CHANNEL SHOALING PREDICTION: A METHOD AND APPLICATION

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ABSTRACT

Due to concerns of possible shoaling problems, an extensive field survey program was carried out at the site of the proposed Cerrejon coal port on the Caribbean coast of northeast Colombia. The program yielded considerable data on winds, waves, currents, and sediment factors. Techniques for the primary measurement of sedimentation-related tendency included dredged test pits, scour crosses, and suspended sediment samplers.

The port plan includes dredging a 4.6 kilometer long channel varying from 12 to 21 meters in depth. In order to assess the magnitude of maintenance dredging and related problems, a method was developed for incorporating the sediment response measurements into predictions of the areal and seasonal distributions of bed load and suspended sediment deposition.

Offshore test pits were monitored for rate of filling and character of the material being deposited. Suspended sediment samplers were similarly observed and also provided data on concentration versus depth.

The procedure which was developed for analysis and interpretation of the data included extrapolation of suspended sediment data to the seabed, investigation of correlations between wind activity and deposition rates, application of test pit data to a channel of larger dimensions, and testing of hypotheses regarding transport mechanisms. The procedure concluded that average annual shoaling would be approximately 300,000 m^3 and predicted areal and seasonal variation of deposition rates.

BACKGROUND

A 15 million ton per year coal export terminal is being

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developed on the Caribbean coast in the northeast of Colombia (see Figure 1). The terminal is the outlet for coal received by rail from a mine being opened approximately 150 km inland. The mine, railroad, port and associated facilities are being developed by partnership of International Colombia Resources Corporation, an affiliate of Exxon Corporation, and Carbocol, a company owned by the government of Colombia.

The terminal is being designed to accommodate vessels up to 150,000 dwt. A site selection investigation identified Bahia Portete, a large natural bay near the tip of the Guajira Peninsula, as the optimum port site (see Figure 2). Further optimization studies resulted in a plan, shown in Figure 3, to dredge a 4.6 kilometer long channel extending from just within the mouth of the bay to the 21 meter contour. The channel varies in depth from 12 to 21 meters. The plan resulted from estimates of the relative cost for dredging versus trestle structures, assessment of wave conditions at the coast and further into the bay, and consideration of possibilities for future development of Bahia Portete.

Early site investigations noted the presence of a plume of turbid water flowing to the southwest along the coast of the peninsula and past Bahia Portete. Depending on the tide, the plume was periodically diverted into the bay. At the inside of the east headland of the bay entrance, a sand spit approximately 800 meters long extended into the bay. These conditions gave rise to concern over possible shoaling problems in the channel. As a result, a coordinated field survey program and analytical method were developed to provide predictions of shoaling in the proposed channel.

SITE CONDITIONS

Wind and Wave

The site is located in the tropical trade wind zone at approximately 12 degrees north latitude. As shown in Figure 2, the port will be situated near the northern tip on the leeward side of the Guajira Peninsula. Most wave activity in the area is generated by the easterly trade winds and passes the site farther offshore, north of the tip of the peninsula. Wave activity in the lee of the peninsula includes that which is diffracted around the peninsula and that which is generated by the northeasterly component of the wind regime (parallel to the coast). Little swell activity was observed or recorded during the field survey.

In addition to the protection afforded by the coastline orientation, waves approaching the site are further attenuated by refraction. Wave approach is primarily from the northeast and parallel to the coastal contours. While offshore waves exceed 2 meters 35 percent of the time, waves at the coast are rarely more than 1 meter (only 5 percent of the year). Between the end of the

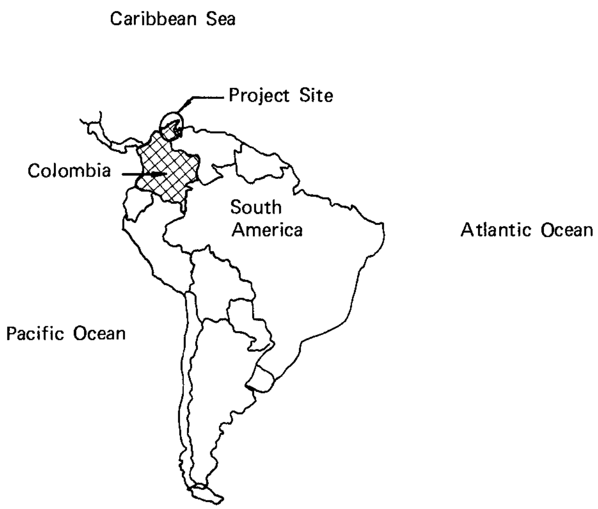

FIGURE 1 - PROJECT LOCATION

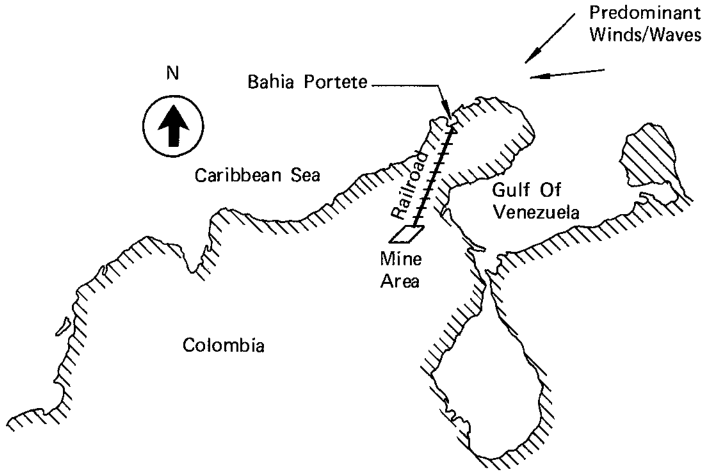

FIGURE 2 - PROJECT AREA

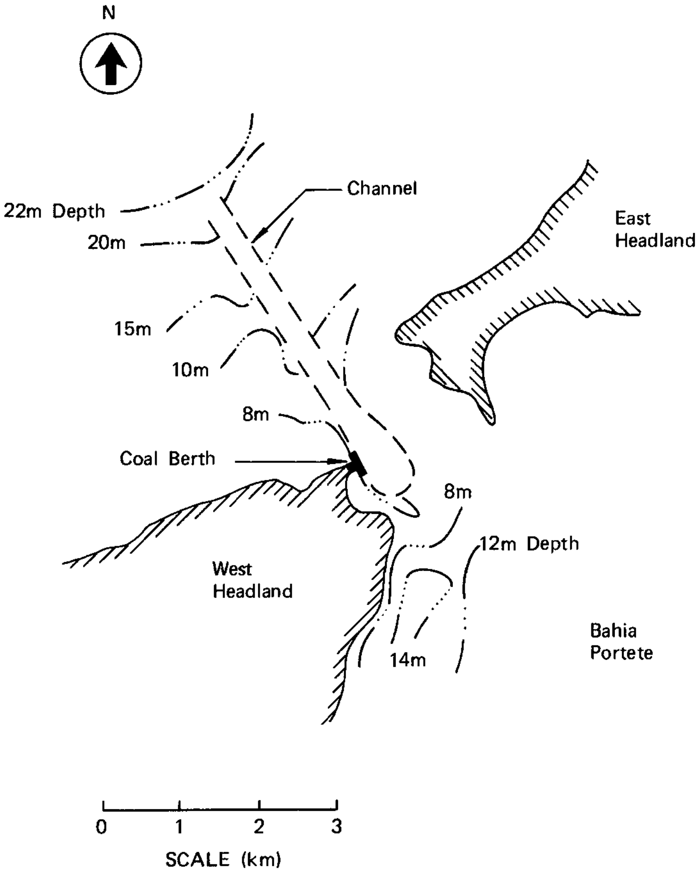

FIGURE 3 - PORT LAYOUT

channel (21 m depth) and the bay entrance, the prevailing waves change direction by up to 45 degrees.

Short wave activity (2-4 secs.) is also generated across the 10-15 kilometer fetch of the bay itself, primarily out of the east and southeast. Typically 0.3 - 0.5 meters in height, these waves can approach directly to the port area from across the bay.

Warm tropical winds persist at 20 to 30 knots for much of the year with June - August and January - April the more severe seasons. Field measurements of both winds and waves, and of sediment deposition rates, encompassed portions of both of these periods.

Climate and Topography

At the site, the Guajira Peninsula is predominantly dry, arid, and flat. There is little vegetation or runoff, and the area is sparsely populated. The shoreline is generally steep and rocky except in the inner reaches of the bay. At the headlands, the shoreline rises nearly vertically to elevations of 5 - 20 meters, except for a few pocket beaches. The face of the cliff-like shoreline is composed primarily of hard sandstone overlaying stiff clays. There is some evidence of shoreline erosion on the west headland, which is subjected to direct attack from offshore waves and those generated across the bay. Upcoast (windward) from the site, however, there is little sign of coastal erosion as the hard sandstone appears to resist the significantly attenuated waves. As such, the site appears to be sand starved, with pocket beaches that are not filled and no trace of an offshore deposit extending from the eastern headland of the bay entrance.

The seabed characteristics vary between the offshore and bay areas. Offshore and in the entrance, the seabed is largely a layer of silty sand up to 12 meters thick overlaying stiff clays and limestone. The entrance is only 3-8 meters deep but there is a natural trough in the entrance and a depression in the seabed offshore that indicate a lack of deposition, either through continued suspension by currents, or lack of a sediment source, or both. In the bay, the depth averages 10 meters and the seabed is very fine, mucky silt that is easily suspended.

There is a sand spit which extends into the bay from the inside of the east headland. The spit appears to be due to a relatively small sediment supply as compared to the transporting capacity of the waves. Thus, the sediment is driven into the bay where equilibrium is found between the Caribbean swell propagating into the bay and the short, locally-generated waves from the east within the bay.

Current and Tide

The tidal range is small, with a maximum range of only 0.5 meters. Runoff is negligible due to the arid nature of the region. Nevertheless, the current regime is complex, consisting of alongshore coastal currents, tidal currents in the bay entrance, and density currents. Offshore of the entrance, currents vary from 0.3 to 0.6 knots, varying in direction with the tidal flow in and out, but generally running to the west. In the entrance, currents reach up to 1.5 knots in order to empty and fill the large area of the bay on spring tides. Also in the entrance, an outward flow exists near the bottom in the form of a warm, relatively dense turbid layer. This turbidity is interpreted to result from the densifying of water in Bahia Portete through evaporation, subsequent sinking, and outflow as a warm bottom layer with fine material in suspension. The material itself possibly results from suspension of fine sediments from the bottom of the bay, some erosion of the western headland, or diversion of alongshore drift into the bay by the incoming tide.

FIELD MEASUREMENT PROGRAM

Physical Factors

The site conditions were established through a nominal one year field survey program. The program included measurements of winds, waves, currents, tides, salinities, water temperatures, water density, and bathymetry.

The wave measurement program utilized both pressure gauges and waverider buoys. The instruments were situated at five different locations during the course of the survey, being moved to avoid repeated incidents of damage by vessels or vandalism, and to optimize the applicability of the data as site phenomena were established and the sediment monitoring progressed. One instrument remained in "deep water" at approximately the 21 meter depth contour for measurement of unmodified waves and correlation to deep water hindcast data. Wave direction was established by instrument aided observation in the offshore area and aerial observations.

The current measurement program included permanent installations of taut line moorings for varied periods at three locations. Two offshore locations, one closer to the entrance than the other, and a location at a proposed berth site in the bay, were monitored. Since the permanent installations included only one meter at a single elevation, vertical profiles were also established through measurements from a survey vessel at six different elevations through four daily tidal cycles in the bay entrance. Diver evaluation of current flows through observation and use of hand held meters were also included.

Bathymetric data were collected over an area including the bay entrance and areas extending 3 kilometers into the bay and 8 kilometers offshore. The data were taken by side-scan sonar and echo sounding on tracks sufficient to define seabed contours for estimates of dredging and more than sufficient for sediment study purposes.

Wind measurements were taken at the point of the west headland, which has good exposure to overwater conditions. Recordings were taken at one hour intervals for the duration of the field survey program.

Tidal data were continuously recorded for four months of the program and correlated to existing data at Cristobal, Panama for establishment of generalized relationships.

The salinity, temperature, and density measurements were concentrated in the entrance where the warm, turbid layer of density current was most evident. The data confirmed diver observations that a significant gradient exists at 1-2 meters above the seabed, below which the flow is warmer, denser, and more saline.

Sediment Monitoring

During the course of the survey of site conditions, suspended and bed load sediment activity were also monitored, primarily through the use of dredged test pits and time integrated sediment samplers (TIS's). Spot sampling of the seabed and suspended sediments; surf zone sampling and current measurements; aerial, coastline, and seabed reconnaissance; and motion pictures were also used to establish qualitative data described herein.

The test pits monitored the deposition of both suspended and bed load sediments at two locations along the proposed channel - one at the projection of the coast across the bay entrance (9 m depth), and a second at the mid-point between the first and the offshore end of the channel (14 m depth). The pits were 12 meters square with a nominal depth of 1 meter. Filling of the pits and scour around them were monitored over a period of 9 months, including the most severe weather periods, and the character of the deposited sediment was established. The intended purpose was primarily to establish the effects of sediments transported alongshore on potential channel filling, although all material being deposited was obviously included.

To facilitate measurement of the filling rates, a total of 21 metal rods were driven into the bottom, extending across and outside the pits (see Figure 4). At approximately monthly intervals, divers measured the distance from the top of each stake to the seafloor. In addition, underwater observations of bottom character and sediment motion were made and cores were taken and analyzed to document the character of material filling the pits.

All along the channel and especially through the bay entrance and adjacent to the test pits, the contribution of suspended sediments to deposition were monitored through collection of material falling through the water column in Time Integrated Samplers (TIS's). Vertically mounted sediment cups on a taut line mooring were open at the top to collect falling material. Six strings with cups located at 10, 20, 30 and 70 percent of the depth

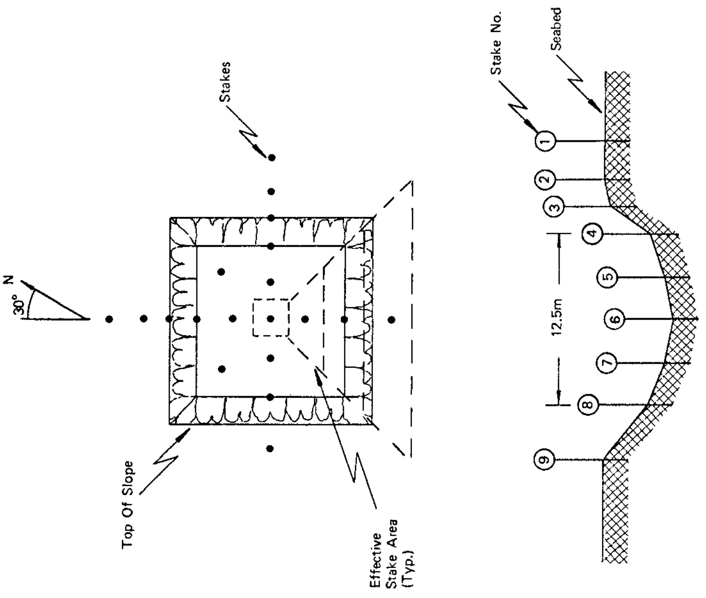

FIGURE 4 - DREDGED PITS PLAN AND PROFILE

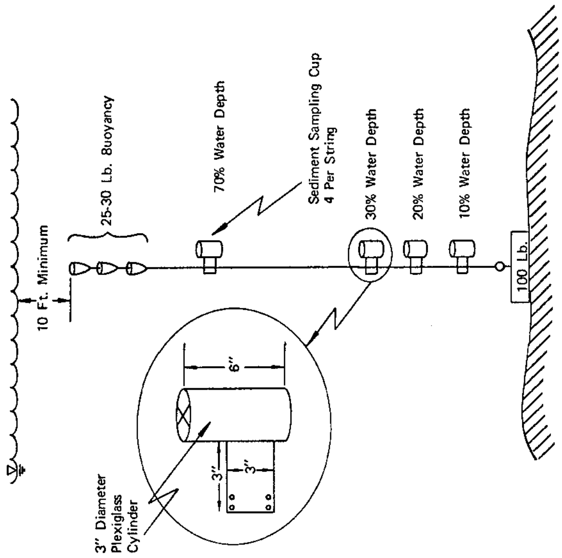

FIGURE 5 - TIS STRING

above the bottom were used (see Figure 5). Cross vanes inside the top of each cup served to reduce turbulence and any tendency for material deposited in the cup to be resuspended. The monthly servicing of these strings by a diver involved first capping each cup to avoid loss of sediment and then retrieving the entire string for fitting of clean collection cups. The dry weight of sediment in the cup was established later in the laboratory and, together with saturated density and porosity characteristics, used as a basis for calculating actual deposition rates in terms of centimeters per day of material added to the bottom.

FIELD DATA

Dredged Test Pits

Data reported from the monitoring of the offshore test pit is shown on Figure 6. The data shows that in spite of its narrow width relative to the proposed channel, the pit did not fill more than 0.5 meters in 27 weeks, and on the average much less than that. Most of the filling (up to 0.3 m) took place between the 18th and 21st week measurements - a period of only 3-4 weeks, but when the wind/wave environment was most severe.

As expected, the pit nearer shore filled somewhat more quickly than the offshore pit, becoming nearly full after 21 weeks. Again, the most rapid filling related only to the most severe wind/wave conditions, in an apparently non-linear manner. More than half of the filling occurred in a period of four of the 21 weeks. Practical assessment of the effect of rapid filling on actual channel shoaling predictions is discussed under "ANALYSIS OF SEDIMENTATION DATA."

In assessing the volume of material deposited in the pits, it was also necessary to consider the effective area of the pits and stake coverage as they bore relation to actual filling rates. Since slumping of the sides occurred and because the more fluid suspended load filled the deep center of the pits more rapidly, the average change in elevation was sensitive to the area considered. In general, the average decreased as greater area was considered. In order not to underestimate deposition, a reduced effective area was established based on analysis of the sensitivity and incorporating, for the most part, only the deeper and more rapidly filled portions of the pits.

Attention was also given to the fact that the deeper deposition at the stakes in the center of the pit represented a lesser area of the pit, due to the square plan of the pit and the pattern of stake placement (refer to Figure 4). Sub-dividing the pit into areas of individual stake coverage, the center stakes became less weighted in calculating the average rate of filling.

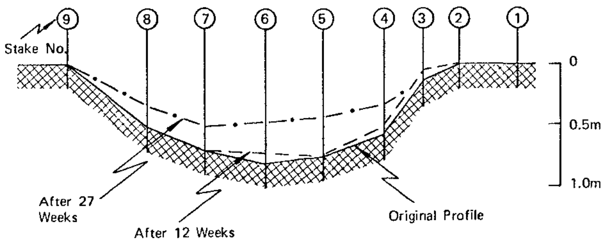

FIGURE 6 - DREDGED PIT DATA

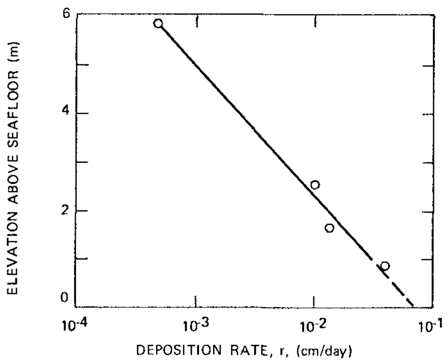

FIGURE 7 - TIS DATA

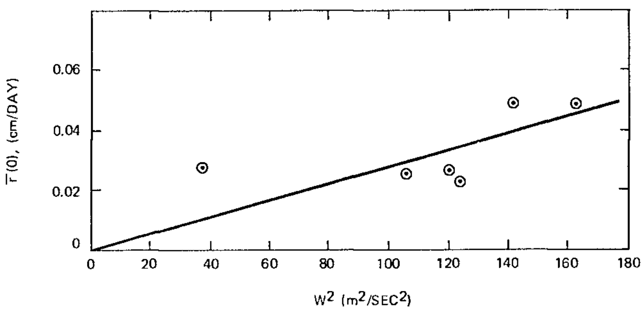

FIGURE 8 - CORRELATION OF SUSPENDED SEDIMENT DEPOSITION RATE, $\overline{r}(0)$, WITH MEAN WIND SPEED SQUARED, TIS 4

TIS Strings

A sample of data reported for one monitoring of a TIS string is shown on Figure 7. The graph shows the variation of material collection rate versus the elevation of the TIS cups above the seafloor. The collection rate was established from the laboratory measurements of the weight of material collected over the sampling interval. As shown, the graph is used to extrapolate collection rates to estimates of material deposited on the seafloor based on an exponential relationship.

Considering: (1) the material in suspension to be of uniform diameter and density and (2) the vertical eddy diffusivity, ε, to be uniform, the concentration, $C(z,t)$, of sediment is

$$C(z,t) = C_o(t)\ e^{-\frac{w}{\varepsilon(t)} z} \tag{1}$$

in which C_o is the concentration at the seafloor, and w is the fall velocity of the sediment. The seafloor concentration, $C_o(t)$, is related in an unknown way to the forcing factors (waves, winds, etc.). It is noted that if there were N components of suspended sediment characteristics, Eq. (1) could be generalized to

$$C(z,t) = \sum_{n=1}^{N} C_{o_n}(t)\ e^{-\frac{w_n}{\varepsilon} z} \tag{2}$$

Returning now to the representation for a single sediment characteristic (Eq. (1)), the sedimentation cups are considered to result in a sheltered environment in which the sediment settles and is collected. In this regard, it is noted that Gardner (1977) has conducted laboratory and field studies of the trapping efficiency of samplers of various geometries in steady currents. For cylinders of the aspect ratio used in this program, the "collection efficiency" is approximately unity. If the sedimentation cups perform as discussed above, the average depositional rate $\bar{r}(z)$ over a time, T, is

$$\bar{r}(z) = \frac{1}{T} \int_{t}^{t+T} wC(z,t)dt \tag{3}$$

and considering the average concentration to have the same form as Eq. (1), the average deposition rate can be expressed in the form

$$\bar{r}(z) = \bar{r}(0)e^{-Kz} \tag{4}$$

and taking the logarithm of both sides of Eq. (4)

$$\ln \bar{r}(z) = \ln \bar{r}(0) - Kz \tag{5}$$

Thus, by plotting on semilogarithmic paper the average depositional rate at four elevations, it is possible to extrapolate to determine the deposition rate to be expected at the seafloor. Recalling the presence of the warm turbid layer of bottom water and the possible contributions from more than one sediment type component, it is important in cases where deviation from a straight line occurs to weigh the lower two measurements more heavily than the upper two in extrapolating to the seafloor.

Other Measurements

The observations and spot samples taken on site were used primarily to confirm the interpretation of the more quantitative data and to relate it to assessments of the overall seafloor processes. The lack of filled pocket beaches, for example, relates to the fact that the pits did not fill rapidly, attesting to the lack of a substantial sediment source. The presence of the seabed trough in the bay entrance is also indicative of either the sediment-starved nature of the area, or of the existence of a sufficient flushing mechanism (e.g. the density and tidal currents). The discovery of the density current at the seafloor supports a correlation of the sedimentation data to wind phenomena on the basis of evaporation (see the following section). The spot sediment samples indicated a generally exponential distribution of sediment concentration in the water column, confirming the TIS data shown in Figure 7.

ANALYSIS OF SEDIMENTATION DATA

An attempt was made to correlate the sedimentation data collected in the suspended sediment samplers and the test pits with relevant measured wind and wave characteristics. The final method developed includes a correlation between the seafloor extrapolated suspended sediment deposition and wind data. This relationship is then utilized to determine the portion of the trapped material in the test pits that is due to bed load transport (total deposition less suspended sediment deposition). These results are then applied to the prediction of shoaling in the navigation channel.

Correlation of Measured Suspended Sediment Deposition Rates With Winds and Waves

A reasonable index of the potential of the waves to cause suspended material sedimentation is the rate at which the waves dissipate energy on the bottom sediments. The average rate of wave energy dissipation is

$$\bar{\dot{e}} = \frac{1}{T}\int_{t}^{t+T} \tau_b U_b dt \quad \alpha \quad \frac{1}{T}\int_{t}^{t+T} |U_b|^3 dt \tag{6}$$

in which U_b is the magnitude of the wave-induced water particle velocity at the bottom. From linear wave theory

$$|U_b| = \frac{H}{2}\,\sigma\,\frac{1}{\sinh kh} \tag{7}$$

in which H is the wave height, h is the water depth, and σ and k are the wave angular frequency and wave number, respectively:

$$\sigma = \frac{2\pi}{T} \tag{8}$$

$$k = \frac{2\pi}{L} \tag{9}$$

with the wave length, L, and wave period, T, being related by the well-known dispersion equation

$$L = \frac{gT^2}{2\pi}\tanh kh \tag{10}$$

The values of $\bar{\dot{e}}$ were calculated and summed for all periods over which the TIS strings were emplaced. For this purpose, the local depth at the TIS string of interest was taken into account as was the transformation of wave height from the wave measurement location to each particular TIS location. For periods with less than 80% wave data return, the results were not included in the analysis.

The effect of the wind on shoaling rates at Bahia Portete is believed to be somewhat unusual due to the interrelationship between wind evaporation rates, densification and sinking of water in Bahia Portete, and the ultimate outflow of warm, dense and turbid water in the lower layers from Bahia Portete. The wind also contributes to shoaling through generation of local waves in Bahia Portete which then attack and erode the cliffs on the western side of the bay. The effect of the wind was characterized through the wind stress, or more simply, by the square of the wind speed, W^2. Since local monthly measurements of wind speed were available by percentages Δp_n in various class intervals, the monthly mean square wind speed was approximated by

$$\overline{W^2} = \sum_{n=1}^{N} \overline{W_n^{\,2}}\,\Delta p_n \tag{11}$$

where W_n is the magnitude of the wind speed associated with the n^{th} speed category. Table 1 summarizes values of extrapolated seafloor

TABLE 1

SUMMARY OF SEDIMENTATION RATES AND WAVE AND WIND DATA USED IN CORRELATION

TIS Location No.	Date Installed	Date Removed	No. of Days	$\overline{r}(0)$ (cm/day)	$\overline{\dot{e}} \times 10^3$ (m^3/sec^3)	$\overline{W}^2$ (m^2/sec^2)
1	1/13/79	2/28/79	46	0.038	7.48	122.0
1	2/27/79	3/26/79	28	0.013	2.69	37.6
2	7/23/78	9/30/78	69	0.072	7.76	138.1
2	8/12/78	9/12/78	31	0.082	4.34	140.5
2	11/13/78	12/13/78	30	0.062	5.20	119.2
2	12/13/78	1/14/79	32	0.052	24.06	105.9
2	2/27/79	3/27/79	29	0.028	9.44	37.4
3	11/13/78	12/12/78	29	0.022	7.55	119.3
3	2/27/79	3/27/79	29	0.041	14.47	38.0
4	7/13/78	8/12/78	30	0.049	8.06	163.3
4	8/12/78	9/12/78	31	0.049	1.67	140.5
4	11/13/78	12/12/78	29	0.026	2.07	119.3
4	12/12/78	1/15/79	34	0.026	11.90	105.7
4	1/15/79	3/1/79	45	0.023	13.21	124.0
4	2/27/79	3/27/79	29	0.028	4.48	37.4
5	7/16/78	8/12/78	27	0.065	29.42	163.0
5	8/12/78	9/12/78	31	0.018	6.80	140.5
5	11/13/78	12/13/78	30	0.062	7.91	119.2
5	1/15/79	2/28/79	46	0.049	45.03	123.5
5	2/27/79	3/27/79	29	0.041	13.57	37.4
6	2/27/79	3/27/79	29	0.121	13.57	37.4

deposition rates, the wave energy dissipation factor, $\bar{\dot{e}}$, and $\overline{W_j^2}$, for each T1S string and each intersurvey period.

The monthly mean seafloor deposition of suspended sediments was correlated with the monthly mean wave energy dissipation factor and the monthly mean square wind speed in the linear form

$$\bar{r}_j(0) = K_1 \bar{\dot{e}}_j + K_2 \overline{W_j^2} \tag{12}$$

using the method of least squares. In addition, the goodness-of-fit parameter, μ , was calculated for each T1S string, where

$$\mu \equiv \frac{\sqrt{\sum_j \delta_j^2}}{\sqrt{\sum_j [\bar{r}_j(0)]^2}} \tag{13}$$

in which

$$\delta_j \equiv \bar{r}_j(0) - (K_1 \bar{\dot{e}}_j + K_2 \overline{W_j^2}) \tag{14}$$

To provide insight into the interpretation of μ values, if Eq. (12) provided a perfect fit to the measured data, then μ would be zero. The maximum value of μ if no correlation existed would be unity as would be obtained by $K_1 = K_2 = 0$.

The results of the least squares procedure showed, somewhat surprisingly, that the sedimentation rates were very poorly correlated with the waves. However, there was quite good correlation with the wind. There are several possible explanations for wind appearing as an important causative factor. Wind is related to the local waves and, due to the predominant direction, the wind contributes to the westerly current which carries sediment from the shores located to the east of Bahia Portete. As noted previously, wind also causes evaporation of the water in Bahia Portete, thereby creating dense water which outflows as a turbid bottom current.

Because waves did not prove to be a strong correlative factor, the least squares procedure was again carried out with W^2 (which is proportional to wind stress) as the only correlation factor. The results are presented in Table 2 and an example given in Figure 8. Some of the fits are extremely good (T1S 1 and 2), whereas one is poor (TIS 3 - based on only two data points), and the others are reasonable and considered to provide a good basis for calculating the deposition rates due to suspended load.

Correlation of Bed Load

Deposition of material transported as bed load depends on the available energy to transport the material and the availability of such material to be transported. Since there were available

TABLE 2

SUMMARY OF BEST FIT COEFFICIENTS, K, AND NORMALIZED STANDARD DEVIATIONS, μ , FOR SUSPENDED SEDIMENT DEPOSITION RELATIONSHIP TO WIND STRESS

TIS No.	No. of Data Points	K (cm sec^2)/(day m^2)	μ
1	2	3.1×10^{-4}	0.03
2	5	5.4×10^{-4}	0.08
3	2	2.7×10^{-4}	0.70
4	6	2.8×10^{-4}	0.29
5	5	3.6×10^{-4}	0.42
6	1	Insufficient Data	

results from only two test pits, as compared to meaningful results from five TIS strings, and since the test pits are judged to remain effective in trapping over only eight months or so, the correlation for the pits is necessarily relatively less comprehensive. Fortunately, in the prediction results to be presented later, the bed load component constituted only 20% of the total deposition.

As noted previously, the bed load component in the test pit deposition was estimated from the total deposition as the complement of the suspended load as determined by extrapolation of the TIS data to the sea floor. (It is noted that a TIS string was located in proximity to each of the test pits.). The bedload was found to correlate best with the wave energy dissipation index (Eq. (6)) and that correlation was employed in the later predictions of shoaling rates in the navigational channel.

PREDICTION METHOD FOR CHANNEL SEDIMENTATION RATES

The two basic premises for prediction of deposition rates in the navigation channel are: (1) the test pits and TIS units accumulated representative measures per unit area of the suspended sediment that will occur in the channel and (2) per unit length, the test pits entrap the same bed load amount as would the channel.

The average daily total sedimentation rate, r_t, per unit area is expressed as the sum of the bed and suspended load components

$$r_t = r_B + r_S$$

which applies to both the test pits and to the navigation channel and in which the subscripts "t", "B" and "S" denote total, bed load and suspended load, respectively. Since the suspended sediment deposition rate is the same in the test pits and the navigation channel

$$(r_S)_{NC} = (r_S)_{TP} \tag{16}$$

where "NC" and "TP" denote "navigation channel" and "test pits," respectively. Since it is assumed that the bed load sediment deposition rate per unit channel length will be the same for both the navigation channel and test pit, it follows that

$$(r_B)_{NC} = (r_B)_{TP} \frac{W_{TP}}{W_{NC}} \tag{17}$$

in which W_{TP} and W_{NC} denote the respective widths of the test pit and navigational channel. The average daily total deposition rate for the navigational channel is then

$$(r_t)_{NC} = (r_t)_{TP} \frac{W_{TP}}{W_{NC}} + (1 - \frac{W_{TP}}{W_{NC}}) (r_S)_{TP} \qquad (18)$$

These concepts were applied using the correlation between wind and deposition rate to predict total seasonal deposition rates and annual deposition rates along the channel length.

RESULTS

The results of the correlation and prediction methods described in the previous section were applied to the estimation of: (1) total annual shoaling rate, (2) distribution of annual shoaling rate along the navigation channel, (3) seasonal distribution of total shoaling rates, and (4) shoaling due to extreme events.

The total annual shoaling rate was estimated at 306,000 m^3. The associated depositional distribution along the channel is presented in Figure 9. The monthly variation of shoaling is shown in Figure 10 and is reasonably constant due to the fairly steady winds which cause the dominant suspended sediment shoaling components.

SUMMARY AND CONCLUSIONS

A method has been developed and applied for predicting sedimentation in a reasonably deep dredged navigation channel. The procedure requires a substantial field component including measurement of suspended sediments and sedimentation in dredged test pits. Additionally, measurements and/or hindcasts are required of the potential causative factors: winds, waves, and currents.

In application of the method to a coal loading terminal at Bahia Portete, Colombia, which will require a 21 meter channel, the strongest correlation for suspended sedimentation rates occurred with wind speed squared rather than a measure of wave energy dissipation. The bed load deposition correlated best with the wave energy dissipation. Considering suspended and bed load deposition in the navigation channel to be plan area and perimeter dependent, respectively, predictions were made of seasonal, areal and total annual deposition rates.

The predictions are believed to slightly overpredict sedimentation due, in part, to the rather small size and equal plan dimensions of the test pits which results in the tendency to trap and weight equally the two orthogonal components of bed load whereas the navigational channel would entrap only that component perpendicular to the channel axis. The model does not account directly for density currents that result from high concentrations of suspended load near the bottom. This phenomenon would result in

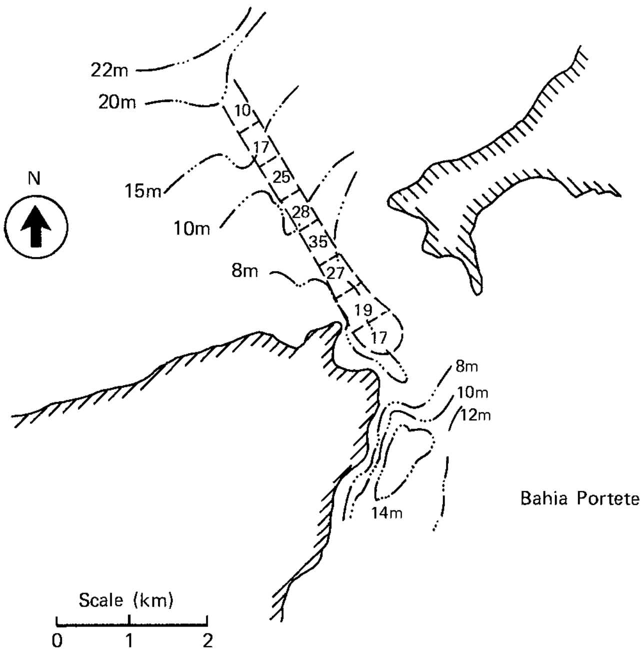

FIGURE 9 - ESTIMATED ANNUAL DEPOSITION RATES (IN cm/YR) FOR EACH ONE-HALF KILOMETER OF CHANNEL LENGTH

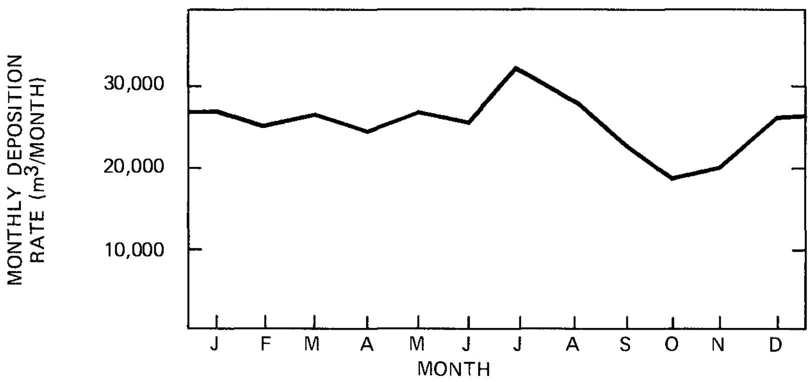

FIGURE 10 - AVERAGE MONTHLY DEPOSITIONAL RATES

greater deposition in deep channels than in shallow channels. Although this mode of transport (density currents) can dominate in some locations where very high turbidity exists, it is not believed to be a major factor at Bahia Portete.

As an overall summary statement, a qualitative assessment is that the uncertainties in the methodology and data are such that the shoaling predictions are somewhat excessive (say 10 - 15%). The coal exporting facility is now being constructed and it will be of interest to compare future maintenance dredging requirements with the predictions presented here.

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