CHAPTER 217

Turbidity and Suspended Sediment Associated With Beach Nourishment Dredging

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Abstract

A field observation program was carried out to measure natural and man-induced fluctuations in suspended sediment and turbidity in connections with a beach nourishment project. The project was carried out at Longboat Key, on the west coast of Florida. The analysis of the manual turbidity, sedimentation, and wave data revealed several significant facts concerning the differences between the hard bottom sites and control sites and the interactive dynamics between these three phenomena. The sedimentation measurements indicate that the sand sedimentation rates are highly variable, particularly with time. In contrast, the fines sedimentation rates are relatively less variable with respect to both location and time. It is evident from the examination of the sedimentation data that the sand sedimentation rates at the hard bottom sites were approximately 2.5 times higher than those of the control sites. The statistical analysis indicated that there is less than a 10% probability that this difference is due to chance. In contrast, there were no significant differences in fines sedimentation rates between the hard bottom and control sites. The manual turbidity measurements indicate high variability in space and time. Based on approximately 15 measurement dates, following nourishment the hard bottom sites experienced approximately 50% less turbidity than the control sites. The variations in sand sedimentation rates are believed to be directly related to the hydrodynamic forces resulting primarily from waves. The wave height was approximately 33 % greater at the hard bottom sites.

Introduction

Turbidity, a measure of light scattering due to particles or impurities suspended in solution, is important to underwater visibility and light transmission.

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Periods of high turbidity significantly stress some underwater communities such as coral. Suspended sediment contributes to turbidity and independently stresses corals through the deposition of sediment. Turbidity and suspended sediment concentration vary substantially in the nearshore region under natural conditions. Natural variations in these quantities may be significantly enhanced by engineering activities such as beach nourishment dredging.

A field observation program was carried out to measure natural and man-induced fluctuations in suspended sediment and turbidity in connections with a beach nourishment project. A large scale beach nourishment project was carried out at Longboat Key, Florida, during the period of observations. Sedimentation, turbidity, and wave climate were measured over a two year period. Figure 1 is a time line of these activities.

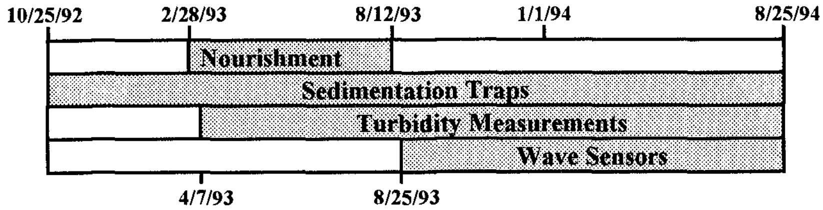

Figure 1: Time Line of Nourishment and Monitoring Activities

The monitoring locations (see Figure 2) include four stations at hard bottom study sites along Longboat Key and three control stations on adjacent Siesta Key, Anna Maria Island and Long Key. Table 1 provides the names, locations and mean lower low water depths of each site during the period of wave measurements. Sedimentation rates and turbidity measurements were obtained at all seven sites. Wave sensors were deployed at the Long Key and Siesta Key control sites and the Longboat Key #34 and Longboat Key #2 hard bottom sites.

Table 1: Monitoring Locations

Site	Latitude	Longitude	Depth
Siesta Key - SK	27°15'40" N	82°33'09" W	4.6 m
Longboat Key #6 - LBK6	27°23'21" N	82°38'43" W	4.5 m
Longboat Key #2 - LBK2	27°23'38" N	82°38'57" W	5.6 m
Longboat Key #43 - LBK43	27°25'28" N	82°40'34" W	4.6 m
Longboat Key #34 - LBK34	27°25'19" N	82°40'42" W	5.3 m
Anna Maria Island - AM	27°30'47" N	82°43'33" W	4.6 m
Long Key - LK	27°42'27" N	82°44'39" W	4.5 m

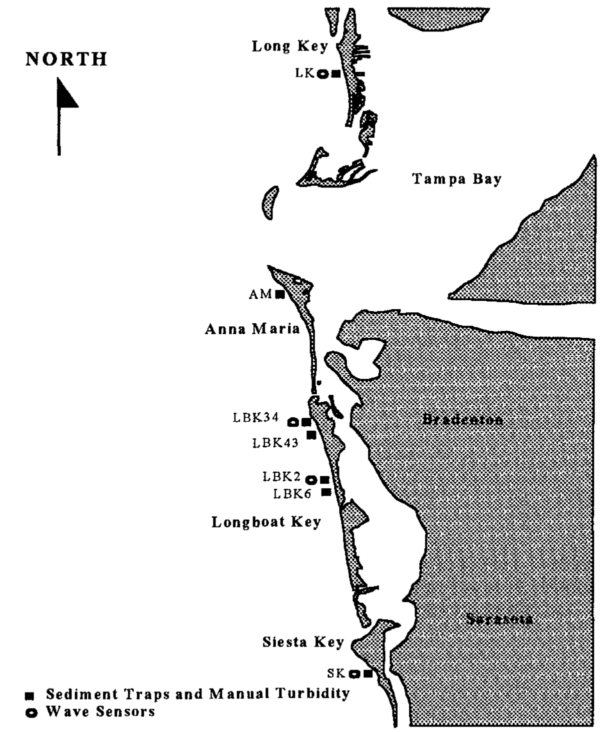

Figure 2: Location Map of Monitoring Sites

Sedimentation Monitoring

Sediment traps are deployed in order to measure the relative amounts of sand sized sediments and fine sediments suspended in the water column. The sediment trap used in this study is shown in Figure 3. The traps function by capturing suspended sediment which have sunk into the trap opening due to the tendency for sediment to settle downward due to gravity. Once inside the trap, sediments are presumably not resuspended or eroded. Thus the measured sedimentation rates are actually a measure of the product of the concentration of suspended sediments and the settling velocity of the sediments. The sedimentation rates are not a measure of deposition rates upon the bed. In fact, high sedimentation rates can sometimes indicate low deposition rates, because the sediment is suspended above the bed and advected away by currents.

After the initial deployment in October, 1992, field trips to retrieve the samples were scheduled for the first week of January, 1993 and approximately every four weeks thereafter during nourishment. After the completion of nourishment, field trips were scheduled at a maximum of every six weeks.

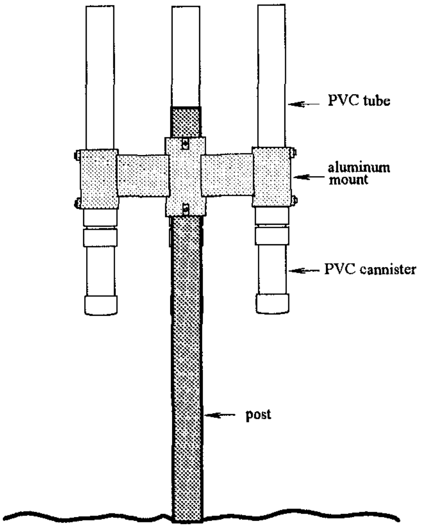

Figure 3: Sediment Trap and Mounting

Each sample was separated into sub-samples of sand and fines by wet sieving with a 63 micron sieve. These sub-samples were then dried at 110° C and weighed to determine dry weight of the sand and fines portion. Finally, the samples were ashed at 500 ° C for two hours and re-weighed to determine the weight of organic matter. Sedimentation rates, given in milligrams per centimeters squared per day, were calculated by dividing mass by the area of trap entrance and Julian days between deployment and retrieval. The sedimentation rates for multiple traps at each station (for each deployment) were then averaged to provide the best estimate of the sedimentation rate for that site during the measurement period.

Table 2 shows the average sand sedimentation rates of the four hard bottom sites off Longboat Key and of the three control sites for each deployment. Of the nearly 350 sedimentation samples, there were three cases in which one of the three sediment traps was significantly different from the other two traps at the same location. For these cases the deviant measurement was discarded. The bottom row is the average of all of the hard bottom samples and all of the control samples over all deployments.

Table 2: Average Sand Sedimentation Rates (mg/cm^2/day)
Hard Bottom Sites vs. Control Sites
(Continued on next page)

DATE		SITE	
Installation	**Retrieval**	**Hard Bottom**	**Control**
10/26/92	1/2/93	3.8	1.8
1/2/93	2/6/93	1.3	1.0
3/6/93	4/7/93	485.2	148.4
4/7/93	5/1/93	8.5	6.2
5/1/93	5/29/93	1.3	0.9
5/29/93	6/26/93	6.3	1.2

6/26/93	7/14/93	7.0	2.2
7/14/93	8/25/93	1.6	3.0
8/25/93	9/29/93	1.7	1.7
9/29/93	11/10/93	67.1	47.0
11/10/93	12/22/93	19.1	13.7
12/22/93	2/16/94	131.4	58.5
2/16/94	3/22/94	189.5	50.4
3/22/94	4/30/94	7.0	2.4
4/30/94	6/12/94	1.0	1.5
6/12/94	7/18/94	3.5	2.8
7/18/94	8/25/94	38.5	4.7
OVERALL AVERAGES		47.5	20.4

Table 3 provides the average fines sedimentation rates for the four hard bottom sites and the three control sites.

Table 3: Average Fines Sedimentation Rates (mg/cm^2/day)
Hard Bottom Sites vs. Control Sites

DATE		**SITE**	
Installation	**Retrieval**	**Hard Bottom**	**Control**
10/26/92	1/2/93	16.1	18.3
1/2/93	2/6/93	23.2	35.1
3/6/93	4/7/93	66.6	58.9
4/7/93	5/1/93	27.3	27.3
5/1/93	5/29/93	18.6	10.7
5/29/93	6/26/93	8.5	5.7
6/26/93	7/14/93	12.1	9.4
7/14/93	8/25/93	9.6	7.9
8/25/93	9/29/93	8.3	7.6
9/29/93	11/10/93	30.8	22.8
11/10/93	12/22/93	34.1	31.7
12/22/93	2/16/94	41.2	31.8
2/16/94	3/22/94	43.5	30.5
3/22/94	4/30/94	16.8	16.4
4/30/94	6/12/94	6.8	12.5
6/12/94	7/18/94	7.9	11.4
7/18/94	8/25/94	14.8	11.7
OVERALL AVERAGES		21.4	20.6

The sand sedimentation rate data is punctuated by high sedimentation rates for the deployment retrieval dates of 4/7/93, 11/10/93, 12/22/93, 2/16/94, 3/22/94 and 8/25/94. These coincide with periods of high waves, as is discussed further in the wave data analysis. There is a pronounced difference in sand sedimentation between the hard bottom and the control sites. It seems evident that the sedimentation rate is much higher for the sites at Longboat Key. This result is partially explained by the spatial variations in wave climate, which is presented later.

In contrast, the difference in fines sedimentation rates between hard bottom and control sites is small. These data reflect high values for the deployments retrieval dates of 4/7/93, 11/10/93, 12/22/93, 2/16/94, and 3/22/94. However, the increase in fines sedimentation rates during these times was not as dramatic as for sand sedimentation. The sedimentation rates for the fine material is essentially similar at all study locations, particularly relative to the enormous variations measured for the sand sedimentation rates. The overall mean and standard deviation of the fines sedimentation rate are 21.1 and 15.9 mg/cm^2/day, respectively. The means of each site are well within one standard deviation of the overall mean.

The sedimentation rates can be compared before, during, and after nourishment. Because the nourishment project occurred over a period of approximately 6 months, the beach upland of each hard bottom site was nourished at different times as the project progressed along the coast. Rather than subjectively determining 'before, during, and after" dates for each site, we choose rather to apply the same dates to all sites, as described in the introduction to this report. This allows for the grouping of hard bottom sites and control sites, as will be statistically justified in the following section on statistical analysis. Table 4 gives the average sand and fines sedimentation rates for hard bottom (HB) and control sites (Con) before, during and after nourishment. These values are given in mg/cm^2/day. The average value of the ratio HB/Con is also given. The hard bottom sites have sand sedimentation rates which are approximately 2.5 times the control sites, but the fines sedimentation differ only slightly at the hard bottom and control sites.

	Sand Sedimentation Rates			**Fines Sedimentation Rates**		
	HB	**Control**	**HB/Con**	**HB**	**Control**	**HB/Con**
Before	2.5	1.8	1.7	19.6	18.3	0.8
During	85.0	27.0	2.5	23.8	20.0	1.3
After	51.0	20.3	2.5	22.7	19.6	1.1

Table 4: Average sedimentation rates before nourishment (1/2/93 and 2/6/93 retrieval dates), during nourishment (4/7/93 to 8/25/93 retrieval dates) and after 9/29/93 to 8/25/94 retrieval dates). Values are given in mg/cm^2/day.

In summary, the study period was characterized by moderate sedimentation through the first nine months with the notable exception of the hundred year storm in March, 1993. In contrast, sedimentation in the Fall/Winter of 1993/1994 and again in Summer of 1994 were marked by significant activity, especially at the hard bottom sites. There is a notably greater sand sedimentation rate for the hard bottom sites. Finally, the data shows that fines sedimentation rates are less variable than sand sedimentation rates.

A statistical analysis of these data indicate that were no significant differences within the hard bottom sites and also no significant differences within the control sites. The sites were therefore combined into two categories: hard bottom and control. These data were then paired for comparison during the nourishment project and following the nourishment project. The comparison was made using the Binomial Sign test. The Sign test provides the probability that the number of positive differences is greater (or less) than random chance (50 % of the values). For the sand sedimentation rates measured during the nourishment project, the results of the Sign test indicate P=0.094. For the sand sedimentation rates measured after the nourishment, the results of the Sign test indicate P=0.087. There is less than a 10% probability that the differences between the hard bottom and control sites in sand sedimentation rate both during and following nourishment occurred by chance.

Manual Turbidity Monitoring

Manual measurements of turbidity were obtained through the use of SCUBA divers during each field trip. Divers obtained a water sample near the surface, mid-depth, and near the bottom of the water column. The surface and bottom samples were generally obtained approximately two feet from the surface or bottom. The water samples were then sub-sampled on board the boat and inserted into an H-F Scientific Model DRT-15C portable turbidimeter for reading.

Table 5 shows the average manual turbidity readings for hard bottom and control sites and presents the ratio of hard bottom to control turbidities (HB/Con) for the nourishment and post nourishment periods.

Table 5: Manual Turbidity Readings (NTU), During and After Nourishment

	level	Hard Bottom	Control	HB/Con
During Nourishment	surf.	4.6	2.9	1.6
	mid	5.8	4.0	1.5
	bot.	7.5	5.5	1.4
After Nourishment	surf.	2.8	4.4	.64
	mid	3.2	5.5	.58
	bot.	4.4	9.2	.48

On the whole, the manual turbidity readings are relatively low compared to the 29 NTU standard. It must be noted here that the turbidity values represent discrete readings and that this sampling cannot be considered random. The manual turbidity samples were taken only when weather permitted. Obviously weather is a very significant forcing mechanism for turbidity. Thus, in all likelihood, these values underestimate actual time-average turbidity levels.

Table 5 clearly illustrates three facts. First, the turbidity at the hard bottom sites was larger than at the control sites during nourishment. Secondly, the turbidity at the hard bottom sites decreased significantly after nourishment. Finally, the turbidity of the hard bottom sites is significantly less than the control sites after the nourishment. These average values are based on seventeen sampling dates.

Wave Sensors

Two instrument package designs were deployed for the turbidity and wave climate monitoring. These packages are referred to as system I and system II. Both systems were self contained, with on-board power and data storage capabilities. The waves were measured using Transmetric pressure sensors.

System I consisted of two model 1 Optical Backscatterence Sensor (OBS), a pressure transducer, and a Marsh McBirney Electromagnetic current meter. This package was used almost exclusively at the Longboat Key #2 hard bottom site. The system I samples at one hertz for 1024 seconds every two hours. The 12V power source required renewal approximately every month. A spare system I was employed until it was damaged in the field during the fifth deployment. The system II package consisted of one model 3 OBS and a pressure transducer. These packages were deployed at the Long Key, Siesta Key, and the Longboat Key #34 hard bottom sites. System II samples turbidity and waves at one hertz for 512 seconds every two hours. The 1Mb RAM is filled approximately every month but the 12 V power source lasted approximately three months. Therefore, the initial plan was to download the data in the field every deployment and perform complete maintenance, which included battery change, every three months. A spare system II was also employed as a backup. The field configuration of the system II package is presented in Figure 4.

All of the instruments required calibration for interpretation. The calibrations of the pressure sensor and current meter are straight forward, and were performed in some cases by the instrument manufacturer. In some cases we also calibrated these instruments at the Coastal Engineering Laboratory at The University of Florida. Turbidity is measured in Nephelometric Turbidity Units (NTU's). Calibration is accomplished using formazin in the laboratory. For the manual turbidity measurements, a HF Scientific model DRT 15C portable turbidimeter is utilized. The OBS calibration is somewhat more problematic. We calibrated the sensors in the laboratory using a formazin solution. Formazin is the turbidity standard accepted by National Institute of Standards Technology. Each time the OBS are removed from the water for cleaning (approximately once per month), they are recalibrated. However, upon deployment in the field, these calibrations were not always accurate.

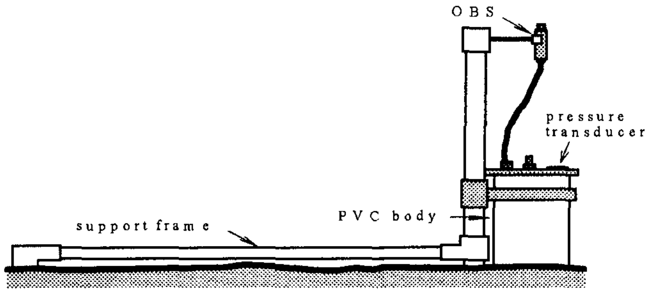

Figure 4: System II Package Field Configuration

The instrument deployment began August 25, 1993 and the preliminary plan was to schedule deployments every month thereafter. However, due to severe biofouling and unforeseen package damage, the deployments were interspersed as conditions demanded. A time line of the wave data coverage for the monitoring project is given in Figure 5. Lapses in coverage were largely due to equipment damage and maintenance.

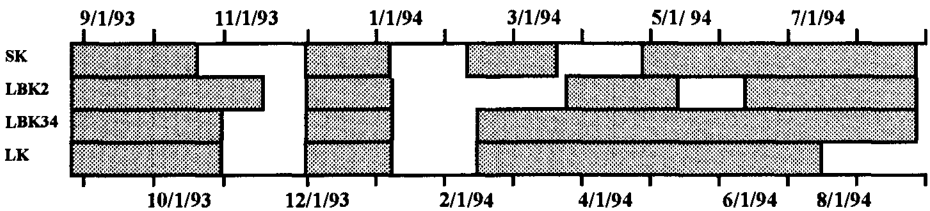

Figure 5: Time Line of Wave Data Coverage

Figure 5 points to two main lapses in wave data coverage. These interruptions occurred from 11/1/93 to 12/1/93 and from 1/11/94 to 2/16/94. The first incident was due to the unexpected severity of the biofouling of the OBS's. The packages were taken back to the coastal lab for maintenance, data offload and recalibration. System I packages suffered extensive damage in the field during the fifth and eighth deployment due to crab traps. The crab traps and buoy lines tended to collect around the instrument package, often becoming entangled in it, and extensive damage was incurred as the crab fishermen retrieved the traps. One system

I package was damaged beyond repair. Each of the sensors on the package was sheared off. In the case of the second system I package, the repairs required almost two months of work. The spare system II was utilized in its place at the Longboat Key #2 site. Even after the repairs to the system I package, the current meter was no longer functioning and much of the OBS signal was unsatisfactory.

As can be seen, maintaining the instrument packages in the field proved to be very demanding. This can be attributed to severe biofouling and field damage to the packages. The biofouling on the face of the OBS was more troublesome than anticipated. It served to block out the OBS signal after a few days in some cases.

The performance of the OBS's was dismal and our painstaking efforts to correct the problem were generally ineffective. Biofouling was anticipated before the initial package deployment and the OBS face was painted with an anti-biofoulant. The OBS were subsequently painted whenever the packages were removed from the field. It was evident that the severity of the fouling was grossly underestimated. As a result, we attached commercially available caustic hoods to the OBS. The manufacturer of these hoods claimed that they would keep OBS's clean of growth and fouling for 2 to 3 months at the project site. Although the hoods did somewhat decrease the amount of fouling, the effect of the hoods were not significant enough to improve the OBS signal. Our next plan of attack was to simply remove the packages more frequently to repaint the OBS face. The system II packages were eventually removed monthly for this purpose. Unfortunately, this provided disappointing results as well. Eventually, we tried underwater field cleaning of the OBS face biweekly. We found that we were not able to obtain valid turbidity data for more than a maximum of seven days after the OBS faces were painted with anti-biofoulant and for more than three days after cleaning with a nonscouring pad in the field. Although this seemed unproductive, we had no recourse. This presented an opportunity to increase the frequency of manual turbidity readings, which were gaining in importance due to the ineffectiveness of the OBS's. By the eighth deployment, we designed and implemented an 'OBS wipe' instrument which was mounted to the OBS to mechanically clean the face of the OBS every hour. Once again, this proved ineffective. Our final decision was to discard the OBS data.

The average values of the depth (Dav), significant wave height (Hmo) and peak period (Tp), as well as the number of days of wave data coverage within the period are summarized in Table 6. For purposes of comparison, the averages in Table 6 were calculated to correspond to the sedimentation data periods. These values represent the averages of the available wave data within these periods. The average values in the last row and column are weighted to reflect the varying days of coverage within periods and monitoring sites.

Table 6: Deployment Averaged Wave Data

Date Start	Date End		SITE LK	LBK34	LBK2	SK
8/25/93	9/29/93	**Dav, m**	4.27	5.55	5.60	4.59
		Hmo, m	0.16	0.26	0.26	0.21
		Tp, s	5.65	4.97	5.02	5.27
		Days	35	34	36	36
9/29/93	11/10/93	**Dav, m**	4.53	5.38	5.52	4.65
		Hmo, m	0.21	0.30	0.30	0.19
		Tp, s	5.02	5.47	5.59	5.44
		Days	32	32	40	23
11/10/93	12/22/93	**Dav, m**	4.51	5.29	5.89	5.00
		Hmo, m	0.26	0.35	0.32	0.29
		Tp, s	5.13	5.92	6.02	5.83
		Days	22	21	30	21
12/22/93	2/16/94	**Dav, m**	4.38	5.02	5.84	4.87
		Hmo, m	0.32	0.40	0.49	0.34
		Tp, s	6.47	6.55	6.33	6.74
		Days	21	20	20	24
2/16/94	3/22/94	**Dav, m**	4.67	5.64		4.47
		Hmo, m	0.26	0.32		0.26
		Tp, s	5.46	5.73		6.10
		Days	36	33		34
3/22/94	4/30/94	**Dav, m**		5.16	5.75	4.59
		Hmo, m		0.24	0.25	0.21
		Tp, s		5.20	5.02	5.11
		Days		38	38	34
4/30/94	6/12/94	**Dav, m**	4.41	5.17	5.35	4.67
		Hmo, m	0.15	0.18	0.15	0.16
		Tp, s	3.84	4.50	3.03	4.32
		Days	42	41	13	42
6/12/94	7/18/94	**Dav, m**	4.85	5.23	5.44	4.80
		Hmo, m	0.21	0.27	0.28	0.25
		Tp, s	4.70	4.34	4.18	4.03
		Days	31	34	34	34
7/18/94	8/25/94	**Dav, m**		5.36	5.54	4.28
		Hmo, m		0.30	0.33	0.23
		Tp, s		5.07	5.13	5.51
		Days		38	39	40
Average		**Dav, m**	4.52	5.32	5.62	4.63
		Hmo, m	.21	.28	.30	.23
		Tp, s	5.07	5.19	5.14	5.27
		Days	33	34	34	34

Discussion

The relatively higher sand sedimentation rates measured at the hard bottom sites relative to the control sites can be explained by examining the wave conditions at the sites. Table 7 compares the average wave characteristics between the hard bottom and control sites. It is evident from this table that the hard bottom sites have experienced larger waves than the control sites.

Table 7: Average Wave Data Characteristics

Characteristic	Hard Bottom	Control
Average Depth, **Dav**	5.47 m	4.58 m
Significant Wave Height., **Hmo**	.29 m	.22 m
Peak Period, **Tp**	5.17 s	5.17 s

In addition to time average data, an examination of discrete storm events provides valuable insight. An examination of the five largest, measured, storm events is presented in Table 8. The maximum significant wave height ($H_{mo(max)}$) and maximum peak period ($T_{p(max)}$) for the storm events are given for each of the sites. The largest waves of our monitoring were recorded at LBK2 and LBK34 from 1/3/94 and to 1/5/94. The most recent storm event beginning on 8/13 and subsiding on 8/18/94 was tropical storm Beryl.

Table 8: Maximum Height and Period for Five Storm Events

Event Date		SK	LBK2	LBK34	LK
10/29/93 to	$H_{mo(max)}$		1.78 m	1.99 m	1.42 m
11/1/93	$T_{p(max)}$		10.7 s	10.7 s	10.7 s
12/14/93 to	$H_{mo(max)}$	1.28 m	1.40 m	1.43 m	1.11 m
12/17/93	$T_{p(max)}$	9.1 s	9.8 s	9.1 s	9.1 s
1/03/94 to	$H_{mo(max)}$	1.84 m	2.23 m	2.15 m	1.62 m
1/05/94	$T_{p(max)}$	10.7 s	11.6 s	12.8 s	10.7 s
3/1/94 to	$H_{mo(max)}$	1.43 m		1.63 m	1.61 m
3/5/94	$T_{p(max)}$	10.7 s		10.7 s	10.7 s
8/13/94 to	$H_{mo(max)}$	1.26 m	1.51 m	1.72 m	
8/18/94	$T_{p(max)}$	8.0 s	7.5 s	8.0 s	

Table 8 illustrates two important facts. First, this data shows that in every case, the hard bottom sites recorded larger maximum significant wave heights for these storm events. Secondly, these five storm events occurred during the periods of highest sand sedimentation rates.

In order to demonstrate the relationship between significant wave height and sand sedimentation rate, Figure 6 displays the deployment averaged measurements for both the hard bottom sites and the control sites. Plotted on a log-log scale, Figure 6 shows that the sand sedimentation rate is an increasing function of the significant wave height. Furthermore, the hard bottom sites and the control sites plot with approximately the same trend. This supports the conclusion that the difference in sand sedimentation rate is largely due to the differences in significant wave height.

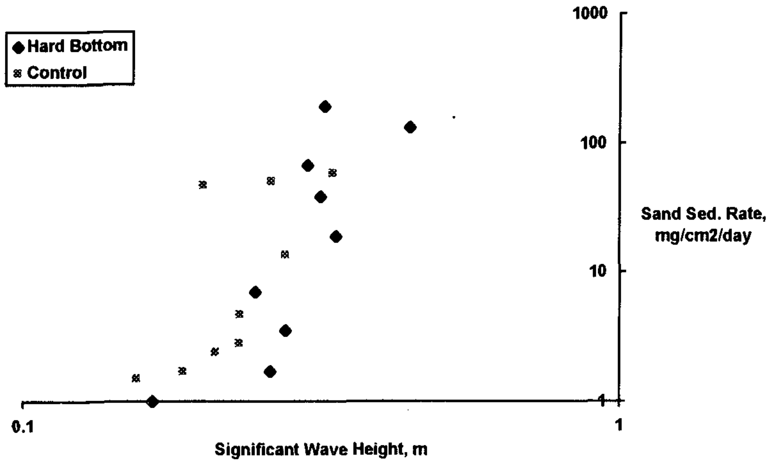

Figure 6: Log-Log plot of sand sedimentation rate versus significant wave height.

Conclusions

The analysis of the manual turbidity, sedimentation, and wave data revealed several significant facts concerning the differences between the hard bottom sites and control sites and the interactive dynamics between these three phenomena.

The manual turbidity measurements indicate high variability in space and time, and were probably under-sampled and biased toward low wave conditions. During the monitoring period, turbidities exceeding 29 NTU were measured only at sporadic locations on 11/10/93, 12/22/93 and 2/16/94. Based upon three measurement dates, the manual turbidity measurements during the nourishment indicate that the hard bottom sites experienced approximately 50% higher turbidity than the control sites. However, based on approximately 15 measurement dates, following nourishment the hard bottom sites experienced approximately 50% less turbidity than the control sites. Statistical analysis confirmed that the lower turbidity at the hard bottom sites relative to the control sites following nourishment is statistically significant at the 0.05 probability level.

The sedimentation measurements indicate that the sand sedimentation rates are highly variable, particularly with time. In contrast, the fines sedimentation rates are relatively less variable with respect to both location and time. It is evident from the examination of the sedimentation data that the sand sedimentation rates at the hard bottom sites were approximately 2.5 times higher than those of the control sites. The statistical analysis indicated that there is less than a 10% probability that this difference is due to chance. In contrast, there were no significant differences in fines sedimentation rates between the hard bottom and control sites.

The variations in sand sedimentation rates are believed to be directly related to the hydrodynamic forces resulting primarily from waves. During periods that included large waves, correspondingly large sand sedimentation rates were measured. Wave forcing also partially explains the trend for higher sand sedimentation rates at the hard bottom sites relative to the control sites. The wave height was approximately 33 % greater at the hard bottom sites. This higher wave height results in the wave energy being approximately 75% higher at the hard bottom sites relative to the control sites. The increased wave energy at the hard bottom site is probably the reason for the relatively higher sand sedimentation rates. Because a high sedimentation rate is an indication of high concentration of suspended sediment, these findings indicate that sand deposited at the hard bottom sites is most likely resuspended into the water column during periods of large waves.

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