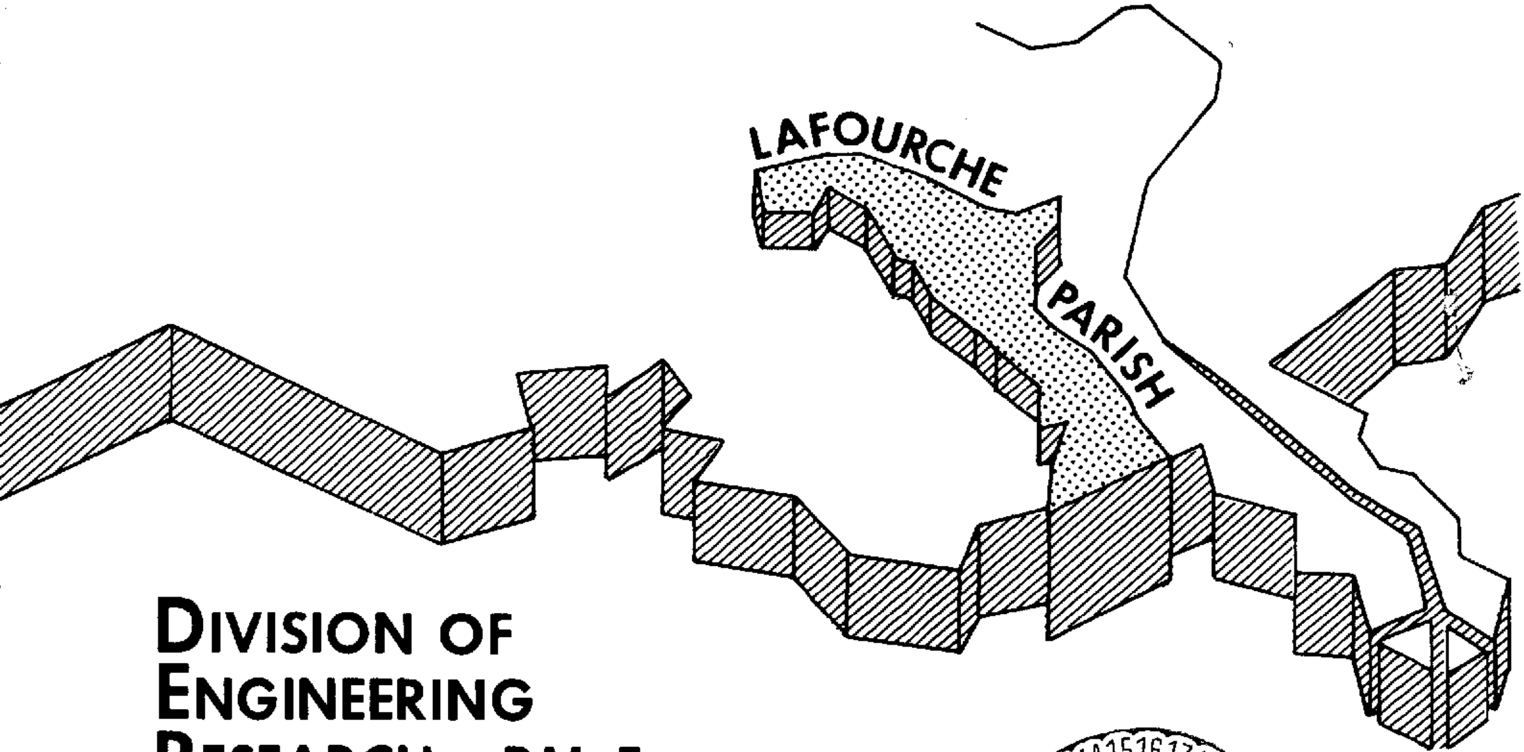

DIVISION OF ENGINEERING RESEARCH - RM 5

GEOMORPHIC PROCESSES ACTIVE IN THE SOUTHWESTERN LOUISIANA CANAL

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GEOMORPHIC PROCESSES ACTIVE
IN THE
SOUTHWESTERN LOUISIANA CANAL
LAFOURCHE PARISH, LOUISIANA

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I. INTRODUCTION

The canals in the Louisiana coastal marshes were dredged through soft muck that is highly susceptible to erosion. Although they were initially man-made features, the canals are undergoing constant changes, as would any natural morphological form in a dynamic environment. Erosive agents such as boat wakes, tidal currents, wind waves, and wildlife activity have resulted in significant widening and deepening.

The morphological changes that presently are occurring in the coastal canals can be deduced from historic records, in which examples are given of <u>trainasses</u> (trapper canals), originally dug three to four feet wide that have become enlarged through use to accomodate oil exploration support vessels (Davis, 1973). Robinson's Canal on Bayou Petit Calliou was a <u>trainasse</u> cut in about 1859; it now averages 150 feet in width (USGS Quadrangle, Lake Quitman, 1964). The widening was due primarily to boat traffic (Davis, 1973). Van Lopik (1955) noted that on the 1921 Coast and Geodetic Survey chart #1277 a narrow cut, or pirogue trail, joined two lakes (now Fearman's Lake). By 1955, this trail had enlarged "naturally" to a width of 1600 feet and a depth of 3.5 feet.

Undercutting and consequent slumping of spoil banks and the gradual erosion of natural banks introduces into the canal a large volume of sediment that is either transported by the water or deposited along the bottom -- depending on the flow regime, tide, and wind.

Many canals adjacent to the coast experience bidirectional tidal currents. The flow can be further disrupted at intersections with other canals, bayous, or lakes. Deposition may often occur at these junctions with resulting shoals and other obstructions.

This junction problem is serious for larger waterways. In the Intracoastal Canal, severe shoaling occurs in seven to ten locations annually along the 300-mile waterway in Louisiana (Bordelon, 1973). The shoaling is more frequent in canals that have no tidal influx; many inland canals silt up completely. By contrast, immediately adjacent to the coast, channels with large tidal prisms and strong tidal currents are flushed of sediment.

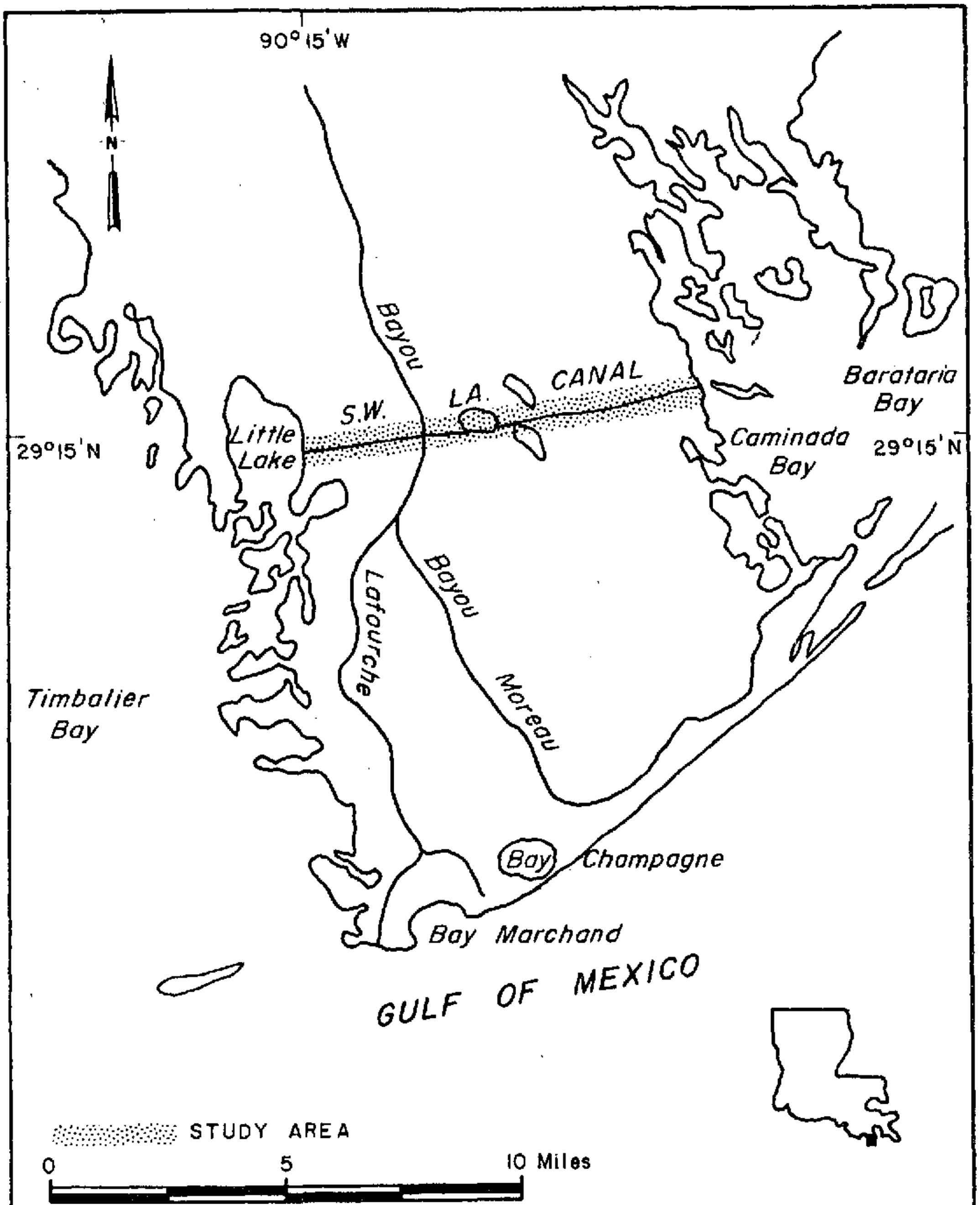
II. STUDY AREA

The Southwestern Louisiana Canal (East-West Canal), chosen as the study area, was originally cut by the South Louisiana Canal and Navigation Company as part of a proposed major east-west waterway across the Lafourche delta (Figure 1). Construction was begun in 1879 and completed before 1888. An investigation during the planning of the project indicated that a small trainasse, 3 to 4 feet wide, already existed between Bayou Lafourche and Bayou Manuel. The new canal was cut 30 feet wide and was not less than four feet deep at mean tide. Little maintenance was required to keep it open, although silting became a problem at Lake Jesse. In August 1881, a 20-foot wide channel had to be cut through a 985-feet long bar at this point.

In 1951, the State of Louisiana acquired ownership of the canal and through the State Department of Public Works, conducted a detailed survey. Cross-sections were surveyed at 500-foot intervals along its entire length. The eastern section from Bayou Lafourche to Caminada Bay was dredged to give a depth of 9.5 feet below sea level and a bottom width of 90 feet. The spoil was placed 30 to 50 feet back from the water line. The western section, from Bayou Lafourche to Little Lake, was left in the original state and, to date, has not been dredged except at pipeline crossings. Spoil along this section, the result of dredging from intersecting canals, is deposited only at the junction corners.

In only one location have the banks been reinforced by the Department of Public Works. Riprap was placed on the Northeast corner of the Bayou Lafourche - Southwest Canal intersection to protect the Le Fort cemetery at Leeville. Even so, much of the cemetery has been destroyed as the banks continue to be eroded.

In 1967, the Department of Highways replaced a drawbridge on Route 1 that crossed the canal and Bayou Lafourche just southwest of the intersection. The new bridge is parallel to and south of the old bridge (since removed). During construction



LOCATION MAP

SOUTHWESTERN LOUISIANA CANAL

90° 15' W

FIGURE 1

the western section of the canal was dammed off by highway embankment fill so that water no longer flows directly through the old intersection. Instead, a new access channel was cut, trending southeast, to join Bayou Lafourche south of the new bridge.

At present, the canal is 9 1/2 miles long and has an average width of 250 feet. Just west of Bayou Lafourche, it runs through the Texaco oil field. The banks are riddled with numerous smaller access canals cut perpendicular to it. The high traffic on both sections of the waterway consists of barge tows, crew boats, shrimp and oyster boats, and pleasure craft.

III. STUDY TECHNIQUES

Field work, laboratory analyses, and interpretation of infrared color imagery were used to provide data for study. The field work was conducted from May to October of 1973 to quantify the rates of erosion and locate areas of deposition. Samples of bank material were analysed in the laboratory to determine the differences in physical characteristics of three bank types -- natural, shell, and spoil and to relate these differences to the erosion rates.

The erosion rates were determined along the canal for a period of four months at 25 sites representing the three bank types and a variety of environmental conditions (Figure 2). Two plexiglass rods, each 60.0 cm long and 0.93 cm in diameter, were driven horizontally into the bank at each site. As the bank retreated, the exposed lengths of the rods were measured.

The erosion rates were determined from comparisons of these measurements, data from a 1954 survey by the Louisiana Department of Public Works, air photos taken in 1953 and 1969, and field measurements made in 1973.

Flow analyses were based on field observations and interpretations of infrared color photographs. The National Aeronautics and Space Administration provided two rolls of infrared color (contact duplicates) made from imagery taken on May 14 and October 25, 1973.

The May imagery (recorded with a Wild RC-8 camera that produced 9" by 9" transparencies at a scale of 1:6000) had sharp detail which was excellent for interpreting the turbidity patterns and bank types.

The October infrared color imagery (also contact duplicates) had a square format (2 1/4" by 2 1/4") and a scale of 1:11500. The smaller scale (70 mm film in a Hasselblad) was adequate for the study. An I^2S camera also recorded black and white multiband imagery (scale, 1:4600) in four spectral ranges: 1) 400-470 nm; 2) 470-580 nm; 3) 580-700 nm; and 4) 720-900nm.

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These remote sensing techniques provided an overall view of distribution patterns that may not be evident at ground level. Infrared color accentuated turbidity patterns and allowed good analyses of the interchange of water between intersecting channels and flow patterns where two water masses meet.

Water samples for determining suspended sediment concentration were collected at six sites (Figure 2) during the tropic and equatorial tides for a period of ten weeks. One-half liter samplers were suspended in the water at 0.2 and 0.8 water depth. In the laboratory, each sample was filtered through Millipore filter paper (.47μ pores) to determine the weight of sediment.

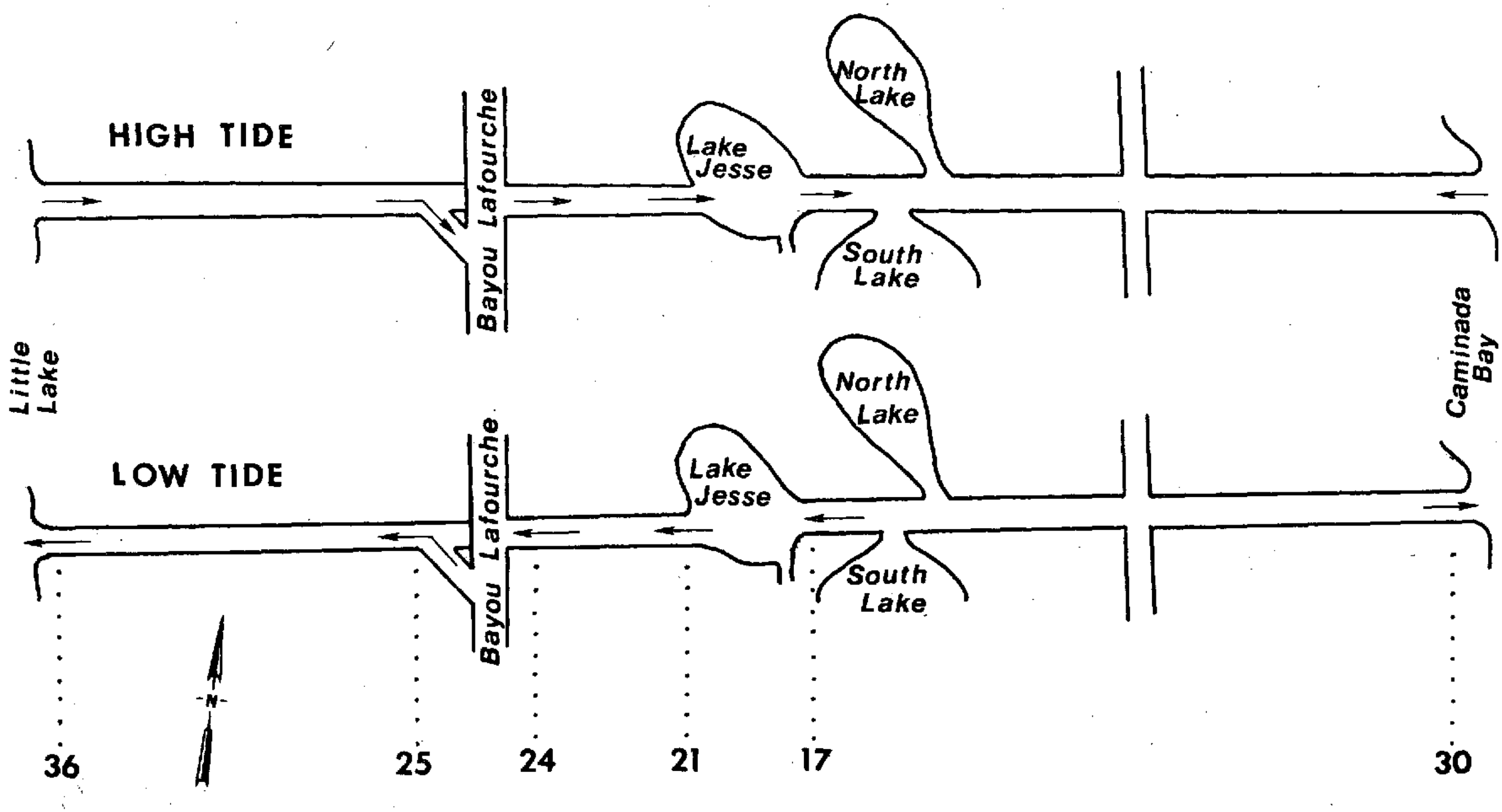
IV. PHYSICAL PROCESSES

Erosion and deposition in the canal depend on the active physical processes and the composition of the soils through which the canal is cut. In navigation canals, wake waves and currents are the two major erosion agents. Wave attack is evident wherever traffic is heavy, but erosion and sediment transport occur only where the current velocity is fast enough and persistent. Where currents are disrupted at the intersection with a smaller canal or by rough, winding channels, deposition will occur. Therefore, the characteristic flows in a canal and the effects of tides, winds, and intersecting water bodies on that flow must be analyzed to provide an understanding of the overall changes resulting from erosion and deposition.

Characteristic Flows

The complexity of the Southwestern Louisiana Canal is due to both the large number of intersecting smaller canals and waterbodies and two sets of tidal currents originating at opposite ends of the canal -- in Little Lake and Caminada Bay. The eastern section of the canal, between Caminada Bay and the east side of Lake Jesse, is about five miles long (Figure 3). The tide range at the Caminada Bay entrance averages 30 cm; on the east side of Lake Jesse, it averages 17 cm. The range at the bay entrance is directly controlled by the tides of the bay itself. The water flows westerly into the canal at high tide and easterly, out of the canal, at low tide.

Near the eastern side of Lake Jesse, however, the flow is more complex. The hydraulic gradient from Caminada Bay to Lake Jesse at high tide is small because of the five-mile distance. At the entrance to Lake Jesse, the flow is generally eastward (opposite to that at Caminada Bay) because the water level in Lake Jesse depends the flow conditions in Bayou Lafourche, which is about a mile west. Only during strong northeast or east winds is westward flow maintained from Caminada Bay all the way to Lake Jesse.



Flow Direction

Tidal Range in cm. 30

FLOW DIRECTIONS AT HIGH AND LOW TIDE
AND
AVERAGE TIDAL RANGES
SOUTHWESTERN LOUISIANA CANAL
(NOT TO SCALE)

FIGURE 3

High tide occurs in Bayou Lafourche (24 cm average tidal range) several hours after high tide at Caminada Bay (30 cm average range). Tidal currents from the Bayc flow east toward Lake Jesse which is about a mile away. At low tide in Bayou Lafourche, the water flows from Lake Jesse toward the Bayou. On the west side of Lake Jesse, the tide range is 21 cm.

The western section of the canal, between Bayou Lafourche and Little Lake, is unusual in that Bayou Lafourche and Little Lake experience high and low tides almost simultaneously. Because the tidal range at Little Lake averages 36 cm, the high tides there are consistently above those in the bayou. Therefore, although both may experience high tide, the higher level at Little Lake causes the water to flow toward the bayou. At low tides, the opposite situation occurs; the water flows westward from the bayou, which has the higher water surface.

Winds may either reinforce or restrict the tidal currents. Strong easterly or westerly winds can accentuate or inhibit the weak currents to the extent that all flow is in the same direction through one tidal cycle.

At ground level, turbulence and flow patterns could not be differentiated. The direction of flow was difficult to determine other than at sample spots. However, remotely-sensed imagery provided an overall view of the flow. Two sets of infrared color aerial photographs and one set of multi-band imagery had been provided by NASA. Although they had not been taken precisely at times of high or low tide, the photographs illustrated flow directions and turbidity patterns for specific wind and tide conditions (Figures 4 and 5).

The May imagery (Figure 4) was taken two to four hours after high tide (depending on location in the canal), with northerly winds at twelve knots. Due to the dominance of these winds the flow was to the west throughout the entire canal; it was not in accordance with the predicted normal flow. On the eastern end of the canal, water was blown northwest into the channel from the marsh through cuts in the spoil bank; canal water was blown out through them: for example, as at North Lake.

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In May, the most prevalent features on the eastern reach of the canal were small gyres of turbidity along the irregular banks (Figure 4, Location A). These gyres were not noticable from ground level. Dye had to be used to determine their exact configuration. Water adjacent to the banks flowed opposite to the major flow in the center of the channel. As the bank-edge flow encountered a protruding portion of the bank, it separated and entered the main flow. With a change in tide and direction of dominant flow, the gyres subsided and all water flowed in the same direction. Along less irregular banks, the gyres were forced out in the direction of dominant flow (straight arrows in Figures 4 and 5).

When the canal water from the east section enters Bayou Lafourche, no mixing is evident. A sharp boundary between the two water masses remains (Figure 4, Intersection B) because the southward-flowing bayou carries a higher concentration of sediment and has less salinity. The fresher water from the bayou flows over brackish water entering from the canal.

In the reach west of Bayou Lafourche, fewer gyres or noticeable circulation patterns developed. Water from Bayou Lafourche enters the canal and flows eastward. No distinct difference in turbidity was noticeable at junctions with smaller canals.

The October imagery (Figure 5) was taken one to three hours after low tide, with a north wind of four knots. In the eastern section of the canal, the reversal of the current had not yet occurred, and the water was still flowing as in a low-tide condition.

East of North Lake, the water was turbulent. The flow direction between South and North Lake was difficult to ascertain (Figure 5, Location A), while west of South Lake, the flow was reversed and the water was moving west. The distance between Caminada Bay and Lake Jesse decreases the effect of the water-surface gradient, and the area is controlled by the water levels in Lake Jesse.

Near North Lake, water flows through the cuts into the canal. A sharp delineation occurs between the water flowing from the cuts and that in the canal (Figure 5, Location B). In the small dammed canal (Location A, Junction A), particulate matter has settled out of the stagnant water. However, a break in the spoil dam allows interchange of water between the two canals.

From Lake Jesse, the water flows westward to Bayou Lafourche and thence southward as a distinct water mass that is separate from that in the bayou (Figure 5 Location C, Junction C). West of Bayou Lafourche, the water flows toward Little Lake. The water masses entering from the canals intersecting the north bank have a distinctly different color. At the western end (Intersection D), a large plume indicates the entry of canal water into Little Lake.

Bank Erosion

The erosion rates along the Southwestern Louisiana Canal vary with the physical characteristics and location of three types of banks: spoil, shell and natural -- each differing in constituent material, configuration, height, vegetational cover, and response to active processes.

The spoil banks range in height from 30 to 90 cm and display a steep unvegetated face on the canal side. The remaining bank surfaces are vegetated by Iva frutecens, Batis sp., elderberry, and the toothache tree. Because of the bank heights, the plant roots do not penetrate to the water level. Consequently, the vegetation does not prevent erosion in this maximum zone of attack.

Morphological changes are more rapid on the spoil banks. Wakes and currents erode the base, remove material, and undercut the bank. The undercut condition may persist for several days before a portion of the bank sloughs off, particularly where root systems bind and strenghten the upper bank surface. The loss of material is most prevalent after the decline of high water levels, when the saturated material with the added weight of water and the seepage forces decrease the bank stability and increase the slumping rate.

Fiddler crabs also commonly burrow into the spoil banks. This natural process also contributes to bank destruction through a breakdown of the internal soil structure and reworking of the sediments. However, the importance of this effect, in comparison to other physical agents, cannot be determined.

The shell banks have an average height of 60 cm. They are rounded in cross section except where large portions have been eroded away. The sparse vegetation (dwarf

Iva), and the root structure does little to prevent erosion. Recession is less apparent than on banks without shell. It occurs gradually as the result of winnowing of the finer materials rather than by slumping.

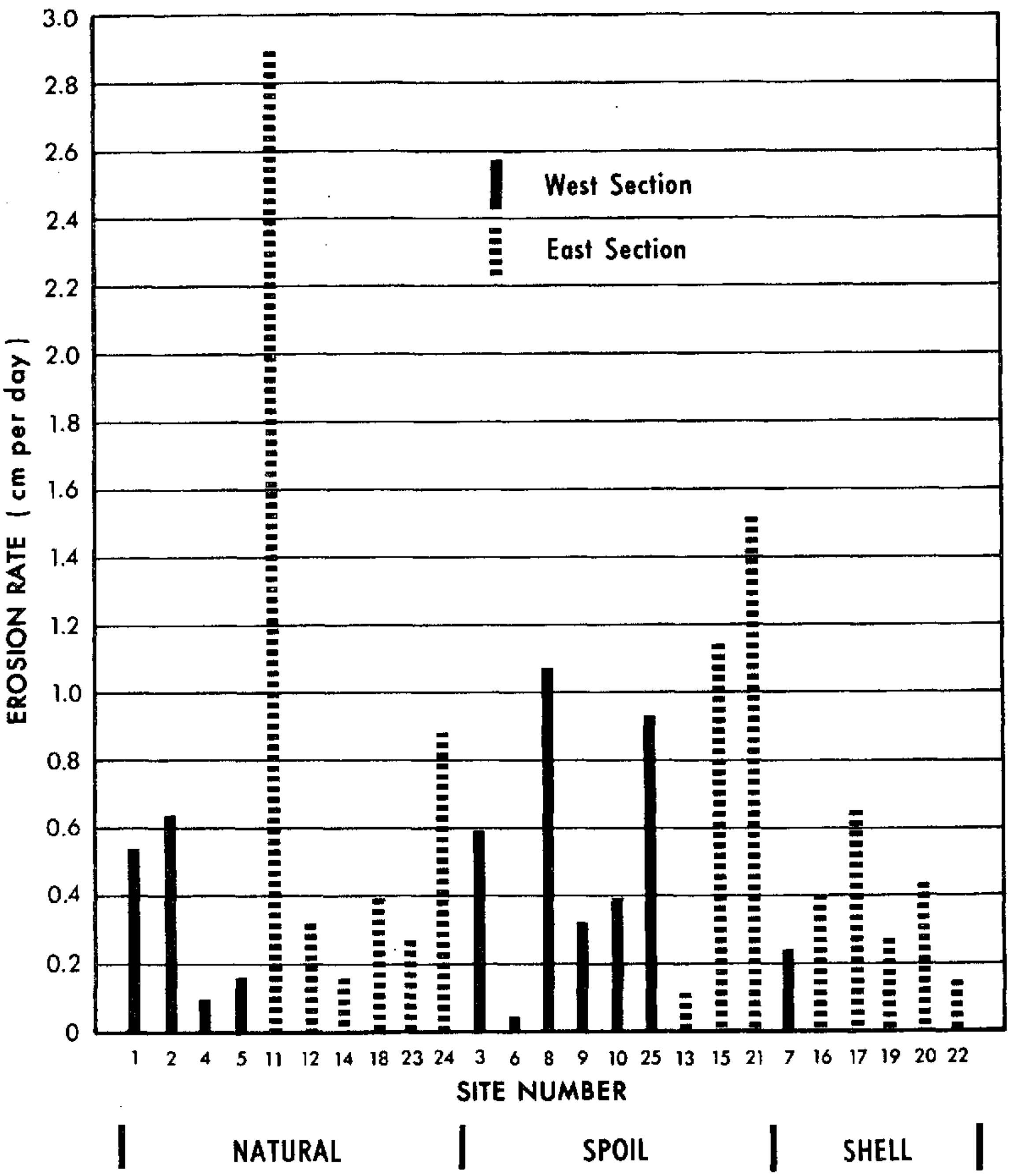
The natural banks, because of seasonal climatic conditions, remain inundated during the summer months and are exposed during the winter months. The banks are covered by salt-tolerant plants such as *Spartina alterniflora*, *Spartina patens*, and *Salicornia* sp. that have dense root structures capable of retaining and binding the material to help resistance to erosion. Thus the recession of natural banks is gradual. Soil material is first removed just below the *Spartina* root mass; eventually the overhanging plants are torn loose and carried away.

Erosion rates measured at 25 sites along the Southwest Louisiana Canal differed according to bank type and location (Figure 6; see also Table 2). The spoil banks exhibited the highest average daily rate, 0.36 cm per day. The mean erosion rate for natural banks was distorted by one extreme anomaly, 2.9 cm, observed for a particular site at the junction of the Southwest Canal and another heavily-traveled canal. The corners of canal junctions are particularly susceptible to erosion by waves, which are refracted as they approach a corner or any irregular protrusion in the bank with the wave energy being concentrated at that point. High erosion rates at spoil sites 8, 15, and 21 also resulted because of similar conditions (Figure 6; see also Table 2).

Variations in the erosion rate of one bank type occurred because of the differences in location. It has already been pointed out that banks at junctions have higher erosion rates. However, there may be broader differences between sections of the canal if traffic volumes or current velocities vary. A comparison of the two sections east and west of Bayou Lafourche indicate that the highest rates were on the east section (Figure 6), which had an average of 0.735 cm; the west section, only 0.455 cm.

Three explanations for the differences are possible:

1. Differences in the distribution of bank types among those sampled: Of 6 shell banks, 5 were on the east reach; 3 of the 9 spoil banks were on the



DAILY EROSION RATES

TWENTY-FIVE SITES

SOUTHWESTERN LOUISIANA CANAL

FIGURE 6

east reach; and 6 of the 10 natural banks were also on the east reach. Despite this uneven distribution of sites, a comparison of the erosion rates for each bank type indicates that the east reach is eroded as fast or faster than the west section. This fact suggests that factors other than the uneven distribution of bank types are responsible for the differences in erosion rates.

2. Differences in types and frequency of traffic: No quantitative data is available on the type and frequency of traffic. However, 6 months of observations indicate little difference between the east and west in this respect. Both accomodate barges, tugs, commercial fishing boats, crew boats, and pleasure craft.

3. Differences in tidal current velocities: Marmer (1959) stated that currents in the east section are stronger with a maximum velocity of 1.6 knots (2.7 ft./sec.) and a minimum velocity of 0.7 knots (1.2 ft./sec.). The west section has a maximum velocity of 1.0 knots (1.7 ft./sec.) and a minimum velocity of 0.4 knots (0.7 ft./sec.). The higher velocities in the east section seem to contribute to the higher erosion rates.

Scouring, Deposition, and Dredging

During the last 10 years, the Southwest Louisiana Canal has become wider at a faster rate than it had in the past (Table 1). The progressively increased annual rates of widening are the result of two factors: the development of faster boats and powerful motors with a consequent increase in bank and bottom erosion; and the subsequently larger tidal prism. With widening and deepening, a larger volume of water can flow through the canal with increased tractive force and thus a greater erosive ability. Presently the canal is widening at an average annual rate of 16.3 feet. It should be noted that the erosion rate has been significantly reduced at station 15000 (Figure 2 and Table 1), on the northeast corner of the intersection with Bayou Lafourche. This site has the lowest erosion rate because it was reinforced with several layers of riprap by the Louisiana Department of Public Works in 1953 and 1962 to protect the Le Fort Cemetery.

Deepening of the canal, as well as widening, is evident from comparing of cross sections surveyed in 1880, 1953, and 1973 (Figure 7). In 1954, the east section

TABLE 1

CHANNEL WIDTHS AND ANNUAL EROSION RATES
SOUTHWESTERN LOUISIANA CANAL
1880-1973

	WIDTH (Feet)				EROSION (Feet/Year)			
Station	1880	1953	1969	1973	1880-1953	1953-1969	1969-1973	Station
0	30	130	200	240	1.4	4.4	10.0	0
3000	30	120	185	240	1.2	4.1	13.6	3000
6000	30	130	200	240	1.4	4.3	10.0	6000
9000	30	130	270	320	1.4	2.4	12.5	9000
12000	30	130	300	350	1.4	4.3	12.5	12000
13100	30	110	200	280	1.1	4.7	20.0	13100
15000	30	140	155	190	1.5	0.9	8.8	15000
18000	30	145	220	320	1.6	4.6	25.0	18000
21000	30	120	150	200	1.2	1.8	10.0	21000
24000	30	140	240	310	1.5	6.2	18.5	24000
27000	30	120	210	270	1.2	5.6	15.0	27000
30000	30	110	215	300	1.1	6.5	21.2	30000
33000	30	120	250	320	1.2	8.1	18.5	33000
36000	30	130	250	330	1.4	7.5	20.0	36000
39000	30	125	230	320	1.3	6.5	22.5	39000
42000	30	140	250	300	1.5	6.8	12.5	42000
45000	30	150	270	360	1.6	7.1	20.0	45000
47500	30	150	270	360	1.6	7.5	22.5	47500
					1.4	5.6	16.3	Average

Note: See Figure 2 for Station Locations and Figure 7 for Cross Sections

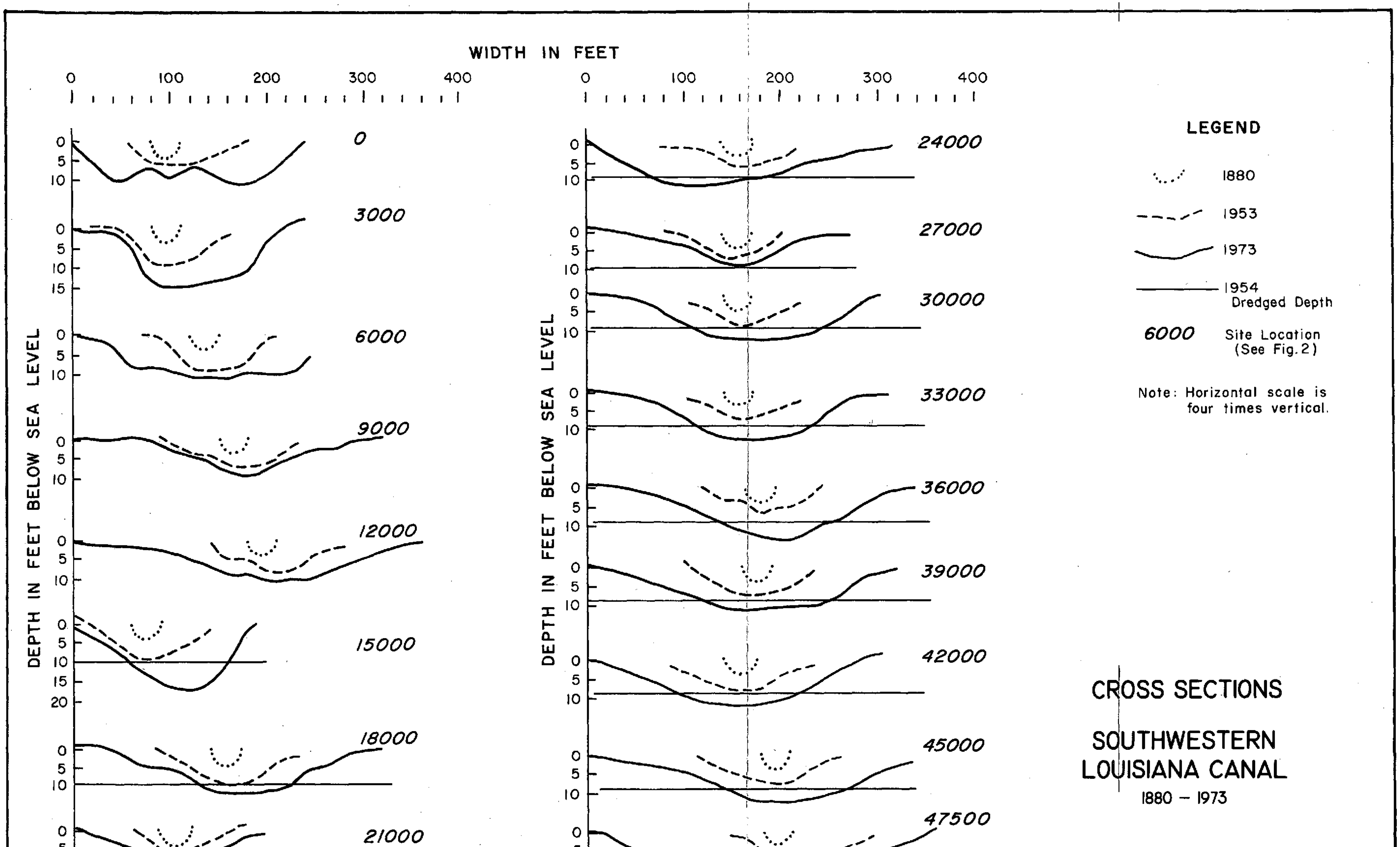


FIGURE 7

FOLDOUT FRAME

FOLDOUT FRAME

was dredged between Stations 15000 and 47500 to a depth of 9.5 feet below sea level. The increase in cross-sectional area between 1880 and 1953 and the differences between the dredged depth and the 1973 cross sections are the result of scouring and flushing of sediment by tidal currents.

Two portions of this section have not deepened naturally. At Station 21000, where the canal is routed through Lake Jesse, the flow no longer remains channelized. The reduced velocity allows suspended sediment to settle out. This sedimentation has persisted since 1880 (Minute Books, South Louisiana Canal and Navigation Company). Similar current disruption and sediment deposition occurs to the east of Lake Jesse at South Lake and North Lake where the flow often stagnates, and suspended material settles out.

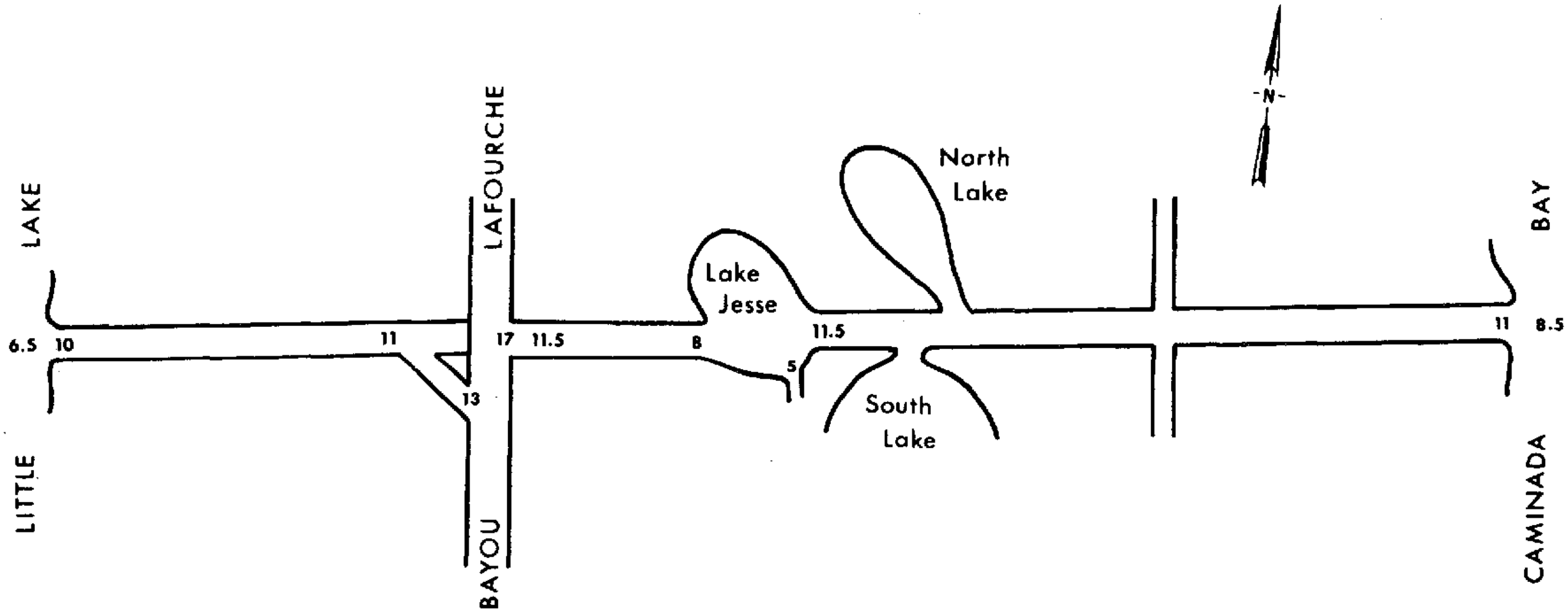
Variations in the bottom configuration indicate other areas of deposition and scouring. Large shoals occur at the east and west ends of the canal. The depth on the east end is 11 feet, but shoals to 8.5 feet beyond the entrance to Caminada Bay (Figure 8). At Little Lake, the west end, the depth of the bottom decreases from 10 feet to 6.5 feet. These shoals result from the decreased velocity as the sediment-laden canal water enters the bays.

Where the canal enters Bayou Lafourche, the bottom drops off sharply due to the scouring action of the bayou (Figure 8).

The eroded material from the banks and channel bottom is carried away as suspended and bed load or is deposited in the channel and adjacent water bodies. Deposition and transportation are seasonal phenomena that depend on the flow regime and weather conditions.

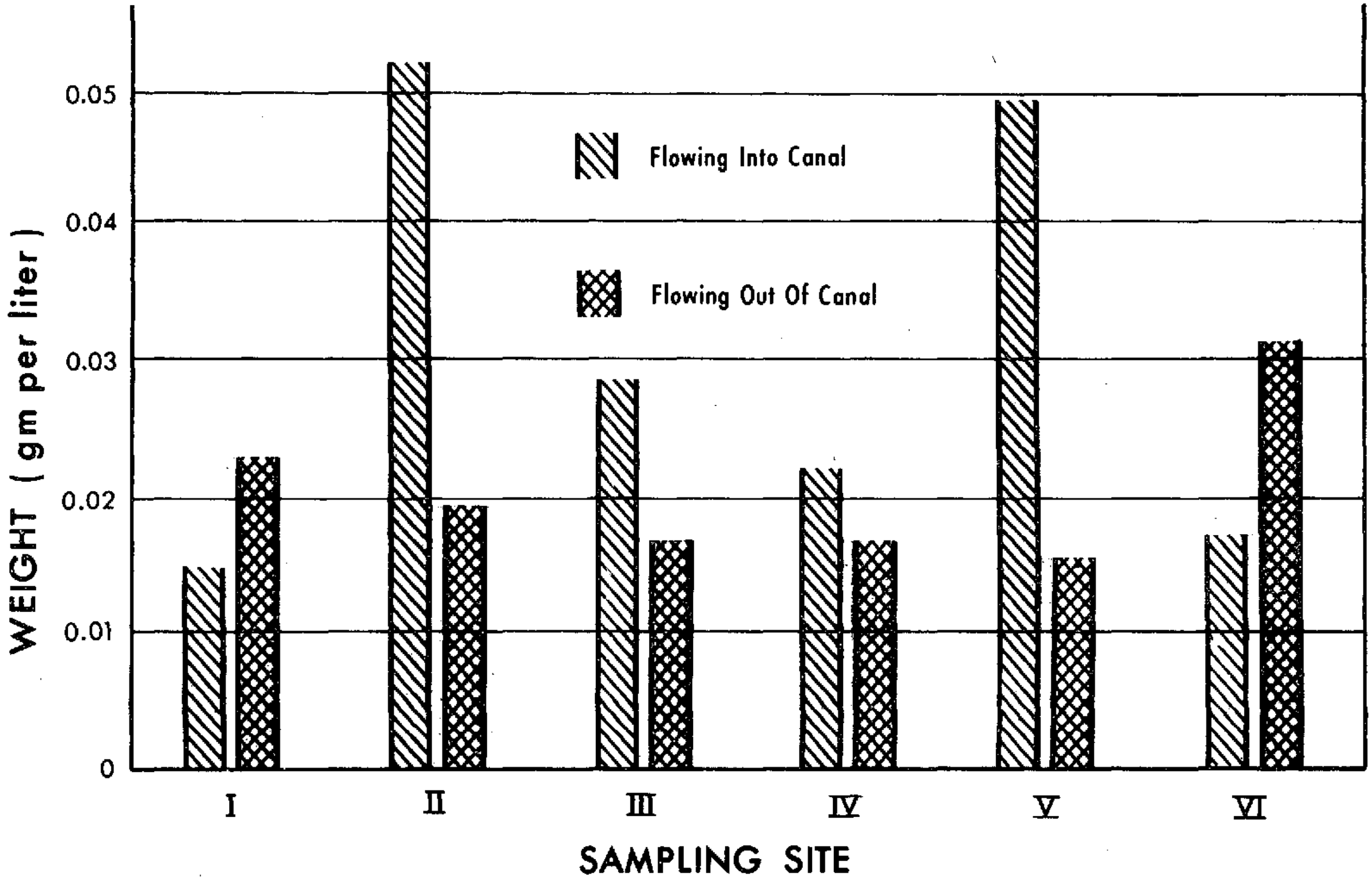
Six sites (Roman Numerals, Figure 2) along the canal illustrate the exchange of suspended sediment during the summer months. Samples were collected during the ingoing and outgoing tides once a week for eight weeks at each site. Average weights of sediment per liter of water were analysed and categorized according to sampling location and the direction of flow (Figure 9).

Suspended sediment is transported out of the canal at Caminada Bay and Little Lake (Figure 9). However, the quantity brought during the summer months into the



DEPTH IN FEET BELOW SEA LEVEL
AT SELECTED SITES
SOUTHWESTERN LOUISIANA CANAL
(NOT TO SCALE)

FIGURE 8



Note: See Figure 2
for site locations

AVERAGE WEIGHT OF SUSPENDED SEDIMENT
SOUTHWESTERN LOUISIANA CANAL

FIGURE 9

main channel from tributary water bodies (Lake Jesse and Bayou Lafourche), by exceeding the amount removed, results in a temporary accumulation of sediment in the canal. This condition is not necessarily maintained throughout the year. In the previous discussion of the cross sections, it was indicated, however, that there is a net annual loss of material due to scouring, with relatively little permanent accumulation of sediment within the canal.

Meteorologic and tidal conditions account for the seasonal differences in sediment transport and deposition. Wave and wind intensities on the Louisiana coast are lowest during the summer months. In the winter, they are two to three times greater (Stone, 1972). A slow alluviation of the bottom takes place during the summer, while large volumes of sediment are scoured and transported out of the canal during the winter. Much of the suspended material may be accumulating in the adjacent smaller canals and water bodies.

No bed load samples were collected. It is possible that much of the sediment removal occurs as bed load in the form of clay balls.

V. PHYSICAL PROPERTIES OF CANAL BANK MATERIALS

The soil materials in the three bank types (natural, shell, and spoil) vary in grain size, moisture content, organic content, and shear strength. These variations in physical characteristics result in different erosion rates. Bank samples from the 25 erosion sites (Figure 2) were analysed in the laboratory to determine the composition of each type. The data were then used in a regression analysis in an attempt to correlate physical properties with the erosion rate.

Grain Size Distribution

The variation of grain size among bank types is shown on a triangular classification chart (Figure 10). Because of extreme values, the median point rather than the mean was used as the basis for comparison among bank types. Spoil and shell banks are very similar in composition and have almost identical distributions. The median grain sizes for spoil banks are: 26% clay, 48% silt, and 22% sand. Shell banks have: 25% clay, 47% silt, and 25% sand. Natural banks show a different distribution: 13% clay, 53% silt, and 32% sand.

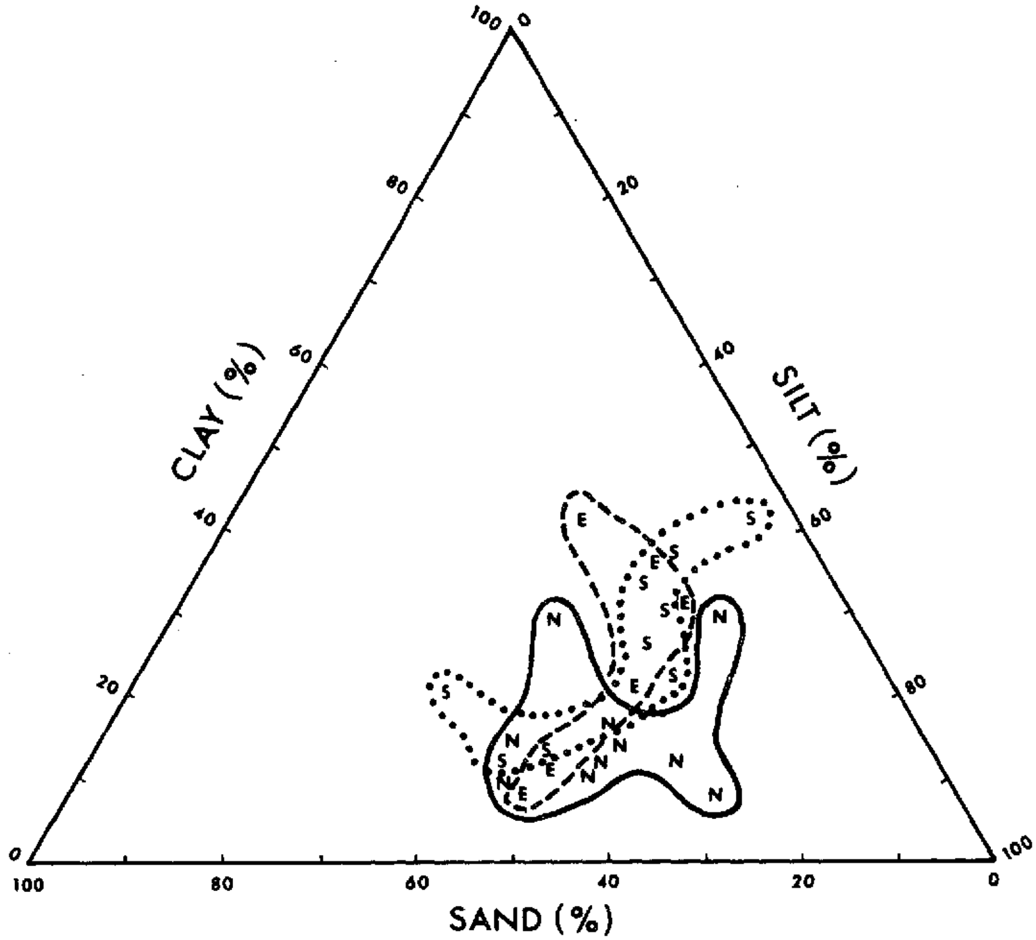
Moisture Content

Moisture content analyses showed considerable differences existing between natural banks and those consisting of spoil or shell (Table 2). The natural banks are low and are frequently inundated. Arman (1969) states that the fibers in organic soils as well as the pore spaces absorb water. Because of their higher relief, the spoil banks are not saturated like the natural banks.

Water in soils is a major factor influencing their response to erosion. The addition of water to the bank material reduces the angle of internal friction and consequently, its shear strength.

Organic Content

Tests for organic material content were conducted for only natural banks. The values ranged between 3.1 and 25.4 percent (Table 2).



TYPE OF BANK

Natural	N	——
Spoil	S	••••
Shell	E	- - -

GRAIN SIZE DISTRIBUTION
IN BANK MATERIALS
SOUTHWESTERN LOUISIANA CANAL

FIGURE 10

TABLE 2

PHYSICAL CHARACTERISTICS OF BANK MATERIALS
SOUTHWESTERN LOUISIANA CANAL

Bank Site	Erosion Rate (cm/day)	Clay Content %	Silt Content %	Sand Content %	Moisture Content %	Vane Shear Strength (lb/in^2)	Organic Content %
Natural							
1	0.542	8	67	25	68.5	-	11.9
2	0.632	12	53	35	57.2	-	8.9
4	0.094	12	61	27	79.2	-	22.7
5	0.156	10	53	37	80.2	-	26.4
11	2.868	29	40	31	43.7	-	3.1
12	0.321	16	52	32	64.0	-	15.0
14	0.155	14	43	43	71.6	-	22.5
18	0.396	29	57	14	42.6	-	18.0
23	0.268	10	45	45	61.2	-	16.0
24	0.880	14	54	32	71.8	-	16.5
Spoil							
3	0.584	22	56	22	32.1	10.01	-
6	0.048	37	48	15	30.8	14.38	-
8	1.070	33	47	20	36.3	9.45	-
9	0.318	30	51	19	38.3	8.37	-
10	0.393	41	54	5	36.0	11.00	-
13	0.114	26	51	23	35.2	11.16	-
15	1.140	20	33	47	36.6	11.16	-
21	1.515	12	43	45	44.3	8.77	-
25	0.929	13	47	40	27.6	11.39	-
Shell							
7	0.241	31	52	17	35.4	9.25	-
16	0.400	41	37	22	34.4	9.38	-
17	0.647	8	47	45	25.1	7.68	-
19	0.275	20	52	28	27.5	6.04	-
20	0.433	36	47	17	29.4	5.63	-
22	0.146	12	48	40	27.8	3.88	-

Note: See Figure 2 for Testing and Sampling Locations

Shear Strength

A field vane shear device was used to obtain the shear strengths of the bank materials. However, the instrument was used only on the spoil and shell banks because the saturated state of the natural banks made shear tests impossible.

Shear strength is a function of normal stress on the shearing surface, soil cohesion, and the internal angle of friction. In the tests, the normal stress was held constant. Therefore, the differences in shear strengths resulted only from differences in cohesion and the internal angle of friction.

A comparison of the values in Table 2 for spoil and shell banks shows that shell has, in general, lower shear strengths. Shell in the bank material reduces the angle of internal friction.

Shear strengths were not determined for the natural banks. However, Arman (1969) gives an excellent discussion on the strength of organic soils. Compression tests on cylindrical specimens of organic soils show that they do not experience a normal shearing surface failure, but rather yield or bulge. Organic soils have a very high strength due to the presence of organic fibers, which act like tension reinforcement. Microscopic examinations showed that there is an attraction between the clay and the organic fibers (Arman, 1969, p. 44):

> "The clay was able to develop additional strength by using the strength of the organic fibers. Also the presence of organic fibers "fixed" or absorbed some of the free moisture available to the clay minerals and this helped increase the strength of the total mixture."

Arman's tests indicated that there is a direct relation between strength and organic content.

Statistical Correlation of Physical Properties

Linear, multiple, and stepwise multiple regression analyses were used in an attempt to relate bank soil characteristics to erosion rates. Most of the results were inconclusive. For natural banks, a high correlation coefficient indicated that organic content increases the erosion resistance. For spoil and shell banks, low correlation coefficients and high significance values indicated that the relationships between variables (clay, silt, sand, and shear strength) could have occurred by chance. The shear strength of shell banks is not a good indicator of erosion resistance due to the armoring effect of the shells.

VI. CONCLUSIONS

Destruction of banks by boat wake waves, a major problem in navigation canals, becomes more important in canals subject to tidal influxes. Tidal currents flush sediment from the canal and scour the bottom and sides of the waterway. The cross-sectional area thus increases. An increase in the size of the canal results in a larger tractive force against the wetted perimeter of the channel. It also allows larger and faster vessels to frequent the waterway. As a result, the channel continues to widen and erosion rates increase.

Erosion is the major process occurring in the Southwest Louisiana Canal, with deposition being evident in only two locations. The erosion is self-perpetuating. The continuous decrease in the slope of the canal banks and the increase in the dispersion of energy is accompanied by an increase in the erosive energy as the tidal prisms increase in size. The ratio of the increase of energy dispersion to the increase of current energy is not known.

Erosion rates measured during this study ranged between .094 and 2.868 cm per day, but these rates also varied according to bank material and location. Such high rates are not unique to the Southwestern Louisiana Canal. Rates equally high or higher have been measured in other canals in the coastal marsh.

The problem of bank destruction in marshland navigation canals is serious but it defies an easy solution. Addition of shell to the banks slows the erosive processes, but does not alleviate the problem. Riprap along the Le Fort Cemetery significantly reduced the rate of widening yet even there widening continues. The effects of bulkheads at the corners of canal junctions were not considered in this study but such construction may be a possible erosion retardant at these locations.

Of the 4572 miles of dredged canals and channels south of the Intracoastal Waterway, about 1000 miles are navigable. Little concern is given to the processes active in these canals. However, widening results in destruction of valuable marshland and estuarine environments. Landowners with property adjacent to canals are constantly losing land. These losses have become a serious legal problem, particularly in large canals such as the Intracoastal Canal, where the right-of-way has already been exceeded.

The knowledge gained concerning the active physical processes in the Southwestern Louisiana Canal are applicable to other waterways in coastal marshes, although the processes which dominate may vary according to location and to the individual characteristics of the waterway. These processes must be understood along with other natural events because coastal marshes are valuable regions containing renewable resources, such as fish and wildlife, as well as mineral resources. Yet little consideration has been given to the existing problems of canal erosion or to the future prospect of loss of land area.

The study reported here has shown that channel erosion rates progressively increase, with no indications of stabilization. The canals continue to widen until they eventually merge with other waterways and cannot be distinguished from natural water bodies.

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