CHAPTER 92

OPENING AND MAINTAINING TIDAL LAGOONS & ESTUARIES

by

Scott A. Jenkins; Douglas L. Inman
Shore Processes Laboratory A-009
Scripps Institution of Oceanography
La Jolla, California 92093

and

James A. Bailard
Civil Engineering Laboratory
Port Hueneme, California

1. INTRODUCTION

Sedimentation in tidal lagoons and estuaries has become an acute problem, particularly where there has been over-dredging to accomodate today's deep draft vessels, 0(15m). The rise in mean sea level, which created natural estuaries, has not kept pace with the demand for greater draft ships. The limited number of navigable lagoons confronting a growing demand for more inland waterways has encouraged reconstruction dredging of some closed or partially filled lagoons.

Man's efforts to deepen existing or relict estuarine systems have disturbed the steady state equilibrium of the systems. Sedimentation acts continuously to restore this equilibrium by either of two processes. One is floculation of fine-grained fluvial born sediments, a process accelerated when an estuary is deepened thereby allowing greater salt wedge intrusion. The other is the interception of the longshore transport of coarse grained beach sediments by the lagoon inlet. The larger tidal prism of an enlarged lagoon draws a greater percentage of the longshore transport into the lagoon from the adjacent surf zone. In the absence of wave suspension within the lagoon, very little of this sediment is carried back out of the lagoon on ebbing tides.

These sedimentation processes confront the coastal engineer with several distinct problems. A particular set of counter-measures are needed against accumulations of cohesive fines from the rivers, another set against accretion of cohesionless coarse grained sediments from the beaches. Still other methods are needed to reopen a closed lagoon.

Dredging has been the most widely practiced solution to all of these problems for the past 150 years. It is a solution we may not be able to afford indefinitely. In addition to intrinsic high rates of energy consumption and equipment breakdown, there are ever-growing costs associated with dredge spoils disposal. Ninety percent of the material annually dredged is contaminated by heavy metals, concentrated in the flocs from either natural erosion of country rock or industrial sources (Malloy, 1980). Further contamination results from chemical and oil spills, sand blasting, paint removers and other shipyard and harbor activities. Sand is rarely contaminated because it is chemically inert. The contaminated sediments pollute the disposal sights, imposing additional costs to measure the pollution and minimize its effect. Recent climatic cycles and real estate developments have accelerated erosion and sediment runoff, ultimately bringing many spoils ponds to full capacity before their expected lifetime (N.E.S.O., 1976). Ocean dumping of poisoned spoils is environmentally unsound and strictly limited by environmental protection laws. Alternative spoils ponds are generally available only at great distance from the lagoon, requiring expensive booster stations and additional pumping capacity to transport the dredge spoils (Little, 1975).

This paper reports on five separate prototype scale field experiments that test alternative measures to dredging. Two of these experiments evaluate techniques of resuspension and exclusion for reducing fine sediment accumulations in quiet water, cul-de-sac berths, where the observed shoaling rates are greatest and dredging most difficult. These berths are essentially sediment settling basins where currents are insufficient to resuspend new deposits. The fine sediment control studies were performed in and around berths at Mare Island Naval Shipyard. Another two experiments involved by-passing sand around the inlet of Agua Hedionda Lagoon, California using fluidized trenches funnelling into a crater sink. The final experiment used open trench fluidization to reopen Penasquitos Lagoon, California.

2. SEASONAL AND EPISODIC MUD ACCUMULATION IN BERTHS

There is abundant data showing that the deposition rates of settled flocs in berthing areas and around structures within a tidal estuary exceed those in unosbtructed navigation channels (NESO, 1978; Van Dorn, Inman, McElmury, 1977; 1978). This was dramatically shown in Mare Island Straits, California, during the record flood winter and spring of 1978 that brought an end to the California drought that began in 1945. Figure 1 compares the average bottom shoaling rates along a line extending across the navigation channel with the shoaling rates at two stations within the finger pier complex at Mare Island Naval Shipyard, pictured in Figure 2. Mare Island Straits are over-dredged to 13 m and situated at the confluence of the Napa and Sacramento Rivers on the eastern side of San Pablo Bay in the San Francisco Estuary. The shoaling at both stations within the finger pier berths at Mare Island were found to be three times the mean sedimentation rates across the navigation channel. Mud was found to accumulate at nearly uniform rates in both the channel and berthing areas through the wettest months of February and March, when the combined fresh water discharge of the Napa and Sacramento Rivers ran as high as $2.12 \times 10^3 m^3/sec$, about 1/2 the tidal flux in Mare Island Strait. When the river discharge dropped to $1.13 \times 10^3 m^3/sec$ by the end of April with subsidence of Pacific storms, the sedimentation rate in the finger pier berths abruptly increased. By this time 2 meters of new deposition occurred, 4 times the shoaling during the previous drought year of 1977 (Van Dorn, Inman, and McElmury, 1978).

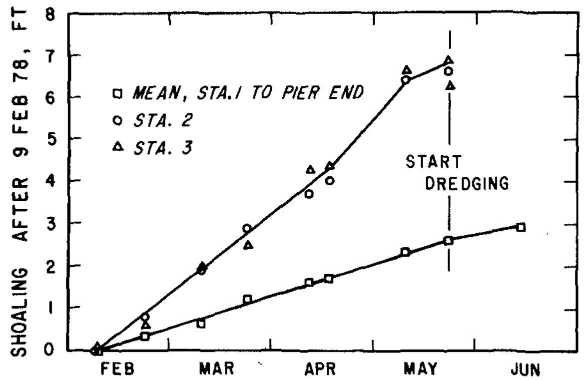


Figure 1 Shoaling history within a berth and across a navigation channel.

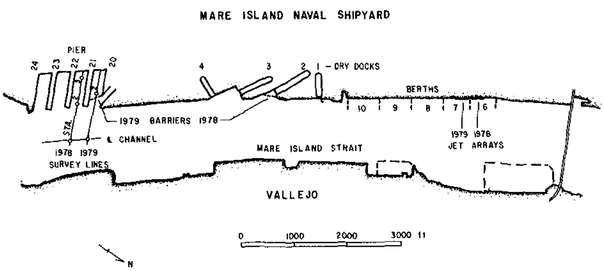


Figure 2 Mare Island Strait, ebb current and river flow to the left.

Initially new deposits of mud are fairly mobile, fluid mud, with a low threshold of motion of typically 15 cm/sec depending upon the time of immobility of the mud (Le Mer, 1962, and Van Dorn et al, 1977). In the navigation channels these threshold stress levels, ≅ (1 dyne/cm^2) are exceeded more frequently, particularly if not over-dredged. Some fraction of the newly deposited fluid mud is resuspended and flushed out by tidal circulation. The remaining fraction of resuspended floc settles again next slack water, eventually reaching quiet water. The quiet water of the berthing areas allow for much less resuspension of fluid mud and greatly restrict circulation that might remove the resuspended material. Low density fluid mud (10-15 gm/l) which is not resuspended within 24-72 hours begins to compact under gravity, driving out interstitial water. After a week it becomes a high density (1.22 gms/cm^3) anerobic mud, (Krone 1962) which can only then be moved by mechanical means. Eddies from pier piles, ship hulls and other vertical structures in and around the berth increase particle collisions and mix the higher salinity bottom water into the remainder of the water column, further promoting floculation. These factors all play a role in contributing to the higher siltation rates of berthing areas, although the relative importance of each may vary from place to place.

The seasonal variations of runoff in turn cause seasonal variation in sediment abundance and water properties. Figure 3 shows the vertical distributions of suspended sediment concentration, C, salinity, S, and temperature, T, from mid winter through summer 1978 at Station 3 inside the berth at Pier 23. Salinity and temperature are scaled on the horizontal axis in °/₀₀ and °C along with concentration in gm/l. These data were collected during spring tides at four phases of tidal elevation labeled H, L, F and E for high, low, flood and ebb respectively. The salinity profiles show that the river discharge during the maximal rainfall months, from February until mid April, produced a thick lens of fresh water on the surface and rather low bottom salinities of 1-7 °/₀₀. The salinity was uniform over depth at low tide indicating total retreat of the salt wedge from the berths by the end of ebbing tide. By mid June most of the Sierra snow pack had melted and the discharge of the Sacramento and Napa had fallen to $1.7 \times 10^2 m^3$/sec. The fresh water surface lens then grew thinner into summer until finally an isohaline vertical distribution of 20 °/₀₀ results from the tidal flux. The temperature distribution remains isothermal since thermal diffusivities $\cong$ ($10^{-3} cm^2$/sec) are large compared with diffusivities of salts, $\cong$ ($10^{-5} cm^2$/sec).

With the declining river discharge in late March, the salt wedge intrudes more freely into the berthing areas and bottom salinities reach the floculation threshold of 7-10°/₀₀ (see Krone 1962). From this time on through summer, suspended sediment profiles show a high concentration toe, $\cong$ (100 mg/l) in the lower meter of the water column. The toe is due to the settling of flocs toward the bottom boundary and the resuspension of those flocs by the tidal and eddy motion over pier piles, dredge banks and other bottom obstructions. However during periods of subthreshold salinities, e.g., following a train of local storms, 9 March 1978, the sediment remains uniformly distributed through the water column in spite of high sediment abundance.

The bi-weekly profiles of discrete properties in Figure 3 give a good resolution of the seasonal trends but may be somewhat aliased by weekly or daily variations. These short term fluctuations are most prevalent during the wet months as river discharge fluctuates daily in response to local storms passing over the water shed. As a result of these fluctuations, fine sediment deposition will exhibit episodes of extremely rapid build up, or "mud storms" when bottom salinities are near the floculation threshold (7-10 °/₀₀) while rivers remain laden with charged clay particles from recent runoff. Under these conditions four such mud storms, each depositing 0.6 m or more of new fluid mud at a time, were observed in the entrance to Pier 21 N at Mare Island during a near record flood winter in 1980 (see Figure 4). This echogram was taken using a 40 kHz echo transceiver. Each dated horizon is a veneer of loose floc trapped between thick layers of denser more consolidated fluid or anerobic mud. The trapping of these floc layers implies that the subsequent build-up of mud occurred so rapidly that insufficient

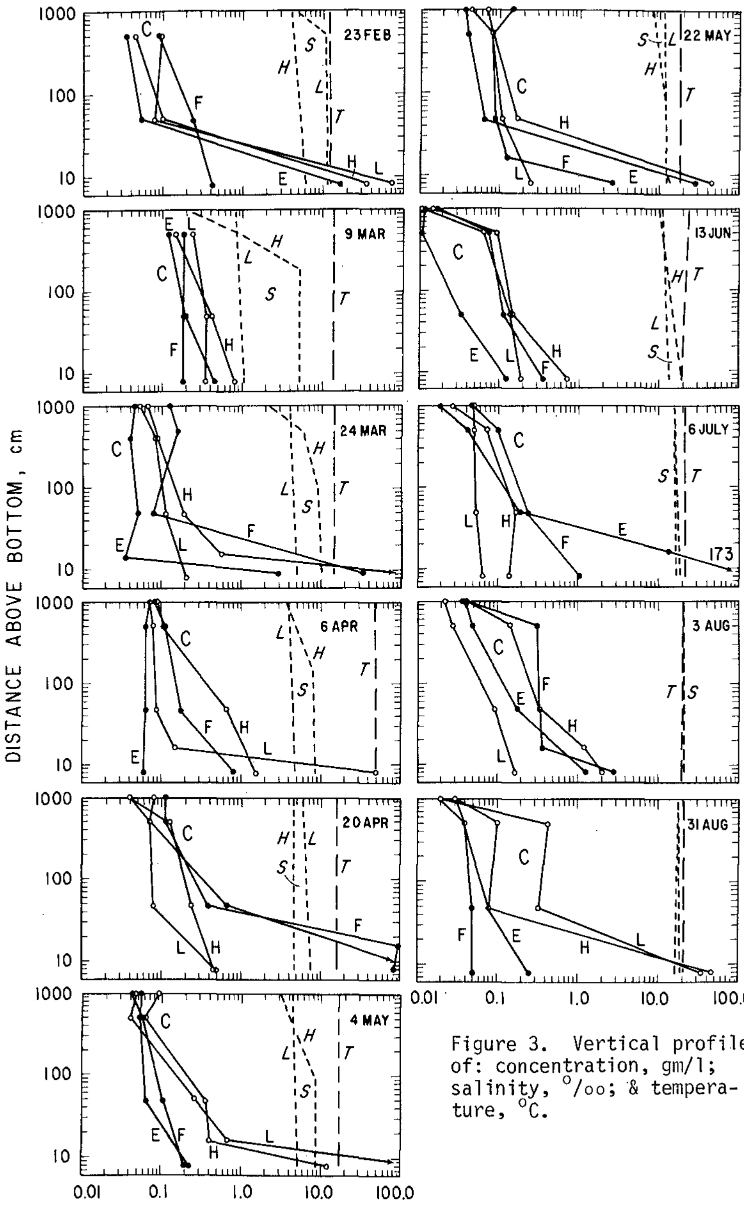


Figure 3. Vertical profiles of: concentration, gm/l; salinity, °/oo; & temperature, °C.

time had lapsed for the water content of the floc layer to diminish. The accumulations of these mud storms are found between the dates of the horizons following the initial pulse of runoff from series of Pacific storms. The rise in bottom salinity in between these pulses triggers floculation and a subsequent abrupt build-up in fluid mud. The flocs themselves appear as a speckled pattern in the water column between the surface reflection and the first bottom horizon on the echogram.

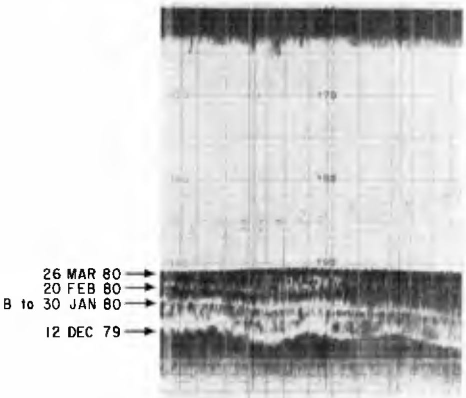


Figure 4

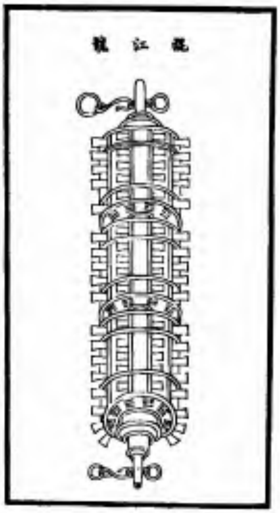


Figure 5

To a lesser degree the river discharge fluctuates during drier summer months, principally in response to manipulation of containment reservoirs and dam diversions. These fluctuations do not produce the episodes of rapid sediment accumulation found during the wet winter months. Shoaling in the summer months is characterized by a nearly steady state build up of about 0.25 cm/day. Whereas the controlling variable for shoaling in the winter is a bottom salinity of sufficient magnitude to induce floculation in the presence of high sediment abundance, the summer shoaling rate in the presence of higher salinities appears strictly limited by the small amounts of suspended sediment brought in by the rivers. Krone (1959, 1960) has shown by tracer studies that suspended loads in the lower 80% of the water during the summer are in fact resuspended by wind waves over permanent shoals elsewhere in the estuary and carried subsequently into berthing areas by the density-stratified tidal flows.

Although these seasonal and episodic variations of water properties and fine sedimentation were observed at a single place, the mechanisms of floculation and resuspension are at work in most every tidal lagoon and estuary. The fact that these observations were made during an extreme in the weather cycle and covered maximum ranges of temperature, salinity, suspended sediment, and shoaling rate, should make them a useful design guide for sediment control measures anywhere.

3. CONTROL OF MUD ACCUMULATION BY RESUSPENSION

The first attempt to control mud accumulation by resuspending newly deposited layers of fluid mud date back to the Chinese in the 5th century A.D. Figure 5 shows a rolling suspensifier, the hun chiang lung, first illustrated in the Ho Kung Chhi Chii Thu Shuo and reproduced here from Needham, 1974. This device was drawn along the bottom by a vessel or team of horses proceeding upstream. The teeth on the roller raised clouds of silt which were carried away on the ebbing tide.

The modern equivalent of the Chinese suspensifier is the tide actuated water jet array shown in Figures 6 and 7 tested on the water front of Mare Island at Berth 7 shown in Figure 1. The fundamental environmental constraint in the successful application of any such resuspending device is the presence of unidirectional currents for a sufficient period to advect away the material which has been resuspended. Berth 7 at Mare Island is ideal in this respect. This berth rests along the streamlined western shore of Mare Island Strait where 1200 m of unobstructed concrete quaywall stabilizes the bank against over-dredging to a depth of 10 m. Here bottom ebb current commences about 2.5 hours before high tide and persists for about 5 hours giving a rather long window to transport resuspended material. The weakest ebb current amplitudes at low river discharge, $10^2 m^3/sec$, still produce near threshold stresses for newly deposited fluid mud, rising from 20 cm/sec at 0.5 meters above the bottom to 80 cm/sec on the surface. The tide actuated switching circuit entered in Figure 7 was synchronized for a 4 hour duty cycle through the period of maximum ebbing bottom currents.

The water jet array itself, Figure 6, was designed to operate from a fixed mounting on the quay wall where vulnerability to damage from dragging anchors and channel dredging activities is minimized. The most protruding components, the jet nozzles themselves, are secured to the discharge manifold by a quick-release Camlock clamp for easy diver replacement in the event of damage or malfunction. Ten equally spaced 7.3 cm diameter jet nozzles comprise the linear array 63 meters in length at a depth of 8.2 meters below MLL sea level. The jet array was driven by a 1910 gpm water pump at 92 psi powered by a 140 hp, 220 v electric motor. The automatic switching circuit, Figure 7, sequences the entire pump discharge through each individual nozzle one at a time beginning from the upstream side of the array. This was accomplished through an arrangement of pneumatically operated pinch valves operating on an inlet pressure of 67 psi. In this way each jet is able to produce a discharge velocity of 760 cm/sec, or nearly 1.65×10^8 dynes of static thrust. Wall jet experiments by Poreh, et al (1967) and Sforza and Herbst (1969) indicate that the bottom stress on an immobile boundary will decay with distance, r, from the jet as $r^{-2.3}$. These data suggest that each jet will exert a super-critical bottom stress of 4.6 $dynes/cm^2$

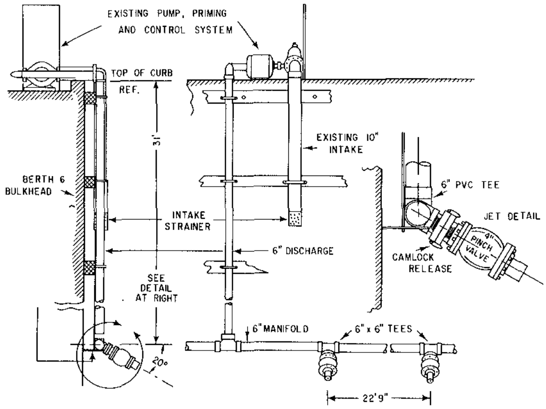


Figure 6: Quay wall Installation of Water Jet Array

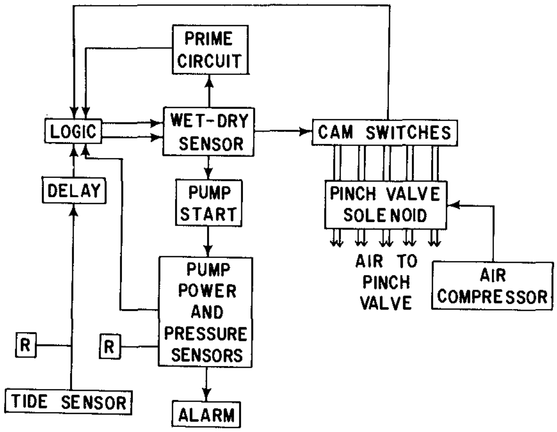


Figure 7 Tide Actuated Duty Cycle Control System for Jet Array

out to the design scour radius of 15.24 m, while not decaying to the threshold stress of fluid mud, 1 dyne/cm^2, until 30 m out from the quaywall. These ranges of coverages are sufficient to protect draft to beam ratios of most modern vessels.

The jet nozzles were inclined downward to allow the jet flow to be directed around the bottom of the hull of a moored ship, given the constraint of mounting the array above the over-dredged depth. A number of deflection angles were tested ranging from 20° to 45° of downward inclination. Figure 8 shows three time staggered bottom profiles along three separate range lines measured out from the concrete quaywall. Those for the control were taken downstream in Berth 8 (see Figure 1). Another control area was monitored on the upstream side of the area in Berth 6. Curves for Jet 3 and Jet 8 compare the effects of different degrees of downward deflection. Jet 3 used 29° of downward deflection while Jet 8 was inclined 35° downward from horizontal. Bottom profiles labeled 30 March were taken just after the completion of dredging in Berth 7. Curves labeled 17 May show the build up of mud over 1 1/2 months while the jet remained inoperative pending Coastal Commission permits. The jet array became operational on 30 May. Therefore the curves labeled 9 August indicate the scour and protection provided by the array over a 2 1/3 month period. The most nearly optimum coverage

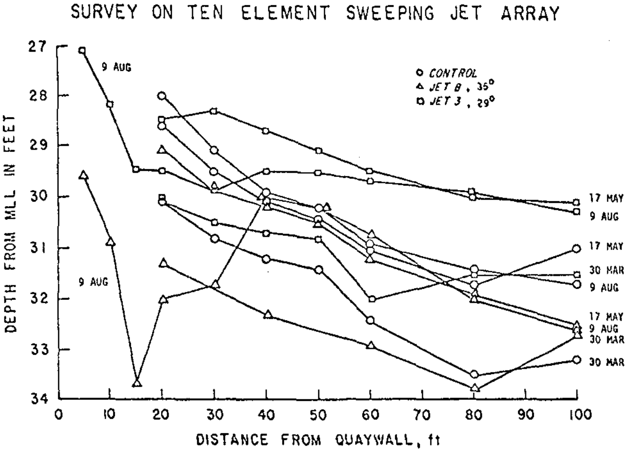


Figure 8

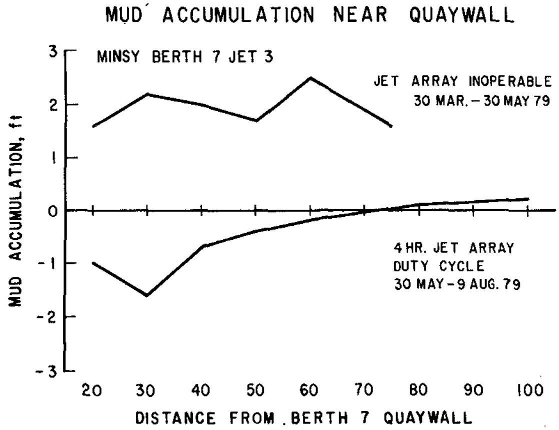


Figure 9

appears to have resulted from the 29^{o} downward deflection provided by Jet 3. The larger downward deflection of Jet 8 is shown in Fig 8 to have excavated a 1.2 m deep impact crater extending from 3.05 to 12.19 m out from the quaywall, but depositing a mound beyond 12.19 out to 21.33 m. The lower curve of Fig 9 plots the net change due to Jet 3, showing scour out to 21.33 m and little new accumulation out to 30 m during the 2 month operational period. Integrating over all survey contours for the entire array, and comparing with the accumulations at the upstream control in Berth 6, it was determined that the jet array prevented or scoured 1200 cubic m of deposition in Berth 7 from 30 May to 9 August.

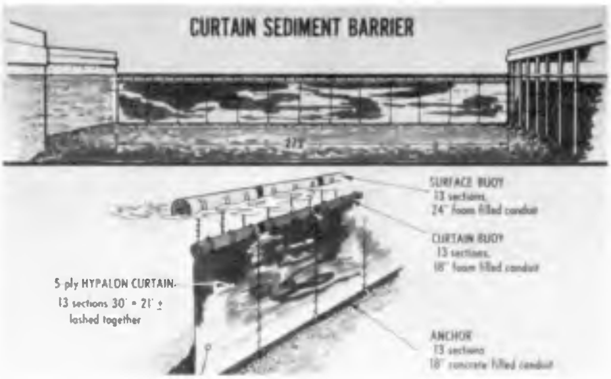
There was also an additional downstream influence from the jet array that can be found in the control contours from Berth B in Fig 8. Here only about 15 cm of new deposition was observed over the 2 1/3 month operational period as compared to an average of 45 cm during the same period at the upstream control in Berth 6. Factors which may have contributed to this apparent downstream influence were the presence of a 13 m diameter submarine and a highly stratified and stable water column with a Richardsons number, $R_i = g(d\rho/dz)/(du/dz)^2 \approx 10^3$ through May and June. Both these factors inhibit vertical mixing and keep the turbulent jet effluent confined near the bottom where it resuspends sediment while being advected downstream with the ebb flow.

The jet array resuspension technique is an attractive alternative to bucket and scow dredging presently used near structures. The jet array was also found to effectively prevent the new accumulations of mud along channel-side quaywalls during hopper dredging of the navigation channel.

4. CONTROL OF MUD ACCUMULATION BY EXCLUSION

Finding that the preponderance of suspended sediment is in the lower portions of the water column (Figure 3) led to the hypothesis that a flexible barrier, or curtain, could block these sediments from continuously circulating and settling into a berth by either tidal density-stratified currents or eddy motions. The finger pier complex notched out of the banks of Mare Island Strait (Figure 2) is well suited for this application. The entrance to the berth in between Pier 20 and

Figure 10



21 was partitioned off from the main channel by a 82.9 m long Hypalon curtain that extended from the bottom up to MLL sea level (see Figure 10). The lateral seal on the berth was provided by an undredged mud bank extending up to MLL water under Pier 21, and by a concrete quay-wall on the Pier 20 side. The 1.2-2.1 m gap over the curtain and mud bank between MLL and MHH water allows Berth 20-21 to equilibrate any sea surface inequality with the channel or neighboring berths during a tidal cycle. The lens of water overtopping the curtain and mud bank would be expected to transport a negligible amount of suspended sediment, even for the nearly isotropic conditions of peak rainfall periods, as during the 9 March extreme shown in Figure 3.

The curtain was constructed in 13 sections, each 6.4 m in length. The Hypalon curtain material on each section was anchored to the bottom by an 18 inch storm drain conduit filled with concrete aggregate weighing 8000 lbs. The 9.14 m high curtain sections were supported vertically in the water by curtain buoys constructed from 18 inch storm drain conduit filled with poly-eurathane foam. A pair of air filled 10 inch diameter PVC pipes were retrofitted to the curtain buoys, seen in Figure 11, to trim the buoyancy against additional water absorption by the foam and concrete aggregate.

Figure 11 Rigging a curtain section for proper buoyancy

To raise the curtain as shown schematically in Figure 12, a second set of buoys at the surface are connected by a length of chain sufficient to extend down to the submerged buoy floats at a higher high water during spring tides. At the low tide preceding curtain opening, the surface floats and buoy floats are at nearly the same level, and the slack chain is drawn up and secured by a stopper arrangement. With the ensuing flooding tide, the additional buoyancy of the 24 inch diameter foam filled surface buoys are sufficient to gradually overcome the bearing stress of the fluid mud, about 20 dyne/cm^2, seen in progress in Figure 13. At high tide the curtain floats free of the bottom illustrated in Figure 11, whence it can be swung open into the berth by towing behind a small tug boat as shown in Figure 14. The end about which the curtain pivots was anchored to Pier 21 by cutting a notch in the slope of the mud bank and allowing the first curtain sections to become buried. The curtain rotates about tongue and pin joints between the second and third sections. Consequently it was not necessary to raise the first two sections allowing surface floats adjacent to Pier 21 to be removed. This gave access to the berth by shallow draft barges while the curtain still remains closed and anchored (Figure 15).

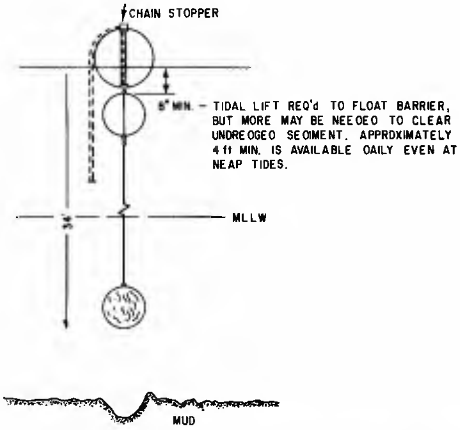


Figure 12 Curtain cross section in raised configuration

Figure 13 Surface buoys while raising anchored sections from the mud during a rising tide

Figure 14 The curtain being opened by the Sea Mule yard tug

Figure 15 The curtain in the closed and anchored configuration as seen looking into the Pier 20-21 berth

The shoaling with time averaged across the Pier 20-21 berth appears in Figure 16, comparing mean shoaling on two survey ranges inside the curtain with another two outside. The range lines were taken across the berth perpendicular to Pier 21 at positions measured from the shoreward end of the 228.6 m length Pier. The shoaling along these range lines is shown in Figure 17 to have been fairly uniform. Four months of

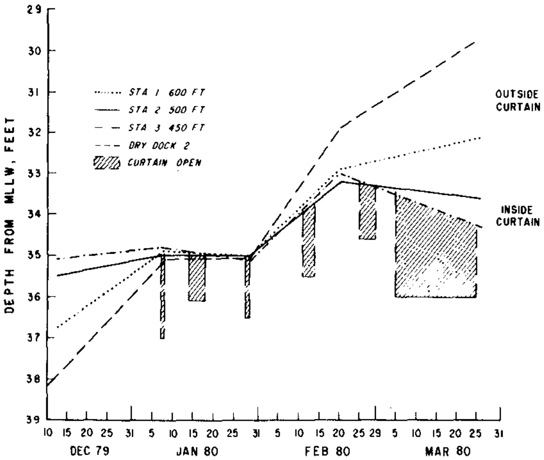


Figure 16 Shoaling history averaged across the berth

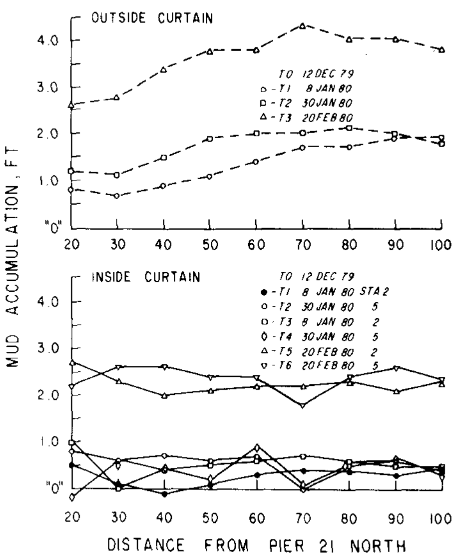


Figure 17 Mud accumulation across the berth beginning from 12 December 79

operational testing with six curtain opening cycles showed that only 0.46-0.76 m of new deposition occurred inside the curtain while 1.52-2.59 m accumulated in the unprotected waters outside the curtain. This represents a 70% effectiveness during high depositional conditions with several protracted periods in the open configuration necessitated by ship movements. An apparent dredging savings of between 18,000 to 30,000 cubic meters was achieved. This 4 month savings payed for the material costs of the curtain considering dredging costs at the present local value of \$2.50/yds^3. Comparing the dates in Figures 16 and 17 with the mud storm events in Figure 4 it is concluded that most of the deposition behind the curtain occurred during February when the curtain was open for only one 3 day period. Only about 6" of deposition inside the curtain occurred in the months of December, January and March when there were 5 opening cycles adding up to 36 open days. Therefore the timing between mud storm events and curtain opening seems critical in achieving maximum protection of a berth by exclusion techniques. It was fortunate in this experiment that the curtain happened to be closed during the mud storms in December and early March when the large mud accumulations are shown in Figure 16 to have occurred outside the curtain.

5. CONTROL OF SAND ACCUMULATION BY CRATER-SINK/FLUIDIZATION

The crater-sink sand by-passing concept, which uses a crater shaped depression in the channel bed to capture sand, was first proposed by Inman and Harris (1970). Several systems based on this concept have been tested in both the laboratory and the field (Harris et al, 1976; McNair, 1976), and full scale systems are currently operating at Mexico Beach, Florida (Pekor, 1977), and at Rudee Inlet, Virginia.

One of the limitations of the crater-sink concept has been the relatively small trapping radius as compared with depositional patterns. Harris et al (1976) found that the trapping radius of a crater could be enlarged by feeding the crater with a fluidized trench cut across the depositional area. These trenches are themselves sinks to the sediment flux. The trench is both cut and maintained by a fluidizer pipe having a line of downward axially slanted water jets along its length. The jets fluidize the neighboring sand and impart momentum to the resulting slurry in the direction of the jet effluent. A momentum survey of the process in closed duct configurations is discussed in Bailard and Inman (1975).

The Agua Hedionda Lagoon selected for these experiments is located 30 miles north of San Diego, California. The lagoon consists of an outer, middle and inner section with a total area of $1.04 \times 10^6 m^2$. The tidal prism is approximately 1.68×10^6 m^3, passing through a stabilized inlet channel with a cross sectional area of 33.4 m^2. One third of the tidal prism is removed from the lagoon each tide cycle and diverted through the cooling condensers of a power plant and discharged into the sea. The corresponding reduction in ebbing currents through the inlet which intercepts the longshore transport of sand results in an average influx of beach sands of about 11,000 m^3/month. This influx is deposited entirely in the outer lagoon where the utility company operates a suction dredge on a yearly or bi-yearly basis.

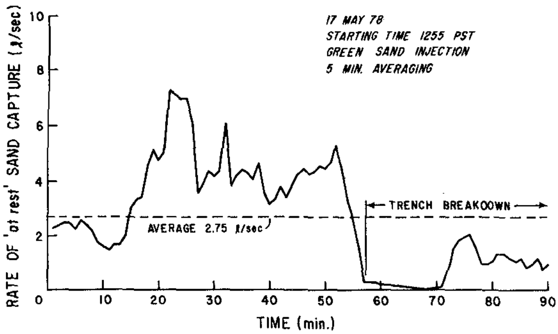
A crater-sink/fluidization sand by-passing system was designed to intercept the inflow of sand and return it to the downdrift (south) beach face (Figure 18). The system was sited at two different locations between

Figure 18

1978 and 1979 near the outer bank of the curved inlet where the centrifugal accelerations on a flooding tide direct the influx, depositing a sand bar. The latest of several system designs for Agua Hedionda Lagoon consisted of a 1-4 m deep crater excavated by a 6"x6", 150 hp centrifugal dredge pump connected to a 270 m long, 6 inch diameter discharge pipeline. A 50 m long fluidizer trench cut across the primary depositional bar powered by a 6 inch 100 hp water pump discharging into the crater on the interior downslope side of the bar. The fluidizer pipe was 4 inches in diameter with 0.282 cm diameter jets drilled at 45^{o} angles and spaced 6.25 cm apart. The flow rate from the fluidizer drive water pump was 784 gpm at 100 ft total head pressure. One third of this discharge was diverted to a 2 inch diameter liquifier jet in the bottom of the crater, dropping the pressure to the fluidizer pipe down to 22 psi. The liquifier jet fluidized the sand at the crater suction inlet to minimize suction losses on the dredge pump. The flow rate through the dredge pump and sand discharge pipeline varied between 890 and 1000 gpm at 180 ft of total head, depending upon the amount of vertical lift required to remove the sand. To minimize the required suction lift, which varied between 2-6 m depending upon crater depth, tidal phase, and sand bar level, the pumping systems were operated from a moored barge.

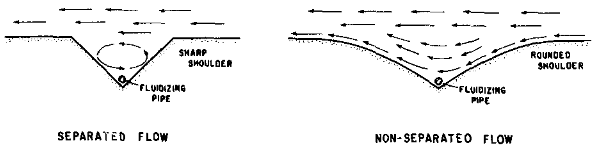
To evaluate the ability of the system to capture and by-pass sand, the flow rate and sand concentration in the discharge line was monitored through the period of maximum flooding tide. Figure 19 shows the by-passing history during the 1978 experiment using a 60 cm deep fluidizing trench. The mean capture rate of 2.75 l/sec accounts for about 1/2 of the average sand influx rate, 4-6 l/sec. Flood currents during this period peaked at 130 cm/sec on the surface above the fluidizer trench. If the sediment transport rate is taken to vary as the cube of

Figure 19



the velocity according to Bagnold (1966) then 1/2 the sand influx would be suspended load at these current speeds. Hence the capture efficiency of the system is in proportion to the bed load. Suspended load is transported over a shallow fluidizer trench. Furthermore underwater observations discovered that the initially sharp lip of the trench became rounded (Figure 20) after about 55 minutes of operation under currents in excess of 1 m/sec. With this round-off the flow no longer separated at the top of the trench, allowing the flood current to sweep into the

Figure 20



trench and carry away sand, as indicated in Figure 19 by the decline in sand capture with the onset of trench breakdown.

To avoid trench breakdown the 1979 experiment was moved further into the lagoon where flooding current amplitudes and suspended load were less. The fluidizer trench was deepened to 3 m to create a flow divergence over the trench that would drop the suspended load. Figure 21 shows bypassing time histories in which the average total sand influx (5-6 l/sec) was exceeded for extended durations without trench breakdown at current speeds as high as 110 cm/sec. However, these experiments were plagued by extra-normal amounts of kelp and bottom debris broken loose offshore by unseasonably high waves and subsequently swept into the lagoon on flooding tide. When captured by the system and mixed into the fluidized sand, the kelp would conglomerate in masses as large as 10 m in diameter which the system had insufficient power to move. A porous screen lid over the trench and crater successfully shielded the system for a two week period but required frequent diver maintenance. Another approach tested was to simply allow a kelp fouled system to become buried. Under the added pressure of the sand overburden kelp decays anerobically to a

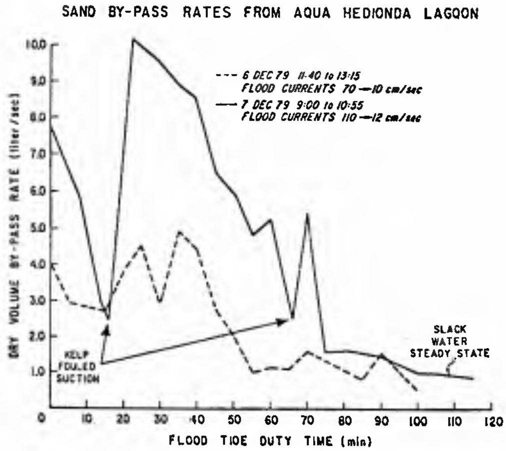


Figure 21

less fibrous black mulch which the system can move again in several days to a week. With a single fluidizer trench this procedure restricts the number of by-passing cycles. To circumvent that in future by-passing schemes, multiple fluidizing trenches extending out from a single crater in a fan arrangement could be alternately cycled and allowed to bury once fouled.

6. OPENING A TIDAL INLET BY OPEN TRENCH FLUIDIZATION

Peñasquitos Lagoon is a relatively small lagoon encompassing about $1.29\times10^6 m^2$ and is located approximately 10 miles north of San Diego. Past studies have shown that the normally closed lagoon inlet channel is periodically opened during times of high precipitation in which the lagoon

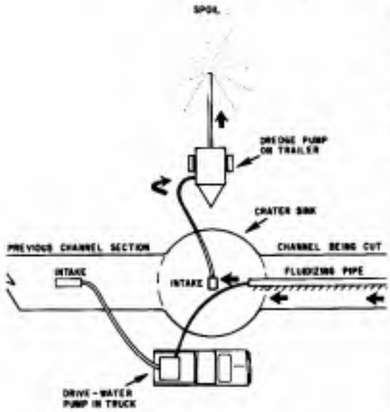


Figure 22

Figure 23

is filled to overflowing. The lagoon then remains open until it is closed by the longshore transport of sand. Closure is enhanced when high waves coincide with neap tides. This condition results in a large influx of sand into the lagoon and causes a sand plug to form in the seaward end of the inlet channel. An overwash fan then forms behind the sand plug, filling the channel with sand.

A crater-sink/fluidization system was designed to cut a new channel across the sand plug. The system consisted of a 6 inch, 100 hp dredge pump connected to a short discharge pipeline, and a 43 m long spiral wound fiberglass fluidizer pipe powered by a 4 inch, 30 hp water pump (Figure 22). The design of the pipe was based on a modified form of the analytic model developed by Bailard and Inman, (1975). The fluidizer pipe was 4 inches in diameter with 0.145 cm diameter jets angled at 45^o and spaced 6.3 cm apart. The water flow rate to the pipe was 520 gpm at a pressure of 3.85×10^6 dynes/cm^2, (55 psi).

The procedure for cutting the channel consisted of starting at the lagoon and "leap-frogging" the system across the overwash fan. The system successfully cut a 210 m long channel in 5 steps (Figure 23) removing 600 m^3 of sand. In fine sand the fluidizer moves sand at a rate of 100 m^3 per hour; however due to the presence of extensive cobble beds, the maximum cutting rate of the system was 30 cubic meters per hour, cutting a 1.5 m deep, 3.7 m wide, 43 m long channel segment in approximately 3.5 hours.

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8. ACKNOWLEDGEMENTS

The Fine Sediment deposition control studies in this paper were funded by the Naval Facilities Engineering Command through the Geography branch of the Office of Naval Research, Contract No. N00014-76-C-0631. The 1977-78 Agua Hedionda and Penosquitos Lagoon experiments were sponsored by NOAA, Office of Sea Grant, U. S. Oepartment of Commerce under grant number UCSD-R/CZ-33D.

The authors are grateful for the efforts of Or. William Van Oorn, who was our colleague in the fine sediment studies prior to his retirement in August 1979. We have appreciated assistance and logistical support from Mr. James Oillard, technical assistant to the public works officer at Mare Island Naval Shipyard. We are further indebted to Marion Horna, plant manager, San Diego Gas and Electric Co. for the support of cable, barges, and electric power in the Agua Hedionda bypassing experiments.