SHOALING WITH BYPASSING FOR CHANNELS AT TIDAL INLETS

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ABSTRACT

A channel dredged at the mouth of a tidal inlet is subject to rapid shoaling because of longshore transport, but this shoaling is slower than would be computed from simple trapping of all the moving littoral drift. The reduction in shoaling rate is due to the bypassing of littoral drift which occurs simultaneously with shoaling. This report presents a systematic method for computing the rate of shoaling in channels subject to shoaling with bypassing. The method also permits estimates of the effect of the dredged channel on the downdrift beaches.

INTRODUCTION

Stable Tidal Inlet. A **tidal inlet** is a waterway that connects a large body of water (usually the ocean) with a smaller body of water (Figure 1). The tidal inlet tends to shoal because ocean waves drive sand into the inlet channel, but a stable inlet channel is kept open because tidal currents prevent the wave-driven sand from depositing.

Waves bring sand to the inlet by the process of **longshore transport.** Longshore transport can occur from the ocean beaches on both sides of the inlet, but usually there is a dominant direction of longshore transport (say from left to right in Figure 1) that permits identification of an **updrift side** (the side from which sand is driven) and a **downdrift side** (the side toward which sand is driven). At a stable tidal inlet, the joint action of the waves and tidal currents results in natural **bypassing** of the sand across the inlet channel from the updrift side to the downdrift side, at a more or less steady rate, when averaged over a period of years.

The tidal currents which maintain an inlet are those which result from the daily rise and fall of tides in the ocean. As the tide rises in the ocean, water flows from the ocean to the bay; as the tide falls in the ocean, water drains from the bay to the ocean. The volume of water which enters the inlet from the time of low water slack to the time of highwater slack is the **tidal prism.** It has been known for a long time that the inlet cross section is proportional to the tidal

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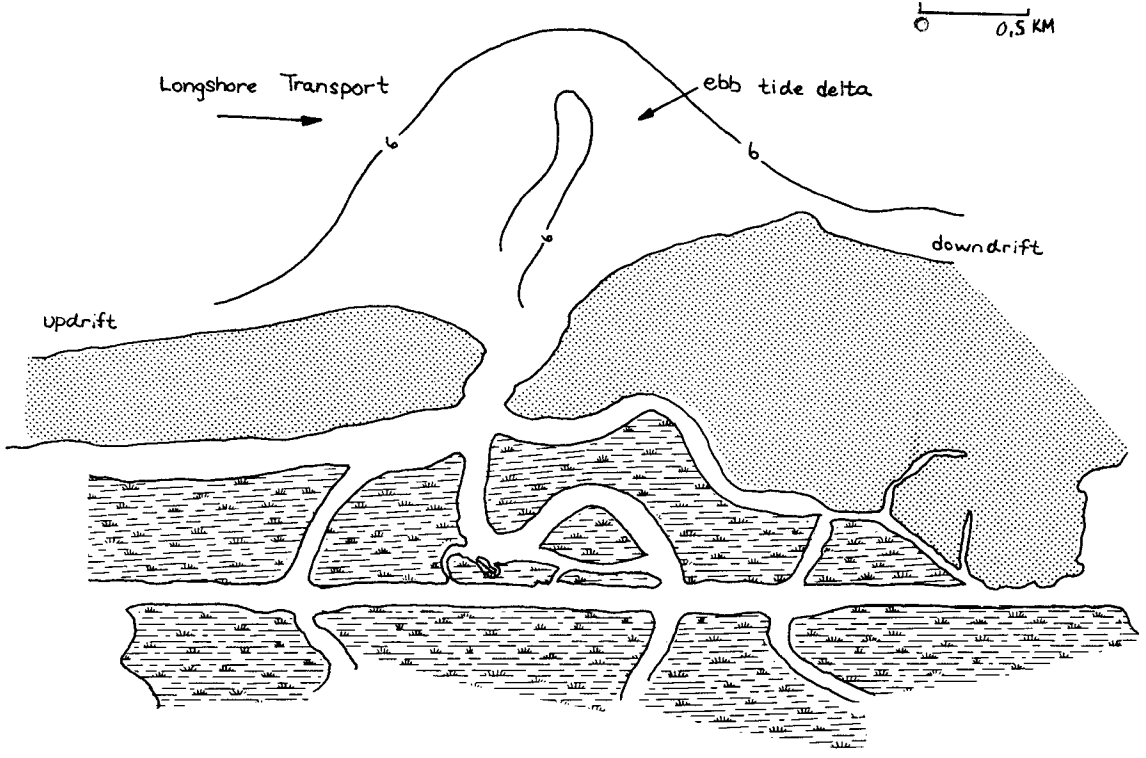

Figure 1. TYPICAL EBB TIDE DELTA AT TIDAL INLET (ADOPTED FROM BREACH INLET, FORT MOULTRIE, S.C. USGS QUAD.)

prism (LeConte, 1905; O'Brien, 1931; Jarrett, 1975). However, the maximum velocity through that section does not vary much with the size of the tidal prism, being on the order of 1 meter per second in naturally stable sandy inlets over a considerable range of tidal prisms.

There is a minimum size to the cross section of an inlet below which the channel will shoal and eventually seal off. This minimum cross section, or the corresponding minimum tidal prism, is proportional to the magnitude of the longshore transport; channels subject to larger longshore transport rates require greater tidal prisms to keep the channel open. Escoffier (1940), Keulegan (1967), O'Brien and Dean (1972) and others have examined the hydraulics of flow in tidal inlets in order to estimate the minimum stable cross section.

Tidal inlets are common on many coasts. For example, on the Atlantic coast of the United States, there are at least 37 permanent tidal inlets between Montauk Point, New York, and Miami, Florida, a shoreline distance of about 2050 kilometers. On many coasts, such as the east coast of India, shallow tidal inlets are the only waterways connecting the open sea with safe harbors along hundreds of kilometers of coast.

Definition of Depth. Seaward of these inlets, tides and waves create an **ebb tide delta.** Minimum depth for navigating through a tidal inlet is usually the sand bar at the crest of this delta. This minimum depth is the **controlling depth,** and the cross section of the channel which contains the minimum depth is the **controlling section.** Natural bypassing by waves and currents transports sand along the ebb tide delta in the downdrift direction (Figure 1). If the controlling section is deepened by dredging, the channel will begin to shoal, mostly from the updrift side. At the same time, because of the relatively shallow depth and flat side slopes of the dredged channel, some sand will be transported out of the channel, mostly to the downdrift side. The difference between the incoming and outgoing transport rates produces shoaling in the channel.

The initial rate of shoaling is a function of the natural controlling depth (d_1) and the initial dredged depth (d_2). At any time after dredging there will be an existing depth (d) such that (Figure 2)

$$d_1 < d < d_2 \tag{1}$$

In applying the analysis in this paper, all depths should be measured from Mean Sea Level (or Mean Tide Level) rather than chart datum, since chart datum is typically Mean Low Water or some lower elevation.

The design question is: how long will it take d to decrease from an initial overdredged value of d_2 to some project depth, d_p, where d_p is defined as the minimum depth for practical navigation by the design vessel. This time interval will be called the duration of project depth, and indicated by the symbol t_p. Time t has a value t = 0 on the day when dredging is completed.

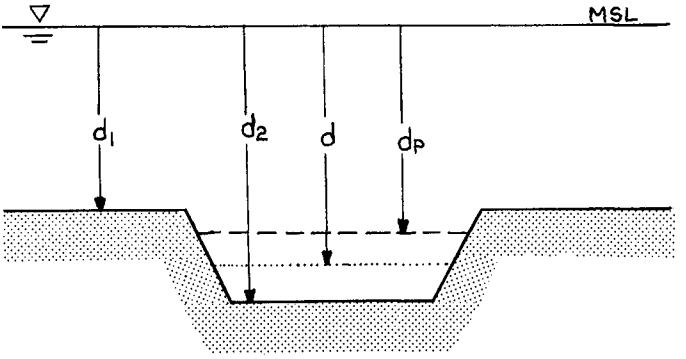

Figure 2. DEFINITION OF DEPTHS AT CONTROLLING SECTION

Purpose. The purpose of this paper is to present and illustrate by example a simple technique to obtain a rational estimate of t_p, the duration of project depth at the controlling section in the dredged channel.

The remaining text of this paper is organized into 4 principal sections. An analysis section derives the shoaling rate equation and presents Lent's solution of this equation. Lent's solution permits direct calculation of t_p. The justification for specific steps in the analysis section is presented in the following discussion section. An applications section follows the discussion to show by examples how to use the results in practical problems. Finally, the text ends with a summary section.

ANALYSIS

Bypassing Sediment Transport Ratio. As a starting point for this analysis, sediment transport rate is assumed to be proportional to the rate of energy expended by the flow:

$$\text{Transport} = \text{Coefficient} \times \text{Shear} \times \text{Velocity} \qquad (2)$$

This equation is assumed to describe sediment bypassing across the ebb tidal delta in the downdrift direction. After the channel has been dredged, the channel traps a greater percentage of the longshore transport due to the greater depth, and bypassing is reduced. The ratio

of the bypassing rate after dredging to the bypassing rate before dredging is defined as the **bypassing sediment transport ratio,** or the transport ratio for short.

$$\begin{matrix}\text{Transport} \\ \text{Ratio}\end{matrix} = \begin{matrix}\text{Coefficient} \\ \text{Ratio}\end{matrix} \times \begin{matrix}\text{Shear} \\ \text{Ratio}\end{matrix} \times \begin{matrix}\text{Velocity} \\ \text{Ratio}\end{matrix} \tag{3}$$

The flow is assumed to be well into the turbulent regime with low relative roughness both before and after dredging so that to a first approximation

$$\text{Coefficient Ratio} = 1 \tag{4}$$

This reduces the solution of (3) to the task of finding expressions for the shear ratio and the velocity ratio.

The shear in equation (2) is taken to be bottom shear induced by the wave orbital velocity on the ebb tidal delta. The general equation for such shear is

$$\text{Shear} = \text{coefficient} \times U^2 \tag{5}$$

where U is the amplitude of the wave-induced orbital velocity on the ebb tidal delta, and the coefficient incorporates a friction factor, density of seawater, and a dimensionless number depending on the definition of the friction factor. As in equation (4), it is assumed that the coefficient does not change significantly after dredging so that

$$\text{Shear Ratio} = U_{after}^2/U_{before}^2 \tag{6}$$

U is known from small amplitude shallow water theory, so that

$$\text{Shear Ratio} = (H_2^2 d_1)/(H_1^2 d_2) \tag{7}$$

The subscripts 1 and 2 refer to conditions before and after dredging, as on Figure 2. Equation (7) can be further simplified using the appropriate form of energy conservation in shallow water (Green's Law) to get

$$\text{Shear Ratio} = (d_1/d_2)^{3/2} \tag{8}$$

Equation (8) is one of the two ratios needed to solve equation (3). The required second ratio is the velocity ratio, which is derived as follows. Let the symbol, q, indicate the unit tidal discharge in the ebb channel at the controlling section. Thus,

$$\text{Velocity} = q/d \tag{9}$$

$$\text{Velocity Ratio} = (q_2 d_1)/(q_1 d_2) \tag{10}$$

The velocity ratio (10) depends on how the unit discharge in the ebb channel is affected by dredging. Two particular end conditions are possible. If the dredging merely increases the channel area, and the tidal prism remains the same, then the ratio q_s/q_1 remains unity and

$$\text{Velocity Ratio} = d_1/d_2 \text{ for constant discharge} \tag{11}$$

On the other hand, it is possible that the dredging may make the channel more efficient and increase the tidal prism. An upper limit to the velocity in this case is expected to be close to the predredging velocity, since scour by the ebb flow maintains the channel against longshore transport. In this case,

$$\text{Velocity Ratio} = 1 \text{ for constant velocity} \tag{12}$$

The transport ratio (3) can now be solved using equations (4), (8) and (10).

$$\text{Transport Ratio} = 1 \times (d_1/d_2)^{3/2} \times (q_2 d_1)/(q_1 d_2) \tag{13}$$

This may be simplified to

$$\text{Transport Ratio} = (d_1/d_2)^m \tag{14}$$

where $$3/2 \leq m \leq 5/2 \tag{15}$$

to account for the two possible end conditions for the velocity ratio given by equations (11) and (12).

Equation (14) is a specific expression for the bypassing sediment transport ratio immediately after the channel has been dredged to a depth d_2. Since the assumptions and reasoning which lead to (14) hold even better for any lesser depth, d, the symbol d_2 in (14) can be replaced by d to indicate the transport ratio for any post-dredging depth.

Shoaling Rate. The objective of this section is to derive an equation for shoaling rate. Shoaling rate will depend on the bottom area of the channel and the quantity of longshore transport reaching that channel bottom. To describe these factors, the following definitions are useful.

- Q longshore transport rate
- R fraction of Q which takes place above depth d_2
- C length of dredged channel (Figure 3)
- W width of dredged channel (Figure 3)

The amount of littoral drift carried into the dredged channel by longshore transport from the updrift side is RQ. Note that RQ is also the bypassing across the channel before dredging, or in other words, the denominator of equation (3).

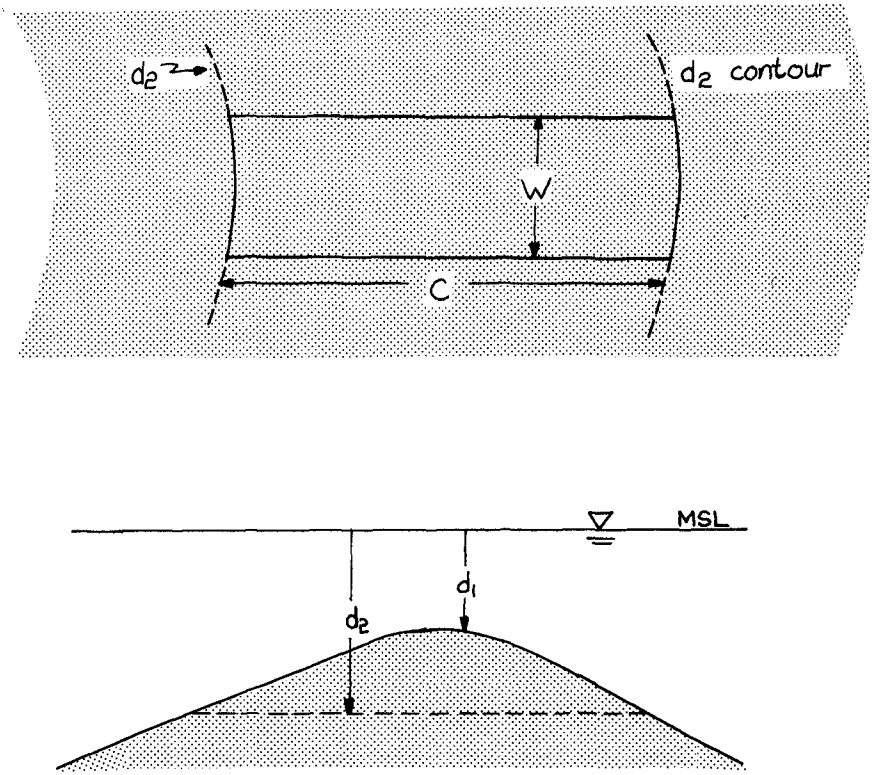

Figure 3. DEFINITION OF CHANNEL DIMENSIONS ACROSS EBB DELTA

The volume of sand trapped by the dredged channel per unit time is the trapping rate. From the above definitions,

$$\text{Trapping Rate} = RQ - \text{Bypassing after, above } d_2 \tag{16}$$

$$= RQ\ [1 - \text{Transport Ratio}] \tag{17}$$

The trapping rate given by (17) is a volume rate. To convert this volume rate to a shoaling rate, divide (17) by the bottom area of the channel, CW. For convenience, define K to be a characteristic shoaling rate.

$$K = RQ/CW \tag{18}$$

Thus, dividing equation (17) by CW and substituting equations (14) and (18) into the result gives

$$\text{Shoaling Rate} = K[1 - (d_1/d)^m] \tag{19}$$

Duration of Project Depth (Lent's Equation). The shoaling rate is mathematically equivalent to the time derivative of the depth

$$d(d)/dt \equiv \text{Shoaling Rate} \tag{20}$$

The duration of project depth, t_p, is obtained by integrating (20)

$$\int_0^{t_p} dt = t_p = \int_{d_2}^{d_p} \frac{d(d)}{\text{Shoaling Rate}} \tag{21}$$

An exact integral solution of (21) has not been found after some searching, but an approximate solution has been developed by Arnold H. Lent (personal communication, 30 Dec 1982). Lent's solution is as follows.

$$t_p \cong \frac{1}{K}\left[(d_2 - d_p) + \frac{d_1}{m}(\ell nA - \ell nB)\right] \tag{22}$$

where

$$A = (d_2 - d_1)/(d_p - d_1) \tag{23}$$

$$B = \frac{1 + \frac{m-1}{2}\left(\frac{d_2 - d_1}{d_1}\right)}{1 + \frac{m-1}{2}\left(\frac{d_p - d_1}{d_1}\right)} \tag{24}$$

Equation (22) approximates equation (21) with a degree of accuracy that exceeds the probable sounding accuracy of measured channel depths.

To find t_p by using equation (22), the values of K, m, d_1, d_2, and d_p must be obtained. The value of K is given by equation (18). The value of m depends on the likely effect of the proposed dredging on the velocity ratio, but is expected to be in the range given by equation

(15). The value of d_1 is the controlling depth obtained from soundings. The value of d_p is the requirement of the user, and the value of d_2 is the design choice to be tested.

DISCUSSION

Qualitative Evaluation. In order to obtain the principal results of the preceding section in minimum space, discussion of key assumptions necessary in the derivation was deferred to this section. But before examining the key assumptions, it is useful to observe that, however equations (21) and (19) were obtained, they agree qualitatively with intuition and experience.

The qualitative agreement is illustrated by the shape of the curves on Figure 4. Figure 4 plots depth on the vertical axis against time on the horizontal axis for three combinations of d_1 and d_2 (d_1 equals 4 feet, 6 feet, and 8 feet, each combined with the same d_2 value of 12 feet). The curves on Figure 4 are numerical solutions of equation (21) using equation (19) for the shoaling rate. Two values of the exponent, m, are used, corresponding to equations (11) and (12), i.e., the constant velocity case (m = 3/2) and the constant discharge case (m = 5/2). The curves on Figure 4 agree qualitatively with intuition and experience in at least 4 ways:

a. The maximum rate of shoaling occurs right after dredging (the curves are steepest at the deepest depth).

b. The channel shoals faster when post-dredging velocity is reduced (constant discharge, m = 5/2) than when the post-dredging velocity is not reduced (constant velocity, m = 3/2).

c. The channel shoals fastest when no bypassing occurs. This is equivalent to $m = \infty$ in equation (19) and plots as the dotted straight line on Figure 4.

d. Shoaling approaches d_1 more slowly when the depth of the dredged cut ($d_2 - d_1$) is smaller, d_2 being held constant.

Transport Equation. The starting point of the analysis is equation (2) which states that bypassing sediment transport rate is proportional to work done by the waves on the bottom. In the absence of an inlet, the bypassing rate is simply the longshore transport rate. The usual "energy flux" method of predicting longshore transport (Galvin and Schweppe, 1980) is, in effect, an assumption that sediment transport rate is proportional to the power supplied by waves to the surf zone. This is physically analogous to equation (2).

The form of equation (2) is also that used by Bagnold (1966) in his stream power hypothesis for sediment transport, which Bagnold assumes involves bed load transport. The proportionality between transport rate

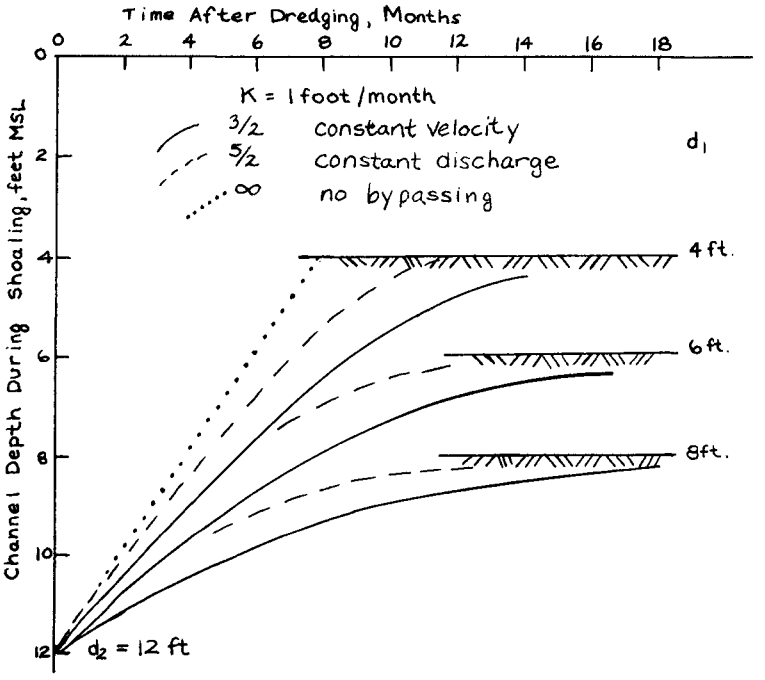

Figure 4. EFFECT OF BYPASSING ON CHANNEL SHOALING FOR THREE CHANNELS DREDGED TO 12 FEET MSL

and bottom shear required by equation (2) has been verified experimentally by Parsons (1972) for sediment grains in laminar flow.

Coefficient Ratios. The friction coefficients in equations (2) and (5) are assumed not to change after depth is increased by dredging. Increase in depth decreases the relative roughness of the flow on the typical friction factor diagram (shown in all hydraulics text books). For the moderate to high Reynolds numbers and small relative roughness expected in the navigation channel, such friction factor diagrams predict little change in f for large percentage changes in relative roughness. Thus, the assumption involved in equation (4) appears justified.

Velocities. There are three velocities to consider in the bypassing with shoaling process involved here. First, there is the ebb current velocity where it passes the controlling section of the navigation channel. This current has a characteristic maximum value of about 1 meter/second. (Flood currents are usually lower than ebb currents when they pass through the controlling section because flood flows are commonly more widely distributed over the ebb delta.)

Second, there is the bottom velocity due to the orbital motion of water particles under waves. The wave-induced bottom particle velocity on the ebb delta has a characteristic maximum amplitude, U, which approaches the magnitude of the maximum ebb current. The periodic reversal of the wave-induced velocity during the passage of each wave makes this velocity more effective in initiating sediment motion than tidal currents, but to first order, the wave-induced motion does not cause a net current.

Finally, there is the velocity of the longshore currents. The magnitude of longshore currents is only a fraction of U, with characteristic values on the order of 0.25 meters/second on open coast beaches. These velocities will be further diminished where they cross the controlling section of the navigation channel due to the deeper water there. Thus, the magnitude of the longshore current is distinctly less than the other two velocities involved in shoaling with bypassing.

The derivation assumes that wave-induced velocities stir up the sediment and that ebb currents distribute the sediment in the channel. The waves provide the shear component of equation (2) and the tides supply a convective velocity. This differs from the usual formulation of (2) in which the velocity that produces the shear is also the velocity causing the convection, but here the shear velocities are periodic and do not provide net transport. The longshore aspect of the motion is imposed on the shoaling equation (19) through the coefficient K which incorporates the longshore transport rate, Q, as given in equation (18).

Note that if U is used to obtain the velocity ratio, the velocity ratio will simply be the square root of the shear ratio (8). This results in a transport ratio exactly of the form given by equation (14) with the exponent m equal to 9/4, which is within the limits on m given by equation (15).

The use of linear shallow water wave theory to estimate U in equation (7) is technically not permissible because the waves on the ebb delta will have a height-to-depth ratio that is not negligible. However, linear theory has been used to describe such conditions many times before with adequate results (for example, Longuet-Higgins, 1970). Further, in the dredged cut, the height-to-depth ratio will be reduced, making linear theory more applicable.

Bypassing Mechanisms. During the meeting at which this paper was delivered (the 18th International Conference on Coastal Engineering), there were two descriptive papers on sediment bypassing at inlets (Sexton and Hayes, 1982; FitzGerald, 1982). Both these papers describe bypassing as the movement of discrete bars of sediment, usually initiated by a shift in the ebb channel from a downdrift location to an updrift location. This well-described process of discrete transport differs from the more continuous bypassing process of this paper, in which the longshore transport continually moves sand across the rim of the ebb delta and through the ebb channel. (This continuous longshore transport may in fact be accompanied by the motion of small bed forms.)

While bypassing undoubtedly occurs as described by Sexton and Hayes (1982) and FitzGerald (1982), it appears that the volume rate of this transport, when averaged over the time for the shifted ebb channel to complete one cycle, is only a fraction of the estimated annual longshore transport rates at the sites. Approximate estimates suggest that 10 to 30% of the longshore transport may be accounted for by the bar bypassing described in those papers.

Further, since dredging makes the ebb channel more efficient, it is less likely to shift in position. The deeper depths of the dredged channel are also expected to inhibit discrete bars moving across the channel. Therefore, in the dredged condition under investigation, most of the bypassing is expected to occur by relatively continuous longshore transport.

APPLICATIONS

Tabulation of t_p'. The following subsections show by example how to apply the analysis to practical problems. To aid in computing the duration of project depth, t_p, it is useful to rewrite equation (22) in dimensionless form.

$$t_p' = Kt_p/d_1 = d_2' - d_p' + \frac{1}{m}(\ell nA - \ell nB) \quad (25)$$

where $$d_p' = d_p/d_1 \quad (26)$$

$$d_2' = d_2/d_1 \quad (27)$$

and K, m, A, and B are defined by equations (18), (15), (23), and (24), respectively.

Equation (25) has been tabulated for m = 3/2 (Table 1) and m = 5/2 (Table 2) over a range of values of d_p' and d_2'. Ordinarily, in typical inland waterways, d_p' would be only slightly less than d_2', the difference due to the allowable overdredging which is rarely more than 2 or 3 feet. However, in dredging shallow tidal inlets in the active littoral zone, significantly more overdredging may be required to maintain floatation of the dredge and to reduce the frequency (and thus cost) of maintenance dredging.

Tables 1 and 2 list the values of t_p', defined by the right hand side of equation (25), as a function of d_p' and d_2', defined by equations (26) and (27). (The selection of m determines which of the two tables is used.) Any combination of d_1, d_p, and d_2 will give values of d_p' and d_2', and these give a value of t_p' either by direct reading of the table or by interpolation if necessary.

In the dimensionless form of equation (25), deep channels and shallow channels with variable amounts of overdredging can be conveniently covered by the same tables. The unit used for depth (feet, meters) does not matter as long as it is not changed during any single calculation, and as long as K is expressed in the same unit per time.

Example 1: Shoaling.

(a) Existing Condition: A permanent shallow draft tidal inlet is located in a relatively sheltered site on a large bay. The controlling depth is 1.5 meters chart datum, which corresponds to a mid tide depth of 2.5 meters. The longshore transport is estimated to be 50,000 cubic meters/year, with 80% of it occurring during the 4 month monsoon season. Characteristic storm waves have breaker heights of about 2.5 meters.

(b) Desired Improvements: A local company wishes to ship high value ore through the inlet during the non-monsoon season. The ore will be transported in barges needing a 4.0 meter project depth, measured from mid tide elevation. To get the barges through the inlet, the company plans to dredge a channel 30 meters wide and 150 meters long.

(c) Question: The shipper would like to dredge only once a year, right at the end of the monsoon season. How deep must he dredge (what is d_2?) in order to maintain a navigable depth for the 8 months until the start of the next monsoon?

Table 1. DIMENSIONLESS DURATION OF PROJECT DEPTH FOR m = 3/2 (Constant Velocity Condition)

Row Number	d_p'	d_2' =	t_p' = 1.10	1.20	1.33	1.50	1.75	2.00	2.25
1	1.05		0.50	1.05	1.49	1.91	2.40	2.81	3.17
2	1.10		x	0.55	0.99	1.41	1.90	2.30	2.67
3	1.20		x	x	0.44	0.86	1.35	1.76	2.12
4	1.30		x	x	0.09	0.51	0.99	1.40	1.77
5	1.40		x	x	x	0.23	0.72	1.13	1.49
6	1.50		x	x	x	x	0.48	0.89	1.26
7	1.75		x	x	x	x	x	0.41	0.77
8	2.00		x	x	x	x	x	x	0.37

Table 2. DIMENSIONLESS DURATION OF PROJECT DEPTH FOR m = 5/2 (Constant Discharge Condition)

Row Number	d_p'	d_2' =	t_p' = 1.10	1.20	1.33	1.50	1.75	2.00	2.25
1	1.05		0.31	0.66	0.96	1.26	1.62	1.94	2.24
2	1.10		x	0.35	0.65	0.95	1.31	1.63	1.92
3	1.20		x	x	0.30	0.60	0.96	1.28	1.57
4	1.30		x	x	0.06	0.36	0.72	1.04	1.34
5	1.40		x	x	x	0.17	0.53	0.85	1.15
6	1.50		x	x	x	x	0.36	0.68	0.98
7	1.75		x	x	x	x	x	0.32	0.62
8	2.00		x	x	x	x	x	x	0.30

(d) Solution: Based on the preceding description:

d_p = 4.0 m
d_1 = 2.5 m
C = 150 m
W = 30 m
t_p = 8 months

To use the table, it is necessary to find the dimensionless duration of project depth, t_p'. This term is defined by equation (25) as a function of K and d_1. Thus, K is needed. K is defined by equation (18) as a function of R, Q, C, and W. To estimate R, the fraction of longshore transport occurring above depth d_2, compare d_2 to the breaker depth of storm waves. The characteristic storm waves are given above as 2.5 meters, which will break in about 3.25 meters. Since this breaker depth is above d_2, assume R = 1.0. The value of Q during the nonmonsoon months is, from the data given above,

$$Q = 0.20 \times 50{,}000 \text{ cubic meters/8 months}$$

$$= 1250 \text{ cubic meters/month}$$

Thus from (18)

$$K = 1.0 \times 1250/(30 \times 150)$$

$$= 0.28 \text{ meters/month}$$

From equation (25)

$$t_p' = (K/d_1)t_p = (0.28/2.5)8$$

$$= 0.90$$

From equation (26)

$$d_p' = 4.0/2.5 = 1.6$$

This value of d_p' falls between rows 6 and 7 on the tables. Table 1 is the most favorable (gives the longest duration of project depth for a given d_2). Examination of Table 1 shows that t_p' = 0.90 between rows 6 and 7 is equivalent to d_2' somewhere between 2.00 and 2.25. Thus based on Table 1, the dredged depth d_2 must be at least twice the controlling depth (5.0 meters at least) in order for the channel to last the 8 months.

If a more exact solution is required, equation (25) can be solved by trial and error for t_p' = 0.90 and d_p' = 1.60. Such a solution for the favorable case of m = 3/2 yields d_2' = 2.14, which indicates d_2 = 5.35 meters.

Example 2: Bypassing

(a) Existing Conditions: Same as in Example 1.

(b) Desired Improvement: Same as in Example 1.

(c) Question: The property owner downdrift of the inlet in question is worried about the interruption in longshore transport due to the trapping of sand in the dredged channel. If d_2 = 5.1 meters, what will be the maximum reduction in bypassing rate?

(d) Solution: From equation (17), the maximum reduction in bypassing will equal the maximum trapping rate right after dredging for the case of m = 5/2 (constant discharge).

$$\text{Max Trapping Rate} = RQ\,[1 - (d_1/d_2)^{2.5}] \tag{28}$$

$$= 1250\,[1 - (2.5/5.1)^{2.5}]$$

$$= 1040 \text{ cubic meters/month}$$

This type of calculation can indicate the rate at which downdrift beaches need replenishment following dredging, if the dredged material cannot be placed directly on the downdrift shore.

SUMMARY

The basic contribution of this paper is to provide an organized method of computing the duration of project depth in a channel overdredged through a tidal inlet.

The duration of project depth, t_p, is predicted by equation (22). To solve this equation, the following data are required: the controlling depth before dredging, the project depth needed for navigation, the proposed depth of dredging, and the length and width of the channel. These parameters are defined in Figures 2 and 3 as d_1, d_p, d_2, C, and W, respectively. In addition, the longshore transport above the depth d_2 must be known, and the effect of dredging on the ebb velocity in the channel must be estimated (the value of m in equation (15)).

The analysis developed here can be used for the following practical problems:

a. computing the duration of project depth (use equation (22) or Tables 1 or 2).

b. testing whether a proposed depth of dredging will last a desired length of time (see example 1).

c. estimating the decreased rate of bypassing caused by a given channel (see example 2).

Based on the techniques used here, a typical shallow draft channel across the ebb tide delta has a lifetime measured in months, but due to bypassing the life of the channel is significantly longer than would be the case for complete trapping of longshore transport.

ACKNOWLEDGEMENTS

The problem implied by the title of this report was originally posed by Stanley Maisel, Chief, Planning Branch, New York District, Army Corps of Engineers. Dr. Arnold H. Lent, Technicare Corporation, Solon, Ohio 44139, provided the approximate solution given as equation (22). Mr. L. K. Ghosh, Central Water and Power Research Station, Pune, India, raised several questions which resulted in improvements to the present manuscript. Data shown in Figure 4 and Tables 1 and 2 were computed by S. J. Weinheimer, J. R. Hill, and D. J. Galvin, Jr. Figures were drawn by P. E. Politi and the manuscript typed by Sheila Zukor.

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