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SIMPLE APPROACH TO TSS SOURCE STRENGTH ESTIMATES

Donald Hayes[1] and Pei-Yao Wu[2]

ABSTRACT

Methods to estimate the rate at which a dredging operation suspends sediment particles into the water column have been developed by Nakai (1978), Collins (1993), Hayes *et al.* (2000b), and Wu and Hayes (2000). Nakai's TGU method is the most widely used, but has mathematical inconsistencies that could lead to erroneous source estimates. The other approaches require detailed knowledge of the dredging operation; this information is often not available and only persons experienced with dredging operations understand the operation adequately to estimate the required parameters. This paper presents a simple approach for estimating resuspension from dredging operations based upon available field data.

Keywords: sediment resuspension, TGU method, dredging impacts, dredging windows, contaminated sediments

INTRODUCTION

Background

Turbidity plumes associated with dredging operations impair water quality. Suspended sediment particles constituting the turbidity plume have the potential to impact the local aquatic ecosystem in a variety of ways ranging from burial of benthic layers to modifying fish behavior. Toxic constituents associated with the sediment particles expand the concerns. Ability to reliably predict the size, extent, and content of these turbidity plumes is crucial. Models capable of predicting downstream fate and transport have been developed (Cundy and Bohlen 1980, Kuo, et al. 1985; Kuo and Hayes, 1991).

Although all are steady-state suspended sediment transport models, these transport models vary considerably. They are for different dredge types, apply different assumptions, and use a variety of mathematical approaches. Yet, they all require the mass flux of suspended sediment, the rate of sediment mass loss, into the water column due to the dredging operation as input. This mass flux rate, referred to here as source strength, varies widely with dredge operation, sediment characteristics, and local conditions. These variations are both temporal and spatial in nature. However, since existing transport models assume steady-state conditions, a source strength model that represents average conditions is adequate. This paper presents a simplified approach for estimating this mass flux rate based upon dredge type and operating conditions. The approach ignores many of the known temporal and spatial variations, but provides a straight-forward method for estimating average resuspension rates.

Previous Source Models

Nakai (1978) proposed the popular TGU method. Nakai's initial formulation and variable definitions were:

$$TGU = \frac{KW_O}{Q_S} = \left(\frac{R_{74}}{R_O}\right)\frac{W_O}{Q_S} = KC\gamma \qquad (1)$$

where W_o = total quantity of turbidity generated by dredging (tons), C = coefficient depending upon dredge type, soil conditions, etc., W_s = total quantity of dredged materials (tons), TGU = turbidity generation unit, tons/m^3, Q_s = volume of dredged materials (m^3), γ = specific weight of dredged materials (tons/m^3), K = R_{74}/R_0, R_{74} = fraction of

[1] Hayes, D.F., Associate Professor, Civil & Environmental Engineering, University of Utah, 122 S. Central Campus Dr., Suite 104, Salt Lake City, UT 84112, USA, (801) 581-7110, (801) 585-5477 (fax), hayes@civil.utah.edu.
[2] Wu, P.Y., Graduate Research Assistant, Civil & Environmental Engineering, University of Utah, 122 S. Central Campus Dr., Suite 104, Salt Lake City, UT 84112, USA, (801) 585-6885, (801) 585-5477 (fax), PeiYao.Wu@m.cc.utah.edu.

particles with a diameter smaller than 74 μm, and R_0 = fraction of particles with a diameter smaller than the diameter of a particle whose critical resuspension velocity equals the current velocity in the field.

Since the immediate interest is in using Nakai's approach to estimate the source strength, the appropriate equation form is:

$$W_O = \frac{TGU(Q_S)}{(R_{74}/R_0)} = TGU\left[\left(\frac{R_O}{R_{74}}\right)Q_S\right] \tag{2}$$

At this point, Nakai redefined W_O as the rate of turbidity generation in kg/sec rather than the units of tons as he did in the previous equation. This requires Q_s also be redefined as the volumetric rate of sediment removal (m^3/sec). Although easy to use, the R_0Q_S/R_{74} term has fundamental problems. First, there is the issue of incompatibility between the weight based fractions R_0 and R_{74} and the volumetric flowrate Q_S. While troublesome, the gross nature of what is trying to be accomplished minimizes its impact. The term R_0Q_S, as defined by Nakai, represents the sediment mass (or volume) with a settling velocity sufficiently low that they will theoretically stay in suspension forever. While there are difficulties with the practicality of defining R_0, the concept is theoretically sound. However, the $1/R_{74}$ term increases as the average particle size increases (i.e. R_{74} decreases), thereby adjusting the rate of resuspension in the wrong direction.

Nakai determined W_O during dredging operations by measuring TSS along laterals normal to flow at 30 m and 50 m downstream from the dredging operation; the original manuscript describes the approach in detail, but does not provide details of the dredging projects investigated. He calculated the total mass of turbidity as:

$W_O = C_{avg}BHU$

where C_{avg} = average concentration of TSS (kg/m^3), B = width (m), H = water depth (m), and U = water velocity (m/sec).

These authors, with assistance from others, (Hayes 1986; Crockett 1993; Hayes, et al 2000; and Wu and Hayes 2000) have developed empirical source strength models for cutterhead dredges that consider dredge-operating parameters; the latest versions of these models, based upon 387 observations from a number of dredging sites, are:

$$DM: \quad \hat{g}(\%) = \frac{(C_S t_C)^{0.676} V_S^{\,2.008}}{10^{3.647} L_S^{\,13.899}} \left(\frac{A_E}{d_C}\right)^{14.575} \left(\frac{Q}{D^2}\right)^{0.805} \tag{3}$$

$$NDM: \quad \hat{g}(\%) = 10^{-3.3293} \left(\frac{A_E}{L_S d_C}\right)^{13.503} \left(\frac{Q}{D^2 V_S}\right)^{0.388} \tag{4}$$

where $\hat{g}$ = predicted rate of sediment suspended by the cutter and transported away from the dredging operation as a fraction of sediment mass dredged (%), C_S = in-situ sediment concentration (g/L), t_C = thickness of cut (m), A_E = cutter surface exposed to free water (m^2), V_S = swing velocity at the tip of the cutter (m/sec), d_C = diameter of cutter (m^2), Q = volumetric flow rate through dredge (m^3/sec), L_s = dredge stepping distance (m); and D = sediment inlet pipe diameter (m). The modified DM model, which is based upon the individual variables that affect dredging operations, resulted in an R^2 value of 0.588. An R^2 value of 0.470 was determined for the modified NDM model, which is based upon non-dimensional groups of the same variables. Although these models are empirically sound, they have several substantial drawbacks: a) they apply only to conventional cutterhead suction dredges, b) the forms of the empirical equations do not allow reliable extrapolation beyond the range of data used to develop them (12-inch to 20-inch dredges), and c) the equations require more knowledge of the dredging operation than is usually known prior to the initiation of dredging. Most readers trying to apply the models lack the knowledge of dredging operations to make reasonable estimates of the operating parameters.

Collins (1995) developed models to estimate the dredging-induced resuspended sediment concentrations near the dredge as a function of the dredge, dredge operation characteristics, and sediment properties. An approach similar to the empirical models shown in equations 3 and 4 was used to develop models for cutterhead and bucket dredging operations. However, these models also require considerable knowledge of the dredging operation and Collins described them as preliminary, unverified models.

MODEL DEVELOPMENT

A variety of mechanical and mixing actions occur in the immediate vicinity of dredging operations. These actions vary both temporally and spatially; they would be rather complex to model. Additionally, these actions associated with dredging operations do not discriminate against particles sizes; all sediment size fractions are initially suspended into the water column. However, sand (and larger) particles resettle quickly in the immediate vicinity of the dredging operation except under extreme flow conditions leaving only silt and clay particles (i.e. particles smaller than 74 μm) in the water column.

Steady-state transport models need the average rate of sediment mass flux leaving this "near-field" area. Thus, the objective of this model is to estimate the average rate of sediment resuspension leaving the immediate vicinity of dredging operations. Only a fraction of the particles smaller than 74 μm exit the near-field area and are subject to transport downstream. In terms of mass [3], this can be written as:

$$g = R\left(\frac{f_{74}\dot{V}_S C_s}{360}\right) \tag{5}$$

where g = mass rate of sediment resuspension (g/sec), R = resuspension factor or sediment mass loss rate (%), f_{74} = fraction of particles with a diameter smaller than 74 μm, and $\dot{V}_S$ = volumetric rate of in-situ sediment removal (m^3/hr).

The resuspension factor, R, represents the mass of sediment suspended into the water column relative to the mass of sediment removed via dredging in units of percent; i.e. if the loss rate is 1%, R would be entered as 1.0. This factor will vary with dredge type and size, sediment characteristics, dredge operation, and local environmental conditions. However, the model formulation presented in Equation 5 is of little use without estimated values for the resuspension factor, R, for different dredges and conditions. The following sections present resuspension factors for different dredge types based upon available data.

RESUSPENSION FACTORS FOR CUTTERHEAD DREDGES

Resuspension data for cutterhead dredges have been presented by a number of authors. Hayes, et al. (2000) and Wu and Hayes (2000) present almost 400 observations of resuspension rate from five field studies. The characteristics of these studies are summarized in Table 1.

Observed Resuspension Factors

Equation 5 was rearranged and solved for resuspension factor, R, using the near-field resuspension data from these dredging operations. Table 1 summarizes the resulting resuspension factor values and their statistical characteristics for each field study. The results are consistent with expectations. The highest resuspension factor is from Lavaca Bay - Phase II. The combination of a small dredge with relatively low horsepower removing highly consolidated, sticky clay in a dynamic environment would be expected to be a poor combination. Small particle sizes and a relatively low production rate exacerbate the problem. New Bedford Pilot Study (Acushnet River) observations were also elevated because of low dredge production, light sediments, and extensive debris. The DUBUQUE operated

[3] All mass values are reported as dry mass.

Table 1. Characteristics of cutterhead field studies used to develop resuspension factors.

		James River	Back River	Calumet Harbor	Acushnet River	Lavaca Bay – Phase II
	Dredge	*ESSEX*	*CLINTON*	*DUBUQUE*	*Ellicott 370*	*Tyro, Jr.*
	Size	18" diam.	18" diam.	12" diam.	10" diam.	12"
	Water Depth (m)	10	6.1, 11.6	8.2	0.6 - 1.5	1.1 – 2.5
	Swing Width (m)	58	46, 61, 92	30	18	18
	Cutter Tip Speed (m/s)	0.2 - 0.4	0.2 - 0.4	0.2 - 0.4	0.15	0.03 – 0.64
	Cutter Diameter (m)	1.5	1.8	0.9	0.8	0.8
	Sediment Removal (m)	1.5	~ 0.9, 6.1	0.9	0.6	0.8
	Cutter Rotation Speed (rpm)	20, 28, 32, 35, 37, 40	6.6, 12, 16	15, 20, 27	20	8.5, 19
	Production (m^3/hr)	504 - 2252	161 - 7379	33 - 56	28	28
	f_{74}	0.98	0.99	0.83	0.74	0.75
	Environment	Estuary (< 1 ppt)	Estuary	Freshwater Lake	Estuary	Estuary
In Situ Sediment	**Type**	Very soft silty clay (CH)	Soft, organic clay/silt mixture	Silty loam	Soft organic clay/silt mixture	Fat Clay
	Moisture Content (%)	186	*	71.1	117-159	43
	Atterberg Limits	LL > 120% PL ≅ 40%	*	LL = 25.4% PL = 25%	LL = 107-123% PL = 55-77%	LL = 58.5% PL = 26%
	Debris Present?	No	No	No	Yes	No
	Specific Gravity	2.73		2.71	2.46-2.55	
	Organic Content	*	*	*	*	*
	Ambient Currents (m/s)	0.1 – 0.8	0.03 – 0.8	0.0 - 0.07	< 0.07	0.0 – 0.07
	Observations	15	28	12	51	282
		Characteristics of Calculated Resuspension Factors, R (%)				
	Average	0.023	0.041	0.003	0.082	0.13
	Standard Deviation	0.017	0.052	0.002	0.087	0.11
	Minimum	0.004	0.003	0.0005	0.01	0.001
	Maximum	0.054	0.21	0.006	0.33	0.51

*missing data

under almost ideal conditions in Calumet Harbor and the resuspension factor reflects that the operation was quite effective.

The 18-inch cutterhead dredges used in the Back River (Savannah, GA) and James River are far larger vessels than one might deduce based simply on their descriptive sizes. Generally, these larger dredges carry powerful hydraulic pumps capable of dredging much greater depths and transporting the sediments much larger distances. Thus, under normal conditions the intake velocities are substantially greater; one would expect this fact alone to result in less resuspension and these data generally support that conclusion. Modest resuspension factors were observed, especially considering that the CLINTON (Back River) undercut a 20-foot bank (which often collapsed) using very aggressive operational tactics. As expected, the more cautious operation used by the ESSEX (James River) (McLellan, et al. 1989) yielded lower resuspension factors. James River sediments were likely more vulnerable to resuspension because of their high in situ moisture content (186%), especially considering that they are greater than the liquid limit (120%). Altho ugh sediment data are not available, the in situ moisture content of the Back River sediments were almost certainly between the plastic limit and liquid limit, or there probably would have a more significant difference.

Combined Evaluation

While matching site-specific conditions, dredging equipment, and operational methods to the above projects is a good way to estimate resuspension rates, water quality analyses are often required in very early stages of projects, long before dredge type, size, or operation is known. An adequate number of observations exist to perform more general evaluations of observed Resuspension Factors for cutterhead dredging operations. While this combined evaluation is not fully comprehensive, it does provide useful insights.

It is useful to evaluate the range and frequency of observed Resuspension Factors. Figure 1 shows a frequency histogram of the 388 observations listed in Table 1. Observed Resuspension Factors range from near 0 to 0.51 with the preponderance of values between 0 and 0.1. The data have a mean of 0.11 with a standard deviation of 0.11. Most of the observations, 282, are from the Phase II pilot study in Lavaca Bay, which has a strong influence over the data set. The data for all of the projects except Lavaca Bay have an average of 0.05 and standard deviation of 0.07.

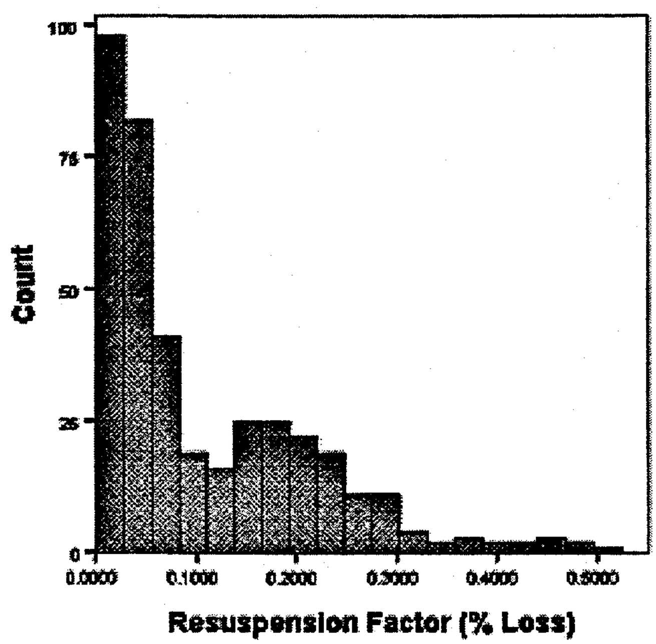

Figure 1. Frequency distribution of resuspension factors for cutterhead dredging operations.

Observed Resuspension Factors used in this paper are from dredges ranging in size from 10-inch to 18-inch. There are sufficient data to evaluate the variation of Resuspension Factor with dredge size. Figure 2 implies that the average and range of Resuspension Factors do not vary consistently with dredge size, except that both are lower for the larger dredge. As discussed earlier, this is probably due to higher vacuum pressures near the intake due to large pump horsepower. Despite this seeming consistency between dredge sizes, care should be exercised in attempting to apply these resuspension values to dredge sizes outside of this range. In particular, the increase in Resuspension Factor for the smaller dredges is likely to be more exacerbated for other dredges. The Ellicott 370 used in the New Bedford study is more adequately powered than other types of similarly sized hydraulic dredges. For example, the Ellicott 370 had a 360 HP engine as compared to 175 HP engine used in the 8-inch horizontal

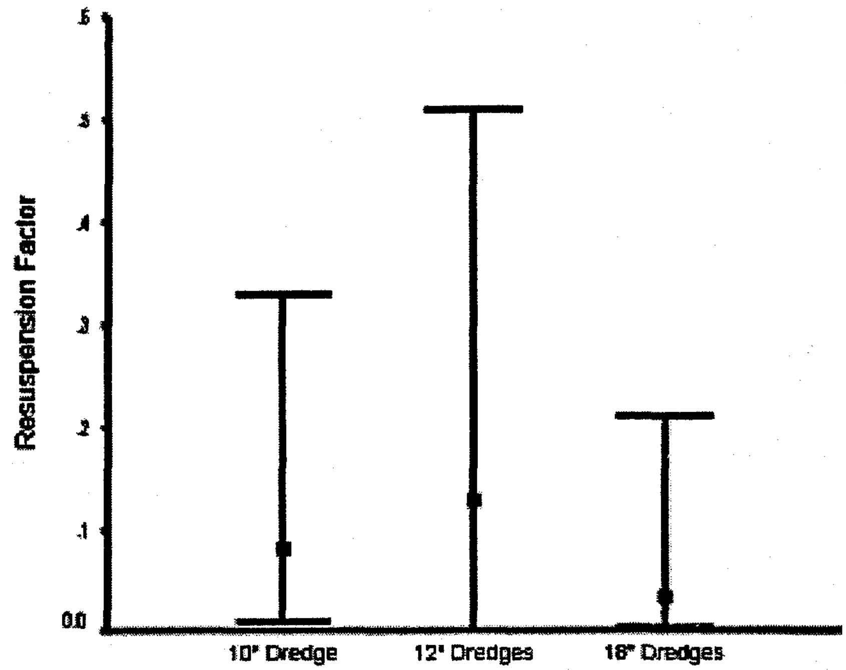

Figure 2. Resuspension Factor variation with dredge size.

auger dredge used later in the study. Many of the smaller specialty dredges were initially designed for dredging sewage sludge which is much more fluid than sediments.

Water quality evaluations often focus on the possibility of exceeding regulatory criteria. These analyses require one to look at a cumulative probability distribution of observed Resuspension Factors. For the data presented here, a resuspension factor of 0.31 is exceeded only 5% of the time ($R_{.05}$); a resuspension factor of 0.46 is exceeded only 1% of the time ($R_{.01}$). It would seem that these values should represent approximate maximums for similar cutterhead dredging operations.

It was also observed that the data fit a log-normal distribution quite well. While this is not utilized here, it provides the possibility to extend the current analysis to a risk-based assessment.

Summary

Although more data would be helpful and the five field studies do not cover all possibilities, the presented values represent a reasonable range of Resuspension Factors for different cutterhead dredge sizes and operating conditions. By matching dredging project characteristics with these field studies, one should be able to develop a reliable estimate of the resuspension factor and, then, the sediment resuspension rate using equation 5. The statistical evaluations show the data are consistent and open up the possibility of risk-based assessments.

RESUSPENSION FACTORS FOR BUCKET DREDGES

Similar amounts of data are available from bucket dredging studies. But, these data have not been as extensively evaluated as those from cutterhead dredges. The proximity of the data to the source is also not as convenient as for the cutterhead dredging operations; the operation of bucket dredges make it difficult to get data in the immediate vicinity of the source. There are, however, sufficient data to develop representative resuspension factor values for bucket dredging operations. Since all data are away from the immediate vicinity of the dredging operation, it is assumed that all particles larger than 74 μm have already settled. Thus, the resuspension factor was not adjusted for this fraction.

Standard (Open) Clamshell Buckets

A number of field studies have used standard clamshell buckets; these are often referred to as "open" buckets to distinguish them from buckets that are fully enclosed in an attempt to reduce turbidity. These data have been reported and analyzed by a number of authors. Table 2 summarizes the studies used in this paper to estimate resuspension factor values.

Kuo and Hayes (1991) used average sediment loss rates from the Thames River, St. Johns River, and Black Rock Harbor to calibrate their transport model for bucket dredging operations. Sediment loss rates for these studies are shown in Table 2. Sediment loss rates for the Thames River and Black Rock Harbor are the same as those presented by Kuo and Hayes (1991). Sediment loss rates for the St. Johns River, however, were adjusted for what appears to be an error in the initial concentration used by Kuo and Hayes. Collins (1995) estimates the source strength to be 0.45 kg/sec rather than the 0.31 kg/sec published by Kuo and Hayes. Since an earlier version of Collins' report was the source of this value, it is assumed to be in error. This increases the sediment loss rate to 0.16%, more in line with the other studies.

A study of open clamshell dredging in the Calumet River (Hayes et al. 1988) also included scow overflow. Collins (1995) calculated a sediment loss rate of 243 g/sec for the Calumet River field study. Although a production rate is not provided, assuming a full bucket and 50 cycles per hour, the production rate would be 380 m^3/hr. Assuming that

Table 2. *Summary of estimated resuspension losses from clamshell (open) bucket operations.*

		Field Study				
		Thames River	**St. Johns River**	**Black Rock Harbor**	**Calumet River**	**Boston Harbor**
	Environment	Estuary	Estuary	Estuary	Freshwater River	Estuary
	Bucket Size (yd^3)	13	12	10	10	26
In Situ Sediment	**Type**	Very soft silty clay	Soft, organic clay/silt mixture	Sandy organic clay	Soft organic clay/silt mixture	Stiff clay with silt
In Situ Sediment	**Moisture Content (%)**	*	*	300	*	*
In Situ Sediment	**Atterberg Limits (%)**	*	*	LL = 170% PL = 65%	*	*
In Situ Sediment	**Debris?**	*	*	Yes	*	*
In Situ Sediment	**Specific Gravity**		2.40	2.39	*	*
In Situ Sediment	**Organic Content (%)**	3-4	*	*	*	*
	Water Depth (m)	12.8	5.5	6.2	7.5	11.7
	Typical Current (m/sec)	0 – 0.5	0 – 0.07	0.07 - 0.25	0 - 0.07	0.17
	Scow Overflow	Yes	Yes	Yes	Yes	No
	f_{74}	> 0.70	*	0.90	0.83	0.99
	Production (m^3/hr)	*	864	688	380	1530
	Data Source	Bohlen *et al.* (1979)	Collins (1995)	Collins (1995)	Hayes, *et al.* (1988)	Hayes and Welp (2000)
	Resuspension Factor, R (%)	0.88	0.16	0.28	0.25	0.66

* missing data

the sediment characteristics are the same as those found in the Calumet Harbor field study (in situ concentration of 920 kg/m^3), the resulting loss is 0.25%.

All of these dredging operations included scow overflow; that is the sediment scow was filled beyond the initial filling to displace supernatant liquid with sediment and increase the economic load. The supernatant overflows the barge and discharges solids into the water column increasing TSS concentrations in the water column; once in the water column, these solids are not distinguishable from resuspension due to mechanical actions of the dredge. Hayes and Welp (2000) present results from a dredging study in Boston Harbor conducted during 1999. Scow overflow was not allowed during these dredging operations; thus, measured sediment resuspension values result from dredging actions only. The conventional 26-cy bucket removed about 2 feet of silt plus a foot or so of virgin clay from the 38-ft bottom. The production rate is assumed to be about 1,530 m^3/hr based upon the dredge operation and bucket capacity. TSS observations during dredging yield a depth-averaged TSS concentration above background of 201 mg/L. The width of the plume was not measured. Considering the short distance between the bucket and sampling location, it is unlikely to be more than twice the bucket width of about 3 m. Assuming that concentration occurs across a 6-m width in a current velocity of 0.17 m/sec the source strength is about 2.4 kg/sec. Assuming an in situ sediment concentration of 844 kg/m^3, the sediment lost to resuspension was 0.66 percent.

All of these studies show higher resuspension factors than the cutterhead dredge studies described previously. Resuspension factors range from 0.16 to 0.66. The results for the Boston Harbor field study are surprising in that they are among the highest value even though barge overflow was not allowed. The other values seem to be in a reasonable range, particularly considering that barge overflow was included. If overflow accounts for 50% of the suspended sediments, the remaining resuspension factors are not substantially different from those for the cutterhead dredges.

The apparent increase in resuspension factor for Boston Harbor may result from the samples being collected much closer to the actual dredging location (within 2 to 7 m) than in the other studies. TSS concentrations at the source for the other studies were extrapolated from samples collected farther downstream. A substantial amount of the TSS in the Boston Harbor study was near the bottom; without that value, the average TSS concentration and source strength would have been reduced by 30% yielding a resuspension factor of about 0.47. This is much more in line with the other studies. It is likely that these additional solids would have settled in the near vicinity of the dredging operation and not been measured in downstream samples as taken in the other studies.

Resuspension factor values from the open clamshell bucket dredges show a strong relationship with water depth (Figure 3). This substantiates previous theories that sediment erosion from the top of the bucket as it moves upward is a primary resuspension mechanism for standard clamshell buckets.

Enclosed Clamshell Buckets

Data are available for two bucket dredging studies that used enclosed clamshell buckets. The first study was conducted in the St. Johns River at the same location and under the same conditions as the open bucket dredging study described above. Collins (1995) did not estimate source strength for the enclosed bucket operation in the St. Johns River, but did report an estimated TSS concentration at the bucket location of 150 mg/L. The estimated TSS concentration at the open bucket was 285 mg/L; since the conditions are the same, the resuspension rate is proportional. Thus, the representative resuspension rate for the enclosed bucket during the St. Johns River study was 0.27 kg/sec and a sediment loss rate of 0.10 %. The resulting resuspension factor is 1,000 and includes bucket overflow.

The most recent data were collected in Boston Harbor in August 1999 (Hayes and Welp 2000) during the operation of a 39-cy enclosed bucket. The enclosed bucket was a conventional 26-cy bucket converted to an enclosed bucket with a 39-cy capacity. The bucket removed about 2 feet of sediment from the 38-ft bottom with an observed depth-averaged TSS concentration of 50 mg/L. Assuming that concentration occurs across a 6-m width in a current velocity of 0.17 m/sec the source strength is about 0.66 kg/sec. The dredge production was about 2,000 cy/hr. Assuming an in situ sediment concentration of 844 kg/m^3, the sediment lost to resuspension is 0.22 percent. The associated resuspension factor is 0.22.

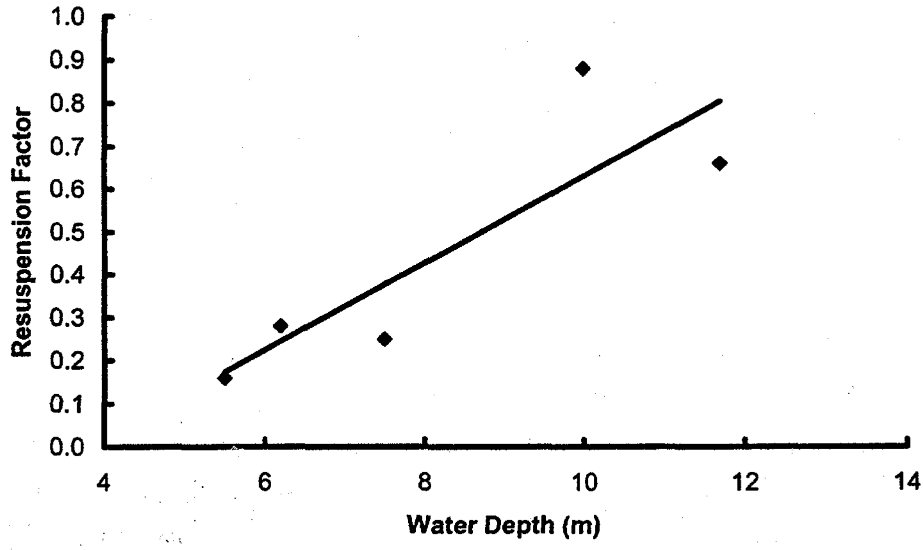

Figure 3. Resuspension factor for open clamshell bucket dredges with water depth.

RESUSPENSION FACTORS FOR OTHER DREDGE TYPES AT NEW BEDFORD

Near-field resuspension data have been collected around other dredge types. The New Bedford pilot study gathered data during horizontal auger dredging operation and a matchbox dredgehead. The US Army Corps of Engineers (1990) provide the data necessary to estimate values of Resuspension Factor for these two dredge types during their operations in the Acushnet River. Although the data sets are not substantial and represent only one location, the resulting Resuspension Factors at least give an idea of how these dredges perform. Table 3 shows the sediment characteristics in the areas that dredging occurred; both dredges operated in each area.

Table 3. New Bedford Pilot Study Sediment characteristics.

	Dredging Area 1	Dredging Area 2
Moisture Content (%)	135.5	158.7
Liquid Limit (%)	116.7	122.8
Plastic Limit (%)	62.2	77.0
% Fines	73.7	77.8
Specific Gravity	2.49	2.46

Horizontal Auger Dredge

An Ellicott SP-915 Mudcat Dredge with 175 HP and an 8-inch suction intake was used for 8 days during the New Bedford pilot study. The dredge removed 6-inches of sediment in each pass moving ahead at 6 to 20 ft/minute. The US Army Corps of Engineers (1990) present 42 observations of resuspension rate for the horizontal auger dredge and average production rates for each period. The resulting Resuspension Factors range from 0.6 to 56 with an average of 12.6 and standard deviation of 11.8. These values are markedly higher than any other dredge type at other locations or at New Bedford. Some of this increase is due to the difficulty the dredge had with debris and the nature of the soft sediments that make them subject to higher resuspension rates. The cutterhead and matchbox encountered similar debris, but were more successful in dealing with it. Lower production rates and suction intake velocities across the 8-ft wide head are also expected to be contributing factors. In general, all studies that have used horizontal auger dredges have resulted in substantially higher water quality impacts than those using more conventional dredges.

Matchbox Dredgehead

The matchbox dredgehead operated under similar conditions. Data were also collected in the near vicinity of the dredgehead and the resulting TSS resuspension rates reported by the Corps of Engineers (1990). Fifty-seven (57) observations are reported along with average production rates for each dredging area. The resulting resuspension factors range from 0.1 to 10 with an average of 2.3 and standard deviation of 2.0. These values are considerably higher than those for the cutterhead dredge at New Bedford, which were all less than 0.33. This substantiates the data presented in the original report (USACE 1990), which show that the matchbox had resuspension rates about five times higher than the cutterhead dredge and a much lower production rate. The production rate was depressed because of the thin lifts removed to avoid difficulty with debris.

SUMMARY AND CONCLUSIONS

A simplified approach based upon the resuspension factor, R, was presented for estimating resuspended sediment source strengths for dredging operations. Resuspension factors were calculated for cutterhead, clamshell bucket, enclosed clamshell bucket, horizontal auger, and matchbox dredging operations covering a variety of conditions. The resulting resuspension factors provide a reasonable range expected from typical dredging operations. They should be adequate for comparing resuspension rates at dredging operations with similar conditions. In particular, there is sufficient data for cutterhead dredges to suggest the values should be representative of many dredging operations. With sufficient data, statistical analyses of resuspension factors can provide sound approaches for estimating water quality impacts from future dredging operations.

Although data from a number of field studies were used to estimate resuspension factors, data from other field studies are available and were not included. Water quality data have also been collected around horizontal auger dredges in the Grasse River and Fox River, a modified dustpan at James River, a matchbox dredgehead in Calumet Harbor, hopper dredges at Grays Harbor and the Snake River, the Ultra/Morey dredge in the Fox River, and the CableArm clamshell in Manistique Harbor. Many of these studies did not gather data sufficiently close to the dredgehead to directly support such calculations. However, a combination of detailed data evaluation and application of previously developed models, such as those by Kuo, et al. (1985) and Kuo and Hayes (1991), to these studies could provide additional estimates of resuspension factor.

The resuspension factor method also provides a basis for future model developments. The fundamental approach incorporated into Equation 5 removes site-specific characteristics such as in situ sediment density, silt and clay fractions, and dredge production. With sufficient data, relationships between the resuspension factor, R, and dredge operation, site conditions, and sediment characteristics can be developed for different dredge types. Theoretical or empirical approaches could provide an ability to estimate the resuspension factor, R, for dredging conditions that have not previously been studied.

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