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DECREASE IN HARBOR MAINTENANCE DREDGING THROUGH THE USE OF PILE DIKES AND RELATED STRUCTURES TOGETHER WITH AN ANALYSIS OF ESTUARINE SEDIMENTATION PROBLEMS.

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Most harbors in the continental United States of interest to the U. S Navy are located within estuaries. Because of the presence of fresh water as well as salt water, special sedimentation problems are created. Sources of sediments in an estuary are discussed.

1. sheet erosion by runoff of precipitation from lands draining directly to the estuary;
2. sediment transported by inflowing rivers;
3. scour of the bottom and banks of the estuary;

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(4) discharge of industrial and sanitary sewage into the estuary;
(5) littoral drift and off-shore sediments carried into the estuary through tidal inlets by tidal currents;
(6) marine life;
(7) improperly deposited material from channel dredging operations;
(8) windblown material.

While there are exceptions, most estuaries are the repository for fine-grained sediments ranging from clay to fine sand in size. In the natural course of events these would eventually fill the estuary. A certain amount of sediment buildup within the estuary can be tolerated. The long-term solution however, is to remove the sediments by dredging and depositing them elsewhere.

In this report a system to accomplish this by means other than dredging is discussed. Part of the system is to entrap estuarine sediment by means of pile dikes to prevent it from entering dredged shipping channels. The pile dike, which consists of two to seven rows of clusters of concrete piles extend perpendicularly to the river bank. The rows are spaced approximately 5 feet apart; the clusters 15 feet to 20 feet apart. Stringers are placed between each row and secured to pile clusters with 3/8-inch galvanized wire strand fastened with boat spikes. Piles are driven about 20 feet to 30 feet below the bottom of the estuary.

A second part of the system is to remove periodically the accumulated sedimentary material by a back-flushing and slurry pumping system. Back-flushing sediments is common practice in water supply filter beds. Slurry pumping systems are presently in use to transport solids over long distances. The slurry may be pumped to barges, used as landfill, or pumped to off-shore spoil disposal areas such as submarine canyons.

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INTRODUCTION

In order to accommodate ships with a draft deeper than the natural water depth in harbors and estuaries, channels are dredged in selected locations within a harbor. The bathymetry of the harbor or estuary before dredging represents the natural effect of sedimentation. Sediments, once deposited, are shifted by tides, river flows, storms, waves, and ship passage. Dredged channels act as catch basins trapping these shifting sediments. Once in deeper channels sediments are not as easily dislodged by water movement, if at all. As a result of the accumulation of these sediments, the underkeel clearance of ships navigating in these channels decreases. Removal of the sediment by maintenance dredging is a necessity to enable the continuation of the flow of ship traffic.

The annual cost of maintenance dredging amounts to many millions of dollars annually and involves removing hundreds of millions of cubic yards of sediment. In addition to the removal problem, maintenance dredging involves the costly spoil disposal problem.

Harbors (the water bodies leading to them) have been classified as follows (Caldwell, 1950):

1. river-channel harbors, such as St. Louis, Mo.
2. off-river harbors, such as Freeport, Texas.
3. fall-line harbors, such as Richmond, Va.
4. channel harbors in tidal estuaries, such as Jacksonville, Fla.
5. off-channel harbors in tidal estuaries, such as Houston, Texas.
6. shore-line harbors such as Chicago, Ill.

All major installations of interest to the U. S. Navy dredging programs are located on channel harbors in tidal estuaries and therefore this is the only type of harbor considered in this study.

SOURCES OF ESTUARINE SEDIMENTS

The sources of estuarine sediments differs in different parts of the world. Along the Atlantic Coast upland erosion contributes sizeable amounts of silts and clays to the estuaries. On the Pacific Coast, large volumes of sand are transported by flow in the Columbia River through the estuary to the Pacific Ocean (Hickson, 1961). Guilcher (1967) cites five sources of sediments in European and African estuaries: sediments coming from the sea (example: the Wadden Zee in the Netherlands); sediments coming from the lower slopes bordering estuaries, (example: the Rance Estuary in France); sediments coming from the mouths of the estuaries, (example: the Kapatchez River, Guinea, West Africa); and sediments coming from upstream by rivers (example: the Loire River, France).

Gorsline (1967) favors the dominance of marine agents indicating that "...the existence of the estuarine environment and its attendant coastal lagoons and barriers is a product of relatively small supply of local stream-borne materials and the dominance of marine agents of transport of sediment from coastal or nearshore sources."

In general, sources of sediments in an estuary may be classified as follows:

1. sheet erosion of land surface by runoff of precipitation draining directly to an estuary and/or draining to streams terminating in an estuary.
2. scour of the bottom and banks of the estuary as well as scour of the bottom and banks of streams terminating in an estuary.
3. littoral drift and offshore oceanic sediments carried into the estuary by tidal currents and wind-driven currents.
4. discharge of industrial and sanitary sewage into the estuary.
5. marine life.
6. improperly deposited material from channel dredging operations.
7. windblown material.

Of all the above perhaps sheet erosion of a watershed is the most important. Sheet erosion of a watershed can be expressed as follows (Gottechalk, 1964):

$$A=f(RKLSCP)$$

where:

A = annual soil loss from watershed

R = rainfall factor

K = soil erodibility factor

LS = slope length and steepness factor

C = cropping and management factor

P = supporting conservation practice (i.e., terracing)

Quantitative evaluation of each factor gives rise to the annual soil loss for a watershed to a stream which may end up in an estuary.

Transport of material overland by precipitation in temperate humid coastal regions is closely connected to precipitation, and temperature. For a long term period, the following hydrologic factors for a watershed determine the streamflow at the point of entry into an estuary:

1. precipitation on land and water surfaces,
2. evaporation from water surfaces,
3. evapo-transpiration from soil and plant surfaces,

4. seepage through the land surface of the watershed to ground water storage,
5. seepage from ground water storage to streams as base flow,
6. runoff from land surfaces to streams,
7. surficial storage in reservoirs, as ice and snow, and temporary storage in stream channels,
8. water moved upstream by tidal action,
9. water moved downstream by tidal action.

In many humid regions precipitation is fairly uniform throughout the year. However, temperatures affect the growing season as well as the evapotranspiration rate. For example, it is possible for five inches of precipitation in the wintertime to produce a large streamflow especially when supplemented by melting snow. In the summertime the same amount of precipitation would result in much less stream flow due to the consumptive effects of evaporation and vegetation. Minimum flows in rivers and streams occur mostly in the summer, a time when stream-flow is derived largely from ground water outflow. It can be generally said that in the summer erosion is a minimum, the sediment transport in streams is a minimum, and the type of estuary can shift due to decreased amounts of streamflow entering the estuary.

Sediment yields from watersheds are shown below:

Table 1. Arithmetic Average of Sediment-production Rates for Various Groups of Drainage Areas in the United States (after Gottschalk, 1964)

Watershed-size sq. mi.	No. of Measurements	Average annual sediment-production rate, acre-ft/sq.mi.
Under 10	650	3.80
10-100	205	1.60
100-1000	123	1.08
Over 1000	118	0.50

Once sediment reaches a water course it is transported as a suspended load and/or as a bed load. The combination of these loads is known as the total sediment load or the bed material load.

The rate of suspended material transport is a function of the stream velocity at the bed (which is related to the rate of streamflow); the depth of water in the river; the settling velocity of a particle (which is related to particle diameter), the grain size distribution of particles in suspension and the concentration of suspended matter in the sample. Formulas interrelating these factors have been verified both in the laboratory and in the field. (Vanoni, 1965)

Bed load transport in streams can take place by water flow dragging or rolling the sediment along the channel bottom or causing the particles to alternately skip from the bottom and then fall back to the bottom in a trajectory.

Laboratory and field observation have indicated that the rate of bedload transport is a function of channel slope, rate of streamflow, the grain size distribution of bottom sediments and the specific weights of the sediment and of the water.

Inasmuch as the bedload fraction usually settles out rapidly as the river discharge enters the estuarine environment, the suspended load, in most cases, becomes the more important concern in the dredging of estuaries.

The material that composes the banks and bottoms of streams and estuaries is largely dependent on geological processes that have taken place in the past. Erosion of these materials is a function of the grain size of the geologic material and the velocity of the water moving against the face of the material.

Studies of the transportation, deposition, and scour of sedimentary particles by Hjstrom (1939) indicate that the average velocity of flow for the erosion of clay is about 300 cm/sec (9.8 ft/sec). This velocity decreases as the particle size increases. For a medium sand the lowest erosional velocity for sedimentary particles is reached. This is about 20 cm/sec (0.7 ft/sec).

As the diameter of the particle increases above that of a medium sand the velocity of flow required for erosion to take place increases rather than continuing in the decreasing trend. For very coarse sand the erosional velocity is about 30 cm/sec (1.0 ft/sec).

In the same study Hjulstrom (1939) found that clay was transported by flow velocities greater than 0.1 cm/sec (0.003 ft/sec). Fine silt is deposited at this velocity. As the grain size increased so did the maximum velocity of flow at which deposition of sediments would take place. Deposition of medium sand took place below a velocity of about 3 cm/sec (0.1 ft/sec). At values of flow less than that required for erosion but greater than that required for deposition, transportation of the sedementary material occurred.

Thus the velocity of water flow is vitally concerned whether the source of the estuarine sediments is the watershed, the estuary itself, or the nearshore ocean.

Offshore sediments can be brought into an estuary by means of tidal currents and by wind wave action. The source of the offshore sand being moved inshore is contained in a relatively narrow zone bounded in a seaward direction by water depths no greater than 60 feet and in some cases water depths no greater than 15 feet depending on deep and shallow water wave conditions and size of sand particles (CERC, 1973).

Once at shore, the sand particles are moved as littoral drift by longshore currents to a place of ingress into the estuary. The annual longshore transport rate of littoral drift has been related to the mean annual nearshore breaker height (H_b) and the associated breaker angle (α_b). The breaker height and breaker angle in turn have been related to the deep water wave characteristics of wave height (H_o), wave length (L_o) and deep water wave angle (α_o) by Munk (CERC, 1973). These in turn are related to deep sea wind conditions in the sea wave generating area.

If the velocity of the longshore current at the inlet to the estuary is sufficiently low, deposition takes place. The broad-process of shoaling at estuarine entrances has been described generally by Wicker (1965) to be comprised of the following sequence of events:

a. Littoral drift material moves into an entrance under the impulse of ocean wave action and begins the formation of a shoal.

b. This shoaling continues until the entrance has been sufficiently constricted to cause tidal currents to increase to the point where shoal material is swept back and forth by the ebb and flood currents of the tide.

c. The shoal is then molded by the interaction of the waves and currents in an attempt to reach a condition of equilibrium.

d. The addition of material to the shoal by wave action bringing in littoral drift tends to enlarge the shoal. This enlargement tends to upset the conditions of equilibrium at the entrance.

e. The net result of the above is, in many cases, a constant shifting in the location and depth of the more or less well-defined channel across the bar or shoal. These changes are, of course, hazards to navigation.

Movement of sand through a tidal inlet has been quantified by Carothers and Innis. (1960) Basically, their investigations indicate that the rate of sand transport is a function of the difference in tidal levels inside and outside of the inlet, the size of the sand being transported, the dimensions of the inlet and the bulking factor of the sand.

Other sources of sediment to an estuary are: the discharge of sewage into an estuary, marine flora and fauna living within an estuary, improperly deposited material from dredging operations and windblown sediments. Inasmuch as the nature of the sediments from these sources is so variable, it is not possible to make accurate allowance for them in any sediment budget written for an estuary..

The factors affecting the source(s) of estuarine sediments that should be evaluated as a primary step in any investigation of reducing maintenance dredging are summarized in Table 2 below:

Table 2: Summary of Factors Affecting the Source of Estuarine Sediments.

Source of Sediments	Component Factors
Watershed	1. Geologic composition of soil horizons a. erodibility b. grain-size distribution
	2. Vegetation a. type b. density c. management
	3. Hydrology of watershed a. precipitation pattern b. runoff pattern c. rate of evapo-transpiration d. ground water storage and base flow relationship e. air temperature f. extent of watershed area g. streamflow characteristics
	4. Morphology a. slope of land b. degree of dissection by erosion
Estuary	1. Wind pattern a. fetch b. velocity
	2. Dimensions of estuary a. length b. width c. depth
	3. Enclosing features between open ocean and estuary.
	4. Erodibility of banks and local watershed together with the associated grain size distribution.
	5. Wave length and wave height characteristics of the estuary.
	6. Interrelationship of river flow rate and tidal flow rate.
Nearshore Ocean	1. Prevalent direction of longshore current.
	2. Quantity of littoral drift.
	3. Other rivers that contribute to the littoral drift.
	4. Wind pattern in nearshore area as well as in sea wave generating area.

Nearshore Ocean (cont)

5. Tidal fluctuations
6. Bathymetry of the nearshore ocean.
7. Deep water wave height, wave length and wave angle characteristics.

THE RELATIONSHIP OF THE MOVEMENT OF ESTUARINE WATER TO THE SEDIMENTATION PROBLEM

Important to the problem of movement of sediment within an estuary is the movement of estuarine water and the inflowing fresh water. An estuary is a semi-enclosed coastal body of water having a free connection with the open sea and within which sea water is measurably diluted with fresh water runoff. Pritchard (1955) has divided estuaries into four types based on the ratio of river outflow to tidal water inflow. Type A is an estuary in which the river outflow is much larger than the tidal inflow resulting in a well-defined salt water wedge lying beneath the seaward-flowing river outflow. In types B, C, and D, the effect of tidal flow predominates and the intermixing of the salt water and the fresh water progressively increases.

The above classification of an estuary is not necessarily permanent, but can change with a change in the rate of river outflow, a change in the tidal currents, and a change in the width of the inlet between the estuary and the ocean (Pritchard, 1955). Shown in Table 3 are changes in estuarine type with time of year for various estuaries in Oregon.

As discussed earlier, the rate of river outflow is affected by various climatologic and hydrologic events. Included are precipitation on the upstream watershed, air temperature and the amount and type of vegetation covering the watershed. These three factors vary with the time of year in most places in the continental United States.

Although in some harbors the velocities of tidal flow are competent to move sand and the problem of sand shoaling is of concern, the problem in general appears to be one of shoaling by silt and clay. Several factors serve to augment the tendency to shoal by silt and clay sedimentation. Among these are:

1. slack water periods between successive tides, during which slack water has no turbulence acting to keep the suspended silt and clay in suspension.
2. the intermixing of the silt-ladened fresh water with the salt water brought into the estuary by tidal currents and density currents, thus intermixing causing flocculation of the suspended material and greatly accelerating its tendency to settle to the bottom.

In all types there is vertical and lateral movement of salt water as well as movement up and down the estuary. The existence of three components of velocity of water movement influence the distribution of sediments within an estuarine harbor. This distribution may play an important role in maintenance dredging.

Table 3. Types of Oregon Estuaries Determined By Salinity Measurements At High Water At The Nearest Station Where Top-To-Bottom Salinity Was 17°/₀₀ (after Burt and McAlister, 1959).

Estuaries	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Columbia	B-11		D-16	B-8			A-6		B-10 B-8			
Nehalem	B-4			A-3 B-3					B-8			
Tillamook	A-6			D-6						D-8		
Netarts	D			D								
Siletz	A-2			A-2						B-5		
Yaquina	D-8	B-9 B-2		B-8	B-8			D-12		D-16 D-16	D-10	
Alsea	B-1		B-2	B-3						B-6		
Siuslaw	A-1		B-4		A-4					D-7		
Umpqua	A-2	A-3	B-6		B-7		D-9			B-8		
Coos	D-12 B-10	D-11	D-10 B-12	D-10	D-11	D-11 B-4	D-15	D-16	D-17	D-15	B-12	D-14

Settling of Estuarine Sediments into Dredged Channels

Sediments settle at a velocity in water described by Stokes law. Factors of importance in Stokes law are density and shape of the particle and the kinematic viscosity of the fluid in which the settling is taking place. Different relationships have been derived for different Reynold's numbers. Generally, different equations apply for various values of Reynold's numbers. The breakdown is as follows: Reynold's numbers less than 1, Reynold's numbers from 1 to 1000, and Reynold's numbers from 1000 to 2500.

Comparing the three formulas for particle settling velocity the effect of the kinematic viscosity and the particle diameter diminish with the increase in Reynold's number.

Another influence that bears upon the settling of estuarine sediments is flocculation. Silt and clay particles in water suspension when entering an estuary have a negative electric charge (cations) on their surface due to the molecular structure of the minerals involved. Adjacent particles have similar charges and are repelled and dispersed. This produces the typical suspensions in fresh water streams.

The total negative charge per particle varies in accordance with the clay mineral(s) present (Grim, 1962). The range of the cation-exchange capacity of the clay minerals is shown in Table 4 below (after Grim, 1953):

Table 4. Cation-Exchange Capacity of Clay Minerals (in Milliequivalents per 100 Grams)

Kaolinite	3-15
Halloysite $2H_2O$	5-10
Halloysite $4H_2O$	10-40
Montmorillonite	80-150
Illite	10-40
Vermiculite	100-150
Chlorite	10-40
Sepiolite-Attapulgite	20-30

Grim (1962) observes: "It follows from the consideration of the factors influencing cation-exchange capacity that there is no single capacity value that is characteristic of a given group of clay minerals. A range of capacity must be shown for each group.

"The clay minerals are not the only components of clay materials that have cation-exchange capacity. All inorganic materials of extreme fineness have a small cation-exchange capacity as the results of broken bonds around their edges. This capacity increases as the particle size decreases, but even with the small size in which non-clay minerals occur in clays the exchange capacity is generally insignificant ... In general, organic material with high exchange capacities is restricted to recent sediments and soils."

Shown in Table 5 are cation-exchange capacities of sediments from selected water bodies.

Table 5. Cation Exchange Capacities of Sediments from Selected Water Bodies.

Sediment	Cation Exchange Capacity me/100g
Wilmington District	25.5
Brunswick Harbor	30.5
Gulfport Channel	46.8
Mare Island Strait	24.5
Flume Sediment	28.9
Delaware River	15.6
Potomac River	9.1
White River	53.5

The wide range of cation exchange capacities shown in Table 5 can be due to variations in the amounts of clay mineral kinds in the several sediments.

When fresh water containing suspended material flows into an estuary having a concentration of one gram of sea salts per liter of water the abundance of anions reduces the repelling effects of the surface charge and permits coalescence of the fine particles to form a floc.

There are three mechanisms for interparticle collisions that are part of the floc formation process:

1. Brownian movement,
2. internal shearing or local velocity gradients in the fluid,
3. differential settling velocities.

All three processes that cause collision of suspended mineral particles have rates of collision directly proportional to the sediment concentration (as indicated by the number of particles present).

These flocs are loosely connected and entrain water within their structure. This in turn reduces the density of the floc which when combined with the increase in size changes the hydraulic characteristic of the suspended sediment (Einstein and Krone, 1961). The settling velocity of the floc may be much more rapid than for the individual component clay particles (Krone, 1972).

Control of shoaling in estuaries where flocculation is an important feature can be accomplished by a means that:

1. reduces suspended sediment inflow, or
2. increases sediment outflow, or
3. maintains sufficient bed shears to keep the sediment in motion (Krone, 1972).

The Lateral Movement of Estuarine Sediments.

Within the salt water wedge there is a movement of salt water. At the bottom of the estuary this movement is upstream which acts to transport bottom material in an upstream direction. River flow moves bottom sediments from upstream along the bottom at the entrance to the estuary. Simons (1955) has indicated that for a highly stratified estuary (Type A), rapid shoaling usually occurs at the region of the tip of the salt water wedge. The heavier particles from upstream in bedload movement come to rest as soon as the tip is reached. The lighter particles in suspension gradually fall through the interfaces. As a result the coarser material is in the upstream part of the wedge grading to the finer material deposited.

In a partially-mixed estuary, such as the Hudson River, Charleston and Savannah Harbors, and the St. Johns River (Types B and C) the wedge moves up and downstream as the tide ebbs and floods, usually over a distance of several miles. The region of heaviest shoaling usually lies between the high tide and low tide positions of the tip of the salt water wedge. The heavier particles of sediment come to rest as they reach the tip of the wedge; the lighter particles may be carried well down in to the estuary before they enter the predominantly upstream flow in the salt-water wedge. This flow then transports them upstream towards the tip of the wedge. The oscillating of the position of the wedge inhibits any appreciable sorting of the various sizes of the sediment particle.

In a well-mixed estuary (Type D), such as the Delaware and Raritan River estuaries, the intermixing of the fresh water and salt waters usually precludes the formation of an interface. The shoaling pattern in a well-mixed estuary does not appear to be related directly to the salinity pattern but is more dependent on weak current velocities and eddies (Simmons, 1955).

The works of man can change the type of estuarine flow pattern. For example, Charleston, S.C. Harbor was a well-mixed estuary owing to the small rate of flow of fresh water entering the estuary. Diversion for hydroelectric purposes of the fresh water yield of the Santee River drainage basin to Charleston Harbor through the Cooper River shifted the well-mixed estuarine circulation pattern to a mixed type establishing a salt wedge. The drainage area of the Santee River watershed was 14,512 square miles as compared to the drainage area of the Cooper River watershed of 1188 square miles. The wedge essentially became a trap for sediments from the increased hydraulic scour caused by the increased river discharge and the increased sediment yield from the larger watershed area. (Neiheisel, 1966).

SEDIMENT CONTROL STRUCTURES

One way to reduce maintenance dredging is to control the amount of sediment reaching an estuary. Sediment control structures for the purposes of this study are considered in four categories: (1) those that prevent erosion of banks or shores, and (2) those that are purposely used to build up banks or shores by deposition, (3) those that prevent deposition and hence prevent shoaling, (4) those that prevent dredged channel filling.

Groins fall in the first category. These structures, which are either permeable groins or impermeable groins, project out from the shore and are usually associated with sand beaches. Permeable groins may be as simple as masses of rock dumped in a line projecting from the shore or may be as complex as a timber crib system. Impermeable groins may be built of timber, concrete planks, sheet steel piling, among other materials.

Dikes fall in the second category. The Corps of Engineers has successfully used dikes along banks of rivers in a program designed to straighten the alignment of river channels as well as channel stabilization (Corps of Engineers, 1963, 1964, 1965, 1966). Some of the rivers concerned are: Savannah River, Ga.; Appalachiola River, Fla.; Rio Grande River, N.M.; Columbia River, Ore; Red River.

Dikes can be categorized as follows (Corps of Engineers, 1964):

1. Pile with a foundation mattress
2. Stone filled
3. Combination pile and stone fill
4. Crib with or without a foundation mattress
5. Chute closure
6. Kellner jetty

Impermeable jetties are in the third category. The jetty is designed to keep a waterway open by preventing the deposition of littoral drift. Sediment may either be by-passed down-shore by pumping or allowed to build up behind the up-drift side of the jetty.

Training walls that encourage deposition in places other than dredged channels are in the fourth category. An example of the efficiency of a training wall is that constructed for the Deepwater Point Range of the Delaware River (Paterson and Simmons, 1950). The Range is 800 feet wide, 40 feet deep and four and one-half miles long. Heavy shoaling, caused by lack of parallelism between the tidal currents and the navigation channel, necessitated dredging at the average annual rate of 2,800,000 cubic yards. Constructing a training wall, known as the Pennsville Dike, 5300 feet long attached to east bank of the Delaware River, effected about a 48 percent reduction in the annual amount dredged to 1,470,000 cubic yards.

A little different training wall is discussed by Leighton (1949). This structure, located immediately outside of the River Mersey in the vicinity of Liverpool, England, consists of two parallel lines of dumped limestone rock. These walls resemble levees in cross-section, having side slopes of one vertical to two horizontal. The top of the training wall is five feet above datum sloping seaward to two feet above datum over a length of about a mile at the seaward end. Based on hydraulic model tests these walls will utilize the velocity of tidal currents to transport sediments that have collected in the dredged channel. The report describing this structure is an interim report; however, in the author's opinion, "There is every reason to think that the training banks will achieve the desired object of the design in regularising the channels and reducing the amount of dredging necessary for their maintenance..."

Although the efficiency of these sediment control structures can be predicted utilizing hydraulic computations, final decisions are usually made using hydraulic models. Most large channel problems attached by the Corps of Engineers have solutions based on hydraulic model investigations such as "Plans for Reducing Shoaling in the Southwest Pass of the Mississippi River" (Simmons and Rhodes, 1965), "Plans for Reduction of Shoaling in Brunswick Harbor and Jekyll Creek, Georgia" (Hermann and Tallant, 1972) and "Results of Hydraulic and Shoaling Studies in Marcus Hook-Schuylkill Reach of Delaware River" (Bobb, 1967).

PROPOSED METHOD FOR THE REDUCTION OF MAINTENANCE DREDGING IN ESTUARIES

Reduction of maintenance dredging in an estuary requires a reduction of the amount of sediment entering shipping channels. Theoretically, it is possible to control the amount of sediments entering an estuary by controlling the factors listed in Table 2. In actuality, many of the factors cannot be controlled. Estuaries tend to be self-annihlating; Einstein and Krone (1961) opined that unless high river flows occur very little sediment moves out of the estuary into the ocean. This comment is substantiated by Fleming (1970) who states, based on an analysis of a sediment balance of the Clyde Estuary, in Scotland, "...all sediment entering the Clyde Estuary is deposited completely in the upper reaches for a distance of 12 miles. This estuary is totally dependent on dredging operations and does not in its present regime transport sediment to sea."

In other words an estuary acts as a sediment trap. Accordingly, the reduction of maintenance dredging resolves itself to finding means cheaper than dredging of removing the sediment from an estuary before the sediment can settle into the deeper shipping channels.

It is with this concept in mind that the following plan is proposed. Three basic phases are involved. Phase I consists of trapping the sediments behind pile dikes extending out from the banks of the estuary.

Fleming, G., 1970, "Sediment Balance of Clyde Estuary," J. of Hydraulics Div., Amer. Soc. of Civil Engineers, Paper No. 7676.

The dikes constructed by the Corps of Engineers extend perpendicularly to the river bank. The common pile dike consists of two to seven rows of clusters of wooden piles. The rows are spaced approximately 5 feet apart; the clusters 15 feet to 20 feet apart. Stringers are placed between each row and secured to pile clusters with 3/8-inch galvanized wire strand fastened with boat spikes. Piles are driven about 20 feet to 30 feet below the river bottom. Owing to the presence of boring organisms in the case of estuaries, the piles should be of precast reinforced concrete. Phase II consists of fluidizing the entrapped sediment periodically with water and/or air. Phase III consists of pumping the fluidized sediment through pipelines to either barges, diked disposal areas, or offshore to submarine canyons.

The above proposal is based on three recognized effects:

1. Pile dikes have been shown to be effective in trapping fine-grained sediments in rivers (Hickson, 1961). A similar entrappment is formed by the piles of navigation slips. According to Simmons (1966), "Navigation slips in estuaries are normally oriented at right angles to the adjacent channels, and these slips are usually subject to a rapid rate of shoaling. Average losses in depth of 6 to 8 feet per year in such slips is not uncommon, and the average loss may reach 12 to 15 feet in extreme cases. The shoaling of navigation slips poses a serious problem to their owners and operators, since dredging of such facilities must usually be accomplished by dipper or clamshell equipment, and the spoil must be hauled by barge to remote disposal areas.

"Available evidence indicates that the supply of sediment to navigation slips occurs almost exclusively during the rising phase of tide, during which the local tidal prism of the slip is being filled. The tidal prism of the slip is usually very small in relation to the cross-sectional area of the entrance, and the inflowing current would be expected to have such low velocity that only very light-weight sediments could be carried well inside the slip. However, since the slips are normally oriented at right angles to the direction of flow in the adjacent channels, the higher velocity currents tend to flow past the slip, and only the very weak currents adjacent to the channel bottom will turn readily into the slip. Since the inflowing water is confined to the bottom 1 or 2 feet, where the highest concentration of sediment is found, it is not surprising that the shoaling rates of such facilities are so high. Furthermore, the velocity of the inflowing water is sufficiently great to transport sediments well back into the slip. During the falling phase of tide, the outflowing currents in the slip are essentially uniform throughout the depth, so that sediments brought into the slip by the concentrated bottom flow are not removed by the relatively weak outflowing currents." The subject proposal reverses this liability and makes it a way to collect sediment before it can reach the shipping channels.

Simmons, H.B., 1966 "Field Experience in Estuaries," Estuary and Coastline Hydrodynamics. McGraw-Hill Book Co., 744 p.

2. Water and air blown through pipes at the bottom of water supply filter beds is used as a standard procedure to fluidize the beds and backwash the granular material in order to permit reuse of the bed in water filtration.

3. Transport of slurries over long distances through pipelines has been used to move iron ore (Griesshaber, H. L., 1969) and for coal (State of Maryland, 1970). In this latter system a slurry pumping system in operation in northern Arizona transports a coal slurry of 50 percent solids and 50 percent water over a distance of 273 miles.

A number of design features of the plan must be worked out. In broad categories these are:

a. dikes
   - distance for bank into estuary
   - type of construction
   - spacing of rows
   - location of dike fields within the estuary

b. fluidizing system
   - rate of flow of fluids for optimum effect
   - diameter of water and/or air lines
   - spacing of lines and details of construction of individual lines
   - sediment buildup over lines before system activation

c. slurry pumping system
   - type of pump and prime mover
   - diameter of discharge pipeline
   - disposal point of spoil
   - frequency of operation
   - manual or automatic operation
   - should deflocculants be injected in pipeline to facilitate deposition of clay and silt at disposal point

In order to obtain more information as to feasibility of testing the proposal on a hydraulic model, the Waterways Experiment Station at Vicksburg, Miss., was visited in December 1975. The problem was discussed with Mr. R. Sager, Chief of the Estuaries Division, who was quite enthusiastic about the plan. The complete cost of testing the plan for two weeks on an estuarine model would be about $10,000. Included in the price would be quantification of sediment build-up behind the dikes and documentation for further study with motion pictures and slides.

While there the problem was also discussed at length with Mr. John Franco, who was Chief of the Waterways Division, now retired, and is the foremost authority on dike fields in river systems. He felt the plan had merit and indicated that he had been requested to investigate the effect of dike fields in estuaries but could never find the time to do so.

TRAVEL ASSOCIATED WITH RESEARCH

Four trips were made by the writer in connection with the NAVMAT Research Grant F.Y. 1976. These were:

1. U. S. Army (COE) Waterways Experiment Station, Vicksburg, Miss., December 1975 for the purposes of discussing with Mr. R. Sager, Chief of the Estuarine Division, the implementation of testing by means of hydraulic models the proposed scheme of using dike fields to entrap sediment.

2. American Society of Civil Engineers' Specialty Conference on Dredging, Mobile, Ala., January 1976 - in order to upgrade knowledge of movement of spoil dumped in estuaries as well as upgrading background in dredging and its environmental impact.

3. Eighth Offshore Technology Conference, Houston, Texas, May 1976 for purposes of finding out the latest international information on offshore dredging and the associated new equipment.

4. U. S. Naval Shipyard, Charleston, S.C., May 1976. On site visit with Dr. William Van Dorn of Scripps Institution of Oceanography. The purpose was to interchange ideas with Dr. Van Dorn concerning each others work on the control of sediments in estuaries to prevent any overlap in effort. Dr. Van Dorn is also under contract to NAVMAT.

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