CHAPTER 75

PHYSICAL CHANGES IN ESTUARINE SEDIMENTS ACCOMPANYING CHANNEL DREDGING

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ABSTRACT

The physical characteristics of estuarine sediments provide useful information about sediment sources, the nature of bottom surface stresses and sediment transport mechanisms. Changes in sediment composition and state are also useful indicators for estimating the effects of unnatural stresses on dependent chemical and biological activities. In this study, the changes in several sediment properties have been monitored for an isolated estuarine dredging project.

The effect of estuarine hopper dredge activities has been evaluated for an Army Corps of Engineers project at Coos Bay, Oregon. The project included suction head dredging at a shoal area within the navigation channel and in bay spoiling at a deep section of channel one mile downstream from the dredge site. Core samples were taken five days before dredging and two, thirteen and seventy days after dredging at the dredge and spoil sites. Subsequent laboratory analysis of the core samples revealed that dredging induced redistribution of bottom sediments produced significant changes in several physical characteristics of the dredged material. Repeated resuspension of bottom sediments during the dredging and spoiling operations caused a net loss of fine grained sediments and light organic constituents. Several symptomatic changes were observed which validate this finding, including: an increase in median grain size and decrease in uniformity of dredge spoils due to loss of fine fractions; a decrease in volatile solids in the dredge spoils due to a net loss of organics; a decrease in porosity at the spoils site due to the ability of the coarse grain sediments to resist resuspension; and a decrease in hygroscopic moisture content due to loss of porous organics and silt-clay material from the spoils.

Conditions following dredging were observed for a period of seventy days. Partial recovery of the sediment system was observed after two weeks with no further recovery in two months. The initial recovery came about due to the availability of local sources of resuspended sediment adjacent to the dredge site. This occured under low flow conditions in early fall. Complete recovery of the system was not observed and probably requires the relatively large sources of sediment which accompany heavy winter and spring runoff. Thus, the immediate effects of dredging may persist until the annual cycle of sediment erosion and deposition have occurred.

INTRODUCTION

Equilibrium Conditions

Estuarine sediment systems tend towards boundary stability as a result of long term sediment transport equilibrium. Short term local events may cause erosion and accretion to be temporarily out of balance and observations over geologic time scales may reveal gradual sedimentation. However, the mean geometrical configuration of an estuary remains quite stable over time periods measured in years, decades and centuries. A complex system of channels, embayments, tidal flats and barriers of varying permeability compose this quasi-stable boundary configuration. The system is in harmony with the flushing patterns and the sediment sorting patterns which ultimately determine the distribution of biological activity within the estuary.

Dredging represents a perturbation in this trend towards boundary stability. Utilization of an estuary as a commercial resource often requires the creation of navigation channels in areas where natural sedimentation has produced shoals. Subsequent deposition of the spoils causes excess accretion in areas where erosion and accretion were previously in balance. As a result, the boundary configuration of the affected areas is changed from the equilibrium condition. The estuary responds by increased accretion in the dredged channels where a local increase in the cross section area reduces mean velocities and reduces the sediment load capacity of the flow. At the spoil sites, excess deposition reduces the flow area, increases the local velocity and causes erosion of the spoiled materials. Thus, the estuary attemps to restore the equilibrium condition and return to the stable boundary configuration. Sedimentation within the navigation channels necessitates further maintenance dredging and cycles of artificially induced erosion and accretion result.

The effects of these dredging induced changes on an estuarine ecosystem can not be determined without detailed information ahout temporal and spatial variation in important ecosystem descriptors. However, it can be postulated that if dredging activities represent a significant input to the total annual sediment budget for a given area, then some response in dependent physical, chemical and biological processes might be anticipated. Furthermore, if dredging is repeated on a regular basis or if dredge scheduling interfers with critical annual cycles such as spawning, then some long term changes in sensitive biota could occur.

The study described herein was undertaken to investigate some short term effects of a small scale dredging project in an estuary which is routinely dredged at an annual rate which approaches the estimated sediment flux from upstream water shed sources. Although other investigators within the interdisciplinary research group studied changes in sediment chemistry and benthic biological acticity, (i.e. Slotta, et al) this discussion is confined to observed changes in the physical characteristics of surface sediments.

Study Site

The study was conducted at Coos Bay, Oregon. Coos Bay is one of the most active timber ports in the world and is located 200 miles south of the Columbia River on the Oregon coast. The estuary surface area encompasses 10,000 acres, half of which is tideland. Waterborne commerce approaches four million tons annually, most of which is associated with the logging industry. The commercial area

of the estuary extends to river mile 17.

Annual maintenance dredging averages about 1.8 million cubic yards of which approximately 30% is removed from the study site at river miles 12 through 15. Prior to the study, this region had not been dredged for more than a year so that relatively undisturbed conditions could be assessed before dredging. A small shoal, 8,000 cubic yards, was removed via hopper dredge from the confluence of the Coos River with Isthmus Slough at river mile 14 to maintain a navigable depth of 30 feet. See Figure 1.

The dredged material was removed in 1800 or less cubic yard loads by the U. S. Army Corps of Engineers' hopper dredge Chester Harding and spoiled in mid-channel at River Mile 13 where the water depth exceeded 35 feet. Spoiling occurred onan ebbing tide with maximum observed bottom currents of 1.5 feet per second.

Hypothetical Dredge Disturbance

A dominant feature of hopper dredging activities is the resuspension of bottom sediments. As a dredge suction head passes through a dredge site, surface sediments are drawn into the head and pass to the hopper. Some of the material around the suction head is disturbed mechanically and thrown into suspension. Heavier particles settle out after the disturbance passes, while lighter particles remain in suspension due to ambient turbulence and may be transported from the original site by local currents. The material which passes into the hopper is initially in suspension, but the heavier particles settle to the hopper bottom. The lighter particles remain in suspension and some are returned to the estuary water column via the hopper overflow. At the spoil area, the contents of the hopper are released and settle to the bottom as a slurry. Surface shear during descent and impact-induced mixing at the bottom resuspend a portion of the material; again, the fines may be transported from the spoil site. As a result of repeated resuspensioning and settling and the subsequent loss of fines, it is hypothesized that dredge spoils may contain smaller fractions of fines than occur at the dredge site. Furthermore, the organic constituents within the sediment can be expected to wash out of the spoil material if they have low specific gravities or small particle sizes.

If a net loss of fines and/or organic constituents does occur, then changes in several physical parameters would include:

1. an increase in mean particle size at the spoil site due to loss of small particles;
2. a decrease in uniformity due to selective removal of fines;
3. an increase in porosity and water content due to slow consolidation rates and decreased uniformity;
4. a decrease in mean specific gravity due to loss of lighter fractions; and
5. a decrease in volatile solids due to loss of organics.

Sampling Program

In order to investigate changes in these parameters, bottom samples are required from the dredge and spoil sites before and after dredging. Post-dreding samples are also required to determine if a tendency exists to return

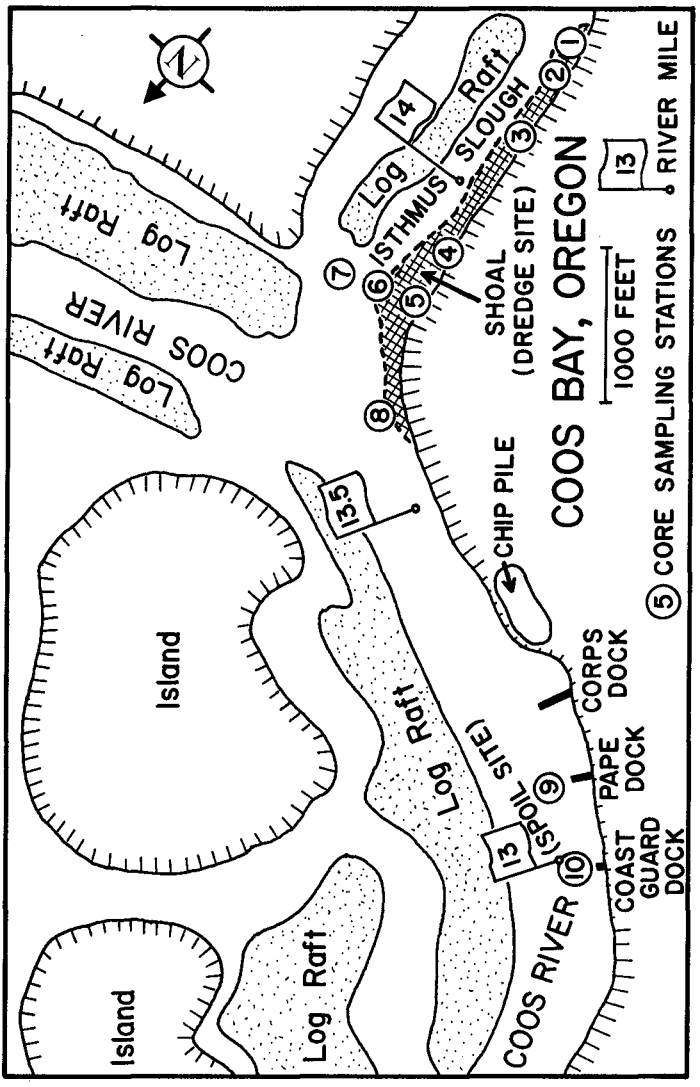

Figure 1. Coos Bay Oregon, River miles 13 to 14. Core sample station locations.

to initial conditions from natural erosion and sedimentation processes. Relatively large and undisturbed samples are required because of the number of tests to be run on each sample. In addition, some profile information is required to evaluate the depth dependence of the properties in question. To satisfy these requirements, the sampling program included:

1. gravity core sampling stations in the dredge and spoil areas to evaluate surface and subsurface physical properties of bottom sediments before and after dredging;
2. a line of sampling buckets along the longitudinal axis of the spoil site to evaluate spoil properties immediately after release from the hopper, and
3. sediment stakes alongside the buckets at the spoil site to investigate subsequent rate of erosion and/or deposition.

The locations of the ten core sampling stations are identified as circled arabic numerals on the chart in Figure 1. Seven of the stations are located in the dredging area (River Mile 13.8 to 14.2) to provide adequate sampling for a limited number of passes by the dredge over a relatively expansive area. Station Eight is two-tenths mile downstream from the dredge area (River Mile 13.6), Station Nine is at the center of the spoil site (River Mile 13.1) and Station Ten is at the downstream end of the spoil site (River Mile 13.0).

Core samples were taken 5 days before, 2 days after, 13 days after and 70 days after the dredge operation. Each sample was obtained with a 300-pound gravity corer constructed by the research team. Core liners (1-7/8 inch diameter acrylic tubing) were used; core lengths varied from 4 to 20 inches.

Twenty-five sampling buckets were placed at 100-foot centers along the assumed center line of the spoil area. Five-gallon paint cans were used with 30 pounds of concrete added as ballast. The buckets were tied to a common line for spacing and lowered from the surface with the sediment stakes attached. SCUBA divers were used to position the buckets and set the sediments stakes in place. SCUBA activities were hampered severely by limited visibility of 6 inches to a few feet. As a result some of the buckets and stakes were not placed properly before spoiling occurred.

The sediment stakes were fabricated from No. 3 reinforcing steel bars, 5-feet long. A 6-inch bar was welded on at the 2-foot level to support a plywood plate to resist penetration into the bottom. Tape rings were placed at one-tenth foot intervals to be used as depth indicators.

LABORATORY ANALYSIS

Sediment samples were stored for a period of two to six months before physical analyses were completed. Cores were kept sealed to prevent loss of pore water and shrinkage, but no attempt was made to stop chemical and biological reactions.

Samples were extruded from the cores in four-inch segments. Consequently, profile information is limited to averages over four-inch intervals. Individual samples were separated and dry prepared according to ASTM Designation D 421-58. Particle size analyses included sieving, hydrometer and hygroscopic moisture content analyses were conducted according to ASTM Designation D422-63 except

that wood chips larger than 0.589 mm (#30 sieve) were removed by sieving in preparation for particle size analysis.

Percent volatile solids were measured as the percent difference in weight after combustion at 600°C for four to six hours. This time was larger than the 15 minutes recommended by Standard Methods due to the large sizes of both the sample and the individual wood chips.

Specific gravity determinations were made in accordance with the procedure recommended by Lambe (1951). Tests were run on all surface samples at the spoil site and on random samples at the dredge site.

Porosity was calculated from the combined measurements of sample volume, oven dry weight and specific gravity. Due to uncertainties involved in sample partitioning and the subsequent volume determination, this quantity can be expected to have large standard deviations.

In the data analysis that follows, specific samples may be identified by number. The sample identification numbers may be interpreted as follows:

1. the first number refers to the station location (Figure 1)
2. the letter refers to the date the sample was taken; e.g.
   A = 5 days before dredging
   B = 2 days after dredging
   C = 13 days after dredging
   D = 70 days after dredging
3. the last number refers to the depth of the sample; e.g., 08 refers to a four-inch long sample extending from the four-inch level to a maximum depth of eight inches.

Thus, sample number 6C04 is from Station 6, thirteen days after dredging and extends from the water-bottom interface to a depth of four inches. Bucket samples are prefixed with a letter "B". Finally, a 12-inch core was taken by SCUBA divers at a mound near Bucket 16 seven days after dredging. The resulting four-inch long sub-samples of that core are designated 16-4, 16-8 and 16-12.

INTERPRETATION OF RESULTS

Repetitive samples were not taken at each station so a statistical analysis could not be performed to evaluate confidence intervals from the data. In lieu of a statistical analysis, the results are presented such that trends in the data for composite regions of interest are isolated. That is, data from individual stations are combined to produce regional characteristics for the dredge site and the spoil site. It should be recalled that Stations 1 through 7 were approximately within the dredge site. Stations 9 and 10 and the buckets were within the spoil site and Station 8 was in between the two regions, but closer to the dredge site.

Particle Size Distribution

Grain size analysis graphs for each sample are presented in the report by Slotta, et al. Three important parameters can be identified from these graphs. The first is the median grain size (D_{50}), which is defined as the

particle diameter which divides the sample into 50 percent portions by weight. This parameter is useful for classifying the gross features of the material as either predominantly sand, silt, or clay. The second is the effective grain size (D_{10}) which designates the particle diameter below which 10 percent of the sample is finer by weight. This parameter correlates well with the permeability of the material (Lambe, 1951) and indicates the ease with which fluid will flow through the sediment, e.g., large D_{10} values indicate less resistance to flow. The third parameter is the uniformity coefficient, defined as D_{60}/D_{10}. which expresses the relative homogeneity of the sediment sample; values less than 2 are termed uniform.

Changes in these parameters could be observed by plotting each parameter versus station number as a function of time. However, a more useful representation is formed by plotting two of the parameters against each other and noting segregation and change as a function of location, time and associated dredging activity. This type of graph also identifies functional relationships between variables.

The technique is illustrated in Figure 2, where the uniformity coefficient is plotted versus median grain size for surface samples five days before and two to seven days after dredging. Station numbers are printed adjacent to the appropriate point. Regional properties are identified by enclosing points with similar features. In Figure 2, it is shown that before dredging, surface samples (above a depth of four inches) at both the dredge and spoil sites grouped fairly well with an average median grain size of approximately 0.04 mm and an

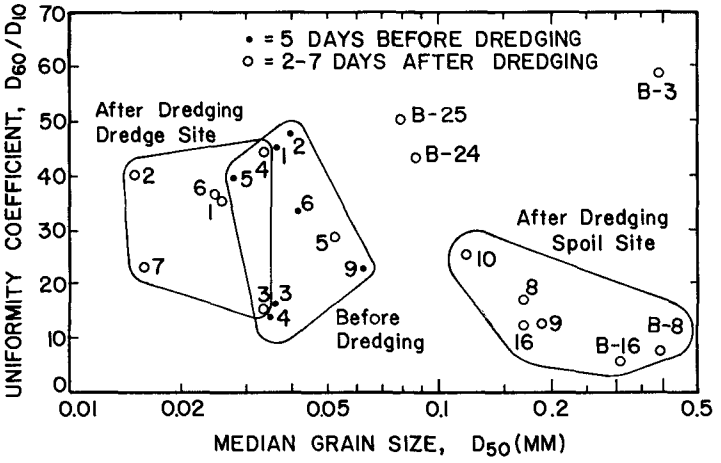

Figure 2. Uniformity coefficient versus median grain size.

average uniformity coefficient equal to 30. Two days after dredging, however, these parameters differed between the dredge and spoil areas. It is apparent from Figure 2 that an average six-fold increase in the median grain size occurred at the spoil site, while the dredge site experienced a decrease in median grain size by a factor of two. Associated with this change is decrease in uniformity at the spoil site.

The spoil site behaved in accordance with the hypothesis that repeated resuspension of the sediment during dredging causes a net loss of fines. This process results in an increase in the median grain size and a more uniformly coarse material. Whereas the dredge material is classified as a well graded silt, the spoil material has the characteristics of a well graded fine sand. Exceptions to the noted trends are evident in spoil samples B-3, B-24 and B-25. This is probably due to the fact that these locations are at the extremes of the spoils area and are not completely indicative of spoil conditions.

The dredge site behavior appears to be an anomoly since a decrease in median grain size is experienced which is contrary to the anticipated effect of combined mechanical and hydraulic agitation of the surface sediment causing a loss of fines. The reason for this behavior is evident from an examination of Figure 3. In this figure, the uniformity coefficient is plotted versus median grain size for surface and subsurface samples at the dredge site before dredging. The graph clearly shows that the surface sediment is more coarse than the subsurface sediments. Thus, the effect of dredging is to remove the surface sediments and expose the finer subsurface materials. The effect of hydromechanically disturbing these subsurface sediments is less significant. However, it is apparent from a comparison of Figures 2 and 3 that the exposed surface sediment properties after dredging are more vaiable than the pre-dredging subsurface properties. This is an indication of sporadic resuspension of the subsurface materials. The variability may be due to the fact that the dredge activities were limited so that uniform coverage of the dredge area was not possible.

The pre-dredge sediment profiles provide insight into the hydraulic and sediment transport characteristics of the system. A layering of sediments would be anticipated. However, one might expect also to find finer sediments near the surface in the summer and fall when low flow conditions permit the finer material to settle out of suspension. The profiles reveal the opposite trend; coarse material near the surface with finer material at depth as shown in Figure 3. This behavior indicates some additional destabilizing forces are working on the surface sediments which cause the fines to be washed into suspension and carried away. The source of these destabilizing forces can possibly be traced to active commercial marine traffic in the navigation channels. Large lumber and wood chip ships frequent these channels and often drag anchors as they approach loading docks. In addition, prop wash from the screws of large vessels in the shallow channels could be sufficient to resuspend bottom sediment on a regular basis. Thus, any material deposited near the surface would probably be overturned and resuspended frequently and the fine sediments would be washed away by this unstable condition.

Figure 4 displays the tendency of the sediment properties to return to original conditions after dredging activities cease. Comparison with Figure 2 reveals that within two weeks the median grain size at the spoil site had decreased by a factor of two which indicates a natural deposition of material containing more fines than the spoils. At the dredge site, less variability is observed

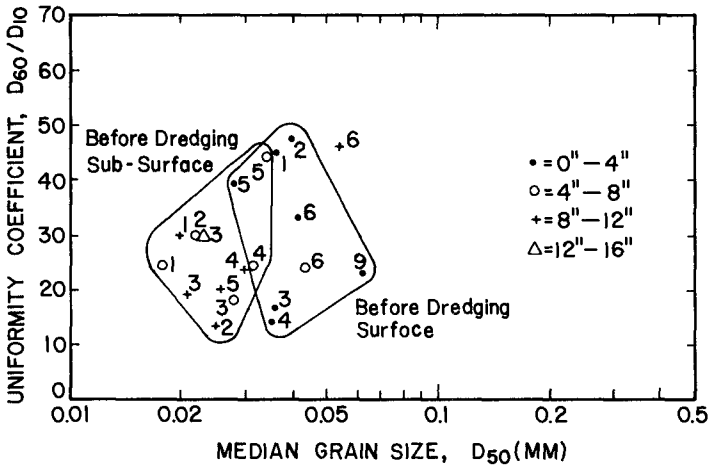

Figure 3. Uniformity versus median grain size, depth dependence.

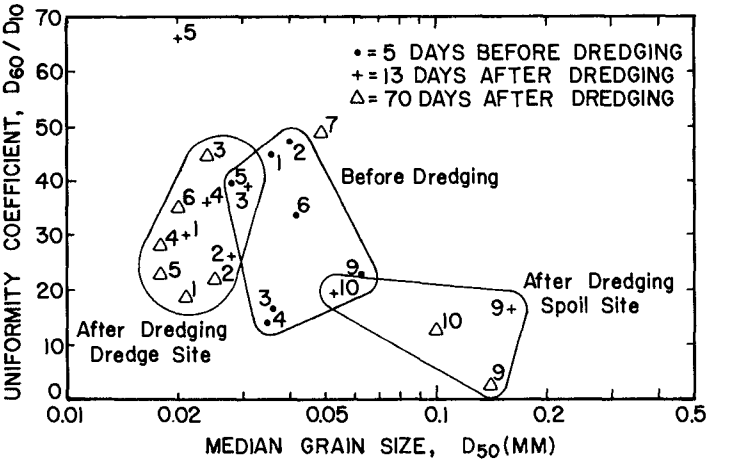

Figure 4. Uniformity versus median grain size, return tendencies.

between stations. This is a further indication of overturning and mixing of surface sediments by man-made and non man-made causes.

The return rate decreases sharply between the two week and two month sample dates. The reason for this possibly is due to the fact that the greatest sources of sediment occur with heavy winter and spring runoffs. During late fall, sediment sources are limited to resuspended materials adjacent to the dredge site. Thus, a complete return to original conditions probably does not occur until the annual cycle of sediment erosion and deposition has elapsed.

Volatile Solids

The change in volatile solids, a measure of organics content, is demonstrated in Figure 5, wherein the percent volatile solids is plotted against median grain size for surface samples five days before and two days after dreding. Segregation by particle size permits the dredge and spoil sites to be distinguished. Figure 5 also shows a change in mean volatile solids from 10 percent before dredging to 8 percent after dredging. The trend is more demonstrable if Core 16 is ignored since it was acquired five days after the rest of the samples. The behavior concurs with the hypothesis that the organics are composed of lighter fractions which are more susceptible to flushing via resuspension than heavier sediments particles.

The average volatile solids level of the natural sediment exceeds the 6.0 percent level established by the EPA for identification of polluted sediments.

Specific Gravity

Specific gravity determinations were made for all surface samples at the spoil site and random samples throughout the dredge area. The results are plotted in Figure 6, along with the median grain size. No measurable change in specific gravity is apparent. This can be explained in terms of the sample constituents. The sand, silt and clay fractions are minerals with a specific gravity normally ranging from 2.6 to 2.7. The only light constituent is the organic material which is largely composed of wood chip and wood fibers. The large wood chips (greater than 0.589 mm) were removed by sieving before the specific gravity tests were conducted. Consequently any change in organics (volatile solids) is masked in the specific gravity measurements. In addition, the 2 percent average change observed in volatile solids would cause a decrease in specific gravity by less than 0.06. The specific gravity results indicate that the mineral constituents are typical for river or marine sediments.

Porosity

Core sample porosity is plotted with median grain size in Figure 7. Data from surface samples five days before and two days after dredging are presented. The results demonstrate a ten percent decrease in porosity for the dredge spoils. This result was not anticipated because it was hypothesized that by losing the fine grained material, voids would remain unfilled between the coarse particles. The explanation for the observed behavior may be the same as that for the decrease in particle size below the surface. Specifically, the destabilizing erosional forces are capable of keeping the finer sediments in a disturbed, less consolidated state. The coarser sediments, on the other hand, are massive enough to resist the erosional forces and are able to consolidate into a more compact

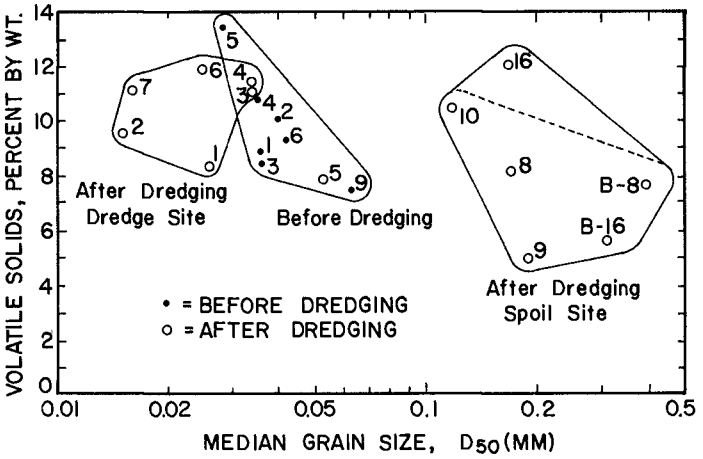

Figure 5. Volatile solids versus median grain size.

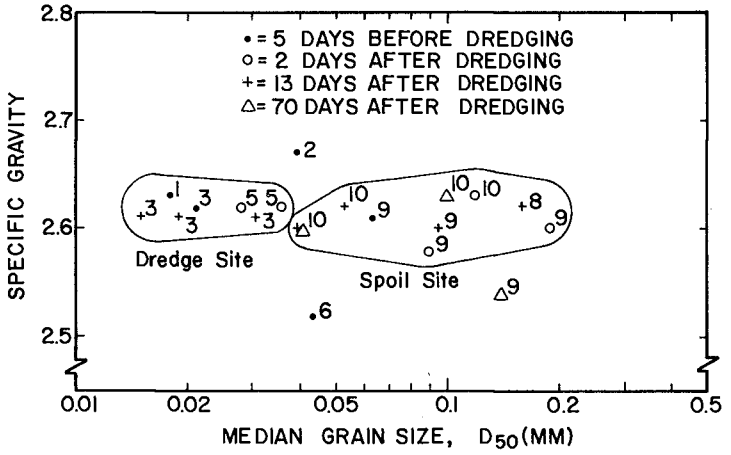

Figure 6. Specific gravity versus median grain size.

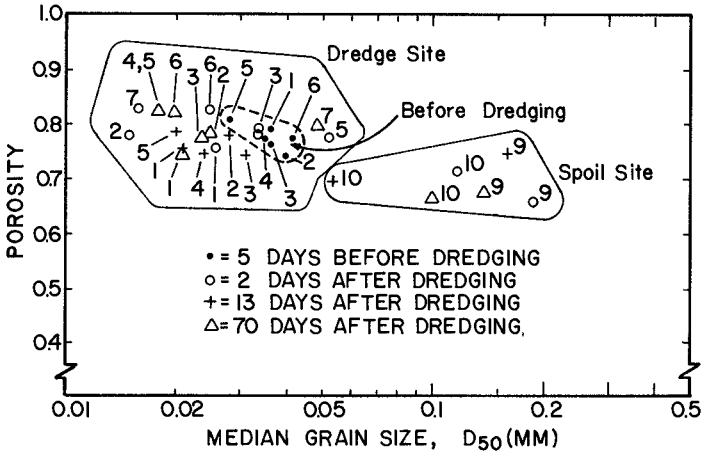

Figure 7. Porosity versus median grain size.

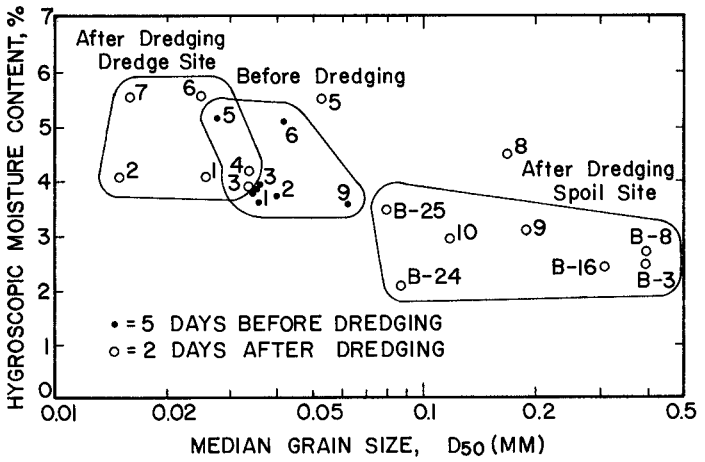

Figure 8. Hygroscopic moisture content versus median grain size.

configuration. As a result, the coarse spoiled sediments are less porous.

Hygroscopic Moisture Content

The hygroscopic moisture content is a measure of the moisture contained within the pores of individual grains of sediment. These pores are to be distinguished from the voids between particles; the latter are accounted for in the porosity measurement. The hygroscopic moisture content is calculated as the water content fraction by weight remaining in the air dried sample at room temperature and humidity. This parameter is generally low for clean sands and high for silt, clay and organic materials. The change in this parameter accompanying dredging is shown in Figure 8, wherein hygroscopic moisture content is plotted versus median grain size for surface samples five days before and two days after dredging. Although the results vary somewhat due to daily changes in temperature and humidity, the trend in Figure 8 is readily apparent: the hygroscopic moisture content decreases significantly at the spoils site and increases slightly at the dredge site. Again, it appears that less clean sediments have been exposed at the dredge site and the fine fractions have been washed from the sediment at the spoil site.

Sediment Stake and Bucket Survey

Very limited success was experienced in determining deposition patterns with the bucket and stake array. Many difficulties were attributable to exceptionally poor visibility in the turbid waters. Approximately one-half of the buckets were either tipped over or missing after spoiling. This was an apparent reaction to the dredge and other marine traffic.

The placement of the linear bucket and stake array is shown in Figure 9.

Spoils were found in buckets ranging from #3 to #25 with some empty buckets in between. Heaviest depositions were found in and around bucket #16 where a 24-inch depth was recorded on the sediment stake. A large mound, 40 to 50 feet in diameter, surrounded the area. The composition of the material included approximately equal portions of wood chips and fine sand. This location coincided with the center of the spoils area. However, a large chip ship was berthed at the Pape Dock and forced the dredge to hold the bucket array to port during many of the downstream spoiling runs. This probably accounted for the sporadic empty buckets found during retrieval operations.

An analysis of the physical properties of the bucket samples was included in most of the foregoing figures. The properties were very similar to those of surface samples taken at Stations 9 and 10 two days after dredging. A large difference occurred in the volatile solids levels. The bucket samples are uniformly high (up to 65%) in volatile solids which concurs with the large percentage of wood chips found in the buckets. This behavior is probably a consequence of spoils falling from the hopper in a quasi-solid mass. The wood chips were trapped in the buckets with the rest of the material and were sheltered from local erosional forces. Around the bucket, the combined effect of currents and ship traffic may have resuspended and eroded the relatively light wood chips. Consequently, wood fragments were absent in core samples taken two or more days later. This is further evidence of unstable bottom conditions exisiting in this area of the Coos River.

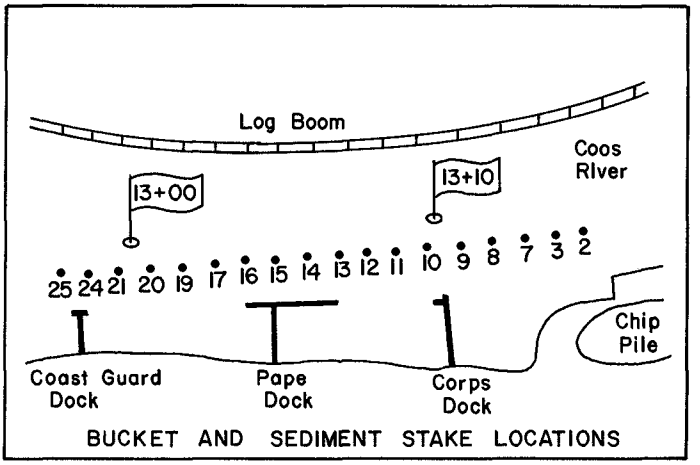

Figure 9. Bucket and sediment stake locations.

SUMMARY

The data presented in the preceding paragraphs substantiate the hypothesis that hopper dredging promotes the resuspension and loss of lighter fractions of bottom sediment. It has been shown that after dredging the sediments:

1. increased in median grain size and decreased in uniformity at the spoil site due to loss of fines;
2. decreased in median grain size at the dredge site due to exposure of fine subsurface material;
3. decreased in porosity at the spoil site due to the ability of the coarse sediments to resist resuspension;
4. retained a constant specific gravity due to uniform density among the major constituents;
5. decreased in volatile solides in the dredge spoils due to the loss of light organics (with the exception that surface spoils were high in volatile solids immediately after spoiling before the wood chips were washed away);
6. decreased in hygroscopic moisture content due to loss of porous organics and silt-clay material.

The data further demonstrate that relatively unstable conditions exist in this reach of the estuary, probably aggrevated by marine traffic, causing frequent resuspension of surface sediments. Physical symptoms of the dredging disturbance persisted for more than two months after the dredging operation was completed even though a very small volume of sediment was removed and spoiled. The results indicate that changes in the physical characteristics of surface sediments may remain until significant natural erosion and deposition occur to mask the disturbance.

ACKNOWLEDGEMENTS

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