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MOBILE BAY TURBIDITY PLUME STUDY
April 1, 1975-March 31, 1976

Submitted: April 14, 1976

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MOBILE BAY TURBIDITY PLUME STUDY

PROBLEMS:

The instrument package has continued to be only marginally reliable and consequently it has been difficult to obtain a significant number of data points when weather, vessels, personnel, instrumentation and a satellite were all present and functioning up to specifications.

ACCOMPLISHMENTS:

Introduction: The effect of suspended particulate material upon the appearance of water is all too obvious, but those quantitative parameters contributing to the optical characteristics are neither easily measured, nor are they readily converted to a meaningful descriptor of the water's appearance. This subjective judgement as to the water's clarity is commonly referred to as "turbidity", a term now unpopular with the research community but adhered to dogmatically by the enforcement agencies.

The purpose of this study has been to seek quantitative correlations between remotely-sensed image density (Land-Sat A&B), optical sea-truth data and actual sediment load. It has been assumed that, if adequate calibrating factors could be established, a review of the existing Land-Sat (ERTS) imagery could be compared with the available information on the driving forces of the suspended load and from that a projection of annual input/output ratios seemed feasible within limits. This goal obviously required a semi-quantitative identification of those driving forces, as well as the calibration factors.

Approach: The study has been divided into two parts, laboratory and field exercises. There has been an attempt to cross-check procedures and results between the two phases. Specific subdivisions have also developed and being pursued concurrently.

LABORATORY STUDIES:

A statistically reliable correlation between suspended load (mg/l) determined gravimetrically and optical characteristics (%T) as transmissivity can be achieved. The substitution of "optical mg/l" for the actual suspended load is purely pragmatic. The time required and dubious accuracy of routine gravimetric determinations in salt water is unacceptable in a program which must achieve a reasonable data base for a large area, in this case over 500 mi^2. The towed field transmissometer seems to provide the speed and an acceptable accuracy, if not operational reliability.

Calibration of the unit was carried out by suspending preweighed quantities of kaolin (Fisher #75185) in a tank containing the transmissometer sensor in distilled water. Temperature and salinity effects on the unit were also tested during the calibration period (Appendix 1). The resulting kaolin-calibration curve is presented in Figure 1.

Attempts to get a satisfactory natural sediment load curve have been less than satisfactory. An artificial reduction of a heavy suspended load pumped into a large tank was attempted by dilution with fresh water. Unfortunately, the poor optical quality of Dauphin Island water would not allow the development of the lower half of the curve. An attempt on a smaller scale utilizing distilled water is planned.

Introduction of preweighed bottom sediment was unsatisfactory due to a large percentage of sand which would not normally be suspended in the water column. The use of random field data have usually yielded an unacceptable scatter of points (variability) and has been avoided to date.
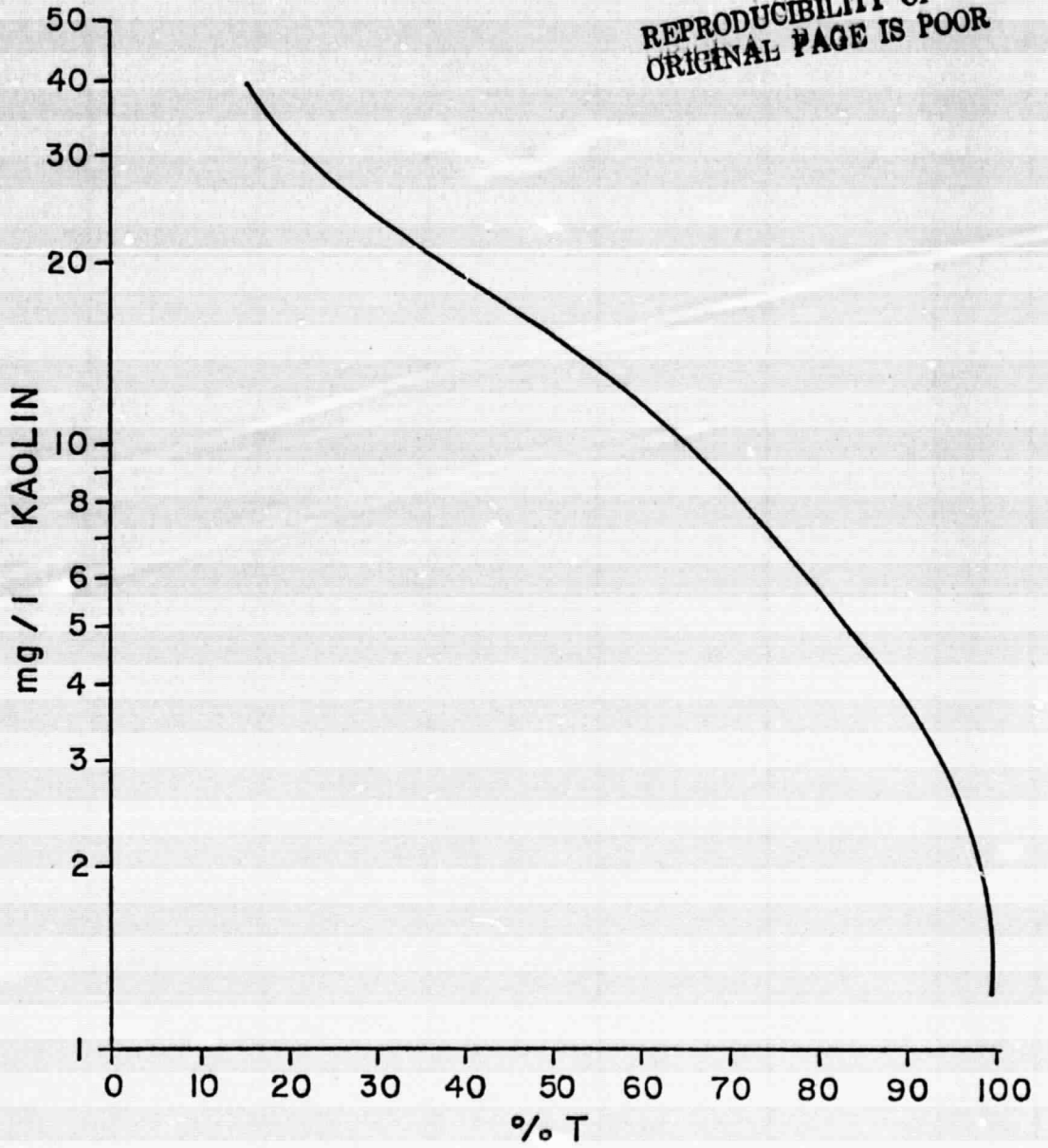
FIELD STUDIES-TRANSECT STUDIES:

Two standard transects (Figure 2) have been established to provide a monitoring mode and data for the dynamics analysis component of the project.

FIGURE 1 - Calibration curve of Hydro Products 612S
transmissometer utilizing a 10 cm path
length and preweighed amounts of kaolin.

mg / l   KAOLIN
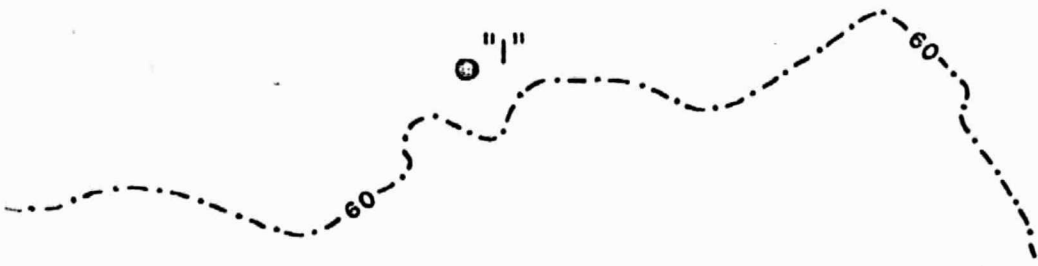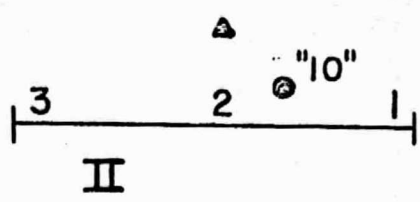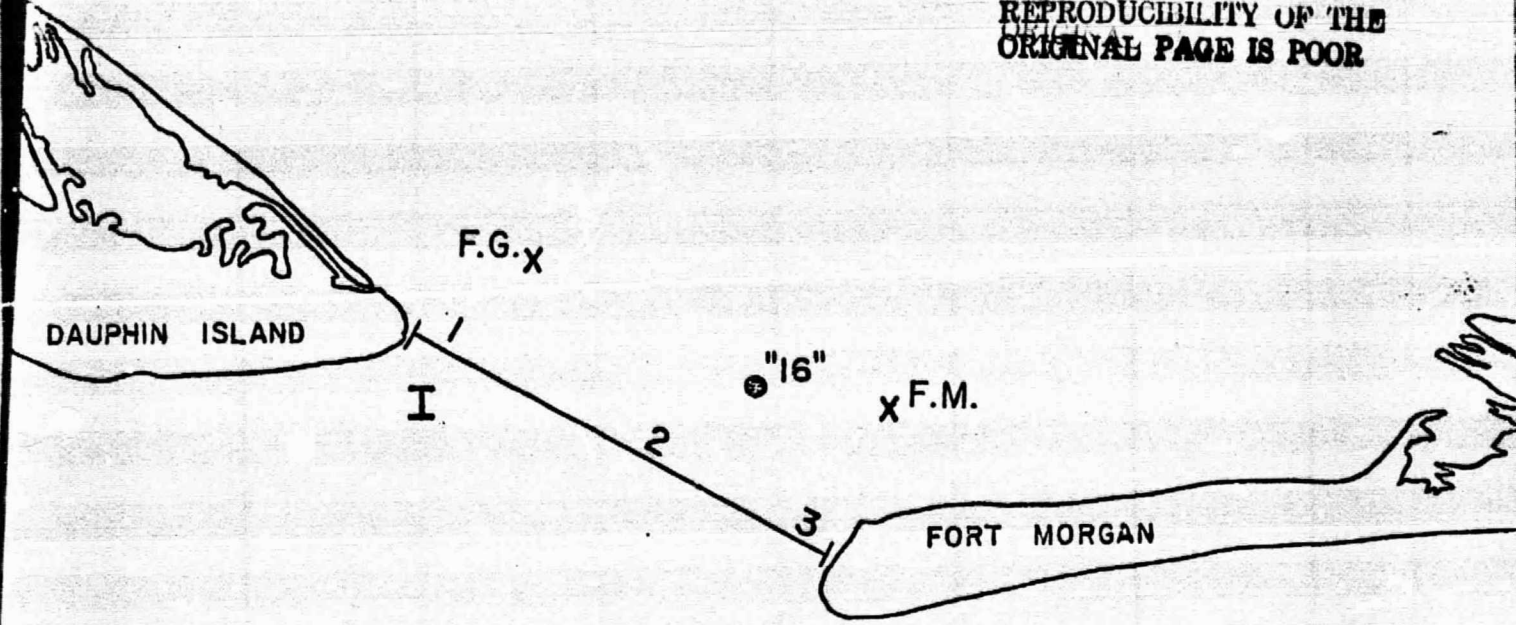
% T

FIGURE 2 - Time series station and transect locations.

"6"

F.G. x

DAUPHIN ISLAND

I

1

2

"16"

x F.M.

3

FORT MORGAN

"14"

3

2

"10"

1

II

"6"

"1"

60

60

The physical history of the system has been developed at least in terms of the environmental parameters of wind stress, recent and immediate, and tidal currents, velocity and direction. The hydraulic head produced by local and regional rainfall/runoff is assumed to play a role, but insufficient data has resulted in an unsatisfying lack of correlation. The appropriate historical data are presented in Table 1. Wind data (velocity and direction) were obtained from the archived data of the Dauphin Island Sea Lab Climate Station while tidal information was computed from the National Ocean Survey Tide Tables.

In order to provide calibrating sea-truth data to the satellite images, two extended cruises were employed to provide the greatest possible range of transmissivities/spectral densities. By crossing the apparent boundary of the offshore plume the largest gradient could be obtained in the shortest period of time. The sea-truth contours of transmissivity from the November 16, 1975 cruise are presented for two different tidal phases, falling (Figure 3) and rising (Figure 4). The data clearly demonstrate the speed of change and movement of the optical plume.

The transmissivity data from Transect II (Figure 5) are of interest principally because they reflect the rate of settling which is evident within 24 hours. The tidal state was similar for both days and no new wind stress intervened between the sampling periods.

Transect I (Figure 6) clearly indicates the water flow pattern associated with the mouth of Mobile Bay in which relatively clear Gulf of Mexico water enters the bay on the eastern side. The higher sediment load of the Fort Gaines (western) side of the bay entrance may be a function of the shallower water. During the reporting periods the maximum tidal current velocities were associated with the incoming tide (Table 1) and the frictional component will entrain some of the sediment depending upon the energy content of the system. Obviously, the
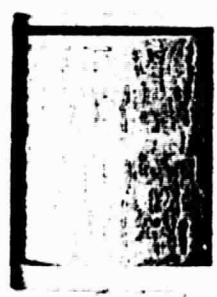
Table 1

TRANSECT STUDIES

Date	Location	Direction	Tide State	Tide Range	Maximum Tidal velocity	Wind Regime Days Prior 4-3	2-1	0
6/25/75	I	E→W	←	1.6	2.2	6-25 NE E	10-20 SE	5-10 SE
7/30/75	I	E→W	→	0.6	0.6	5-15 N	5-10 S	5-25 SW
9/25/75	I	E→W	→	1.3	1.3	6-36 N	20-36 N	5-15 N N N
10/3/75	I	E→W	→	0.2	0.3	<5-15 N S N	10-25 S N	5-15 N
10/10/75	I	E→W	←	1.6	2.1	1-5 S	0-10 N	1-5 N S
11/7/75	I	E→W	←	1.9	2.4	10-5 ESE	5-20 E S	0-5 E S
9/25/75	II	E→W	→	1.3	1.3	6-36 N	20-36 N	<5-15 N S N
9/26/75	II	E→W	→	1.3	1.5	20-36 N	36-6 N	6-15 N

FIGURE 3 - % light transmission value surface contours,
falling tide, November 16, 1975.

⊚ Water Tower

DAUPHIN ISLAND

• 40

• 34

• 43

• 38

35

• 46

• 42

40

• 49

?50

45

• 50

• 50

• 50

50

• 52

MOBILE POINT

SAND ISLAND

• 54

• 55

55
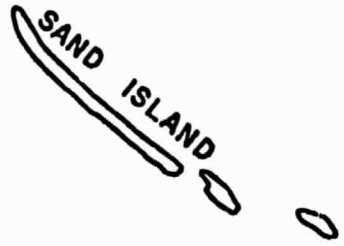
⊚ Sand Island Lighthouse
• 56

• 58

60

• 64

• 66

65
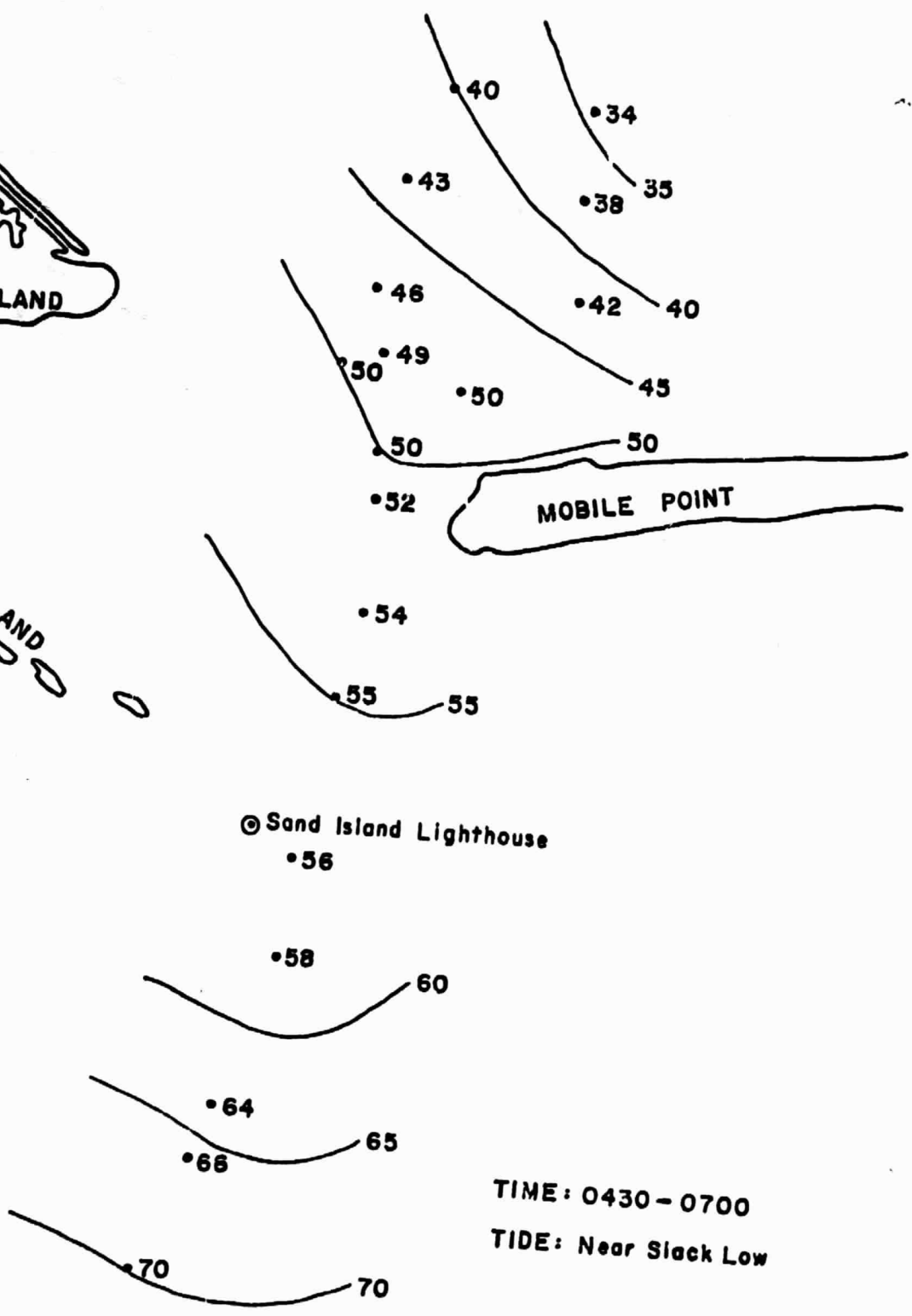
TIME: 0430 - 0700

TIDE: Near Slack Low

• 70

70

FIGURE 4 - % light transmission value surface contours, rising tide, November 16, 1975.

Water Tower

DAUPHIN ISLAND

50   50
55
•54
•58   55
60
•61   •58
•62
65
•59

MOBILE POINT

SAND ISLAND

•68

70
•68
75
•75

Sand Island Lighthouse
80   •77
85
90
95
•95
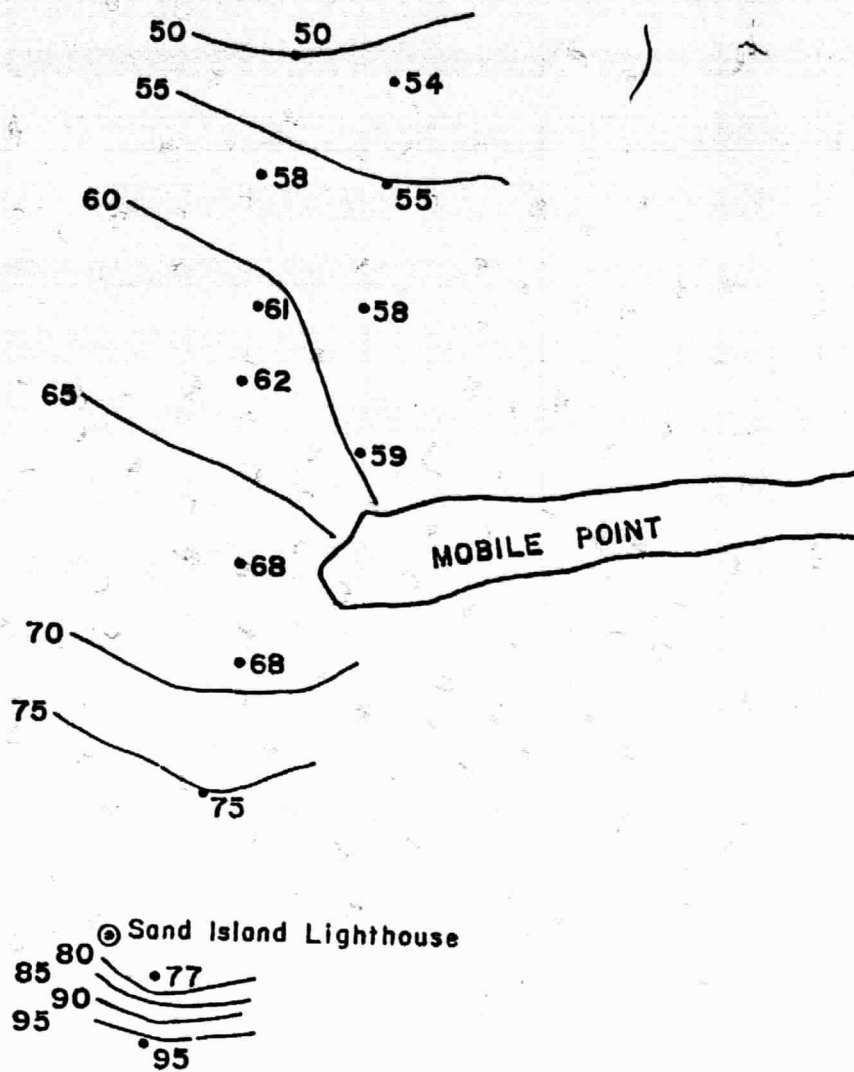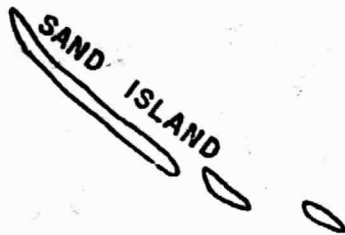
TIME: 0830 – 1100
TIDE: Rising

FIGURE 5 - Transmissivity values along Transect II.

TRANSECT II

9/25   9/26
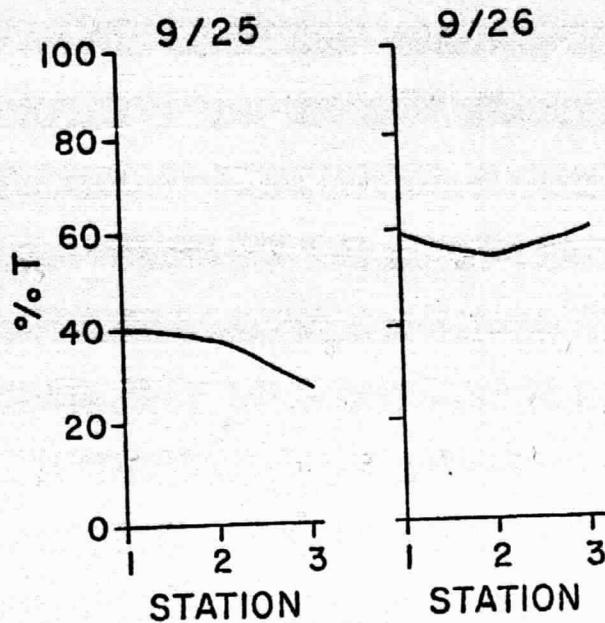
FIGURE 6 - Transmissivity values along Transect I.

TRANSECT I

6/25   7/30   9/25

10/3   10/10   11/7

%T vs STATION
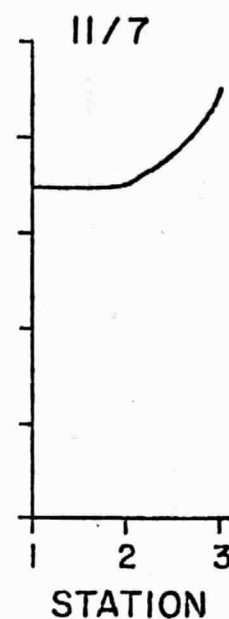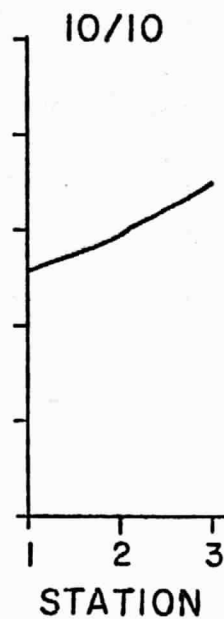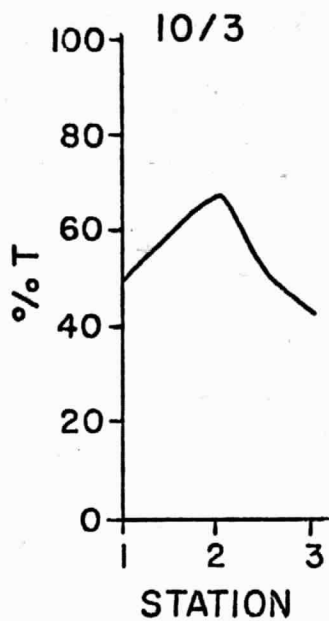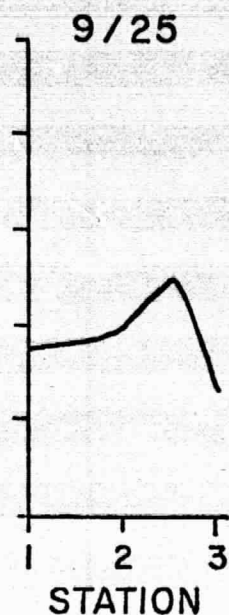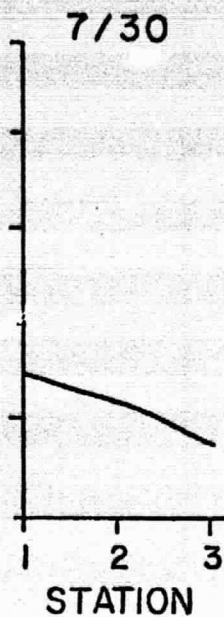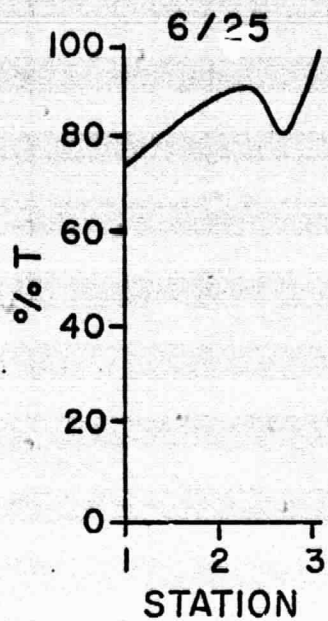
closer the surface is to this region of entrainment, the higher the surface suspended load recorded. The negative peak (6/25) is associated with the ship channel spoil bank. The reverse is true of the falling tide in which the values are generally lower all the way across the transect with a transmissivity maximum usually associated with the deep ship channel. Secondly, the lowest values (7/30) were associated with maximum wind stress on the sampling day; the next lowest (9/25) with maximum wind during the two days prior to sampling. This sample did have a much higher tidal current velocity than either of the other two falling tide samples. The third (10/3) had the least wind stress history, low tidal current velocity and highest transmissivity values. The comparison of these three ebb tide samples seems to confirm the relative importance of wind stress as a driving force in the resuspension process.

TIME SERIES STUDIES:

When time permits, anchor stations occupied continuously over a complete tidal cycle (25-28 hours) provide the most thorough data base from which to analyze the interactions of wind and tide. Again, the environmental history of the system is summarized in Table 2. Routinely, stations have been occupied on either side of the mouth of the bay (Figure 2) and the vertical water column analyzed regularly.

During the summer, the regular failure of the transmissometer forced the use of gravimetric procedures to establish sediment load at predetermined points in the tidal cycle. Gravimetric analysis (mg/l) was carried out on samples taken at high tide, low tide and periods of maximum current velocity during flood and ebb tide. The results of five stations are found in Figures 7-10. The March 21 samples (Figure 7) exhibits the characteristic pattern.

Table 2

TIME SERIES STUDIES

Date	Location*	Tide	Tide Range	Maximum Tidal Velocity	Wind Regime Days Prior 4-3	2-1	0
3/21/75	FM	→ ←	1.8	1.8	6-36 N	6-15 W N	5-10 S
3/21/75	FG	→ ←	1.8	1.8	6-25 S		
4/15/75	FM	← →	1.8	1.8	5-25 S N	10-25 NE	6-15 S N
5/26/75	FG	← →	2.2	2.4	0-15 N S	0-15 SE	0-15 N S
7/1/75	FM	→ ←	0.6	0.4	0-15 E	0-15 NE	5-15 NE
12/2/75	FM	→	2.3	2.2	5-20 NE	5-35 N	5-10 N
1/26/76	FM	↑ →	1.8	2.5	5-15 N	0-15 S	0-25 S N

*FM – Fort Morgan Anchor Station
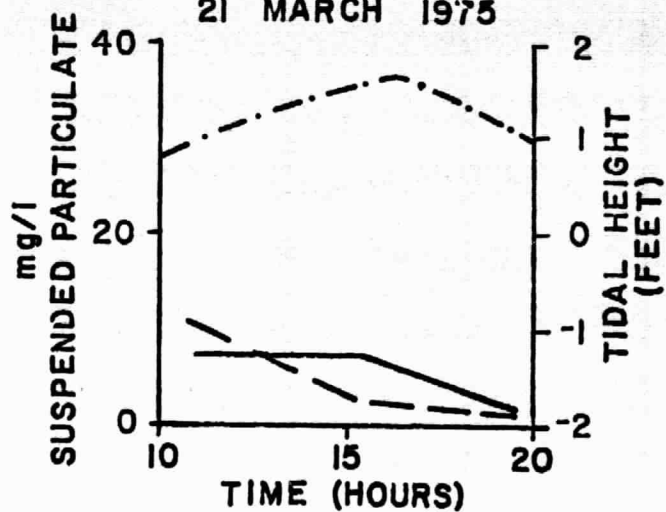*FG – Fort Gaines Anchor Station

FIGURE 7 - Suspended particulate values over a single
tidal cycle (time of day based on 24-hour
day) at Fort Morgan and Fort Gaines anchor
station March 21.

FORT MORGAN
21 MARCH 1975
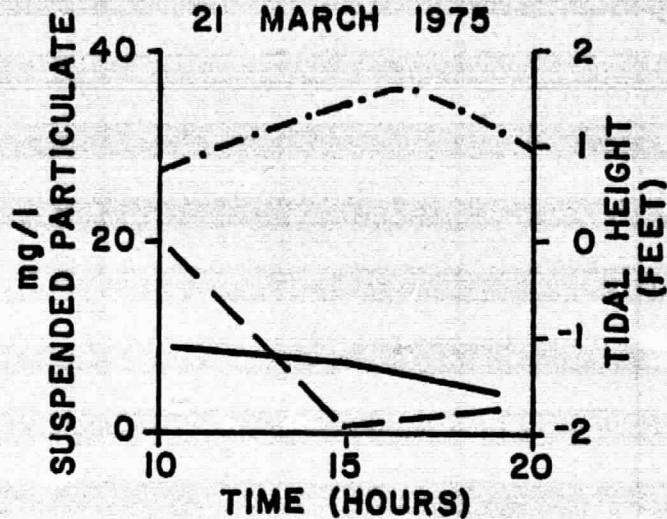
FORT GAINES
21 MARCH 1975

——— Surface
— — Middle
—·— Tidal Height

The maximum suspended load is normally associated with the low tide and declines are seen with rising tide as offshore waters enter the bay. The higher values at Fort Morgan on April 15-16 (Figure 8) seen on the rising tide followed a relatively high wind stress period (Table 2). The suspended load values showed the more common decline with the next rising tide.

The effect of tidal current entrainment can be seen in the May 27 sample (Figure 9). The bottom water begins picking up the bottom sediment as the velocity increases from slack water, while the surface values exhibit the typical decline associated with the flooding tide.

The contrast between the May and July exercises (Figures 9&10) lies principally in the absolute values. Figure 7 shows that the different depth of water does not have a serious effect on gravimetric results, which appear quite similar for the same day. The historical wind regime (Table 2) for May and July is also very similar and contains no significant stress episodes, but the tidal current velocities seen in July are drastically lower. As a result of the combination of low wind and low tidal range, the resuspending forces were at a minimum and the particulate load was markedly reduced in July.

During the Fall, the substitution of the continuously recording transmissometer for the tedious gravimetric point analysis provided a more meaningful data base for comparison (Figure 11). The same pattern of increasing clarity with flood tide and decline with ebb is evident, but there is a dip in surface transmissivity associated with the maximum current velocity which certainly reflects *in situ* resuspension.

The January 27 data clearly demonstrate the immediate wind effects. The gradual decline in suspended load and the maximum clarity normally associated with slack high water was cut off by a frontal movement with associated high winds. The combination of wind and falling tide was clearly synergistic.

FIGURE 8 - Suspended particulate vs. time of day over
24-hour period at Fort Morgan anchor station,
April 15-16.
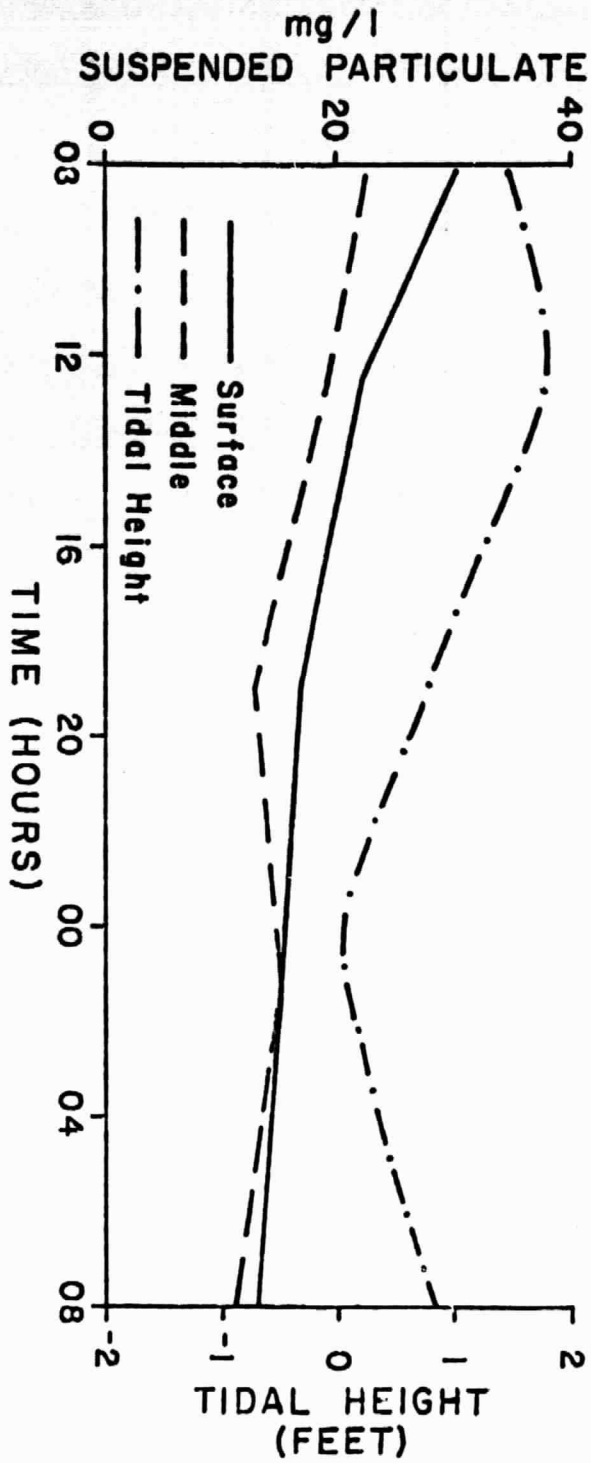
FORT MORGAN
15/16 APRIL 1975

mg / l
SUSPENDED PARTICULATE

Surface
Middle
Tidal Height

TIME (HOURS)

TIDAL HEIGHT
(FEET)

FIGURE 9 - Suspended particulate vs. time of day over
24-hour period at Fort Gaines anchor station,
May 26-27, 1975.

FORT GAINES
26/27 MAY 1975

Legend:
- Surface (solid line)
- Bottom (dashed line)
- Tidal Height (dash-dot line)

Y-axis (left): mg/l SUSPENDED PARTICULATE (0 to 60)
Y-axis (right): TIDAL HEIGHT (FEET) (-2 to 2)
X-axis: TIME (HOURS) (16, 20, 00, 04, 08, 12)
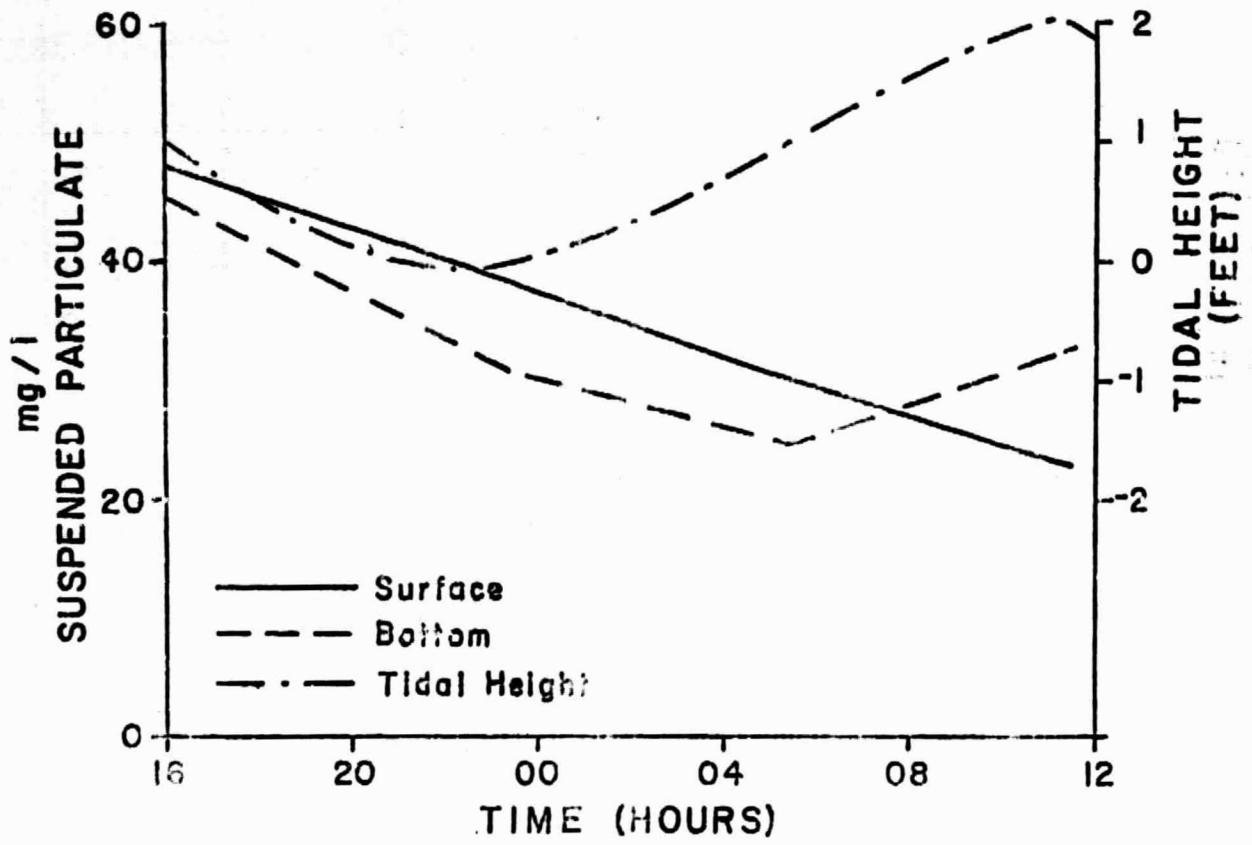
FIGURE 10 - Suspended particulate vs. time of day over
24-hour period at Fort Morgan anchor station,
July 1-2, 1975.
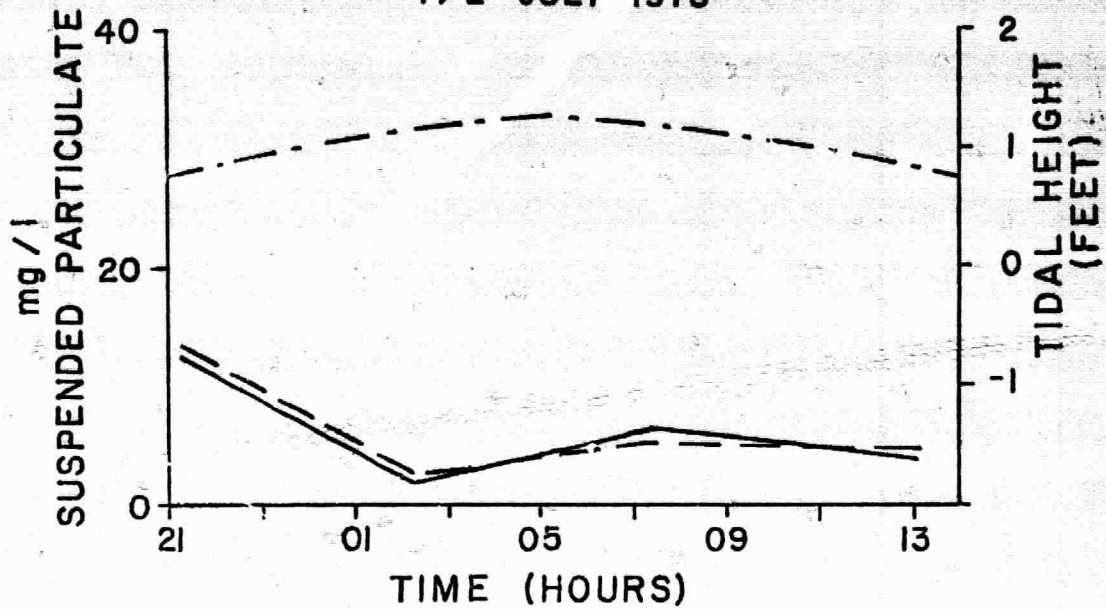
FORT MORGAN
1/2 JULY 1975

Surface
Middle
Tidal Height

FIGURE 11 - Surface transmissivity vs. time of day over tidal cycles December 1-2, 1975 and January 26-27, 1976 at Fort Morgan anchor station.

26/27 JANUARY 1976

TIDAL HEIGHT (FEET)

% T

TIME (HOURS)

1/2 DECEMBER 1975

TIDAL HEIGHT (FEET)

% T

TIME (HOURS)
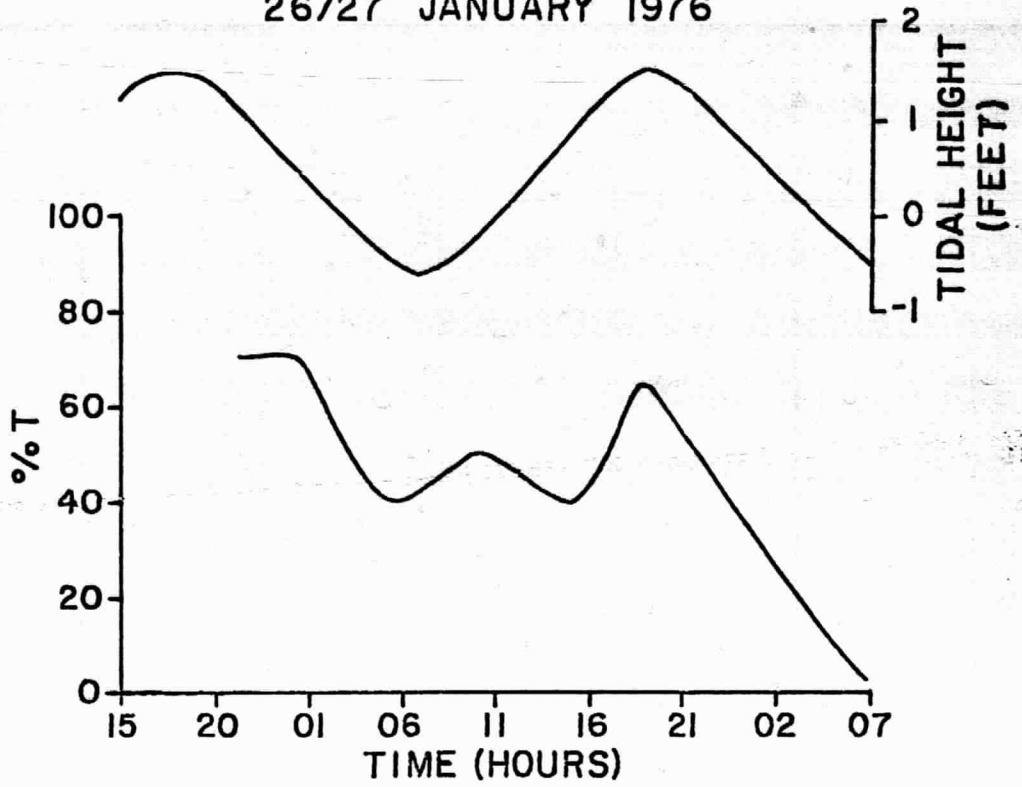
raising the suspended load to extremely high levels and thus reducing the transmissivity to nearly zero.

DENSITY SLICING:

The November 16, 1975 **field** exercise did have all the ingredients of recent and immediate **weather**; operational instrumentation, vessels and personnel; and a **convenient satellite** (Land-Sat B) to produce an image suitable for sea-truth calibration.
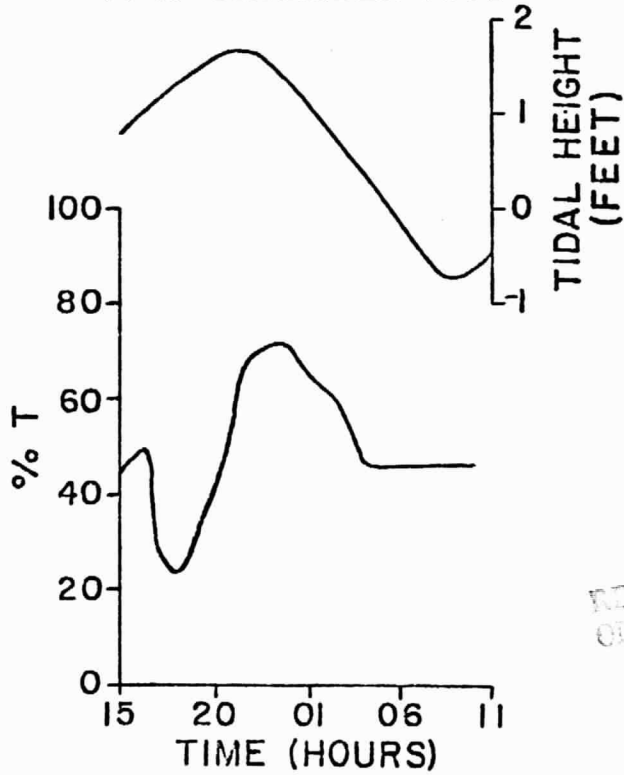
Positive transparencies in the MSS-4 and MSS-5 bands were subjected to density slicing analysis at the National Space Technology Laboratory (EROS center) at Bay St. Louis, Mississippi.

Color assignments were made in a manner which allowed an **analysis** of the range of sea-truth values established. It is possible to extrapolate to those regions for which sea-truth was not available if an assumption of a reasonably uniform gradient is acceptable. The results are presented in Table 3.

It will be possible to determine the area of a given suspended load range by color analysis, but the analyzer was not functioning properly during the initial phase and the work **has not** been completed.

SUMMARY DISCUSSION:

The complex interactions of all the phases of matter are more than adequately obvious in this study of wind, water and sediment. A thorough quantitative understanding of the processes involved will require multi-variate analysis but the fortuitous mix of experimental circumstances in this study has provided clear indications of the relationships between the opposing forces.

Table 3. Relationships of suspended load (kaolin) to transmissivity (10 cm path length) colors assigned by density slicing and turbidimetric units (Formazin Turbidity Units).

mg/l	%T	Assigned Color	FTU
0	93	Yellow (>90)	4.8
5	81	Orange (80-90)	6.8
10	70	Green (65-80)	8.5
15	57	Violet (55-65)	13.0
20	45	Cyan (45-55)	16.0
25	33	Blue (<45)	
30	21	Blue (<45)	
35	9	Blue (<45)	
40	0	Blue (<45)	

The suspension of a solid in water allows the use of some concepts and terminology more familiar to colloid chemistry than hydrology but the analogies are clearly drawn and thus meaningful. The stability of colloidal systems are dependent upon the total energy balance and upon the prior physical treatment (hysteresis) of the system. This is equally true of natural "turbid" water systems as demonstrated in this project.

Wind and tidal movement represent the readily monitored energy inputs to the system while the hydraulic thrust of riverine flow presumably plays a role of undefined magnitude. On the other hand, the rivers do represent the principal source of sediment which then becomes exposed to the resuspension forces of wind and tide in the estuarine system. The data would seem to preclude the possibility of any significant transport of sediment from the open Gulf of Mexico into Mobile Bay.

Tidal current velocities near or in excess of two knots appear to be effective inducing high levels of resuspension within the study areas near the mouth of the bay, but with nearly equal velocities of both ebb and flow tides it seems likely that significant outward transport may be more likely under conditions of maximum hydraulic head and/or a maximum suspended load gradient between the bay and gulf. The latter situation is consistently generated by wind stress on the shallow bay system.

The data presented here are not adequate for statistical analysis or firm conclusions, but it would appear that wind stress in excess of 15 knots has a marked impact on the system and winds of 20-25 knots or greater produce a maximum suspended sediment load. This is particularly true at the mouth of the bay when the synergistic impact of an ebbing tide is considered. Any combination of these factors can produce movement of the bed load from the sediment source at the head of Mobile Bay, but only one may be relatively ineffective.

If a sediment concentration gradient is established at the bay mouth in conjunction with a reasonably high tidal current velocity and any hydraulic thrust at all, a maximum offshore sediment "plume" will result and this is evident in several of the available images. Extension of the density slicing values from the November 16 overpass to a number of image/driving force combinations should allow an estimation of the sediment transport function for Mobile Bay. By further analysis of the hysteresis of the system as defined in wind and tidal records, it may be possible to produce an annual transport value based entirely on climatological and tidal information.

PROJECTIONS/RECOMMENDATIONS:

The hypothesis presented above must be modified in the cold, hard light of computer analysis and the mathematical model of Mobile Bay. It must also be tested further from the mouth of the Bay where the tidal effects may be reduced and/or affected by the riverine dynamics.

THE EFFECT OF PYCNOCLINE-INDUCED *SCHLIEREN* ON BEAM TRANSMISSOMETRY

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INTRODUCTION:

The use of beam transmissometers as field "turbidimeters" in estuarine and nearshore systems is becoming more common (McCarthy et.al., 1974; Drake, 1971; Ludwick and Melchor, 1972) due in part to their simplicity and cost-effectiveness in establishing an adequate data base within a reasonable time frame. By cautious use of calibration curves and acceptance of certain assumptions concerning the quality of the particulate system, useful quantitation values of "optical mg/l" (Griffin, 1974) may be obtained. Attempts are currently being made to correlate a variety of optical sea truth data with measurements made via remote sensing imagery (Crozier and Heath, 1976; Klemas, et.al., 1973). Drake (1971) demonstrated an occasional apparent relationship between temperature gradiants of 0.1°C and accumulations of particulate matter as indicated by reduced light transmission. His data indicate that a density change, such as that associated with a thermocline, can constitute an effective boundary limiting the dispersion of the suspended particulate material. Heathershaw and Simpson (1974) reported both positive and negative changes in light transmission associated with fine temperature structure in the water column.

During a series of studies within the "turbidity plume" of Mobile Bay, a unique, highly variable signal was recorded in association with the mixing zone between upper bay waters and the underlying saltwater "wedge". It seemed possible that this irregularity might be due to the *Schlieren* patterns familiar to most divers as a visual distortion noted while passing through

either a halocline or thermocline. This study represents an effort to demonstrate the impact of these *Schlieren* on light beams under more controlled conditions in the laboratory.

MATERIALS AND METHODS:

The sensor of a Hydroproducts 612S beam transmissometer was submerged in 27 liters of distilled water containing enough kaolin to produce a meter reading of 53% transmission. The kaolin was kept in homogeneous suspension by means of a circulating pump and intermittent stirring to prevent "dead spaces" from developing.

Temperature and conductivity were monitored throughout by a Hydrolab Corporation model number 6D Water Quality Surveyor. Artificial sea water was prepared from Instant Ocean Sea Salts.

Waters of equal "turbidity" (53% T) but different conductivities (Table 1) and temperatures was siphoned directly into the sensor chamber to create the *Schlieren*. Preliminary trials using distilled water indicated that this method of introduction had no effect on sensor response. Both large and small salinity gradients (C_i/C_b) were tested (Table 1). None of the values are unrealistic for the local estuarine system. Samples of temperatures above and below ambient were also tested. In those instances, the salinity and suspended load were kept identical to the conditions in the aquarium holding the initial 27 liters.

Throughout the procedure, the percentage of light transmitted accross a 10cm path length was monitored on a laboratory stripchart recorder.

TABLE 1

Experiment	Background Conductivity (C_b)	Introduced Conductivity (C_i)	Initial %T	Maximum Deflection %T	Duration of Deflection	Final %T
I	7.5 mmhos (~4.2 o/oo S)	49.9 mmhos (~32.8 o/oo S) 7	53	30	18.06 secs	53
II	9.2 mmhos (~5.1 o/oo S)	29.0 mmhos (~17.8 o/oo S) 3	53	8.5	18.06 secs	53

RESULTS AND DISCUSSION:

With the aquarium water at 7.5 mmhos/cm addition of one liter of water at 49.5 mmhos/cm reduced the transmissivity from 53% to 23% (Table 1, Figure 1). Upon completion of mixing, the transmissivity returned to 53%. A background conductivity of 9.2 mmhos/cm resulted. When a liter of water at 29.0 mmhos/cm was added (Table 1), the transmission dropped from 53% to 44.5% and again returned to 53% (Figure 2).

A liter of water with a temperature of 12.0°C was added to the aquarium with a temperature of 22.5°C. The change in transmissivity was only from 53% to 52%, and again returned to 53% T. It appears that a temperature gradient sufficient to produce the magnitude of deflection seen in the field or with salinity-induced *Schlieren* would be totally unrealistic, so further test were not attempted.

Water movment, sensor movement, different salinities, or temperatures had no effect on the light transmission characteristics. As long as the suspended load was kept constant, the addition of salt without inducing a gradient within the sensor had no effect on the absolute % Transmission recorded.

The consistency of the system may be further inferred from the correspondence of maximum % T deflection and the magnitude of the gradient induced (C_i/C_b ratios) as well as the duration of disturbance as related to the volume of introduced solution (Table 1). We do not suggest a quantitative relationship, only that it seems logical in light of the hypothesis.

Fig. 2

Fig. 1

Anyone familiar with equeous or atmospheric (heat waves) ∧ *Schlieren* will acknowledge the dynamic nature of the visual disturbance and no effort has been made to quantitate this phenomenon. We assume that the rapid and complex shifting of the refractive index within the *Schlieren* may be capable of disrupting and deflecting some percentage of the light beam reaching the photo cell, thus the reduced transmission values. This suggestion may be far too simplistic and does not seem to explain the positive changes reported by Heathershaw and Simpson (1974) with regard to small temperature gradients.

This phenomenon can be a source of error to those individuals using a beam transmissometer to obtain data concerned with the vertical distribution of suspended particulate in estuarine systems. Particles certainly do accumulate at these density boundaries (Meade et.al., 1975) but it would be difficult to obtain reliable optical quatitation of the suspended load in a system where a significant pycnocline exists.

On the other hand, the trace recorded from the suspected *Schlieren* is intriguingly unique and it may in fact be possible to chart the areal and vertical distribution of salt or fresh waters by tracking the mixing zone itself and logging its depth. Whether the *Schlieren* actually provide an adequate signature of this boundary is unknown at this time, but the frequency of occurrence in our experience makes it seem possible.

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