NEAR-FIELD WATER QUALITY MODELING OF DREDGING OPERATIONS IN THE DELAWARE RIVER

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SUMMARY

The U.S. Army Corps of Engineers (USACE), Philadelphia District is planning to deepen the Delaware Estuary navigational channel from its current federally authorized depth of 40 feet MLW to 45 feet MLW. Current plans call for the dredging to start late in the year 2001 or early 2002. Near-field concentrations of metals released during dredging operations were estimated to determine whether potential sediment contaminants that may be released during dredging could exceed Delaware River water quality criteria. These evaluations were conducted for cutterhead hydraulic dredging in the shipping channel and for a bucket dredge in berthing areas. The model selected for this evaluation is the DREDGE model, developed for near-field (i.e., within a 200-foot mixing zone) evaluation of dredging operations.

DREDGE was developed to assist in making a-priori assessments of environmental impacts from proposed dredging operations. DREDGE estimates the mass rate at which bottom sediments become suspended into the water column as the result of hydraulic and mechanical dredging operations and the resulting suspended sediment concentrations. These are combined with information about site conditions to simulate the size and extent of the resulting suspended sediment plume. DREDGE also estimates particulate and dissolved contaminant concentrations in the water column based upon sediment contaminant concentrations and equilibrium partitioning theory.

The results of the DREDGE model indicate the following. At some point within the simulated area for cutterhead dredging, four of the dissolved metals (chromium, mercury, selenium and silver) and the total PCB concentrations were above the most stringent of the DNREC or DRBC acute or chronic water quality criteria. The remaining six metals never exceeded these criteria at any point in the simulated dredging, using the maximum sediment metal and PCB concentrations found in the area to be dredged. Three of these metals (chromium, selenium, and silver) only exceeded standards at the bottom and not at 0.5 m above the bottom. Mercury exceeded the standard at 0.5m above the bottom but not at 1.0 m above the bottom. Only selenium exceeded acute water quality criteria at any point and then only to a distance of 50 m from the point of dredging. The other three metals and the total PCBs exceeded only the chronic criteria. PCBs did not exceed chronic criteria beyond 40 m from the point of dredging, while mercury, selenium and silver exceeded chronic criteria based on maximum sediment concentrations, to distances of 350, 120 and 160 meters, respectively, from the point of dredging at the bottom.

None of the dissolved metal concentrations predicted to be released to the water column as a result of bucket dredging were above the most stringent of the DNREC or DRBC acute or chronic water quality criteria, even using the maximum sediment metal concentration measured in the area to be dredged. PCB concentrations were above the most stringent criterion out to a distance of about 30 m from the point of dredging. Even with a more conservative metals partitioning estimation approach, no metals with measurable sediment concentrations exceeded water quality criteria outside of a 60-meter mixing zone.

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1.0 INTRODUCTION

The U.S. Army Corps of Engineers (USACE), Philadelphia District is planning to deepen the Delaware Estuary navigational channel from its current federally authorized depth of 40 feet MLW to 45 feet MLW. Current plans call for the dredging to start late in the year 2001 or early 2002. The State of Delaware Department of Natural Resources and Environmental Control (DNREC) requested that the Corps evaluate the near-field concentrations of metals released during dredging operations. The purpose of this evaluation is to ensure that potential sediment contaminants that may be released during dredging are not likely to exceed the state's water quality criteria. These evaluations were conducted for cutterhead hydraulic dredging in the shipping channel and for a bucket dredge in berthing areas. The model selected for this evaluation is the DREDGE model, developed for the Corps of Engineers for near-field (i.e., within a 200-foot mixing zone) evaluation of dredging operations (Hayes and Je 2000).

DREDGE was developed to assist in making a-priori assessments of environmental impacts from proposed dredging operations. DREDGE estimates the mass rate at which bottom sediments become suspended into the water column as the result of hydraulic and mechanical dredging operations and the resulting suspended sediment concentrations. These are combined with information about site conditions to simulate the size and extent of the resulting suspended sediment plume. DREDGE also estimates particulate and dissolved contaminant concentrations in the water column based upon sediment contaminant concentrations and equilibrium partitioning theory.

2.0 METHODS

2.1 DREDGE MODEL

DREDGE requires information on dredge characteristics (for a cutterhead dredge, this includes: the cutterhead diameter and length, thickness of cut, swing velocity and dry density of sediment; for a bucket dredge, this includes: bucket size, cycle time, settling velocity and dry density of sediment), and site characteristics (including water depth, average water velocity, mean particle size, specific gravity of sediment, and particle characteristics). Representative characteristics were selected for the dredges to be used for this project along with the appropriate site characteristics. Two representative sites were selected, one in the shipping channel and one in a berthing area.

The model has two near-field TSS submodels, the TGU method and the correlation method. Parameters for both submodels were based on the characteristics of the dredge expected to be used and the sediment expected to be encountered. The TGU submodel was much more conservative than the correlation submodel in predicting a much greater sediment source strength and thus was chosen for this study.

In addition to simulation of sediment distribution during dredging, dissolved metals and dissolved total PCBs were simulated. Distribution of these constituents were simulated based on the TSS plume and the equilibrium partitioning method included with DREDGE (version 2.0). A more conservative equilibrium approach was also calculated for the metals, assuming that 80% of the total metal in the sediment can be released in the dissolved form. Concentrations of dissolved metals and PCBs were compared with the more restrictive of the freshwater DNREC or DRBC acute and chronic water quality criteria (Table 2-1).

Details of the model from the user's guide are included in Appendix A.

2.1.1 DREDGE Limitations

There are a number of limitations associated with the models used in DREDGE. The sediment resuspension models are only applicable to dredging operations similar to those used in the development of the empirical equations. The models generally produce reasonable estimates for normal operating characteristics, but unusual operating parameters may yield unreasonable results.

The far-field transport models used assume a dominant, uni-directional current that exists sufficiently long for suspended sediment concentrations to reach steady-state. They also assume a steady source from a specific location (identified in the models as 0,0,0). Although the dredge is moving continuously, the movement is usually slow compared to transport in the water column.

Table 2-1. Water quality criteria for protection of aquatic life; for freshwater, hardness was assumed to be 193 mg/l based on Farrar et al. 2001. (All values are listed or calculated in micrograms per liter.)

	Hardness							
	193							
	STATE OF DELAWARE				DELAWARE RIVER BASIN COMMISSION			
Parameter	Fresh Acute Criterion	Fresh Chronic Criterion	Marine Acute Criterion	Marine Chronic Criterion	Fresh Acute Criterion	Fresh Chronic Criterion	Marine Acute Criterion	Marine Chronic Criterion
Arsenic (III)	360	190	69	36	360	190	69	36
Cadmium	8.2	1.9	43	9.3	8.2	1.9	43	9.3
Chromium (III)	2975	355						
Chromium (IV)	16.0	11.0	1,100	50				
Chromium (trivalent)					2975	355		
Chromium (hexavalent)					16	11	1,100	50
Copper	32.9	20.7	2.9		32.9	20.7	5.3	3.4
Lead	188.6	7.3	140	5.6	48	16	220	8.5
Mercury					2.4	0.012	2.1	0.025
Mercury (II)	2.4	0.012	2.1	0.025				
Nickel	2474	275	75	8.3	2474	275	75	8.3
PCBs (Total)	2.0	0.014	10	0.03	1	0.014	5	0.03
Selenium	20.0	5	300	71	20	5	300	71
Silver	12.6	0.12	2.3		12.6		2.3	
Zinc	204	185	95	86	204	185	95	86

The partitioning of contaminants associated with colloidal particles involves a number of very complex physical and chemical processes. DREDGE uses a linear equilibrium partitioning model to estimate the concentration of contaminants which remain associated with the suspended particles and the concentration of dissolved contaminants in the water column.

2.1.2 Cutterhead Model

DREDGE utilizes a model developed by Kuo, Welch, and Lukens (1985) to estimate the transport of suspended sediment from cutterhead dredges. The model assumes a continuous point source of suspended sediment (located at the point of dredging) transported downstream by a strong directional current. The model calculates the suspended sediment concentration at any position in the water column including depth. The cutterhead dredge model is as follows (equation variables are described in Table 2-2):

$$TSS_{wc}(x,y,z) = \frac{m_R}{4\pi x\sqrt{k_y k_z}} \exp\left[\left(\frac{y^2}{4k_y\frac{x}{u}}\right) \frac{\left(z + \omega\frac{x}{u}\right)^2}{4k_z\frac{x}{u}}\right]$$

Note that the dredgehead position is at X = 0, Y = 0, and Z = 0 (bottom). The settling velocity of the suspended sediment particles are calculated according to Stokes' Law. Parameters used in the cutterhead model are listed in Table 2-3. Appendix B contains results of a sensitivity analysis of parameters used in the DREDGE model for this application.

2.1.3 Bucket Dredge Model

DREDGE utilizes a model developed by Kuo and Hayes (1992) to estimate the transport of suspended sediment from bucket dredges. The model assumes a vertical line source of suspended sediment located at the point of dredging. The model calculates the depth averaged suspended sediment concentration at any position in the water column. The bucket dredge model is as follows (equation variables are described in Table 2-2):

$$TSS_{wc}(x,y) = \frac{m_R}{uh\sqrt{4\pi k_y\frac{x}{u}}} \exp\left[\left(\frac{y^2}{4k_y\frac{x}{u}}\right) \left(\frac{\omega x}{uh}\right)\right]$$

Note that the vertical line source which represents the dredge position is at X = 0 and Y = 0. The settling velocity of the suspended sediment particles are calculated according to Stokes' Law. Parameters used in the cutterhead model are listed in Table 2-4. Appendix B contains results of a sensitivity analysis of parameters used in the DREDGE model for this application.

Table 2-2. Variable conventions used in the DREDGE model equations and documentation.

a	rotational speed of cutterhead, radians/sec
µ	dynamic viscosity of the water, g/cm-sec
g_(sed)	bulk density of the sediment, kg/m^3
d	internal angle between the cutter blades and the undredged sediments, degrees
r	density of water, g/cm^3
r_s	density of sediment particles (specific gravity), g/cm^3
q	angle between the dredge ladder and the horizontal, degrees
w	particle settling velocity, m/sec
A_C	total area of cutter surface, m^2
A_E	area of cutter surface exposed to free water, m^2
b	characteristic bucket size, m
C_(diss)	dissolved contaminant concentration on sediment, µg/L
C_(ss)	contaminant concentration on suspended sediment, µg/L
C(^T)_(sed)	total contaminant concentration on the sediment, µg/L
d	average particle diameter, cm
D_f	full cut depth, m
f_oc	fraction of organic matter in the sediment, g/g
g	gravitational acceleration, m/sec^2
G	mass rate of sediment resuspended per volume rate of sediment dredged (turbidity generation unit), kg/m^3
h	predredging water depth, m
K	= Ro/R74
K_oc	organic carbon partition coefficient, L/g
K_ow	octanol-water partitioning coefficient, unitless
K_p	equilibrium partitioning coefficient, L/g
k_cb	coefficient of bucket effectiveness, unitless
k_y	diffusion coefficient normal to the direction of flow (y-direction), m^2/sec
k_z	vertical diffusion coefficient (z-direction), m^2/sec
L_c	length of cutter, m
L_(dredge)	Bow-to-stern length of dredge plant, m
L_L	Ladder length (excluding cutter), m
m_R	mass rate of sediment resuspension, kg/s
m_s	mass rate of sediment approached by cutter, kg/hr
P	ratio of thickness of cut, tc, to full cut depth, Df, unitless (P £ 1.0)
Q_(dredge)	dredge flowrate, m^3/sec
q	intermediate calculation variable for AE/AC, unitless
q_i	contaminant concentration on sediment, µg/g
q_S	volume rate of sediment removal, m^3/sec
Ro	particle fraction that has a critical resuspension velocity smaller than the

Table 2-2. (Continued)

ambient current velocity, unitless

R74	particle fraction less than 74 μm, unitless
r_c	cutterhead radius, m
S_(loss)	sediment loss rate, %
t_c	thickness of cut, m
T_c	total bucket cycle time, sec
T_u	time for bucket to be raised from bottom position to above the water surface, sec
T_o	time for which the bucket is completely out of the water, sec
T_d	time for bucket to fall from raised position to bottom, sec
TSS_wc	suspended sediment concentration at a specific position in the water column (located at x,y,z), mg/L
u	uniform velocity in the x-direction, m/sec
V_B	bucket volume, m^3
v_d	forward speed of dredge, m/sec
V_i	suction intake velocity, m/sec
v_s	swing speed of cutter tip, m/sec
V_t	tangential velocity of cutterblades relative to the water, m/sec
w_a	horizontal auger width, m
w_h	draghead width, m
x	downstream distance from the dredgehead, m
x_p, y_p	intersection coordinates of the mudline and front of cutter surface, m
y	lateral distance from the dredgehead, m
z	vertical distance from the dredgehead, m

Table 2-3. Input parameters for DREDGE model for cutterhead dredge scenario for the Marcus Hook area.

Parameter	Value	Source
<< Cutterhead Dredge Data >>		
Cutterhead diameter	= 1.525 (m)	size of dredge
Cutterhead length	= 1.525 (m)	size of dredge
Thickness of cut	= 1.525 (m)	depth of dredge
Swing velocity at cutter	= 0.127 (m / sec)	typical operation
In-situ dry density	= 877 (kg/m^3)	local sediment characteristics
<< Near-Field Model - TGU method >>		
Cutterhead length	= 1.525 (m)	size of dredge
Thickness of cut	= 1.525 (m)	depth of dredge
Width of turbid area	= 120 (m^2)	width of plume based on field experience
Turbidity generation unit	= 12000 (g/m^3)	rate of resuspension and transport; based on Nakai (1978) and dredge characteristics
<< Far-Field Model >>		
Lateral diffusion coefficient	= 10000 (cm^2/sec)	typical values: 10^5-10^7; lower value more conservative
Vertical diffusion coefficient	= 5 (cm^2/sec)	typical values without stratification: 1-10; middle of range chosen
Settling velocity	=.001263 (m/sec)	calculated from Stoke's Law and Mean particle size
Downstream locations	= 100 (m)	output range and intervals
X-step	= 10 (m)	
Lateral locations	= 100 (m)	
Y-step	= 10 (m)	
<< Site Characteristics >>		
Water depth	= 12 (m)	average depth in area of dredging
Ambient water velocity	= 0.5 (m/sec)	range: 0-1.4 m/s
Mean particle size	= 40 (um)	area sediment characteristics
Specific gravity of sedi.	= 2.65	area sediment characteristics

Table 2-4. Input parameters for DREDGE model for open-bucket scenario for the Sun Marcus Hook Berth area.		
Parameter	**Value**	**Source**
<< Dredge Characteristics >>		
Bucket size	= 19.13 (m^3)	Size of bucket
Cycle time	= 72 (sec)	typical time for operation
Settling velocity	= 0.00125 (m/sec)	calculated
In-situ dry density	= 877 (kg/m^3)	area sediment characteristics
<< Near-Field Model - TGU method >>		
Bucket size	= 19.13 (m^3)	size of bucket
Cycle time	= 72 (sec)	typical time for operation
Turbidity generation unit	= 45000 (g/m^3)	rate of resuspension and transport; based on Nakai (1978) and dredge characteristics
R74 (fraction of sediment < 74um)	= 0.77	area sediment characteristics
Ro (fraction < critical velocity)	= 0.99	area sediment characteristics
<< Far-Field Model >>		
Lateral diffusion coefficient	= 10000 (cm^2/sec)	typical values: 10^5-10^7; lower value more conservative
Vertical diffusion coefficient	= 5 (cm^2/sec)	typical values without stratification: 1-10; middle of range chosen
Settling velocity	=.001263 (m/sec)	calculated from Stoke's Law and mean particle size
Downstream locations	= 100 (m)	output range and intervals
X-step	= 10 (m)	
Lateral locations	= 100 (m)	
Y-step	= 10 (m)	
<< Site Characteristics >>		
Water depth	= 12 (m)	average depth in area of dredging
Ambient water velocity (m/sec)	= 0.5	range: 0-1.4 m/s
Mean particle size	= 40 (um)	area sediment characteristics
Specific gravity of sediment	= 2.65	area sediment characteristics

2.2 CHEMICAL ANALYTICAL DATA

Bulk sediment samples from the area proposed for navigation channel dredging were collected in 1991 through 1994 (23 samples) in the Marcus Hook range (USACE, 1992; Greeley-Polhemus Group, 1993; Urie and Ettinger, 1995). Samples from the area proposed for the dredging of a berthing area were collected in 1995 (4 samples) in the Sun Marcus Hook Berth (Taylor, 1996). These sediment concentrations are presented in Tables 2-5 and 2-6 and the sample locations are presented in Figure 2-1. Total PCB concentrations in sediment were assumed to be represented by the maximum sediment value of 152 ng/g found in Burton (1997).

2.2.1 Contaminant Mobilization at the Point of Dredging

Equilibrium partitioning theory is a simple mathematical method of estimating the proportion a chemical sorbed to sediment to the chemical dissolved in water. With a known concentration of chemical per unit weight of sediment/soil, and a known weight of total sediment/soil, this method can be used to determine the concentration of the chemical in the water. This model was first proposed by Samuel W. Karickhoff (Karickhoff et al. 1979; Karickhoff 1981). Assuming linear relationships between sediment concentration, fraction of organic carbon, and the octanol/water partition coefficient, concentrations of organic chemicals in sediment can be multiplied by a factor to yield a concentration of that chemical in the water column. The model was later refined by Thomann and Mueller (1987). Their model states that the partition coefficient is a function of not only the fraction of organic carbon and the octanol/water partition coefficient, but a function of TSS as well.

2.2.1.1 Dredge Model Contaminant Partitioning

DREDGE calculates downstream water column contaminant concentrations based upon the equilibrium partitioning concept. DREDGE uses a linear partitioning model to convert initial contaminant concentrations on in-situ sediment and downstream suspended sediment concentrations to particulate and dissolved contaminant concentrations. The concept of equilibrium partitioning is that a consistent relationship exists between particulate and dissolved concentrations of a specific contaminant under equilibrium conditions. The linear partitioning model used by DREDGE further assumes that the relationship between particulate and dissolved concentrations of a specific contaminant is a constant. The linear partitioning coefficient is defined as:

$$K_p = \frac{\text{Contaminant concentration on sediment } (\mu g/g)}{\text{Contaminant concentration in water } (\mu g/l)}$$

Table 2-5. Bulk sediment data from several sites in the Delaware River representing what would be dredged from the Marcus Hook range of the Delaware River navigation channel (units in mg/kg)

Delaware River - Metals in Sediment from Marcus Hook Region, mg/kg												
	Stations											
Metal	L1-C	M1-C-0'	M1-C-9.75	M2-C-0'	DRV-5	DRV-6	DRV-7	L-1-0.25	L-1-1.95	L-1.4.2	L-2-0.0	L-3-0.0
Arsenic	7.39	13.2	4.1	10.9	1.29	2.65	0.7	6.62	11	1.29	4.53	7.9
Cadmium	1	0.2	0.081	0.25	1	1	1	0.386	0.691	0.291	0.441	0.45
Chromium	15.1	63.7	43	46.9	8	12	6.5	18.7	24	16.9	23.3	30.2
Copper	7.47	31.6	13.3	15.3	13.5	21	13.5	4.78	21.5	9.97	9.45	7.46
Mercury	0.1	0.15	0.16	0.19	0.019	0.153	0.056	0.154	0.276	0.116	0.176	0.18
Nickel	13.2	20.6	24.9	23.9	14.5	17	24.5	12.4	21.2	12.2	15.3	17.1
Lead	36.4	46.4	8.3	9.7	14.5	36.5	10	8.3	13.8	5.82	10.8	11.8
Selenium	4.2	0.74	0.81	0.93	0.25	0.25	0.25	0.401	0.912	0.239	0.282	0.423
Silver	1.67	0.15	0.16	0.19	0.5	0.5	0.5	0.772	1.38	0.582	0.882	0.899
Zinc	37.4	198	60.5	67.7	56	115	47	31.3	59.9	34.9	42.9	46.8

Table 2-5. (Continued)

Delaware River - Metals in Sediment from Marcus Hook Region, mg/kg													
	Stations												
Metal	M-1-0.0	M-2-0.0	N-1-0.0	N-2-0.0	N-3-0.0	DVR- 7-94 C-0.0	DVR-7-94 C-5.0	DVR-8-94 C-0.0	DVR-8-94 C-5.0	DVR-9-94 C-0.0	DVR-9-94 C-7.2	MAX	AVG
Arsenic	8.81	7.95	7.45	6.95	7.53	11.6	5.25	9.57	5.88	18.4	5.87	18.4	7.25
Cadmium	0.436	0.479	0.484	0.468	0.483	2.97	2.18	2.6	2.43	4	3.07	4	1.15
Chromium	40.3	33.3	36.9	31.1	35.3							63.7	28.54
Copper	9.28	8.1	8.76	7.75	9.19	21	5.86	19.8	7.54	38.4	6.84	38.4	13.54
Mercury	0.175	0.192	0.193	0.187	0.193	0.381	0.156	0.196	0.155	0.484	0.172	0.484	0.18
Nickel	21.1	18.6	20.7	17.5	19.5	21	17.8	19.9	18.4	31.6	20.2	31.6	19.27
Lead	18.7	12.9	15.2	12	12.6	44.8	22.1	41.8	20.3	78.9	23.8	78.9	22.41
Selenium	0.209	0.22	0.6	0.627	0.512	90.2	101	80.1	86.8	119	96.7	119	25.46
Silver	1.13	0.958	1.08	0.936	0.965	0.874	1.14	0.89	0.774	1.64	0.858	1.67	0.84
Zinc	63	51.1	54.7	48.5	53.3	126	50.3	130	51.4	240	55.6	240	74.84

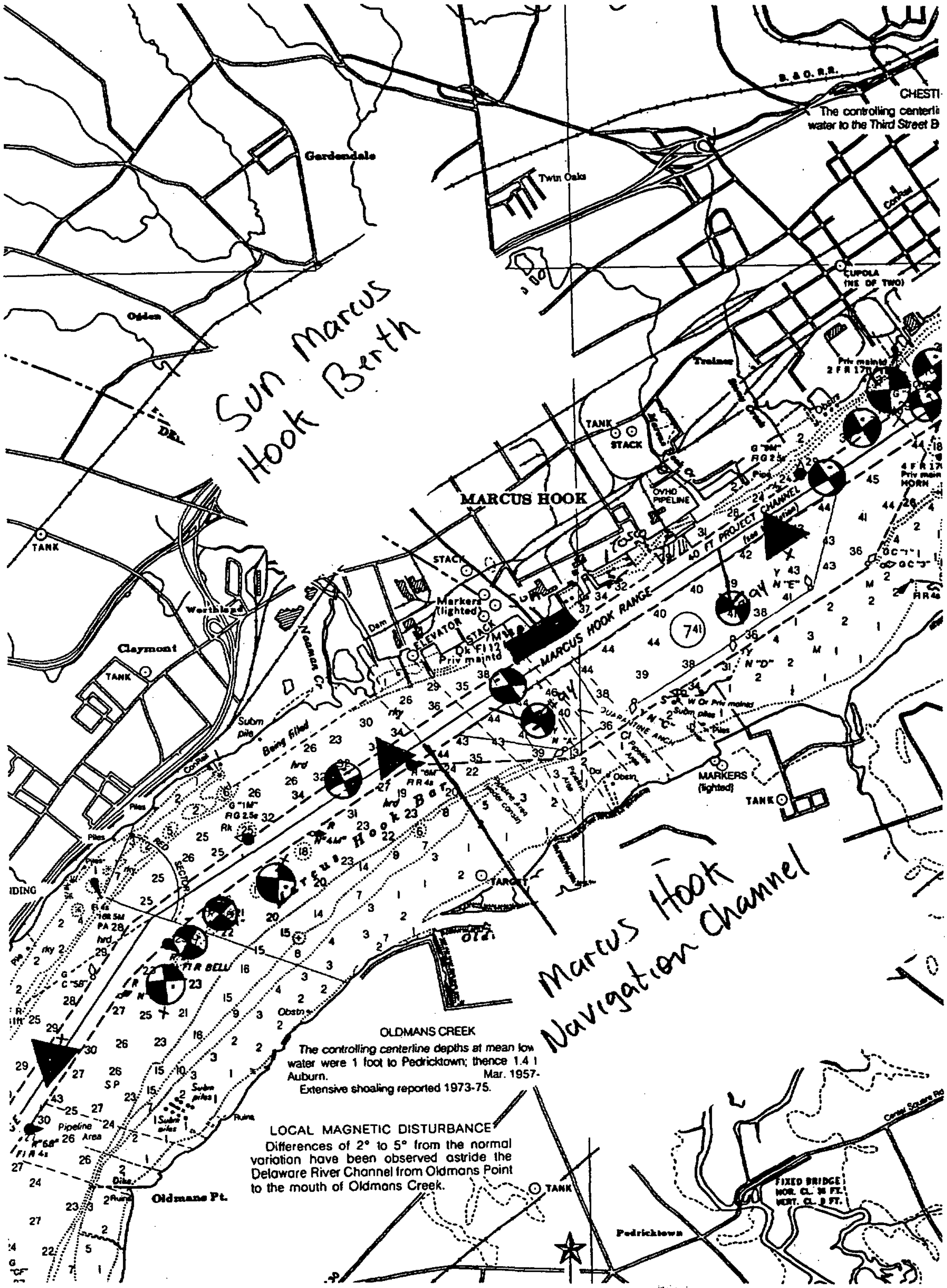


Figure 2-1. Approximate sediment sample locations used to estimate metal contaminants for DREDGE modeling of the Marcus Hook range of the Delaware River.

Table 2-6. Bulk sediment data from several sites in the Delaware River representing what would be dredged from the Sun Marcus Hook Berth of the Delaware River (units in mg/kg)

Delaware River - Metals in Sediment from Berthing Areas, mg/kg						
	Stations					
Metal	SMH-1-95- C-0.0	SMH-1-95- C-1.4	SMH-2-95- C-0.0-R1	SMH-2-95- C-0.0-R2	MAX	AVG
Arsenic	6.40	2.80	4.50	1.40	6.40	3.78
Cadmium	0.39	0.09	0.16	0.03	0.39	0.17
Chromium	37.80	20.50	21.60	9.10	37.80	22.25
Copper	24.70	16.00	14.20	8.00	24.70	15.73
Mercury	0.16	0.12	0.12	0.11	0.16	0.13
Nickel	21.80	14.80	13.40	7.70	21.80	14.43
Lead	22.80	6.00	10.40	1.60	22.80	10.20
Selenium	0.30	0.22	0.21	0.21	0.30	0.24
Silver	0.30	0.06	0.06	0.09	0.30	0.13
Zinc	98.60	29.20	36.70	22.20	98.60	46.68

2.2.1.2 Partition Coefficients for Metal Contaminants

Thomann and Mueller (1987) suggest that the linear equilibrium partition coefficient for most metal contaminants can be estimated using the equation

$$K_p = \frac{250}{\gamma_{sed}}$$

While this equation is useful as a starting point, the strong relationship between metal solubility and pH may be an important factor. Thus, DREDGE includes the following empirical relationships between Kp and pH as presented by Tessier et. al. (1994):

Metal	Equation	Observations	R^2
Cadmium	log Kp = 0.73pH - 3.29	26	0.81
Copper	log Kp = 0.43pH - 1.08	31	0.43
Nickel	log Kp = 0.48pH - 1.64	21	0.67
Lead	log Kp = 0.60pH - 1.14	7	0.81
Zinc	log Kp = 0.74pH - 3.03	33	0.83

DREDGE allows the user to enter any desired value or utilize the above equations to estimate Kp.

Additional Kd values for metals were obtained from Schroeder (pers. comm.) to estimate dissolved metal concentrations for those metals not included in the above table for which there were water quality criteria. Based on observations from laboratory testing of marine and freshwater sediments, apparent Kd are:

Arsenic	350 L/kg
Chromium	5000 L/kg
Mercury	5000 L/kg
Selenium	6 L/kg
Silver	750 L/kg

2.2.1.3 Partition Coefficients for Organic Contaminants (used for Total PCB Estimation)

The linear equilibrium partitioning coefficient for organic contaminants is proportional to the organic content of the sediment. Thomann and Mueller (1987) present the following equation for Kp based upon the organic fraction (foc) and the octanol-water partition coefficient (Koc).

$$K_p = \frac{2f_{oc}K_{ow}}{1 + 0.714f_{oc}K_{ow}TSS_{wc}}$$

Alternatively, Koc can be estimated based upon Kow (see below), then Kp can be calculated from the equation:

$$K_p = f_{oc}K_{oc}$$

Experimental correlations of log Koc with log Kow

Chemicals Tested	Equation for log (Koc)	Source
Pesticides	log(Koc) = 0.544log(Kow) + 1.377	Hemond and Fechner 1994
Aromatics, polynuclear aromatics, triazines, and dinitroanline herbicides	log(Koc) = 0.937log(Kow) - 0.006	Hemond and Fechner 1994
Aromatic and polynuclear aromatics (2 chlorinated)	log(Koc) = 1.00log(Kow) - 0.21	Karickhoff, et al. 1979
Insecticides, herbicides, and fungicides	log(Koc) = 1.029log(Kow) - 0.18	Hemond and Fechner 1994
Substituted phenylureas	log(Koc) = 0.524log(Kow) + 0.855	Hemond and Fechner 1994

alkyl-N-phenylcarbamtes
Contaminant Concentrations in the Water Column

As suspended sediments are transported downstream, contaminants initially absorbed onto the in-situ sediments reach a new equilibrium in the water column environment. Since the majority of contaminants remain attached to the sediments, it is assumed that at any point in the water column,

$$C_{SS} + C_{diss} \approx C^{T}_{sed}$$

Based upon this assumption and the linear partitioning relationship, DREDGE calculates the particulate associated contaminant concentration as:

$$C_{SS} = \frac{10^6 K_p q_i (TSS_{wc})^2}{1 + 10^3 K_p TSS_{wc}}$$

Similarly, DREDGE calculates the dissolved contaminant concentration as:

$$C_{diss} = \frac{10^3 q_i TSS_{wc}}{1 + 10^3 K_p TSS_{wc}}$$

2.2.1.4 DNREC Metal partitioning method

DNREC (1998) describes a procedure to calculate the dissolved contaminant concentration in the water column from the sorbed contaminant concentration in the sediment. Results from bulk sediment analysis are presented with the units mass of analyte per mass of sediment, Cs. The TSS values obtained from McLellan, et. al. (1989), are assumed to be the mass of sediment in the water column. The various TSS concentrations, in units of mass per volume, are multiplied by the bulk sediment concentrations to yield the sorbed concentrations in the water column, Cp,w, in units of mass of sorbed chemical per volume.

$$C_{p,w} = C_s * TSS \qquad (1)$$

Once the sorbed pollutant concentration in the water column has been calculated, the amount of pollutant that leaves the particulate phase and becomes dissolved in the water column may be calculated. The dissolved contaminants may become mobilized and exceed water quality standards. Equilibrium partitioning theory assumes that the distribution of contaminants between particulate and dissolved phases occurs rapidly and continuously. The fraction of organic compounds that dissolve (fd) in the water column is a function of TSS, the fraction of organic carbon, foc, in the sediment, and the octanol/water partition coefficient, Kow, according to Thomann and Mueller (1989). The fraction of the total amount of chemical in the water column that stays sorbed (fp) is defined by:

$$fp = 1 - fd \qquad (2)$$

As a very conservative approach for metals, fd and fp remain constant (Thomann and Mueller 1987). Eighty percent of the metal is assumed to dissolve and twenty percent is assumed to remain sorbed.

Once the fractions are calculated, the total chemical concentrations in the water column, CT,w, (sorbed plus dissolved) and the dissolved chemical concentrations in the water column, Cd,w, are estimated.

$$CT,w = Cp,w / fp \qquad (3)$$

$$Cd,w = CT,w - Cp,w \qquad (4)$$

3.0 RESULTS

3.1 CUTTERHEAD DREDGING

Figures 3-1 and 3-2 illustrates model results for TSS levels of a cutterhead dredge simulation using the DREDGE model. Figure 3-1 shows a plan view of TSS levels laterally and downstream of a dredging operation, at the bottom and at depths 0.5 and 1.0m above the bottom. Figure 3-2 shows a concentration vs. downstream distance plot, along the plume centerline, also at the bottom and at depths 0.5 and 1.0m above the bottom.

Results show that TSS levels are greatest at the bottom (zero meters) and decrease rapidly downstream and with distance above the bottom. TSS levels more than 0.5m above the bottom are predicted at levels that would not be detected above natural background levels. Model-predicted TSS levels at the bottom and higher in the water column are consistent with levels measured in the field with the same type of dredge (Farrar et al. 2001). Results from that study showed that TSS levels averaged 159 mg/l and ranged from 0 to 505 mg/l above ambient levels at the river bottom at a distance of 80 to 100 meters downstream of a dredging site. Levels predicted by the DREDGE model were 138 to 179 mg/l at distances of 80 to 100 meters from the point of dredging at the river bottom. Sediment levels measured at the surface and middle of the water column downstream of this dredging operation were not measurably different from background levels; the DREDGE model also did not predicted sediment levels at depths more than 0.5m above the bottom.

Dissolved concentrations of various constituents in the water column near the cutterhead as predicted by the DREDGE model using the equilibrium partitioning method described in section 2 are listed in Appendix C. At some point within the simulated area for dredging, four of the dissolved metals (chromium, mercury, selenium and silver) and the total PCB concentrations were above the most stringent of the DNREC or DRBC acute or chronic water quality criteria. The remaining six metals never exceeded these criteria at any point in the simulated dredging, using the maximum sediment metal and PCB concentrations as listed in Table 2-5. Three of these metals (chromium, selenium, and silver) only exceeded standards at the bottom and not at 0.5 m above the bottom. Mercury exceeded the standard at 0.5m above the bottom but not at 1.0 m above the bottom. Only selenium exceeded acute water quality criteria at any point and then only to a distance of 50 m from the point of dredging. The other metals and the total PCBs exceeded only the chronic criteria, which generally apply to continuous discharges rather than to short-term releases resulting from dredging operations. Distances to which constituents exceeded chronic criteria are as follows: mercury 350 m at the bottom and 180 meters at 0.5 m above the bottom; selenium 120 m at the bottom; silver 160 m at the bottom; and PCBs 40 m at the bottom. Using average metal concentrations, mercury exceeded chronic criteria at the bottom out to 150 m, selenium* to 40 m at the bottom and silver to 100 m at the bottom. Metal and PCB concentrations at the edge of a 60 m mixing zone are listed in Table 3-1.

As a much more conservative approach, TSS predictions from the DREDGE model were used to estimate dissolved metal values, assuming 80% of the metal sorbed to sediment may become dissolved upon suspension into the water column (Appendix D). Using the maximum metal concentrations found in the sediments in this area of river, Table 3-2 shows the distance downstream of the point dredging that metal concentrations would exceed chronic and/or acute water quality criteria. Even with this more conservative approach, none of the metals exceeded water quality criteria at the edge of a 60-meter mixing zone except within 0.5 meters of the bottom.

* It is important to note that the selenium levels upon which this analysis is based may be too high. Six of the samples listed in Table 2-5 for selenium were analyzed by the same laboratory and are in the range of 100 times higher than the other samples analyzed for that metal. Although laboratory records do not indicate an analytical problem, the higher values are not consistent with any other samples that were analyzed by more than one other laboratory for this metal.

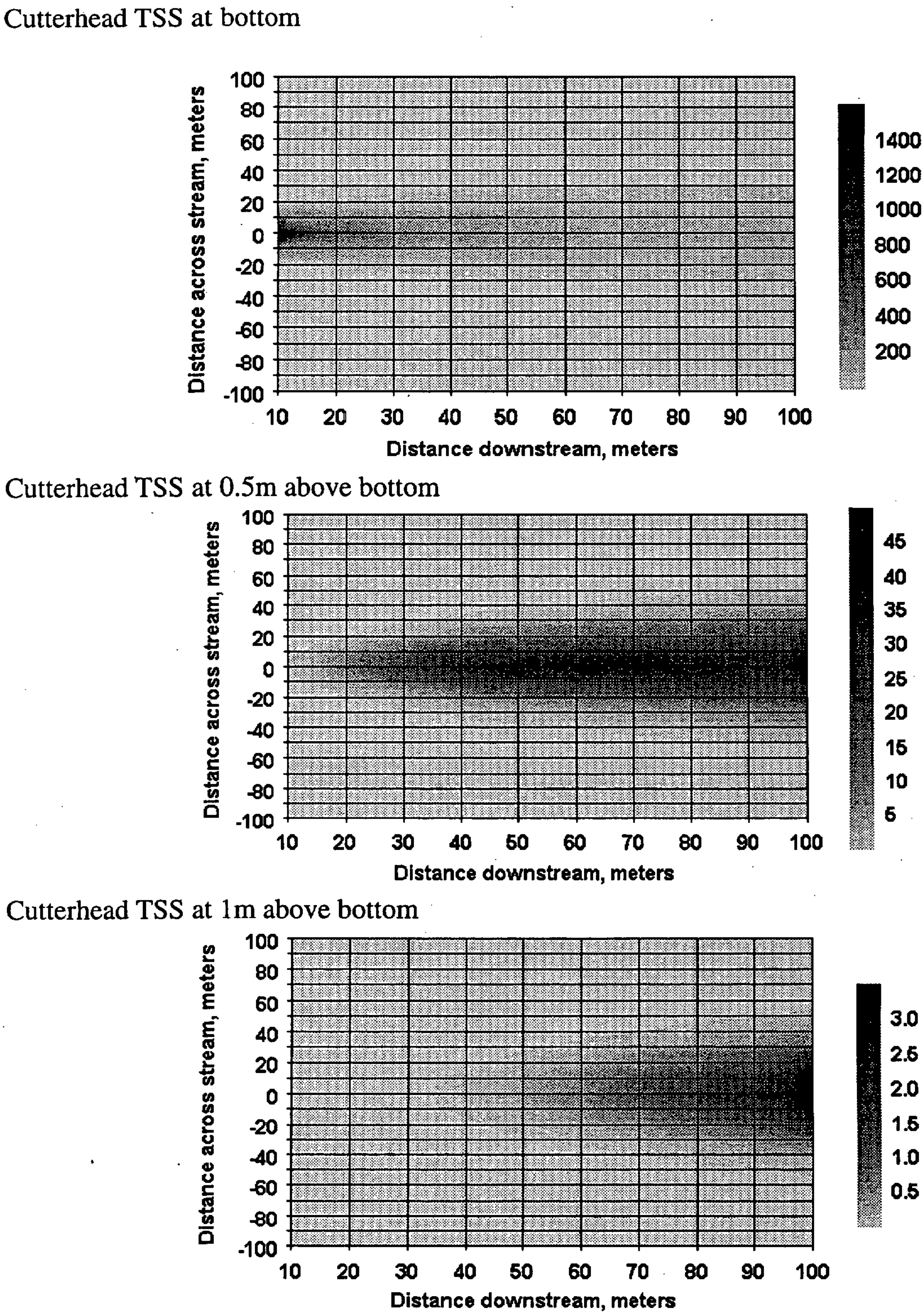
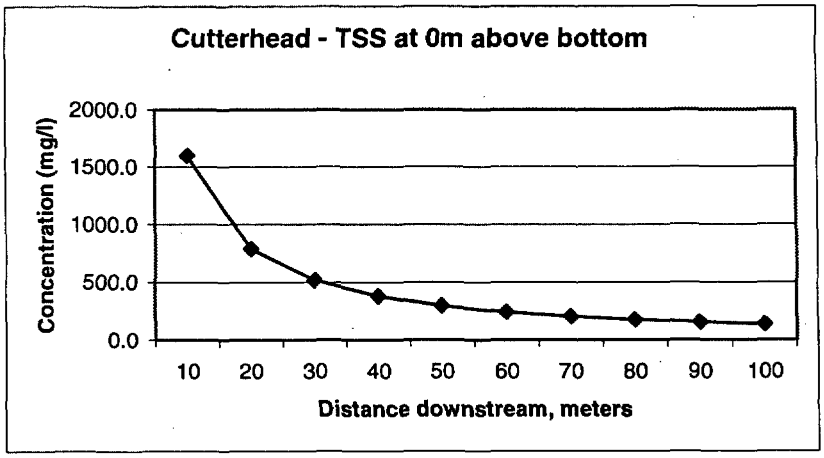
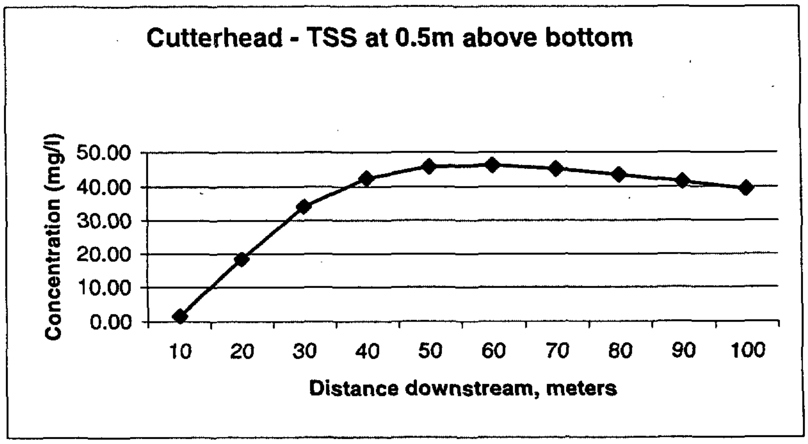


Figure 3-1. Plan view of DREDGE model output of TSS concentrations (mg/l) downstream of a cutterhead dredge which would be used in the Marcus Hook Range of the Delaware River.

Cutterhead Dissolved TSS at bottom



Cutterhead Dissolved TSS at 0.5m above bottom



Cutterhead Dissolved TSS at 1m above bottom

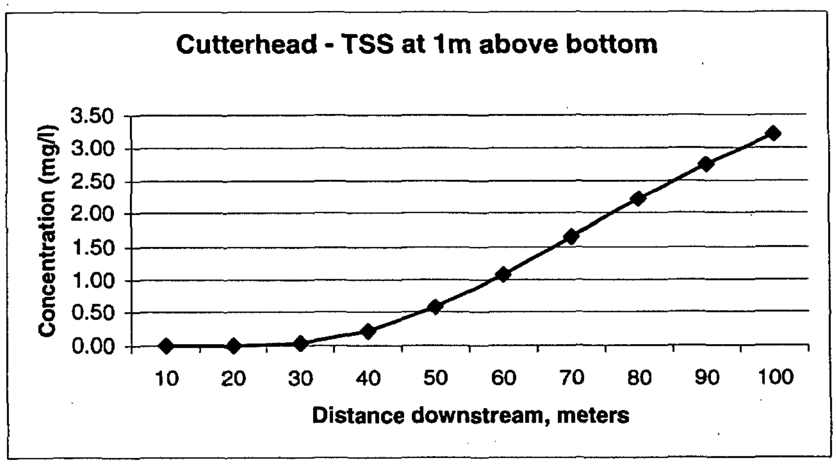


Figure 3-2. DREDGE model predictions of TSS concentrations downstream of a cutterhead dredge which would be used in the Marcus Hook Range of the Delaware Range.

Table 3-1. Metal concentrations (mg/l) during a cutterhead dredge operation simulation, at the edge of a 60-meter mixing zone at various depths above the bottom, using the equilibrium partitioning method included with the DREDGE model.

Metal	**Chronic Criterion Value**	**Depth Above Bottom**	**Concentration 60 m Downstream***
Arsenic	190	0	4.5
		0.5	0.8
		1	0.1
Cadmium	1.9	0	0.6
		0.5	0.5
		1	0.0
Chromium (IV)	11	0	**15.6**
		0.5	2.93
		1	0.06
Copper	20.7	0	0.43
		0.5	0.36
		1	0.04
Lead	7.3	0	0.07
		0.5	0.07
		1	0.04
Mercury	0.012	0	**0.119**
		0.5	0.022
		1	0.000
Nickel	275	0	0.56
		0.5	0.43
		1	0.03
Selenium	5	0	**17.4**
		0.5	1.19
		1	0.00
Silver	0.12	0	**0.408**
		0.5	0.075
		1	0.001
Zinc	185	0	1.65
		0.5	1.47
		1	0.22
Total PCBs	0.014	0	0.010
		0.5	0.002
		1	0.000

* bold values indicate potential water quality criteria exceedances

Table 3-2. Metal concentrations (mg/l) during a cutterhead dredge operation simulation, at the edge of a 60-meter mixing zone at various depths above the bottom, assuming a very conservative 80% of sorbed metals becomes dissolved due to dredging.

Metal	Chronic Criterion Value	Depth Above Bottom	Concentration 60 m Downstream*
Arsenic	190	0	18
		0.5	3.4
		1	0.1
Cadmium	1.9	0	**3.9**
		0.5	0.7
		1	0.0
Chromium (IV)	11	0	**62.6**
		0.5	**11.8**
		1	0.3
Copper	20.7	0	**37.8**
		0.5	7.1
		1	0.2
Lead	7.3	0	**77.6**
		0.5	**14.6**
		1	0.3
Mercury	0.012	0	**0.476**
		0.5	**0.089**
		1	0.002
Nickel	275	0	31.1
		0.5	5.8
		1	0.1
Selenium	5	0	**117**
		0.5	**22**
		1	0.5
Silver	0.12	0	**1.64**
		0.5	**0.31**
		1	0.021
Zinc	185	0	**236**
		0.5	44
		1	1.0

* bold values indicate potential water quality criteria exceedances

3.2 BUCKET DREDGING

Figures 3-3 and 3-4 illustrates model results for TSS levels of a bucket dredge simulation using the DREDGE model. Figure 3-3 shows a plan view of TSS levels laterally and downstream of a dredging operation, throughout the water column, as the model assumes a vertical line source and is therefore depth-averaged. Figure 3-4 shows a concentration vs. downstream distance plot, along the plume centerline. Results show that TSS levels are less than about 162 mg/l at the point of dredging and decreases downstream away from that point but the rate of decrease is less than for the cutterhead dredge.

Dissolved concentrations of various constituents in the water column near the bucket dredge as predicted by the DREDGE model using the equilibrium partitioning method described in section 2 are listed in Appendix E. None of the dissolved metal concentrations were above the most stringent of the DNREC or DRBC water quality criteria, even using the maximum sediment metal concentration as listed in Table 2-6; metal and PCB concentrations at the edge of a 60 m mixing zone are listed in Table 3-3. PCB concentrations were above the most stringent criterion out to a distance of about 30 m from the point of dredging, assuming a sediment concentration value of 152 ng/g, a maximum sediment value found in Burton (1997). As a much more conservative approach, TSS predictions from the DREDGE model were used to estimate dissolved metal values, assuming 80% of the metal sorbed to sediment may become dissolved upon suspension into the water column (Appendix F). Using the maximum metal concentrations found in the sediments in this area of river, chromium exceeded criteria only out to a distance of 40m from the point of dredging. The only other metal to exceed any criterion level at any point in the model was mercury, which apparently exceeded criteria out to a distance of 100 m. However, mercury levels in the sediment were below method detection limits at all four sampled stations and the value used was one-half the detection limit, which could be substantially higher than actual values. Thus, even with a very conservative estimation approach, no metals with measurable sediment concentrations exceeded water quality criteria outside of a 60-meter mixing zone.

Open Clamshell TSS

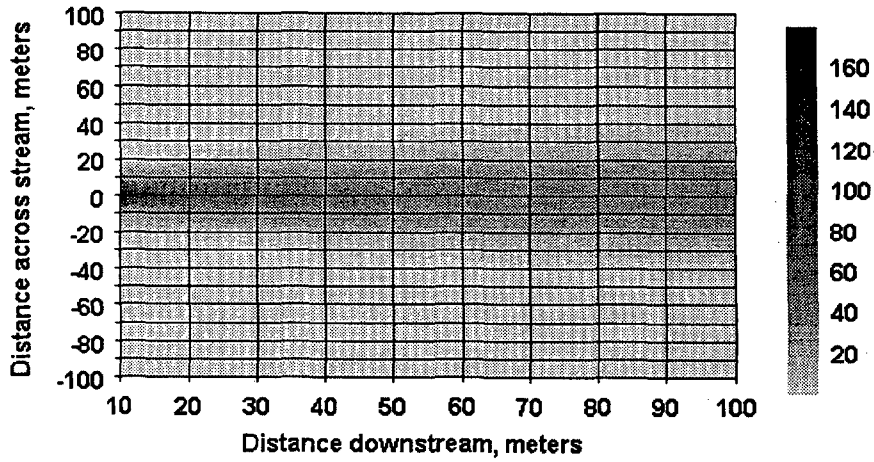


Figure 3-3. Plan view of DREDGE model output of TSS concentrations (mg/l) downstream of a bucket dredge which would be used in the Sun Marcus Hood Berth of the Delaware River

Open Clamshell Dissolved TSS

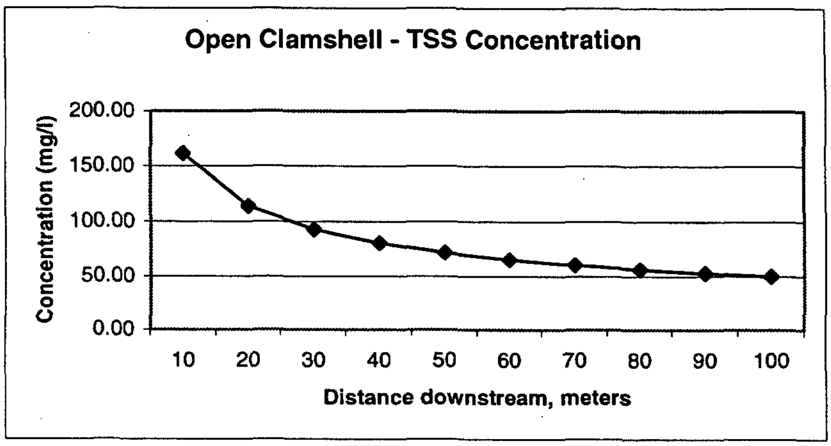


Figure 3-4. Dredge model predictions of TSS concentrations downstream of a bucket dredge which would be used in the Sun Marcus Hook Berth of the Delaware River.

Table 3-3. Metal concentrations (mg/l) during a bucket dredge operation simulation, at the edge of a 60-meter mixing zone, assuming a very conservative 80% of sorbed metals becomes dissolved due to dredging.

Metal	Chronic Criterion Value	Concentration 60 m Downstream	
		DREDGE model equilibrium method	DNREC equilibrium method
Arsenic	190	0.40	1.7
Cadmium	1.9	0.00	0.1
Chromium (IV)	11	2.45	9.8
Copper	20.7	0.24	6.4
Lead	7.3	0.02	5.9
Mercury	0.012	0.005	0.021
Nickel	275	0.32	3.8
Selenium	5	0.01	0.1
Silver	0.12	0.02	0.04
Zinc	185	0.63	25.7
Total PCBs	0.014	0.003	(not applicable)

4.0 CONCLUSIONS

At some point within the simulated area for cutterhead dredging, four of the dissolved metals (chromium, mercury, selenium and silver) and the total PCB concentrations were above the most stringent of the DNREC or DRBC acute or chronic water quality criteria. The remaining six metals never exceeded these criteria at any point in the simulated dredging, using the maximum sediment metal and PCB concentrations found in the area to be dredged. Three of these metals (chromium, selenium, and silver) only exceeded standards at the bottom and not at 0.5 m above the bottom. Mercury exceeded the standard at 0.5m above the bottom but not at 1.0 m above the bottom. Only selenium exceeded acute water quality criteria at any point and then only to a distance of 50 m from the point of dredging. The other three metals and the total PCBs exceeded only the chronic criteria. PCBs did not exceed chronic criteria beyond 40 m from the point of dredging, while mercury, selenium and silver exceeded chronic criteria based on maximum sediment concentrations, to distances of 350, 120 and 160 meters, respectively, from the point of dredging at the bottom.

None of the dissolved metal concentrations predicted to be released to the water column as a results of bucket dredging were above the most stringent of the DNREC or DRBC water quality criteria, even using the maximum sediment metal concentration measured in the area to be dredged. PCB concentrations were above the most stringent criterion out to a distance of about 30 m from the point of dredging. Even with a more conservative metals partitioning estimation approach, no metals with measurable sediment concentrations exceeded water quality criteria outside of a 60-meter mixing zone.

5.0 REFERENCES

Burton, W.B. 1997. Delaware River Philadelphia to the Sea Project High Resolution PCB analysis of Channel Sediments. Prepared for U.S. Army Corps of Engineers, Philadelphia District, DACW61-95-D-0011, Delivery Order 0030.

DNREC (Delaware Department of Natural Resources and Environmental Control). 1998. Chemical Contaminants in Sediments of the Red Clay Creek in the Vicinity of Glenville, Delaware. Prepared by Division of Water Resources, Watershed Assessment Branch. June, 1998.

Delaware River Basin Commission (DRBC). 1998. Study of the loadings of polychlorinated biphenyls from tributaries and point sources discharging to the tidal Delaware River. Delaware River Basin Commission, West Trenton, NJ. 1998.

Farrar, J.S. et al., 2001. Oldmans Confined Disposal Facility Water Quality Analysis. Prepared for U.S. Army Corps of Engineers, Philadelphia District, DACW61-00-D-0009, Task Order 0007.

Greeley-Polhemus Group, Inc. 1993. Delaware River Comprehensive Navigation Study Chemical Analysis of Sediments. Final report prepared for U.S. Army Corps of Engineers, Philadelphia District, DACW61-91-D-0009, Task Order 0017.

Hayes, D.F. and C. Je. 2000. Dredge Model User's Guide. Prepared by the Dept. of Civil and Environmental Engineering, University of Utah for the U.S. Army Corps of Engineers Waterways Experiment Station.

Hayes, D.F., Q. Tang, C. Je, and D. Averett. 1996. DREDGE Technical Documentation from model help file. Prepared by the Dept. of Civil and Environmental Engineering, University of Utah and the U.S. Army Corps of Engineers Environmental Engineering Division, Waterways Experiment Station.

Karickhoff, S.W., Brown, D.S., Scott, T.A.. 1979. Sorption of Hydrophobic Pollutants on Natural Sediments. Water Research. 13:241-248.

Karickhoff, S.W.. 1981. Semi-Empirical Estimation of Sorption of Hydrophobic Pollutants on Natural Sediments and Soils. Chemosphere. 10:833-846.

McLellan, T.N., Havis, R.N., Hayes, D.F., Raymond, G.L. 1989. Field Studies of Sediment Resuspension Characteristics of Selected Dredges. April, 1989. Prepared for Department of the Army, Washington, DC., by Waterways Experiment Station.

National Oceanic and atmospheric administration (NOAA) and National Ocean Service. 1998. Navigational Map Coast Survey. 38th Ed., Feb 28, 1998. 12311. Published in Washington D.C.

National Oceanic and Atmospheric Administration (NOAA). 1983. Hydrographic Survey H-10112. Delaware—New Jersey, Delaware River. Reedy Island to Pea Patch Shoal. HSB-10-3-83.

Taylor, J.P. 1996. Results of Berthing Area Vibracore Sampling along the Delaware River from Beckett Street Terminal in Camden, NJ to Sun Oil Refinery in Marcus Hook, PA. Prepared by Black and Veatch Waste Science, Inc. for the U.S. Army Corps of Engineers, Philadelphia District, DACW61-94-D-0013, Delivery Orders 0005, 0006, & 0009.

Tessier, A., Carignan, R., and Belzile, N. (1994). "Reaction of Trace Elements Near the Sediment-Water Interface in Lakes," Chapter 8, in Transport and Transformation of Contaminants Near the Sediment-Water Interface, Eds. by Joseph V. DePinto, Wilbert Lick, and John F. Paul, Lewis Publishers, Boca Paton, Florida.

Thomann, R.V. and J.A. Mueller. 1987. Principles of Surface Water Quality Modeling and Control. Harper and Row, Publishers, NY.

Urie, J.T. and W.S. Ettinger. 1995. Delaware River – Philadelphia to the Sea Chemical Analysis of Sediments. Draft report prepared by the Greeley-Polhemus Group for the U.S. Army Corps of Engineers, Philadelphia District, DACW61-91-D-0009, Task Order 0036.

U.S. Army Corps of Engineers, Philadelphia District. 1992. Delaware River Comprehensive Navigation Study Main Channel Deepening Final Interim Feasibility Report - Final Environmental Impact Statement.

Versar. 2001. Oldmans Confined Disposal Facility Water Quality Analysis. Prepared for the U.S. Army Corps of Engineers, Philadelphia District.

Versar. 1998. Water Quality and Sediment Chemical Testing for C&D Canal Planning, Engineering, and Design Delaware and Maryland. Prepared for U.S. Army Corps of Engineers, Philadelphia, PA.

APPENDIX A

DREDGE Model User's Guide

DRAFT

DREDGE Module User's Guide

by

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July 2000

DREDGE Module User's Guide

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INTRODUCTION

DREDGE was developed to assist users in making a priori assessments of environmental impacts from proposed dredging operations. DREDGE estimates the mass rate at which bottom sediments become suspended into the water column as the result of hydraulic and mechanical dredging operations and the resulting suspended sediment concentrations. These are combined with information about site conditions to simulate the size and extent of the resulting suspended sediment plume. DREDGE also estimates particulate and dissolved contaminant concentrations in the water column based upon sediment contaminant concentrations and equilibrium partitioning theory.

The basic features of DREDGE include:

1. Easy and rapid calculation of dredge plume concentrations resulting from mechanical and hydraulic dredging operations.
2. Graphical user interface (GUI) for user data input, spreadsheet output, and graphical output.
3. Relational database system with point-and-click interface for contaminant modeling.
4. Extensive toxic organic chemical and heavy metal database system plus default K_{ow} values for over 200 chemicals.
5. On-line help system to guide user through the application.
6. Spreadsheet and graphical output capabilities.
7. Ability to save all output information in MS Excel (*.xls) file format.
8. Source strength models for mechanical and hydraulic dredging operations.
9. 2-D analytical transport model to predict the fate of resuspended sediments without particle flocculation in a water column.

DREDGE is a module of the Automated Dredging and Disposal Alternatives Modeling System (ADDAMS) distributed by the U.S. Army Corps of Engineers through the

Environmental Laboratory, USAE Research and Development Center Waterways Experiment Station. ADDAMS consists of approximately 20 modules to assist in design and evaluation of various aspects of dredging and dredged material disposal operations. Information about other ADDAMS Modules can be found at http://www.wes.army.mil/el/elmodels/ or by contacting Dr. Paul R. Schroeder at (601) 634-3709.

The purpose of this User's Guide is to provide the user with a convenient reference to learn and use DREDGE. It provides essential information for applying the software to specific project sites. The User's Guide includes the following topics:

- Installation and minimum hardware requirements
- DREDGE basis
- Use and operation

HARDWARE REQUIREMENTS

DREDGE utilizes a graphical user interface (GUI) to simplify data entry and editing and provide output in a useful, understandable manner. DREDGE should operate properly for all Microsoft Windows© operating environments and typical PC hardware configurations. DREDGE requires the following minimum system configuration:

- Microsoft Windows 95/98, or Windows NT 3.5 or later (Note that if user is using Windows NT 4.0, user must install the Service Pack 3 before installing DREDGE).
- IBM compatible computer with an Intel 486 or equivalent CPU; Pentium CPU or equivalent is recommended.
- 8 MB of RAM required; 16 MB RAM recommended
- 5 MB available hard disk space
- Mouse
- VGA screen resolution (640 x 480); SVGA (800 x 600 or higher) recommended

USE AND DISTRIBUTION RESTRICTIONS

DREDGE is furnished by the U.S. Government and is accepted and used by the recipient with the express understanding that the U.S. Government gives no warranties, expressed or implied, concerning the accuracy, reliability, usability, or suitability for any particular purpose of the information and data contained in this program or furnished in connection therewith. The United States of America shall be under no liability whatsoever to any person by reason of any use made thereof. This program belongs to the U.S. Government, therefore, the recipient further agrees not to assert any proprietary rights therein, or to represent this program to anyone as other than a U.S. Government program. Distribution of the DREDGE module is restricted by the Export Administration Act of 1979, 50 App. USC 2401-2420, as amended, and other applicable laws or regulations.

HOW DO I OBTAIN THE DREDGE SOFTWARE?

The setup files for DREDGE and all other ADDAMS modules can be downloaded from http://www.wes.army.mil/el/elmodels/ or obtained as a set of floppy disks by sending a written request (preferably on company letterhead) to:

USAE Research and Development Center Waterways Experiment Station
ATTN: CEERD-EE-P/Dr. Paul R. Schroeder, P.E.
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

INSTALLING DREDGE

DREDGE downloads as a single compressed file, DREDGE.EXE, which contains all of the associated setup files. DREDGE.EXE should be placed in a temporary directory (e.g. **C:\TEMP\DREDGE**) where it can easily be removed after setup is complete. Once DREDGE.EXE is downloaded, executing it expands the setup files into the same directory. If DREDGE is obtained on floppy disks, the setup files are already expanded and contained on the disks.

DREDGE is installed by executing **SETUP.EXE** from either the temporary directory or Disk 1 of the floppy disk set. In either case, setup guides you through the installation process by asking a few simple questions. The general installation procedure is:

Step 1. Insert the floppy diskette into drive A (floppy disk installation only).

Step 2. Run the installation program **SETUP.EXE.** Press the **START** button on the Windows taskbar and select **RUN**. Type in the proper directory and file name (e.g. "**A:\SETUP.EXE**" or "**C:\TEMP\DREDGE\SETUP.EXE**") or press the **BROWSE** button to locate the file. Press the **OK** button to proceed with the installation.

Step 3. DREDGE will ask for the desired installation directory and provide C:\ADDAMS\DREDGE as the default. Modify the directory as desired, then press **NEXT>** to continue the installation.

Step 4. DREDGE installation should complete automatically from this point, then notify you that installation is complete. Press **OK** to complete the installation.

Once installation is complete, click the **START** button on the Windows taskbar, then select **Programs**, then **DREDGE Module**, then **DREDGE** to start the DREDGE software.

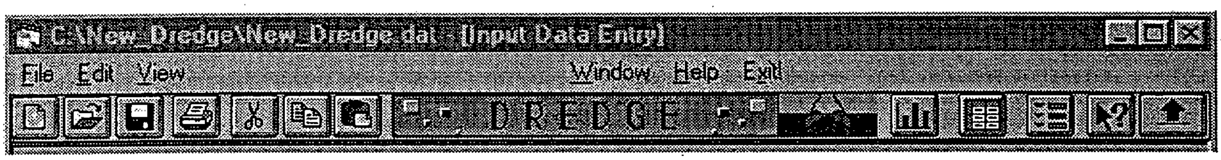
USING DREDGE

Three main windows control the operation of DREDGE and display results of requested analyses: 1) **Input Data Entry** window, 2) **Spreadsheet Output** window, and 3) **Graphical Output** window. DREDGE begins with the Input Data Entry window displayed, but the user can toggle between the main windows at any time using buttons provided at the bottom of each window or by selecting **Windows** or **View** from the menu at the top of the window. DREDGE recalculates all values (if data are available) anytime the **Spreadsheet Output** or **Graphical Output** window is displayed. This ensures the displayed results always reflect the latest input data, but it can result in slight delays in the window being displayed on slower computers.

The DREDGE interface is designed to be intuitive. Although specific instructions on using the software follow, they are more easily followed if the user spends some time now becoming familiar with the look and feel of the software. Certainly, the user is encouraged to experiment with the options as they read through this guide.

MENUS AND BUTTONS

The same menu options and quick-launch buttons are available from all three primary screens. These menus and buttons are described and shown below and operate similarly to those found in many other Windows applications. Pressing the left mouse button while over the menu title displays a dropdown menu with a list of options. Each individual drop-down menu is not shown, but Table 1 shows the lists of options and the specific actions associated with each option.



The button bar provides direct access to the most commonly used menu items. An icon on each button suggests the action that results from pressing the button; allowing the mouse pointer to hover over the button momentarily will display a tool-tip description. Pressing the left mouse button while the pointer is over the rectangular area of the button initiates the associated action. Table 2 describes the available buttons and the associated actions.

Table 1. Menu selections and associated program actions.

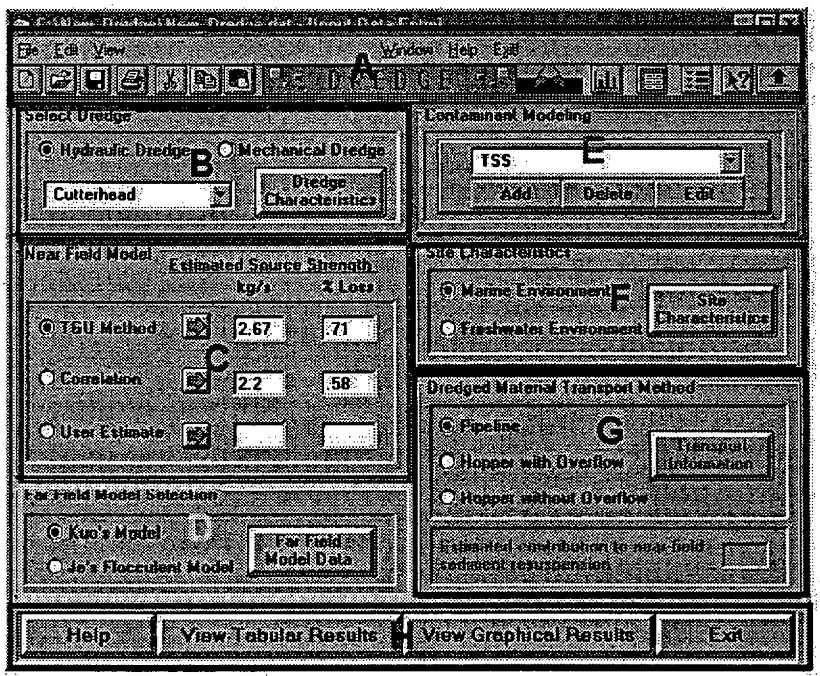
Menu	Submenu	Shortcut	Action
File	New	Alt + f + n	Resets all variables to zero and clears all calculations.
	Open	Alt + f + o	Opens Windows standard dialog box to allow user selection of data files.
	Save	Alt + f + s	Writes the current data to the existing filename; if a filename has not been specified, opens the same dialog box as "Save As"
	Save As	Alt + f + a	Opens a Windows standard dialog box which allows the user to specify a file name and location to save the file.
	Print	Alt + f + p	Prints the input data and results to the default printer.
	Exit	Alt + f + x	Exits DREDGE.
Edit	Cut	Alt + e + t	Cuts a highlighted selection and moves it to the clipboard.
	Copy	Alt + e + c	Copies a highlighted selection to the clipboard.
	Paste	Alt + e + a	Pastes clipboard contents to cursor location.
View	Data Input	Alt + v + d	Displays the **Input Data Entry** window.
	Tabular Output	Alt + v + d	Displays the **Spreadsheet Output** window.
	Graphical Output	Alt + v + d	Displays the **Graphical Output** window.
Window	Data Input	Alt + w + d	Displays the **Input Data Entry** window.
	Tabular Output	Alt + w + d	Displays the **Spreadsheet Output** window.
	Graphical Output	Alt + w + d	Displays the **Graphical Output** window.
Help	Contents	Alt + h + c	Displays HELP contents.
	Search	Alt + h + s	Displays search engine for HELP
	How to use HELP	Alt + h + h	**Not currently used**
	Technical Support	Alt + h + t	**Not currently used**
	About DREDGE	Alt + h + a	Displays an information box about DREDGE.
Exitl	-	Alt + x	Exits DREDGE.

Table 2. Shortcut buttons and associated actions.

Button	Action	Button	Action
	Resets all variables to zero and clears all calculations.		Pastes clipboard contents to cursor location.
	Opens Windows standard dialog box to allow user selection of data files.		Displays the **Graphical Output** window.
	Writes the current data to the existing filename; if a filename has not been specified, opens a Windows standard dialog box to allow the user to specify a file name and location to save the file.		Displays the **Spreadsheet Output** window.
	Prints the input data and results to the default printer.		Displays the **Input Data Entry** window.
	Cuts a highlighted selection and moves it to the clipboard.		Initiates online HELP for DREDGE.
	Copies a highlighted selection to the clipboard.		Exits DREDGE.

ENTERING AND EDITING DATA

DREDGE handles all data entry tasks through the **Input Data Entry** window shown to the right. This window is automatically displayed when the application begins. Specific and detailed data on the dredging project are required to perform the necessary calculations. Data requirements include physical site conditions, physical and chemical sediment properties, sediment volume, and dredge type and operation. The **Input Data Entry** window facilitates data input by dividing the required data into logical groups. The figure to the right outlines the different areas of this initial window. Areas B – G represent different types of data entry and are described in detail below. The user must enter data for areas B-F, in that order. The data in area G are not currently used, but the space is reserved for use in later versions.



A – Menu and Buttons

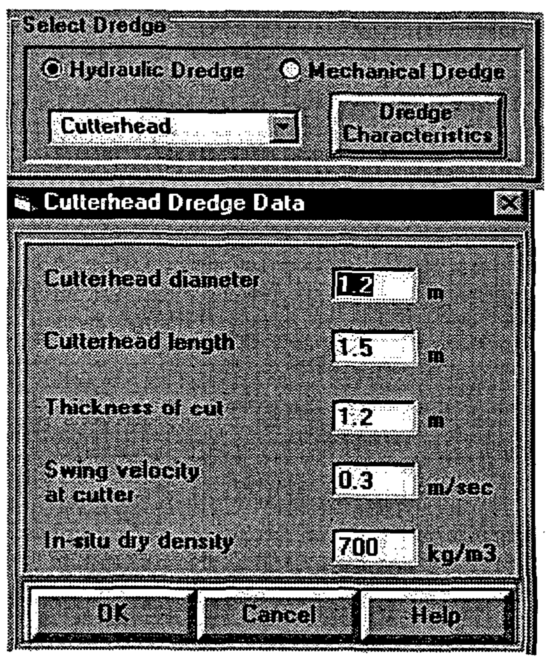
The drop-down menus and shortcut buttons are part of all three primary screens. They provide direct access to common software operations and operate similar to most menus and buttons associated with other software applications. These operations were described above with details presented in Tables 1 and 2.

B – Dredge Information

All models included in DREDGE are specific to individual dredge types. Thus, the user should first select the type of dredge they wish to model by pressing either "Hydraulic Dredge" or "Mechanical Dredge." The user should then select the specific dredge they wish to model. Hydraulic dredges include self-propelled hopper dredges and spud-driven dredges such as cutterhead dredges, although a variety of suction heads may be used; i.e. dustpan, matchbox, traditional cutter, etc. Many types of mechanical dredges exist, but DREDGE only has models for traditional crane-type bucket dredges using either open clamshell or watertight clamshell buckets. At this time, DREDGE only supports the dredge types for which sufficient resuspension data has been collected to support the development of at least a limited source generation model – cutterhead and open bucket dredges.

Once the dredge type is selected, the user should press the DREDGE CHARACTERISTICS button to enter physical and operational information about the dredging operation. These data correspond to the specific dredge type selected and may be lost if the dredge type is modified after they are entered.

<u>*Cutterhead Dredge Characteristics.*</u> Pressing the DREDGE CHARACTERISTICS button with Cutterhead Dredge selected displays the dialog box. Values must be entered for every variable (i.e., every box) for DREDGE to calculate the in situ sediment removal rate. The requested data and recommended default values are:

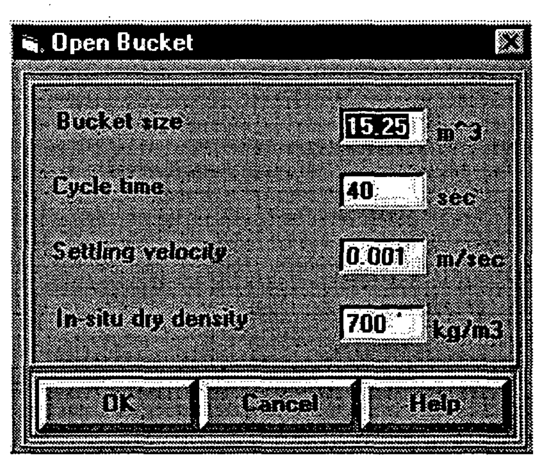


- *Cutterhead diameter* – cutterhead dredges are typically sized according to the pipe diameter associated with the pump, e.g. 12-inch dredge, 18-inch dredge, etc.

Cutterheads come in all shapes and sizes, but most cutters are 2 to 3 times the size of the pump size (in terms of pipe diameter). If better information is not available, assuming a cutter diameter approximately equal to 2.5 times the pump size in pipe diameter is a good rule of thumb.

- *Cutterhead length* – the discussion above applies here too, but a general rule of thumb is the cutter length equals 3.0 times the pump size.
- *Thickness of cut* – the sediment depth being removed on each swing; typically this should not be much larger than the cutter diameter nor should it be extremely thin except for clean-up cuts.
- *Swing velocity at cutter* – the tangential speed of the dredge at the tip of the cutter; typically, this value is between 0.1 m/sec and 0.4 m/sec.
- *In-situ dry density* – the dry density of the sediment in units of kg/m^3. Most recently deposited sediments (e.g. maintenance dredging) are unconsolidated with a density of about 700 kg/m^3. Sediments with high organic content can have lower densities of near 500 kg/m^3, but these are quite uncommon. Consolidated sediments often have densities near 1000 kg/m^3 or greater. A density of 1500 kg/m^3 is not unusual in consolidated clays or dense sands. Because of the potential variation in density, sediment samples should be collected to determine the actual value for any given system.

<u>Open Bucket Dredge Characteristics.</u> Pressing the DREDGE CHARACTERISTICS button with Open Bucket Dredge selected displays the dialog box below. Values must be entered for every variable (i.e., every box) so DREDGE can calculate the in situ sediment removal rate. Descriptions of the data required for open bucket dredges and recommended default values follow:

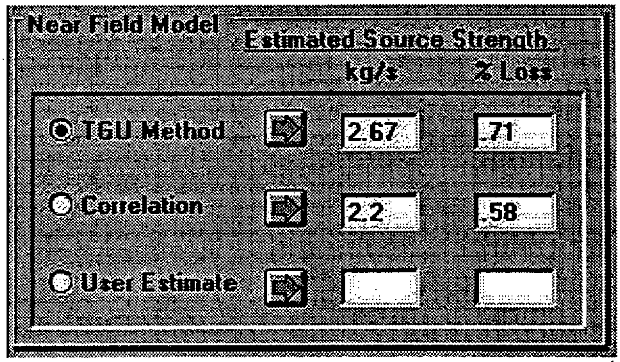


- *Bucket size* – volumetric capacity of dredge bucket being used. Buckets are available in volumes ranging from about

1 m^3 to 100 m^3 because of the range of crane capacities available. A 20-m^3 bucket would be considered by most to be a mid-sized bucket. Note the input box requires units of m^3 even though bucket volumes in the US are usually expressed in units of yd^3; the conversion factor is 1 yd^3 = 0.765 m^3.

- *Cycle time* – the cumulative time it takes for the bucket to fall through the water column, grab sediment from the bottom, be raised to the surface, swing over to the sediment barge, empty its load, and swing back to the water surface; this varies with many factors and with each cycle. But, the average cycle time normally ranges from 30 to 90 seconds, with about 60 seconds being most common under normal operating circumstances. Note that this may be intentionally slowed in some environmental dredging operations in an attempt to reduce sediment loss to the environment.
- *Settling velocity* – average settling velocity of the sediment being dredged.
- *In-situ dry density* – the dry density of the sediment in units of kg/m^3. Most recently deposited sediments (e.g. maintenance dredging) are unconsolidated with a density of about 700 kg/m^3. Sediments with high organic content can have lower densities of near 500 kg/m^3, but these are quite uncommon. Consolidated sediments often have densities near 1000 kg/m^3 or greater. A density of 1500 kg/m^3 is not unusual in consolidated clays or dense sands. Because of the potential variation in density, sediment samples should be collected to determine the actual value for any given system.

C – Near-field TSS Models



DREDGE provides three ways for the user to estimate the rate at which a dredging operation releases sediment into the water column as suspended sediment – the TGU method, the correlation method, or a user estimate. The desired method is selected by clicking the left mouse button while over the circle to the left of the method. If data for the selected method have not been entered, DREDGE automatically displays the appropriate data entry dialog. If data have been entered, the user can review and edit the values by pressing the green arrow to the right of the selected procedure.

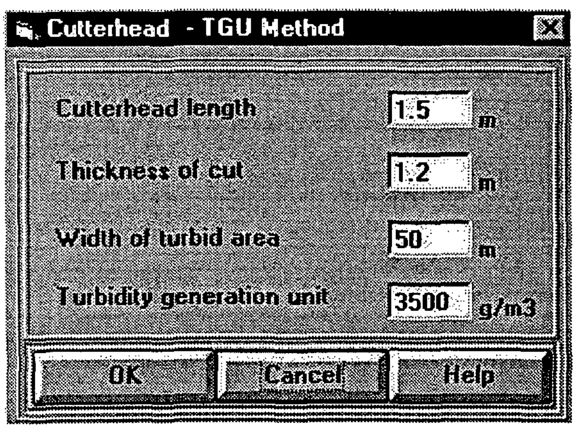
> **What is a Near-field Model?**
>
> DREDGE breaks suspended sediment transport from dredges into two distinct areas. The area in the immediate vicinity of the dredging operation is dominated by mixing and currents induced by the dredging operation itself and is termed the "near-field." The suspended sediment in this area results primarily from the dredge operation. Thus, the near-field models require information about the dredging operation to provide estimates of this "source-strength" in mass per time units. The physical extent of the "near-field" is not definitive, but generally ends 10 to 20 meters downstream from the dredging operation.

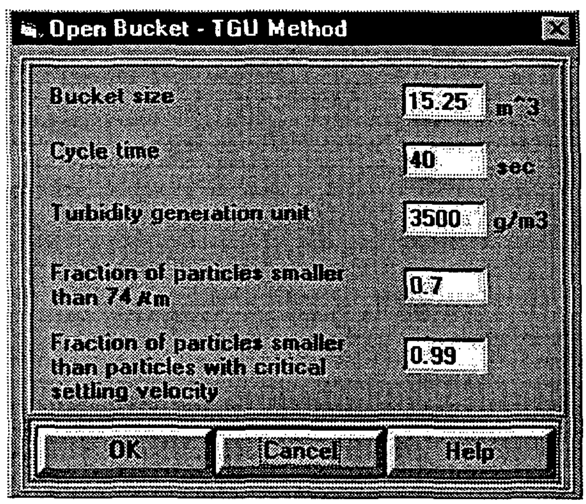
Near-field model results are provided in both kg/sec (mass flux) and % loss. The latter units are more easily understood in an environmental context. In the absence of additional information, a conservative estimate of 1% loss would be appropriate for typical dredging operations. Because there is considerable uncertainty associated with source strength estimates, the user is encouraged to utilize both models then enter a judgment-based value as the user estimate. A sensitivity analysis should be conducted by entering a range of values in the user estimate box.

TGU Method Data Entry

The most popular method for estimating sediment resuspension rates from dredging operations has been the method published by Nakai (1978). The method, described in detail in the DREDGE HELP file, is mostly conceptual and relies on a value called the "turbidity generation unit" (thus, the acronym TGU) to distinguish between the resuspension rates of various dredge types. Nakai's method then converts that TGU value to a source generation rate. The input screens below show the data required for DREDGE to make the TGU calculations. Note that many of the values are repeated from other input screens. When a value is changed in one screen, the change is automatically reflected in all other DREDGE calculations. Descriptions of the individual data follow:

- *Cutterhead length* – the discussion above applies here too, but a general rule of thumb is the cutter length equals 3.0 times the pump size.
- *Thickness of cut* – the sediment depth being removed on each swing in meters; typically this should not be much larger than the cutter diameter nor should it be extremely thin except for clean-up cuts.
- *Width of Turbid Area* – the width of the turbidity plume generated by the cutterhead dredge. A logical assumption for this value is the width of the dredge swing or cutting path that is anticipated.
- *Bucket size* – volumetric capacity of dredge bucket being used. Buckets are available in volumes ranging from about 1 m^3 to 100 m^3 because of the range of crane capacities available.





A 20-m^3 bucket would be considered by most to be a mid-sized bucket. Note the input box requires units of m^3 even though bucket volumes in the US are usually expressed in units of yd^3; the conversion factor is 1 yd^3 = 0.765 m^3.

- *Cycle time* – the cumulative time it takes for the bucket to fall through the water column, grab sediment from the bottom, be raised to the surface, swing over to the sediment barge, empty its load, and swing back to the water surface; this varies with many factors and with each cycle. But, the average cycle time normally ranges from 30 to 90 seconds, with about 60 seconds being most common under normal operating circumstances. Note that this may be intentionally slowed in some environmental dredging operations in an attempt to reduce sediment loss to the environment.
- *Fraction of Particles Less than 74 μm* – the fraction of fine sediments in the bottom sediments to be dredged, expressed as a fraction, i.e. the value must be between 0.0 and 1.0.
- *Fraction of Particles Smaller than Particles with the Critical Settling Velocity* – particles with settling velocities less than the Critical Settling Velocity will not settle, but rather remain in suspension due to the ambient currents in the area. The TGU method needs to know the fraction of bottom sediments that have a particle diameter smaller than the diameter associated with the critical velocity.
- *Turbidity Generation Unit* – this value is the rate at which sediment is resuspended into the water column and transported away from the dredging site, reported in kg/m^3. Nakai (1978) published the only TGU values available for different dredging operations. These values are available in the DREDGE HELP files and Table 3.

Table 3. Observed values of Turbidity Generation Unit, G, presented by Nakai (1978)

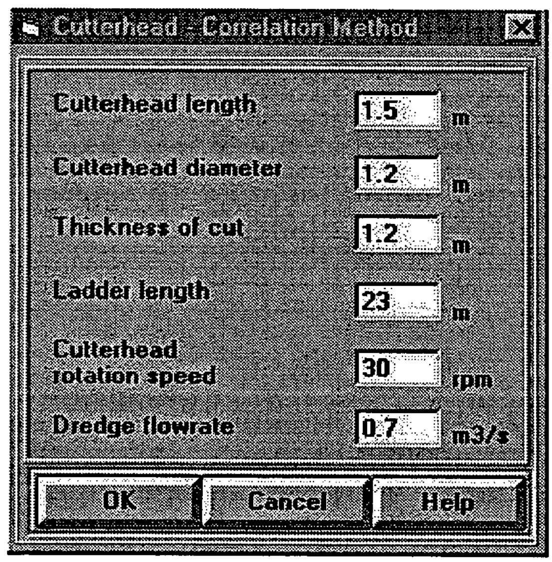
Dredge Type	Pump HP or Volume	Dredged Material Characteristics d* < 74 μm	d* < 5 μm	Classification	TGU kg/m³
Cutter	4,000 HP	99.0 %	40.0 %	silty clay	5.3
		98.5 %	36.0 %	silty clay	22.5
		99.0 %	47.5 %	clay	36.4
		31.8 %	11.4 %	sandy loam	1.4
		69.2 %	35.4 %	clay	45.2
		74.5 %	50.5 %	sandy loam	12.1
	2,500 HP	94.4 %	34.5 %	silty clay	9.9
	2,000 HP	3.0 %	3.0 %	sand	0.2
		2.5 %	1.5 %	sand	0.3
		8.0 %	2.0 %	sand	0.1
Hopper	2,400 HP x 2	92.0 %	20.7 %	silty clay loam	7.1
		88.1 %	19.4 %	silty loam	12.1
	1,800 HP	83.2 %	33.4 %	silt	25.2
Bucket	8 m³	58.0 %	34.6 %	silty clay	89.0
	4 m³	54.8 %	41.2 %	clay	84.2
	3 m³	45.0 %	3.5 %	silty loam	15.8
		62.0 %	5.5 %	silty loam	11.9
		87.5 %	6.0 %	silty loam	17.1

Correlation Method Data Entry

A series of empirical models have been developed that relate dredge operating characteristics and sediment resuspension rates. Hayes et al (2000) published the latest empirical models for cutter dredges, and Collins (1995) published the latest empirical models for bucket dredging operations. DREDGE makes these models available under the "correlation models" option. Details of the models are provided in the DREDGE HELP file.

Each model requires dredge size and operating information, specific for the dredge type selected. Much of the data is also required for other computations and, thus, may be entered through other input screens. All previously entered values will be shown on the input screen when it is displayed. Any changes made on this screen will be reflected in all DREDGE computations once the OK button is pressed.

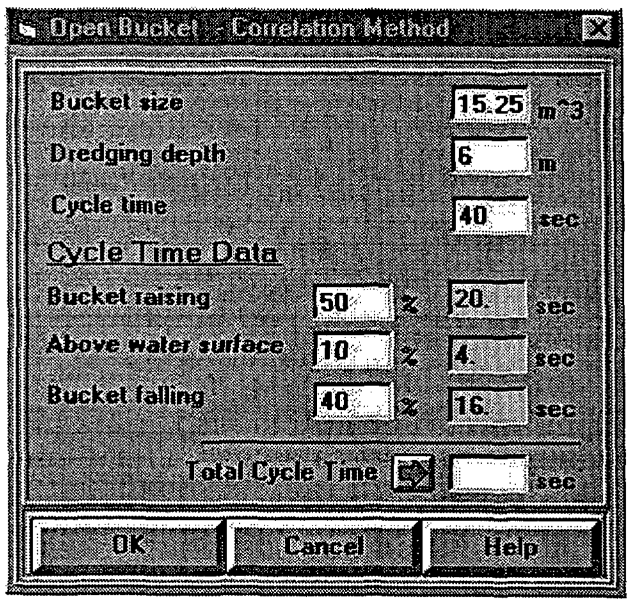
The cutterhead correlation model input screen is shown to the right. The data needed for the cutterhead model include:



- *Cutterhead length* – the discussion above applies here too, but a general rule of thumb is the cutter length equals 3.0 times the pump size.
- *Cutterhead diameter* – cutterhead dredges are typically sized according to the pipe diameter associated with the pump, e.g. 12-inch dredge, 18-inch dredge, etc. Cutterheads come in all shapes and sizes, but most cutters are 2 to 3 times the size of the pump size (in terms of pipe diameter). If better information is not available, assuming a cutter diameter approximately equal to 2.5 times the pump size in pipe diameter is a good rule of thumb.

- *Thickness of cut* – the sediment depth being removed on each swing; typically this should not be much larger than the cutter diameter nor should it be extremely thin except for clean-up cuts.
- *Ladder length* – the length of pipe between the cutterhead and the dredge pump.
- *Cutter Rotation Speed* – the rotational velocity of the cutter in revolutions per minute. This speed can vary considerably, but is generally much slower than expected, especially for large cutters. Typical values range from 2 to 10 rpm with the upper range more applicable to small cutters. As a rule of thumb, the tangential speed of the cutter blades should not exceed 0.5 m/sec for most normal dredging operations.
- *Dredge flowrate* – the volumetric discharge of the dredge in m^3/sec; if better values are not available, this can be estimated using the diameter of the discharge pipe and an average discharge velocity of 4 to 5 m/sec.

The open bucket correlation model input screen is shown to the right. The data needed for the open bucket model include:

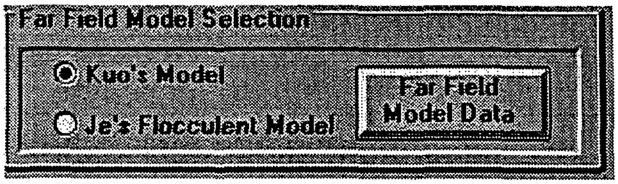


- *Bucket size* – volumetric capacity of dredge bucket being used. Buckets are available in volumes ranging from about 1 m^3 to 100 m^3 because of the range of crane capacities available. A 20 m^3 bucket would be considered by most to be a mid-sized bucket. Note the input box requires units of m^3 even though bucket volumes in the US are usually expressed in units of yd^3; the conversion factor is 1 yd^3 = 0.765 m^3.
- *Dredging depth* – the depth from the water surface to the bottom of the dredging prism in meters.

- *Cycle time* – the cumulative time it takes for the bucket to fall through the water column, grab sediment from the bottom, be raised to the surface, swing over to the sediment barge, empty its load, and swing back to the water surface; this varies with many factors and with each cycle. But, the average cycle time normally ranges from 30 to 90 seconds, with about 60 seconds being most common under normal operating circumstances. Note that this may be intentionally slowed in some environmental dredging operations in an attempt to reduce sediment loss to the environment.
- *Cycle Time Data* – DREDGE also needs to know the breakdown of the cycle time in percent of the total cycle time. Although the values can vary under different conditions, field data under normal operating conditions have shown the following fractional times are reasonable estimates in the absence of better data:

Bucket Fall	Bucket Raise	Above Water
22%	30%	48%

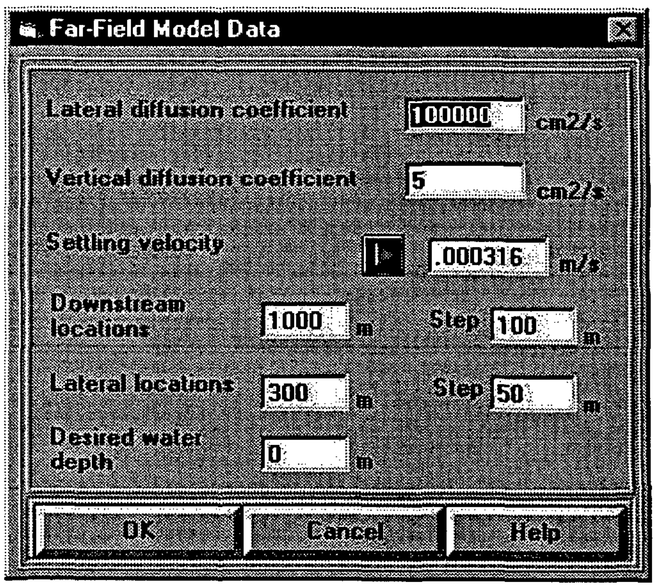
D – Far-field TSS Models



Because of the uncertainty in the source term and its intended application, DREDGE uses relatively simple far-field models to transport suspended sediments downstream. Although different models are used for cutterhead and bucket dredges, the models are conceptually similar. Both models are adequately simple that analytical solutions were obtained, thereby requiring very little computer time to make transport calculations. This allows DREDGE to make numerous calculations with very little noticeable delay.

> **What is a Far-field Model?**
>
> DREDGE breaks suspended sediment transport from dredges into two distinct areas. The near-field area in the immediate vicinity of the dredging operation is dominated by mixing and currents induced by the dredging operation itself. Beyond that zone, suspended sediment transport is dominated by advection, turbulent diffusion, and sedimentation. This is the "far-field" zone and transport models applied in this zone are conveniently termed "far-field models" in the DREDGE software and associated documents.

The transport model used for cutterhead dredges is a 2-D, laterally-averaged steady-state model published by Kuo, et al (1985). Bucket dredge transport calculations utilize a 2-D vertically-averaged transport model published by Kuo and Hayes (1991). Je (1998) developed enhancements to these models that will be included in future versions of DREDGE. For now, that option is disabled. Data for the far-field models are entered using a screen that is displayed when the Far Field Model Data button is pressed (see box to the right). The data required for the far-field models include:



- *Lateral diffusion coefficient* – turbulent diffusion of suspended sediment in the lateral dimension in units of cm^2/sec; typical values are 10^5 cm^2/sec to 10^7 cm^2/sec. The lower values are more representative of laterally bounded water bodies (widths of 100 feet or less); higher values are more representative of water bodies sufficiently wide that the plume never strikes the boundaries.

- *Vertical diffusion coefficient* – turbulent diffusion of suspended sediment in the vertical dimension in units of cm^2/sec; typical values are 10^0 cm^2/sec to 10^1 cm^2/sec unless stratification exists. If density stratification exists, it may inhibit vertical transport sufficiently that vertical diffusion coefficients as low as 10^{-3} cm^2/sec are possible.
- *(Average) Settling velocity* – average settling velocity of the particles in suspension; it should be remembered that only the fine fraction of the sediments is transported downstream. Pressing the arrow brings up a dialog box that calculates the Stokes' law settling velocity for a known particle size and places it in the box.

DREDGE also needs to know the downstream locations at which the output is desired. Each location is considered a node and has a lateral, vertical, and longitudinal component. To avoid having the user enter individual locations for calculations, DREDGE asks for only the total distance from the dredge location and the equal step distances in the lateral and longitudinal dimension. Output is calculated for a single water depth. The actual data requested include:

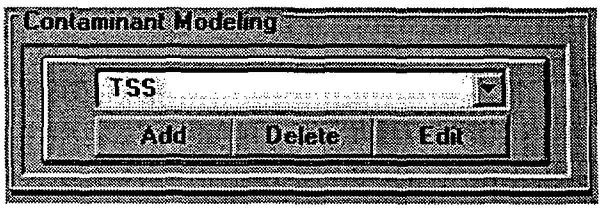
- *Downstream locations (for output)* – enter the maximum distance downstream (meters) that you wish DREDGE to provide any output for in the first box, followed by the increments beginning at 0 that you would like values for in the second box. For the values in the screen shown, DREDGE will provide output for 100 m, 200 m, 300 m, ... to a maximum of 1,000 m. Hint: only in unusual circumstances will a plume be distinguishable beyond 1000 m and in most cases 500 m is adequate.
- *Lateral locations (for output)* – enter the maximum lateral distance (meters) on either side of the centerline that you wish DREDGE to provide any output for in the first box, followed by the increments beginning at 0 that you would like values

for in the second box. For the values in the screen shown, DREDGE will provide output for 50 m, 100 m, 150 m, ... to a maximum of 300 m (a total width of 600 m).

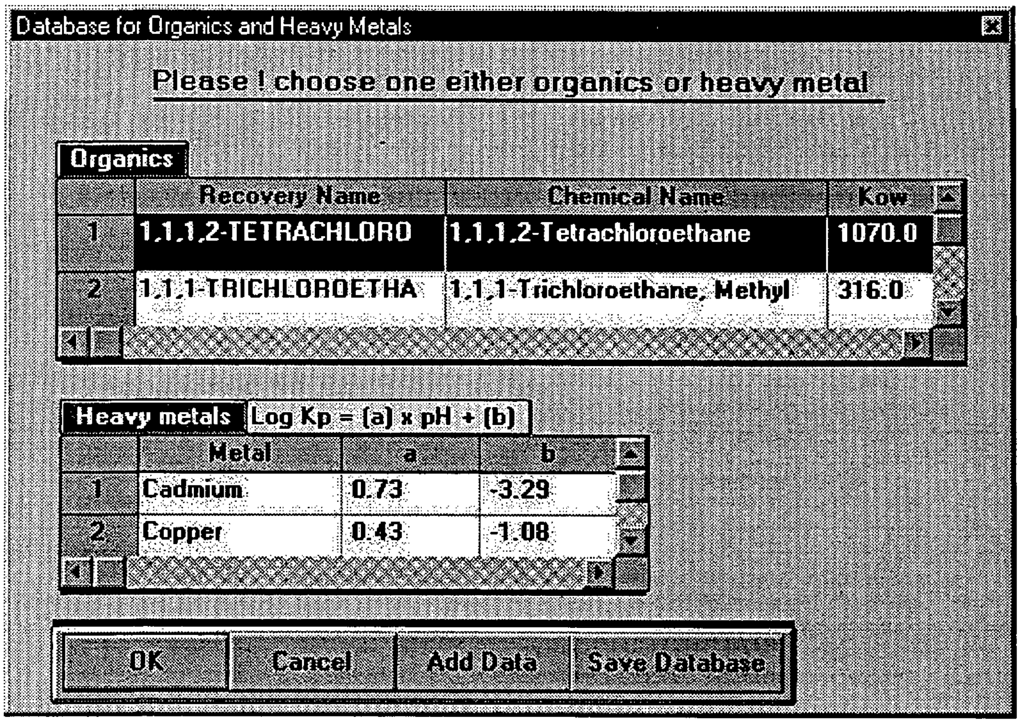
- *Desired water depth (for output)* – enter the water depth at which you desire output; DREDGE will need to be rerun for multiple depths.

E – Contaminant Selection

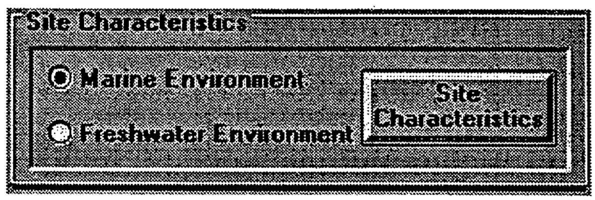
The discussion thus far has focused exclusively on suspended sediment transport, and all DREDGE modeling efforts must include TSS as the primary constituent of interest. However, DREDGE also allows the user to model additional chemical constituents – one metal constituent and one organic constituent during each run. DREDGE includes a database of partitioning coefficients based upon USACE's RECOVERY database (Ruiz and Gerald 2000). The database contains an extensive list of octanol-water partitioning coefficients (K_{ow}) for organic contaminants; partitioning coefficients for most common metal constituents are also included. The user can also update the database by modifying existing values or adding new constituents. The user should follow the steps below to select contaminants from the existing database in DREDGE.



1) Move the mouse to the **Contaminant Modeling** rectangle box in the main **Input Data Entry** window.
2) Click the **Add** button to select the contaminant from the existing database.
3) Then, a database window similar to the one below will be displayed to select either organics or heavy metal for contaminant modeling.
4) By clicking the **OK** button, user will be asked to enter or edit the data required to estimate the partitioning coefficient for specific organics or metal.
5) After completing the data input, simply click the **OK** button to exit input window.
6) Repeat step (1) to step (5) if user wants to add more contaminants for modeling.



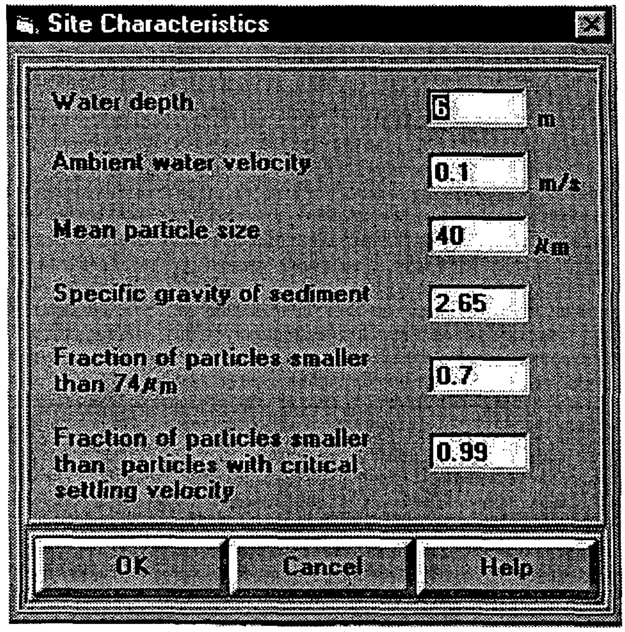
F – Site Characteristics



Although the site characteristics box shows two options on the left side - **Marine Environment** and **Freshwater Environment,** these are not used in the current version of DREDGE. Thus, all site characteristic information is requested through the screen displayed when the Site Characteristics button is pressed (see below). The site characteristics data required include:

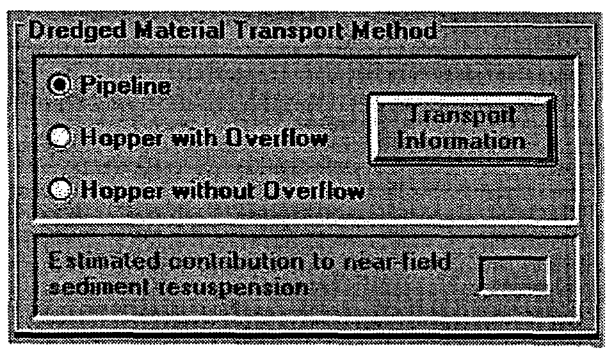
- *Water depth* – the depth from the water surface to the bottom of the dredging prism in meters.
- *Ambient water velocity* – average water velocity in the downstream direction in meters/second.
- *Mean particle size* – average particle size of the bottom sediments in µm.
- *Specific gravity of the sediment* – specific gravity of the bottom sediment; this value typically ranges from 2.4 for highly organic silts to 2.7 for consolidated clays with 2.65 being a common value for sands.

- *Fraction of Particles Less than 74 μm* – the fraction of fine sediments in the bottom sediments to be dredged, expressed as a fraction, i.e. the value must be between 0.0 and 1.0.



- *Fraction of Particles Smaller than Particles with the Critical Settling Velocity* – particles with settling velocities less than the Critical Settling Velocity will not settle, but rather remain in suspension due to the ambient currents in the area. The TGU method needs to know the fraction of bottom sediments that have a particle diameter smaller than the diameter associated with the critical velocity.

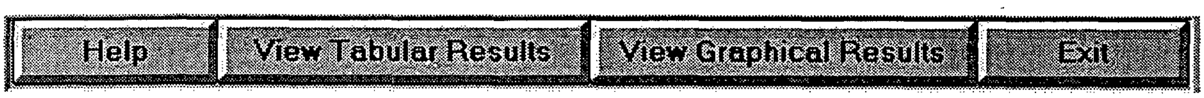
__G – Transport Losses__



This section, shown to the right, is not used in the current version of DREDGE, but is reserved for later use.

__H – Navigation and HELP buttons__

DREDGE facilitates navigation between its three primary windows by a button bar at the bottom of each screen. The same bar, shown below, provides direct access to the



DREDGE HELP system and allows the user to exit DREDGE. The two buttons in the middle of the bar change depending upon the screen shown.

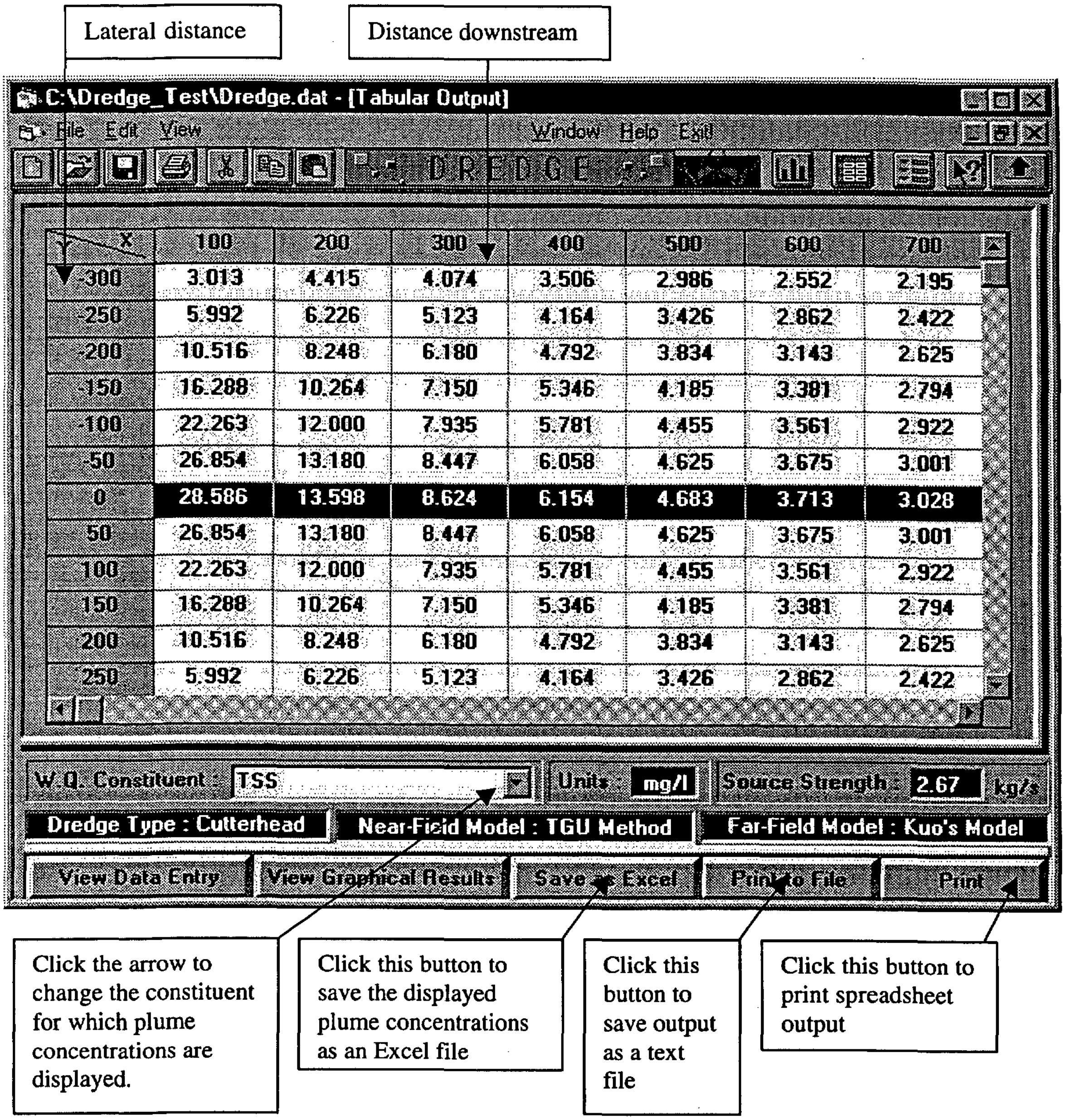
VIEWING RESULTS

DREDGE provides the transport calculation results in both tabular and graphical forms for the convenience of the user. These results can be viewed by pressing either the "View Tabular Results" button or "View Graphical Results" button at the bottom of the data entry screen. Because DREDGE is able to complete the model calculations quickly, the results are not stored as part of the project file; the models are executed automatically each time either output button is pressed. The output screens are described below.

SPREADSHEET OUTPUT

The **Spreadsheet Output** screen displays plume concentration at each of the nodes (nodes are intersections of the lateral, longitudinal, and vertical grids specified by the user). The screen, shown below, initially displays TSS concentrations in mg/L, but other constituents can be displayed by selecting them from the dropdown box below the output grid. The **Spreadsheet Output** window summarizes the calculation options selected by the user - dredge type, near-field model and resulting source strength, and far-field model used – and the current constituent being displayed along with its concentration units. All contaminants are displayed in total concentration units, the sum of both particulate and dissolved fractions.

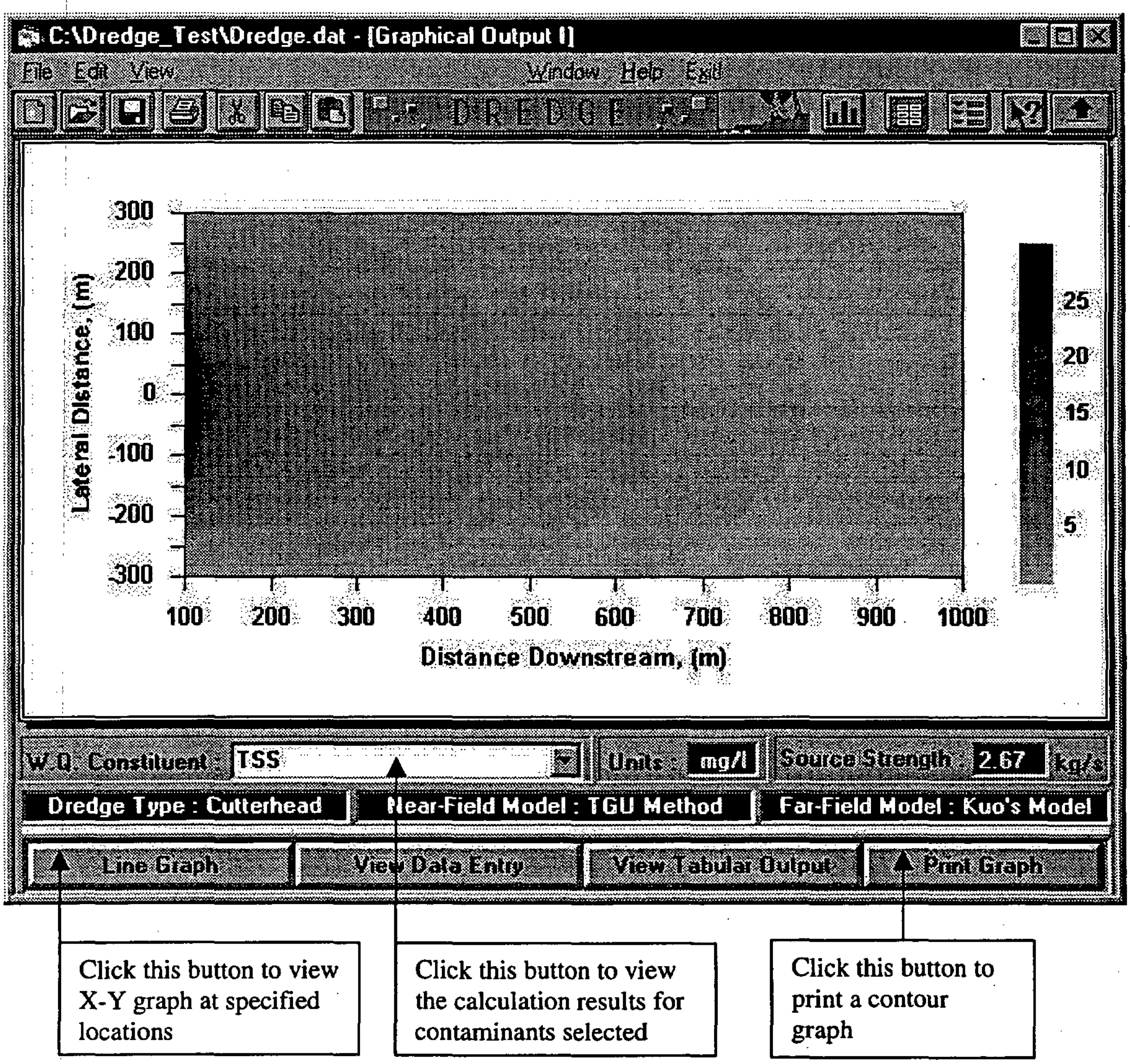
The **Spreadsheet Output** window also allows the user to save the displayed output as either an Excel or ASCII text file by simply pressing the appropriate button on the bottom of the form. The user can print the displayed output by pressing the **Print** button at the bottom of the **Spreadsheet Output** window. In each case, DREDGE saves or prints only plume concentrations for the currently displayed constituent. Other constituents must first be displayed, and then the results can be exported or printed.



Y \ X	100	200	300	400	500	600	700
-300	3.013	4.415	4.074	3.506	2.986	2.552	2.195
-250	5.992	6.226	5.123	4.164	3.426	2.862	2.422
-200	10.516	8.248	6.180	4.792	3.834	3.143	2.625
-150	16.288	10.264	7.150	5.346	4.185	3.381	2.794
-100	22.263	12.000	7.935	5.781	4.455	3.561	2.922
-50	26.854	13.180	8.447	6.058	4.625	3.675	3.001
0	28.586	13.598	8.624	6.154	4.683	3.713	3.028
50	26.854	13.180	8.447	6.058	4.625	3.675	3.001
100	22.263	12.000	7.935	5.781	4.455	3.561	2.922
150	16.288	10.264	7.150	5.346	4.185	3.381	2.794
200	10.516	8.248	6.180	4.792	3.834	3.143	2.625
250	5.992	6.226	5.123	4.164	3.426	2.862	2.422

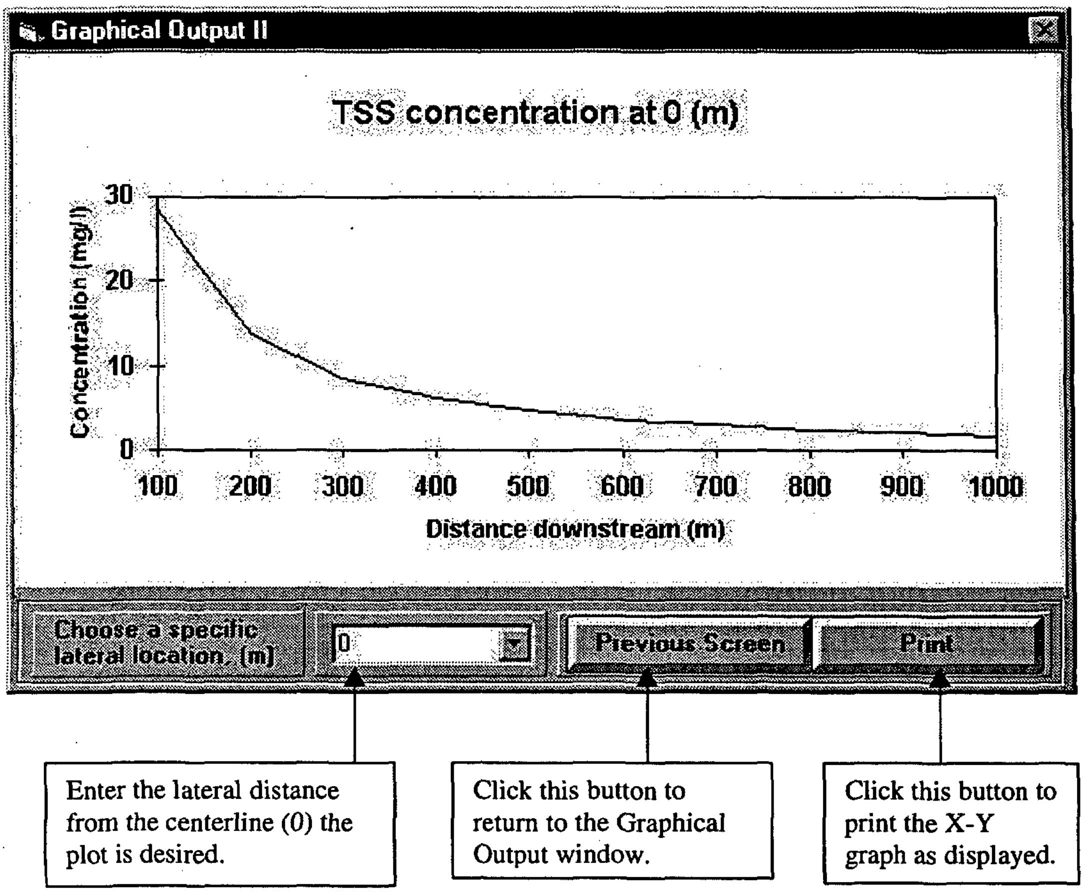
GRAPHICAL OUTPUT

DREDGE provides both contour and X-Y graphs for viewing the output in addition to the spreadsheet display described above. These are available by pressing the "View Graphical Results" button at the bottom of any main screen. This action displays the **Graphical Output** window shown below.



The default graph is a contour graph in which the concentration ranges are displayed using a gradually varying color bar. The user can reformat the graph by pressing the right mouse button while hovering over the graph. This allows the user to format the graph by modifying the scales, color schemes, or axis titles as they wish to have it displayed. The user can then, using the same technique of pressing the right mouse button, save the graph as a graphics file that can be imported into other Windows applications. DREDGE also will print the graph if the user presses the "Print Graph" button at the bottom.

The **Graphical Output** window provides the same model information as the Spreadsheet Output Window. Similarly, the default constituent is TSS, but other constituents can be displayed by selecting them from the drop-down box. DREDGE can also display the results as a more traditional X-Y graph. The user just presses the "Line Graph" button and DREDGE displays a concentration versus distance plot for a given depth and lateral location. This plot can be formatted or saved as a graphics file in a manner similar to that described above for the contour plot. An example is shown below.



REFERENCES

Collins, M.A. (1995). "Dredging-Induced Near-Field Resuspended Sediment Concentrations and Source Strengths," *Miscellaneous Paper D-95-2*, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hayes, D.F., T.R. Crockett, and T.J. Ward, "Near-Field Sediment Resuspension During Cutterhead Dredging Operations," *ASCE Journal of Coastal, Ports, and Waterways*, Vol. 126, No. 3, May/June 2000.

Je, C.H. (1998). "Modeling the Transport of Flocculating Suspended Sediments Resulting from Dredging Operations," Ph.D. Dissertation, University of Utah, Salt Lake City, UT.

Kuo, A.Y. and Hayes, D.F., "A Model for Turbidity Plume Induced by Bucket Dredge," *ASCE Journal of Waterways, Port, Coastal, and Ocean Engineering*, November 1991.

Kuo, A., C. Welch, and R. Lukens (1985). "Dredge Induced Turbidity Plume Model," *ASCE Journal of Waterway, Port, Coastal, and Ocean Engineering*, Vol. 111, No. 3.

Nakai, O. (1978). "Turbidity Generated by Dredging Projects," *Proceedings of the 3rd U.S./Japan Experts Meeting*, US Army Engineer Water Resources Support Center, Ft. Belvoir, VA.

Ruiz, C.E., and Gerald, T. (2000). "RECOVERY Version 2, A Mathematical Model to Predict the Temporal Response of Surface Water to Contaminated Sediments," In Preparation, U.S. Army Engineer Research and Development Center, Waterways Experiment Station, Vicksburg, MS.

APPENDIX B

Sensitivity Analysis Results of the DREDGE Model for Parameters Applicable to the Dredging Simulations of the Delaware River Navigation Channel and Berthing Areas

Tables show results of sensitivity analysis of parameters used in the DREDGE model based on characteristics of the types of dredges to be used for the Delaware River project and characteristics of the sediment and river in the areas to be dredged. For well-known parameters such as the size of the dredge, the parameters were tested plus or minus 10% of the actual value of the parameter. For less well-known parameters, either a known range was tested or the parameter plus or minus 20% was tested. The model was run with the expected values for each parameter while the test parameters were changed one at a time. Results show that the model is most sensitive to the lateral and vertical diffusion coefficients. Based on these results, the conservative value of 10000 for the lateral diffusion coefficient was used for model runs although the expected value would be at least 100,000. For the vertical diffusion coefficient, the mid-range was chosen. The model is also sensitive to the turbidity generation unit (TGU) value for both the cutterhead and bucket dredge. Values chosen were based on the best available literature value.

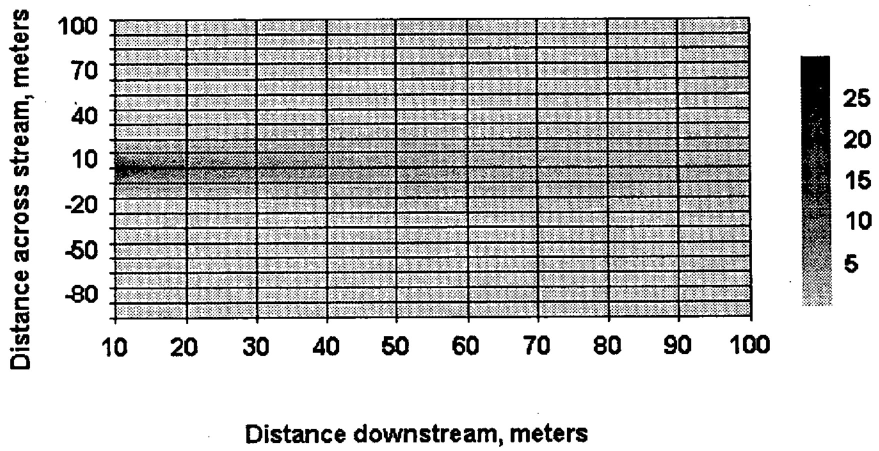
Parameter	Value	TSS Max	TSS at 60m
<< Dredge Characteristics >>			
Bucket size	= 19.13 + 10% (m^3)	177	72
Bucket size	= 19.13 - 10% (m^3)	145	59
Cycle time	= 72 + 10% (sec)	147	59
Cycle time	= 72 - 10% (sec)	179	72
In-situ dry density	= 1053 (kg/m^3)	161	65
In-situ dry density	= 700 (kg/m^3)	161	65
<< Near-Field Model - TGU method >>			
Bucket size	= 19.13 + 10% (m^3)	177	72
Bucket size	= 19.13 - 10% (m^3)	145	59
Cycle time	= 72 + 10% (sec)	147	59
Cycle time	= 72 - 10% (sec)	179	72
Turbidity generation unit	= 45000 + 20% (g/m^3)	194	78
Turbidity generation unit	= 45000 - 20% (g/m^3)	129	52
R74 (fraction of sediment < 74 um)	= 0.77 + 10%	147	59
R74 (fraction of sediment < 74 um)	= 0.77 - 10%	179	72
Ro (fraction < critical velocity)	= 0.99 + 10%	177	72
Ro (fraction < critical velocity)	= 0.99 - 10%	145	59
<< Far-Field Model >>			
Lateral diffusion coefficient	= 100000 (cm^2/sec)	51	21
Vertical diffusion coefficient	= 10 (cm^2/sec)	161	65
Vertical diffusion coefficient	= 1 (cm^2/sec)	161	65
<< Site Characteristics >>			
Water depth	= 14 (m)	138	56
Water depth	= 10 (m)	193	78
Ambient water velocity (m/sec)	= 1.0	114	46
Ambient water velocity (m/sec)	= 0.2	254	101
Mean particle size	= 40 + 10% (um)	161	65
Mean particle size	= 40 - 10% (um)	161	65
Specific gravity of sediment	= 2.65 + 10%	161	65
Specific gravity of sediment	= 2.65 - 10%	161	65

Parameter	Value	TSS Max	TSS at 60m
<< Cutterhead Dredge Data >>			
Cutterhead diameter	= 1.525 + 10% (m)	1597	246
Cutterhead diameter	= 1.525 - 10% (m)	1597	246
Cutterhead length	= 1.525 + 10% (m)	1755	270
Cutterhead length	= 1.525 - 10% (m)	1436	221
Thickness of cut	= 1.525 + 10% (m)	1755	270
Thickness of cut	= 1.525 - 10% (m)	1436	221
Swing velocity at cutter	= 0.127 + 10% (m)	1597	246
Swing velocity at cutter	= 0.127 - 10% (m)	1597	246
In-situ dry density	= 1053 (kg/m^3, max)	1597	246
In-situ dry density	= 700 (kg/m^3, min)	1597	246
<< Near-Field Model - TGU method >>			
Cutterhead length	= 1.525 + 10% (m)	1755	270
Cutterhead length	= 1.525 - 10% (m)	1436	221
Thickness of cut	= 1.525 + 10% (m)	1755	270
Thickness of cut	= 1.525 - 10% (m)	1436	221
Width of turbid area	= 120 + 50% (m^2)	1597	246
Width of turbid area	= 120 - 50% (m^2)	1597	246
Turbidity generation unit	= 12000 + 20% (g/m^3)	1916	295
Turbidity generation unit	= 12000 - 20% (g/m^3)	1278	197
<< Far-Field Model >>			
Lateral diffusion coefficient	= 100000 (cm^2/sec)	505	78
Vertical diffusion coefficient	= 10 (cm^2/sec, max)	1138	182
Vertical diffusion coefficient	= 1 (cm^2/sec, min)	3351	375
<< Site Characteristics >>			
Water depth	= 12 + 2 (m)	1597	246
Water depth	= 12 - 2 (m)	1597	246
Ambient water velocity	= 1.0 (m/sec, max)	1610	258
Ambient water velocity	= 0.2 (m/sec, min)	1559	213
Mean particle size	= 40 + 10% (um)	1597	246
Mean particle size	= 40 - 10% (um)	1597	246
Specific gravity of sedi.	= 2.65 + 10%	1597	246
Specific gravity of sedi.	= 2.65 - 10%	1597	246

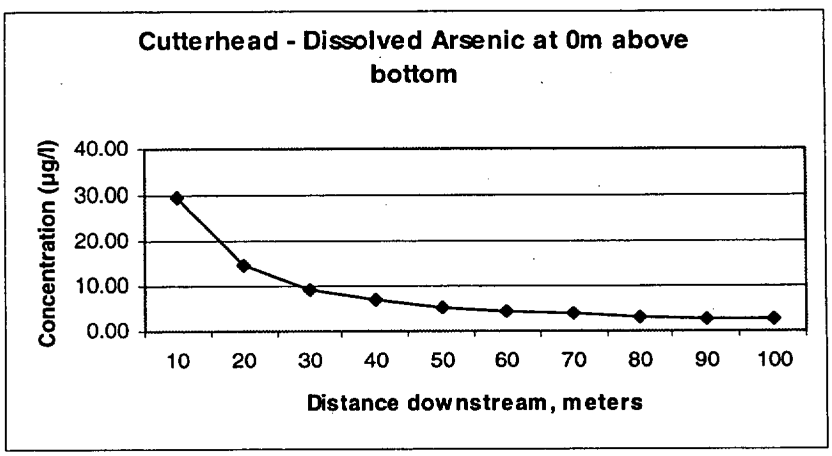
APPENDIX C

Model Results of Cutterhead Hydraulic Dredging in the Navigation Channel of the Marcus Hook Range of the Delaware River, using the DREDGE model with Equilibrium Partitioning Coefficients

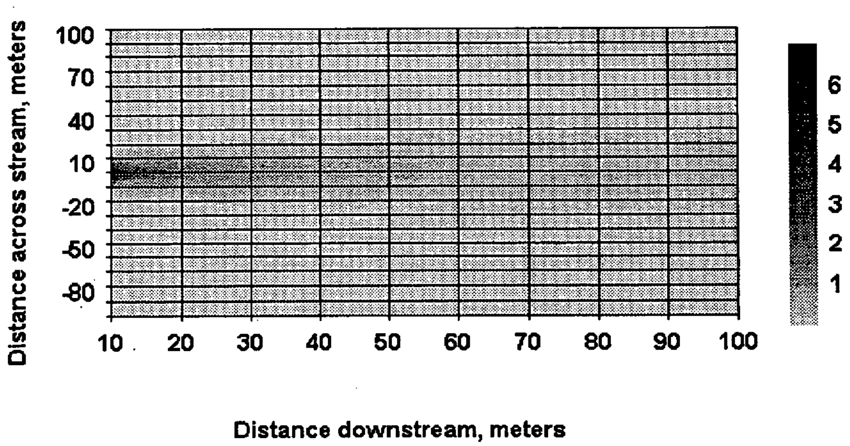
Cutterhead Arsenic at 0m above bottom



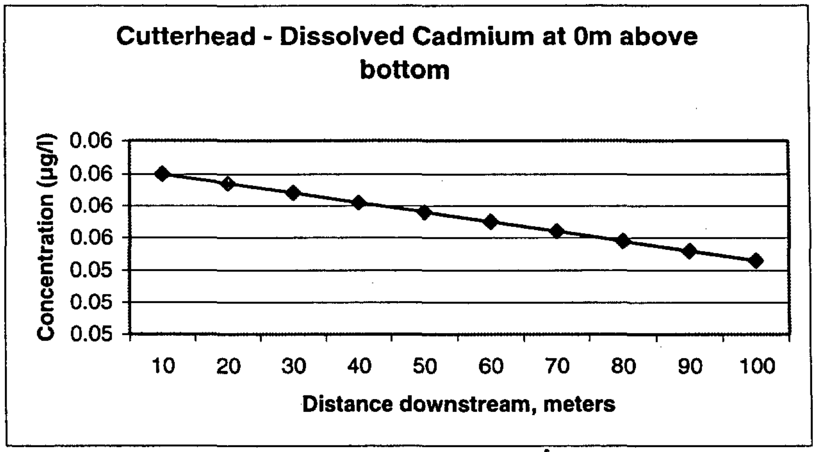
Cutterhead Dissolved Arsenic at 0m above bottom



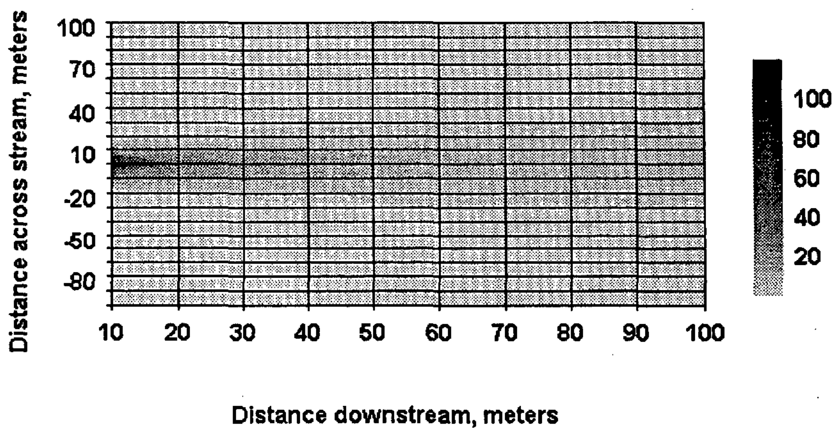
Cutterhead Cadmium at 0m above bottom



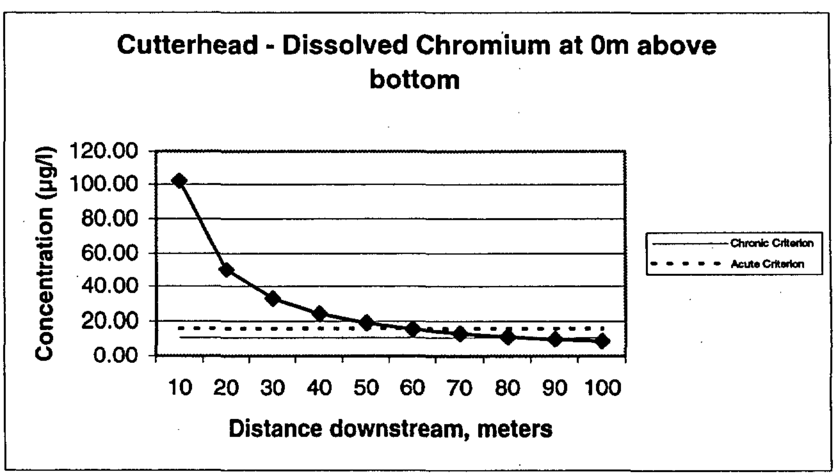
Cutterhead Dissolved Cadmium at 0m above bottom



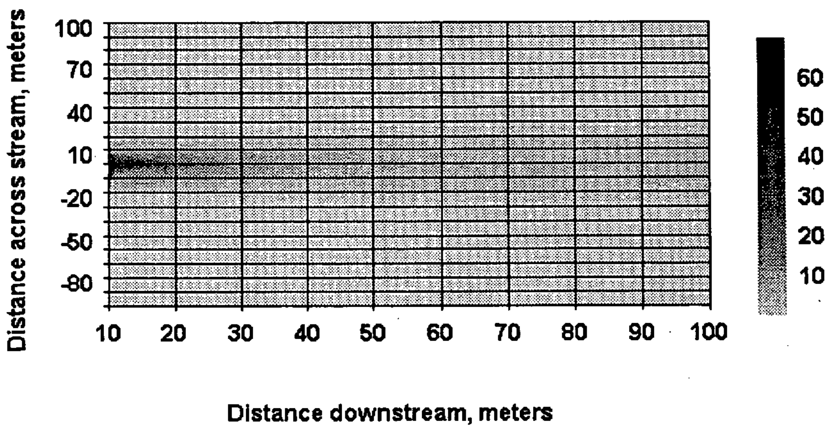
Cutterhead Chromium at 0m above bottom



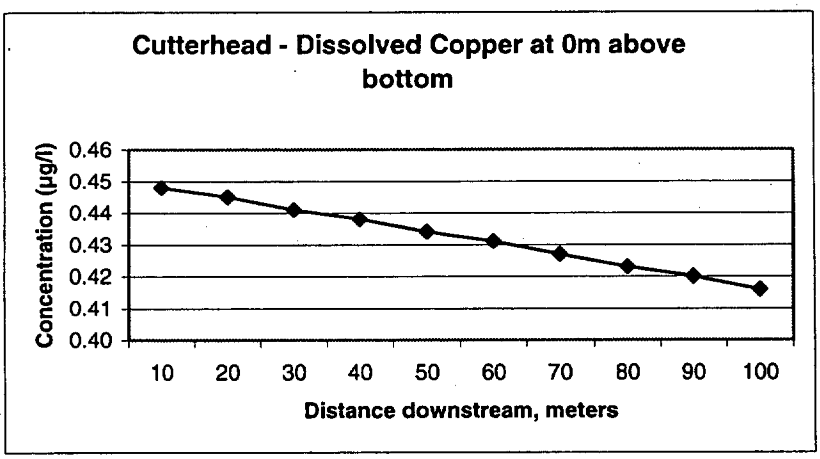
Cutterhead Dissolved Chromium at 0m above bottom



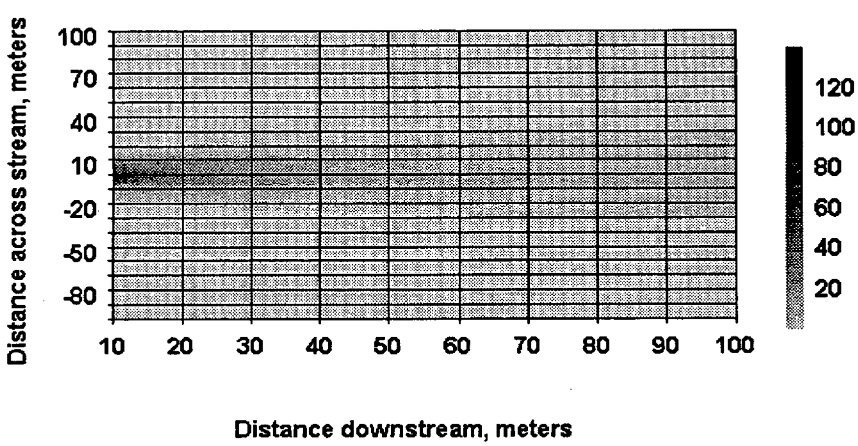
Cutterhead Copper at 0m above bottom



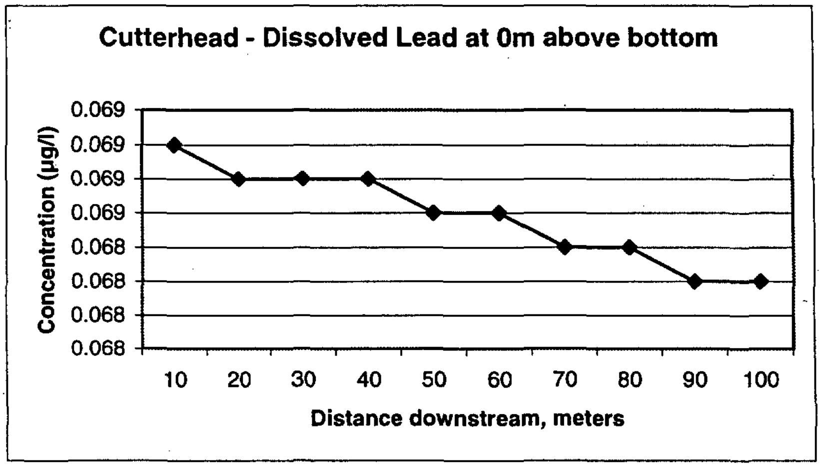
Cutterhead Dissolved Copper at 0m above bottom



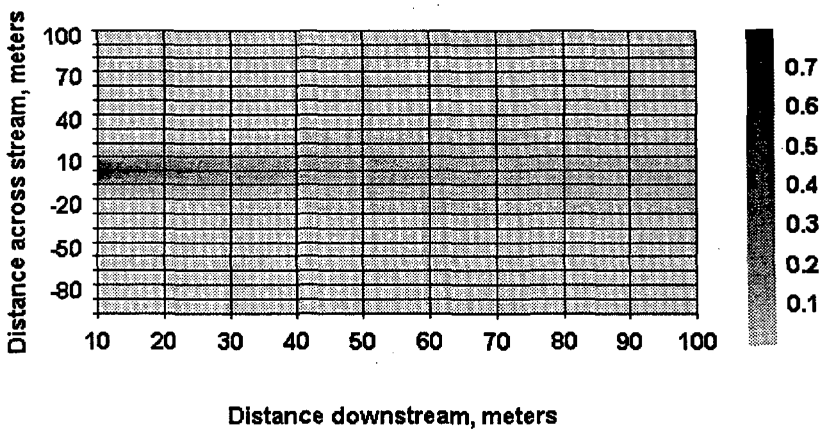
Cutterhead Lead at 0m above bottom



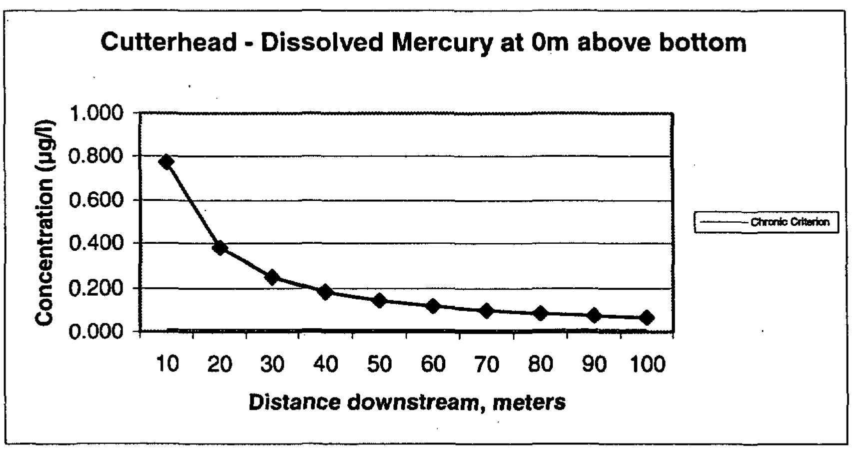
Cutterhead Dissolved Lead at 0m above bottom



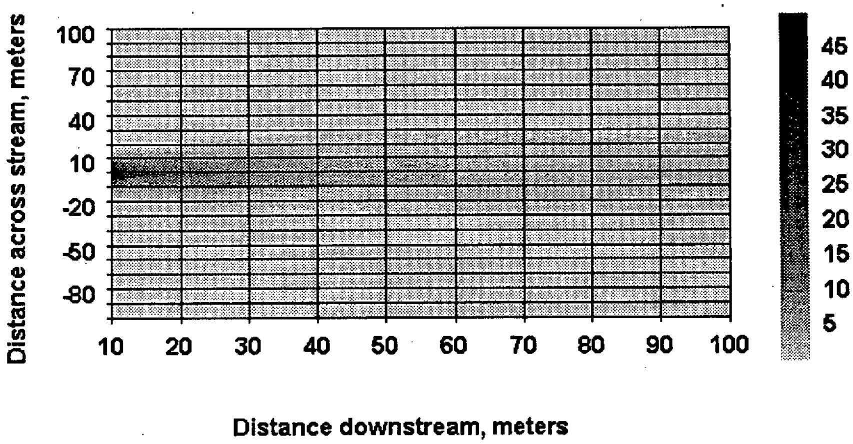
Cutterhead Mercury at 0m above bottom



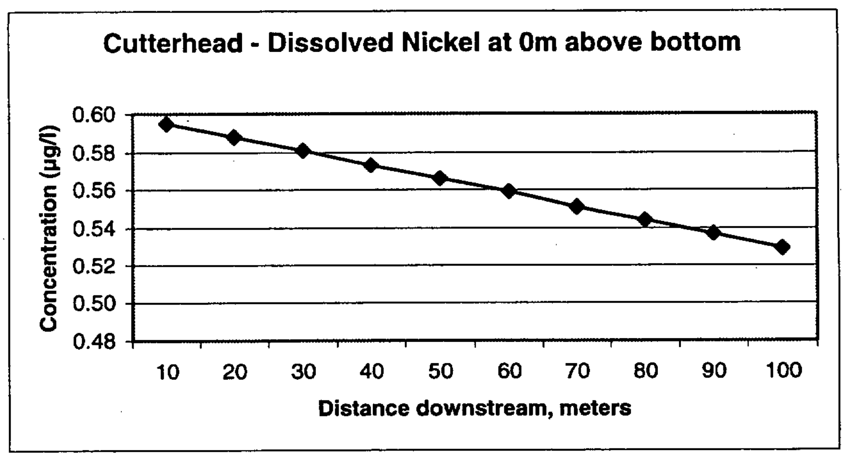
Cutterhead Dissolved Mercury at 0m above bottom



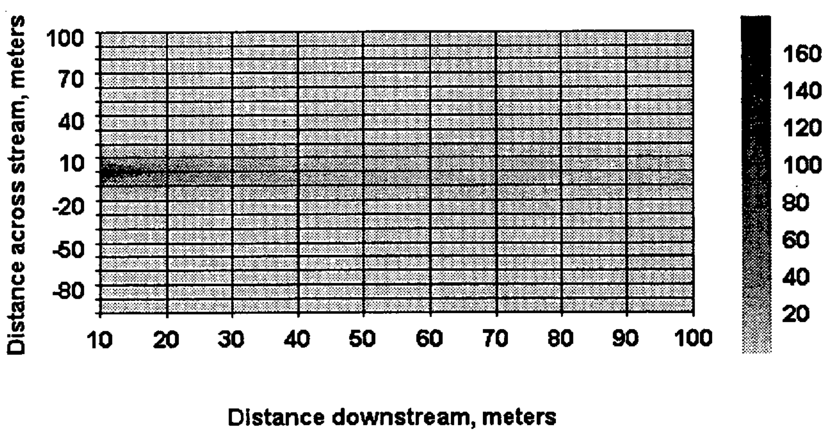
Cutterhead Nickel at 0m above bottom



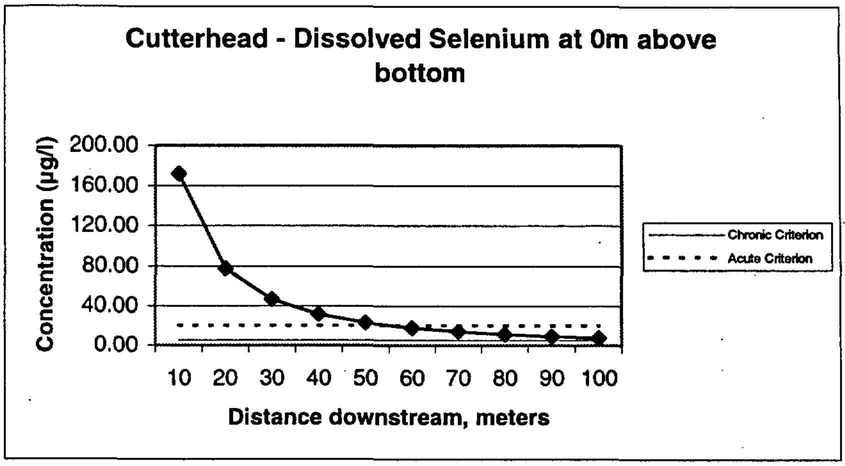
Cutterhead Dissolved Nickel at 0m above bottom



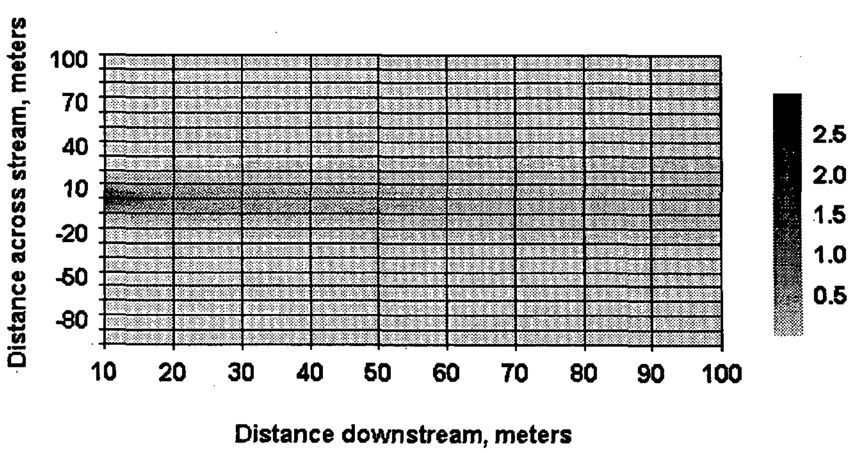
Cutterhead Selenium at 0m above bottom



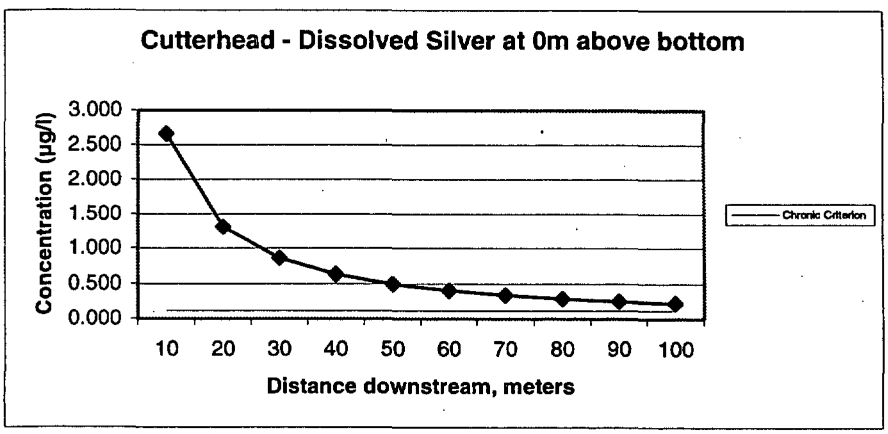
Cutterhead Dissolved Selenium at 0m above bottom



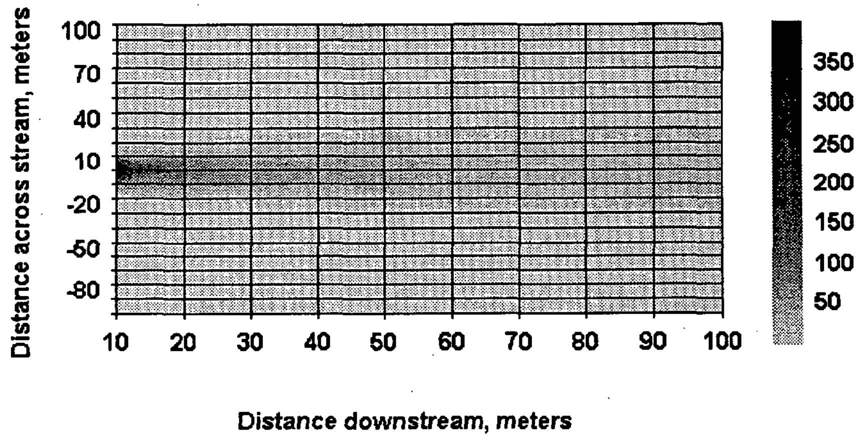
Cutterhead Silver at 0m above bottom



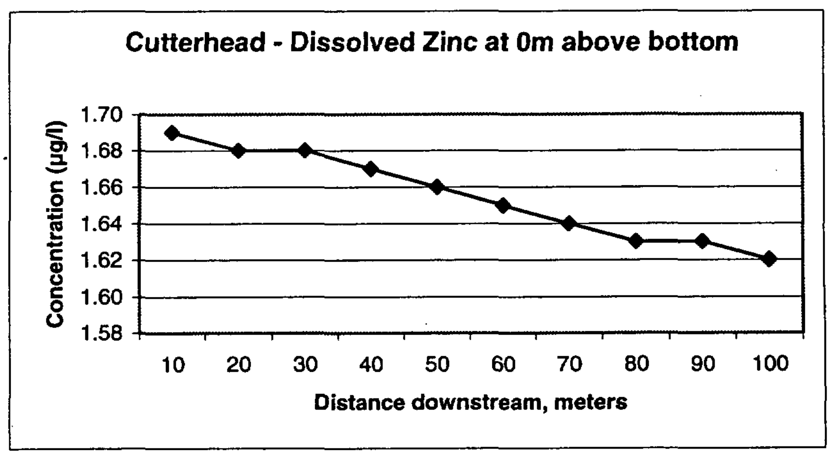
Cutterhead Dissolved Silver at 0m above bottom



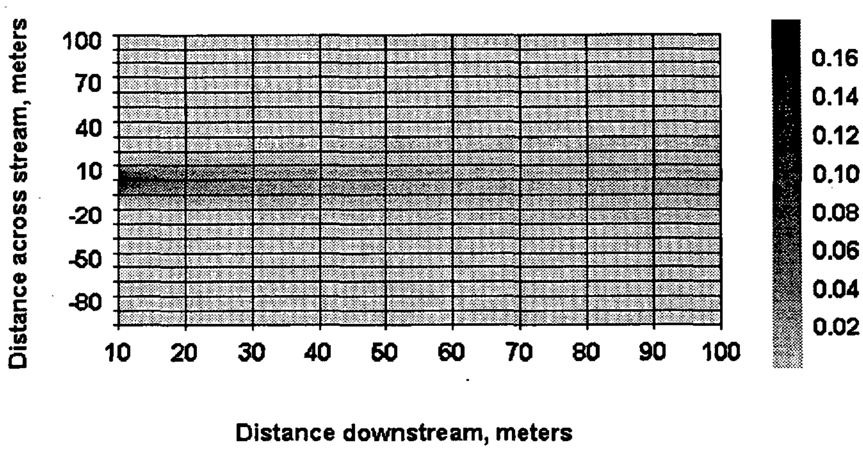
Cutterhead Zinc at 0m above bottom



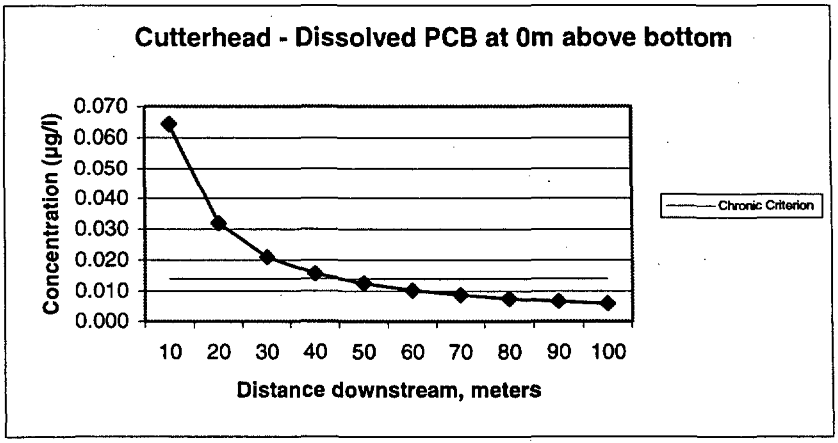
Cutterhead Dissolved Zinc at 0m above bottom



Cutterhead PCBs at 0m above bottom



Cutterhead Dissolved PCBs at 0m above bottom



Dredge Type : Cutterhead										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Arsenic at bottom, μg/l										
	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
-50	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.08
-40	0.00	0.00	0.00	0.02	0.07	0.12	0.18	0.23	0.27	0.30
-30	0.00	0.03	0.18	0.37	0.53	0.65	0.72	0.76	0.77	0.78
-20	0.16	1.14	1.74	1.96	1.98	1.91	1.82	1.71	1.60	1.49
-10	8.37	7.69	6.20	5.07	4.24	3.62	3.14	2.76	2.45	2.20
0	29.30	14.40	9.44	6.95	5.46	4.47	3.76	3.23	2.82	2.49
10	8.37	7.69	6.20	5.07	4.24	3.62	3.14	2.76	2.45	2.20
20	0.16	1.14	1.74	1.96	1.98	1.91	1.82	1.71	1.60	1.49
30	0.00	0.03	0.18	0.37	0.53	0.65	0.72	0.76	0.77	0.78
40	0.00	0.00	0.00	0.02	0.07	0.12	0.18	0.23	0.27	0.30
50	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.08
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type : Cutterhead										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Cadmium at bottom, µg/l										
	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
-50	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02
-40	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.03	0.03	0.03
-30	0.00	0.01	0.03	0.04	0.04	0.04	0.04	0.05	0.05	0.05
-20	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
-10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05
0	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05
10	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05
20	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
30	0.00	0.01	0.03	0.04	0.04	0.04	0.04	0.05	0.05	0.05
40	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.03	0.03	0.03
50	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type : Cutterhead										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Chromium at bottom, µg/l										
	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.09
-50	0.00	0.00	0.00	0.00	0.03	0.07	0.14	0.22	0.30	0.38
-40	0.00	0.00	0.03	0.15	0.34	0.55	0.75	0.92	1.07	1.18
-30	0.00	0.17	0.76	1.44	2.00	2.39	2.63	2.77	2.84	2.85
-20	0.67	4.10	6.19	6.93	7.01	6.79	6.45	6.08	5.70	5.33
-10	29.10	26.80	21.60	17.70	14.90	12.70	11.00	9.72	8.65	7.76
0	102.00	50.10	32.80	24.20	19.10	15.60	13.20	11.40	9.94	8.80
10	29.10	26.80	21.60	17.70	14.90	12.70	11.00	9.72	8.65	7.76
20	0.67	4.10	6.19	6.93	7.01	6.79	6.45	6.08	5.70	5.33
30	0.00	0.17	0.76	1.44	2.00	2.39	2.63	2.77	2.84	2.85
40	0.00	0.00	0.03	0.15	0.34	0.55	0.75	0.92	1.07	1.18
50	0.00	0.00	0.00	0.00	0.03	0.07	0.14	0.22	0.30	0.38
60	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.09
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type : Cutterhead										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Copper at bottom, µg/l										
	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
-60	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.05
-50	0.00	0.00	0.00	0.01	0.02	0.05	0.08	0.11	0.13	0.15
-40	0.00	0.00	0.02	0.08	0.14	0.19	0.23	0.25	0.27	0.28
-30	0.00	0.09	0.23	0.30	0.33	0.34	0.35	0.36	0.36	0.36
-20	0.22	0.38	0.40	0.41	0.41	0.41	0.40	0.40	0.40	0.40
-10	0.44	0.44	0.44	0.43	0.43	0.43	0.42	0.42	0.42	0.41
0	0.45	0.45	0.44	0.44	0.43	0.43	0.43	0.42	0.42	0.42
10	0.44	0.44	0.44	0.43	0.43	0.43	0.42	0.42	0.42	0.41
20	0.22	0.38	0.40	0.41	0.41	0.41	0.40	0.40	0.40	0.40
30	0.00	0.09	0.23	0.30	0.33	0.34	0.35	0.36	0.36	0.36
40	0.00	0.00	0.02	0.08	0.14	0.19	0.23	0.25	0.27	0.28
50	0.00	0.00	0.00	0.01	0.02	0.05	0.08	0.11	0.13	0.15
60	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.05
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type : Cutterhead										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Lead at bottom, µg/l										
	10	20	30	40	50	60	70	80	90	100
-100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003
-70	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.006	0.011	0.018
-60	0.000	0.000	0.000	0.000	0.003	0.009	0.019	0.029	0.038	0.044
-50	0.000	0.000	0.001	0.010	0.027	0.042	0.050	0.055	0.058	0.060
-40	0.000	0.003	0.030	0.051	0.059	0.063	0.064	0.065	0.065	0.066
-30	0.002	0.053	0.064	0.066	0.067	0.067	0.067	0.067	0.067	0.067
-20	0.064	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068
-10	0.069	0.069	0.069	0.069	0.069	0.068	0.068	0.068	0.068	0.068
0	0.069	0.069	0.069	0.069	0.069	0.069	0.068	0.068	0.068	0.068
10	0.069	0.069	0.069	0.069	0.069	0.068	0.068	0.068	0.068	0.068
20	0.064	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068
30	0.002	0.053	0.064	0.066	0.067	0.067	0.067	0.067	0.067	0.067
40	0.000	0.003	0.030	0.051	0.059	0.063	0.064	0.065	0.065	0.066
50	0.000	0.000	0.001	0.010	0.027	0.042	0.050	0.055	0.058	0.060
60	0.000	0.000	0.000	0.000	0.003	0.009	0.019	0.029	0.038	0.044
70	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.006	0.011	0.018
80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003
90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Dredge Type : Cutterhead										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Mercury at bottom, µg/l										
	10	20	30	40	50	60	70	80	90	100
-100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
-50	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0.003
-40	0.000	0.000	0.000	0.001	0.003	0.004	0.006	0.007	0.008	0.009
-30	0.000	0.001	0.006	0.011	0.015	0.018	0.020	0.021	0.022	0.022
-20	0.005	0.031	0.047	0.053	0.053	0.052	0.049	0.046	0.043	0.041
-10	0.221	0.204	0.164	0.135	0.113	0.097	0.084	0.074	0.066	0.059
0	0.773	0.380	0.249	0.184	0.145	0.119	0.100	0.086	0.076	0.067
10	0.221	0.204	0.164	0.135	0.113	0.097	0.084	0.074	0.066	0.059
20	0.005	0.031	0.047	0.053	0.053	0.052	0.049	0.046	0.043	0.041
30	0.000	0.001	0.006	0.011	0.015	0.018	0.020	0.021	0.022	0.022
40	0.000	0.000	0.000	0.001	0.003	0.004	0.006	0.007	0.008	0.009
50	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0.003
60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Dredge Type : Cutterhead										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Mercury at bottom, µg/l										
	50	100	150	200	250	300	350	400	450	500
-100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-90	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001
-80	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001
-70	0.000	0.000	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002
-60	0.000	0.001	0.002	0.003	0.003	0.004	0.003	0.003	0.003	0.003
-50	0.000	0.003	0.005	0.006	0.006	0.006	0.005	0.005	0.004	0.004
-40	0.003	0.009	0.011	0.010	0.009	0.008	0.007	0.006	0.005	0.005
-30	0.015	0.022	0.019	0.016	0.013	0.011	0.009	0.008	0.007	0.006
-20	0.053	0.041	0.029	0.022	0.017	0.014	0.011	0.009	0.008	0.006
-10	0.113	0.059	0.038	0.027	0.020	0.016	0.012	0.010	0.008	0.007
0	0.145	0.067	0.041	0.028	0.021	0.016	0.013	0.010	0.008	0.007
10	0.113	0.059	0.038	0.027	0.020	0.016	0.012	0.010	0.008	0.007
20	0.053	0.041	0.029	0.022	0.017	0.014	0.011	0.009	0.008	0.006
30	0.015	0.022	0.019	0.016	0.013	0.011	0.009	0.008	0.007	0.006
40	0.003	0.009	0.011	0.010	0.009	0.008	0.007	0.006	0.005	0.005
50	0.000	0.003	0.005	0.006	0.006	0.006	0.005	0.005	0.004	0.004
60	0.000	0.001	0.002	0.003	0.003	0.004	0.003	0.003	0.003	0.003
70	0.000	0.000	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002
80	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001
90	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Dredge Type : Cutterhead										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Mercury 0.5m above bottom, µg/l										
	20	40	60	80	100	120	140	160	180	200
-100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-60	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001
-50	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0.002	0.002
-40	0.000	0.000	0.001	0.002	0.002	0.003	0.004	0.004	0.004	0.004
-30	0.000	0.001	0.003	0.005	0.006	0.007	0.007	0.007	0.006	0.006
-20	0.001	0.006	0.010	0.011	0.012	0.011	0.011	0.010	0.009	0.009
-10	0.005	0.015	0.018	0.018	0.017	0.015	0.014	0.013	0.011	0.010
0	0.009	0.020	0.022	0.021	0.019	0.017	0.015	0.014	0.012	0.011
10	0.005	0.015	0.018	0.018	0.017	0.015	0.014	0.013	0.011	0.010
20	0.001	0.006	0.010	0.011	0.012	0.011	0.011	0.010	0.009	0.009
30	0.000	0.001	0.003	0.005	0.006	0.007	0.007	0.007	0.006	0.006
40	0.000	0.000	0.001	0.002	0.002	0.003	0.004	0.004	0.004	0.004
50	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0.002	0.002
60	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001
70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Dredge Type :	Cutterhead									
Near-Field Model :	TGU Method									
Far-Field Model :	Kuo's Model									
Resuspended Material Selected :			Dissolved Mercury at bottom, µg/l, using average values							
	20	40	60	80	100	120	140	160	180	200
-100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-60	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001
-50	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.002	0.002
-40	0.000	0.000	0.002	0.003	0.003	0.004	0.004	0.004	0.004	0.004
-30	0.000	0.004	0.007	0.008	0.008	0.008	0.007	0.007	0.006	0.006
-20	0.012	0.020	0.019	0.017	0.015	0.013	0.012	0.010	0.009	0.008
-10	0.076	0.050	0.036	0.028	0.022	0.018	0.015	0.013	0.011	0.010
0	0.141	0.069	0.044	0.032	0.025	0.020	0.017	0.014	0.012	0.011
10	0.076	0.050	0.036	0.028	0.022	0.018	0.015	0.013	0.011	0.010
20	0.012	0.020	0.019	0.017	0.015	0.013	0.012	0.010	0.009	0.008
30	0.000	0.004	0.007	0.008	0.008	0.008	0.007	0.007	0.006	0.006
40	0.000	0.000	0.002	0.003	0.003	0.004	0.004	0.004	0.004	0.004
50	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.002	0.002
60	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001
70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Dredge Type : Cutterhead										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Nickel at bottom, µg/l										
	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04
-50	0.00	0.00	0.00	0.00	0.02	0.04	0.07	0.10	0.12	0.15
-40	0.00	0.00	0.02	0.07	0.14	0.19	0.23	0.26	0.28	0.30
-30	0.00	0.08	0.23	0.33	0.38	0.40	0.41	0.42	0.42	0.42
-20	0.22	0.47	0.50	0.51	0.51	0.51	0.51	0.50	0.50	0.49
-10	0.58	0.58	0.57	0.56	0.56	0.55	0.54	0.54	0.53	0.52
0	0.60	0.59	0.58	0.57	0.57	0.56	0.55	0.54	0.54	0.53
10	0.58	0.58	0.57	0.56	0.56	0.55	0.54	0.54	0.53	0.52
20	0.22	0.47	0.50	0.51	0.51	0.51	0.51	0.50	0.50	0.49
30	0.00	0.08	0.23	0.33	0.38	0.40	0.41	0.42	0.42	0.42
40	0.00	0.00	0.02	0.07	0.14	0.19	0.23	0.26	0.28	0.30
50	0.00	0.00	0.00	0.00	0.02	0.04	0.07	0.10	0.12	0.15
60	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type : Cutterhead										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Selenium at bottom, µg/l										
	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03
-40	0.00	0.00	0.00	0.00	0.02	0.05	0.09	0.14	0.19	0.23
-30	0.00	0.01	0.10	0.33	0.60	0.83	0.99	1.08	1.13	1.13
-20	0.08	2.14	4.27	5.13	5.22	4.96	4.57	4.14	3.73	3.34
-10	39.90	35.90	27.10	20.70	16.20	12.90	10.50	8.69	7.27	6.14
0	172.00	77.20	46.40	31.50	22.90	17.40	13.70	11.00	8.99	7.47
10	39.90	35.90	27.10	20.70	16.20	12.90	10.50	8.69	7.27	6.14
20	0.08	2.14	4.27	5.13	5.22	4.96	4.57	4.14	3.73	3.34
30	0.00	0.01	0.10	0.33	0.60	0.83	0.99	1.08	1.13	1.13
40	0.00	0.00	0.00	0.00	0.02	0.05	0.09	0.14	0.19	0.23
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type : Cutterhead										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Selenium at bottom, µg/l										
	20	40	60	80	100	120	140	160	180	200
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.03
-50	0.00	0.00	0.00	0.01	0.03	0.05	0.07	0.08	0.09	0.10
-40	0.00	0.00	0.05	0.14	0.23	0.28	0.31	0.32	0.31	0.30
-30	0.01	0.33	0.83	1.08	1.13	1.08	0.99	0.88	0.77	0.67
-20	2.14	5.13	4.96	4.14	3.34	2.68	2.16	1.75	1.43	1.18
-10	35.90	20.70	12.90	8.69	6.14	4.51	3.40	2.63	2.06	1.64
0	77.20	31.50	17.40	11.00	7.47	5.33	3.94	3.00	2.32	1.83
10	35.90	20.70	12.90	8.69	6.14	4.51	3.40	2.63	2.06	1.64
20	2.14	5.13	4.96	4.14	3.34	2.68	2.16	1.75	1.43	1.18
30	0.01	0.33	0.83	1.08	1.13	1.08	0.99	0.88	0.77	0.67
40	0.00	0.00	0.05	0.14	0.23	0.28	0.31	0.32	0.31	0.30
50	0.00	0.00	0.00	0.01	0.03	0.05	0.07	0.08	0.09	0.10
60	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.03
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type :	Cutterhead									
Near-Field Model :	TGU Method									
Far-Field Model :	Kuo's Model									
Resuspended Material Selected :			Dissolved Selenium at bottom, µg/l, using average values							
	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
-40	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.05
-30	0.00	0.00	0.02	0.07	0.13	0.18	0.21	0.23	0.24	0.24
-20	0.02	0.46	0.92	1.10	1.12	1.06	0.98	0.89	0.80	0.72
-10	8.54	7.67	5.81	4.44	3.47	2.77	2.25	1.86	1.55	1.31
0	16.80	16.50	9.92	6.74	4.90	3.73	2.93	2.35	1.92	1.60
10	8.54	7.67	5.81	4.44	3.47	2.77	2.25	1.86	1.55	1.31
20	0.02	0.46	0.92	1.10	1.12	1.06	0.98	0.89	0.80	0.72
30	0.00	0.00	0.02	0.07	0.13	0.18	0.21	0.23	0.24	0.24
40	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.05
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type : Cutterhead										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Silver at bottom, µg/l										
	10	20	30	40	50	60	70	80	90	100
-100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
-50	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.004	0.006	0.008
-40	0.000	0.000	0.000	0.003	0.007	0.013	0.018	0.022	0.026	0.029
-30	0.000	0.003	0.018	0.036	0.051	0.061	0.067	0.071	0.073	0.073
-20	0.016	0.106	0.160	0.180	0.182	0.176	0.167	0.157	0.147	0.138
-10	0.762	0.700	0.565	0.463	0.388	0.331	0.287	0.253	0.225	0.202
0	2.660	1.310	0.859	0.633	0.498	0.408	0.344	0.296	0.259	0.229
10	0.762	0.700	0.565	0.463	0.388	0.331	0.287	0.253	0.225	0.202
20	0.016	0.106	0.160	0.180	0.182	0.176	0.167	0.157	0.147	0.138
30	0.000	0.003	0.018	0.036	0.051	0.061	0.067	0.071	0.073	0.073
40	0.000	0.000	0.000	0.003	0.007	0.013	0.018	0.022	0.026	0.029
50	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.004	0.006	0.008
60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Dredge Type : Cutterhead

Near-Field Model : TGU Method

Far-Field Model : Kuo's Model

Resuspended Material Selected : Dissolved Silver at bottom, µg/l

	20	40	60	80	100	120	140	160	180	200
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
-50	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.02
-40	0.00	0.00	0.01	0.02	0.03	0.03	0.04	0.04	0.04	0.03
-30	0.00	0.04	0.06	0.07	0.07	0.07	0.07	0.06	0.06	0.05
-20	0.11	0.18	0.18	0.16	0.14	0.12	0.11	0.09	0.08	0.07
-10	0.70	0.46	0.33	0.25	0.20	0.17	0.14	0.12	0.10	0.09
0	1.31	0.63	0.41	0.30	0.23	0.18	0.15	0.13	0.11	0.10
10	0.70	0.46	0.33	0.25	0.20	0.17	0.14	0.12	0.10	0.09
20	0.11	0.18	0.18	0.16	0.14	0.12	0.11	0.09	0.08	0.07
30	0.00	0.04	0.06	0.07	0.07	0.07	0.07	0.06	0.06	0.05
40	0.00	0.00	0.01	0.02	0.03	0.03	0.04	0.04	0.04	0.03
50	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.02
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

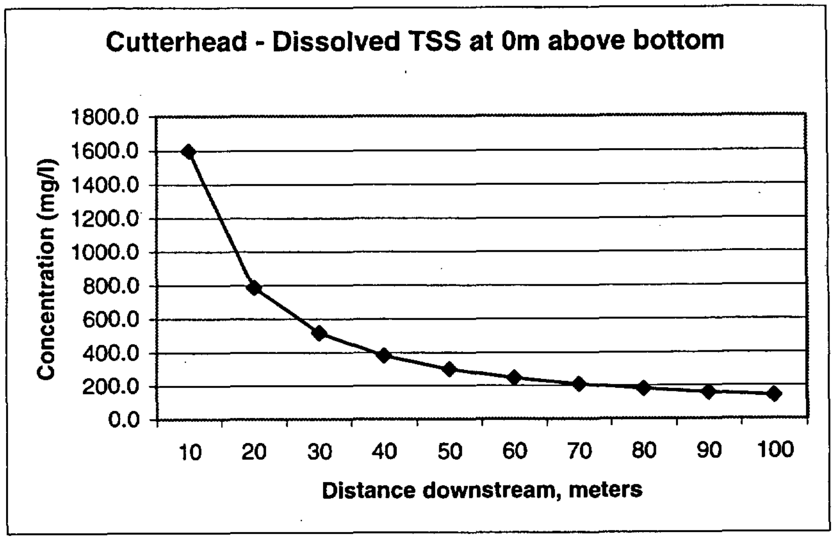
Dredge Type :	Cutterhead									
Near-Field Model :	TGU Method									
Far-Field Model :	Kuo's Model									
Resuspended Material Selected :			Dissolved Silver at bottom, µg/l, using average values							
	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-40	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
-30	0.00	0.00	0.01	0.02	0.03	0.03	0.03	0.04	0.04	0.04
-20	0.01	0.05	0.08	0.09	0.09	0.09	0.08	0.08	0.07	0.07
-10	0.38	0.35	0.28	0.23	0.20	0.17	0.15	0.13	0.11	0.10
0	1.34	0.66	0.43	0.32	0.25	0.21	0.17	0.15	0.13	0.12
10	0.38	0.35	0.28	0.23	0.20	0.17	0.15	0.13	0.11	0.10
20	0.01	0.05	0.08	0.09	0.09	0.09	0.08	0.08	0.07	0.07
30	0.00	0.00	0.01	0.02	0.03	0.03	0.03	0.04	0.04	0.04
40	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

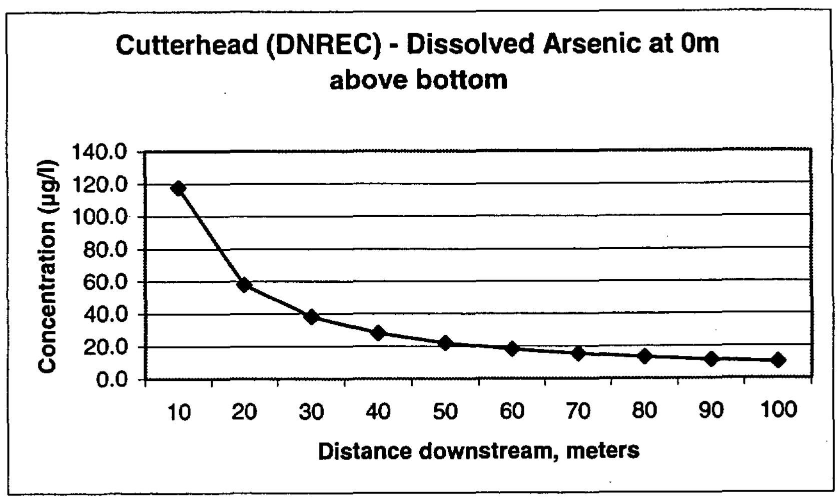
Dredge Type : Cutterhead										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Zinc at bottom, µg/l										
	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.07
-60	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.14	0.22	0.30
-50	0.00	0.00	0.00	0.04	0.13	0.27	0.43	0.57	0.69	0.79
-40	0.00	0.01	0.14	0.45	0.74	0.94	1.07	1.15	1.20	1.23
-30	0.00	0.49	1.07	1.30	1.39	1.43	1.45	1.46	1.47	1.47
-20	1.02	1.53	1.58	1.60	1.60	1.59	1.59	1.58	1.57	1.57
-10	1.67	1.67	1.66	1.66	1.65	1.64	1.63	1.62	1.62	1.61
0	1.69	1.68	1.68	1.67	1.66	1.65	1.64	1.63	1.63	1.62
10	1.67	1.67	1.66	1.66	1.65	1.64	1.63	1.62	1.62	1.61
20	1.02	1.53	1.58	1.60	1.60	1.59	1.59	1.58	1.57	1.57
30	0.00	0.49	1.07	1.30	1.39	1.43	1.45	1.46	1.47	1.47
40	0.00	0.01	0.14	0.45	0.74	0.94	1.07	1.15	1.20	1.23
50	0.00	0.00	0.00	0.04	0.13	0.27	0.43	0.57	0.69	0.79
60	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.14	0.22	0.30
70	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.07
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

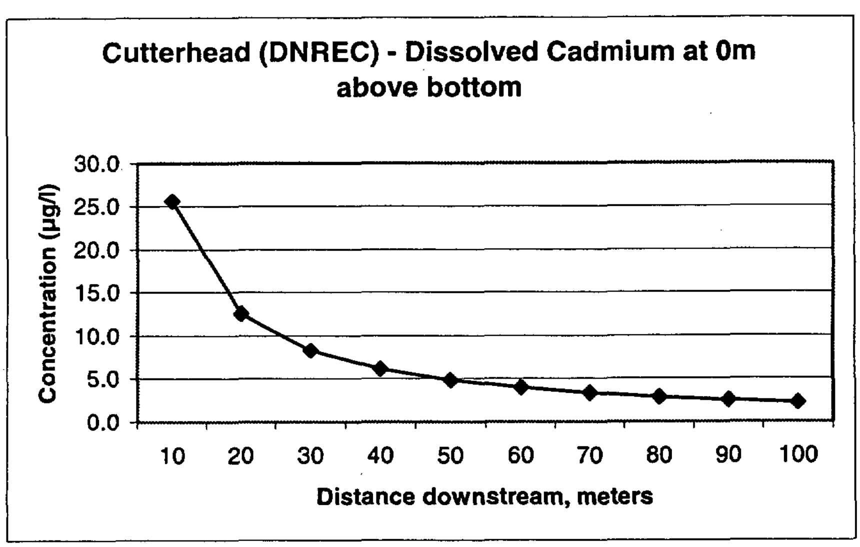
Dredge Type : Cutterhead										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved PCBs at bottom, µg/l										
	10	20	30	40	50	60	70	80	90	100
-100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-40	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001
-30	0.000	0.000	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002
-20	0.001	0.003	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.004
-10	0.019	0.017	0.014	0.012	0.010	0.008	0.007	0.006	0.006	0.005
0	0.064	0.032	0.021	0.016	0.012	0.010	0.009	0.008	0.007	0.006
10	0.019	0.017	0.014	0.012	0.010	0.008	0.007	0.006	0.006	0.005
20	0.001	0.003	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.004
30	0.000	0.000	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002
40	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001
50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

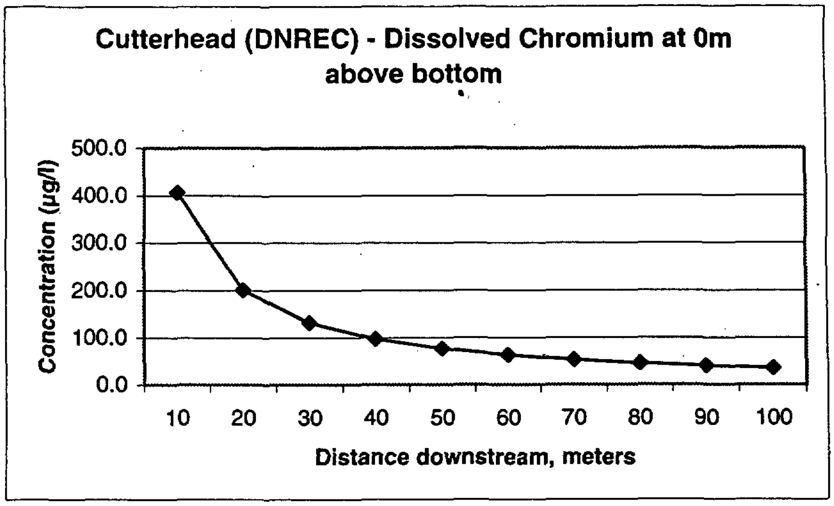
APPENDIX D

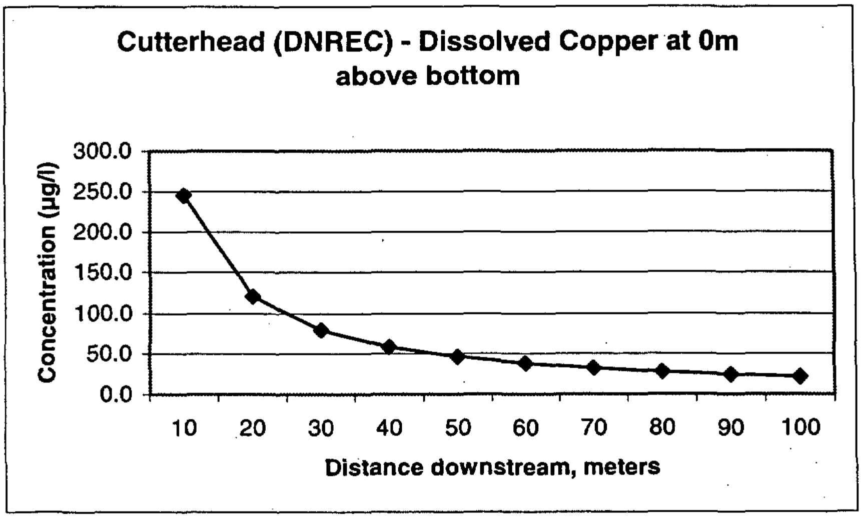
Model Results of Cutterhead Hydraulic Dredging in the Navigation Channel of the Marcus Hook Range of the Delaware River, using DNREC Equilibrium Partitioning Method for Metals

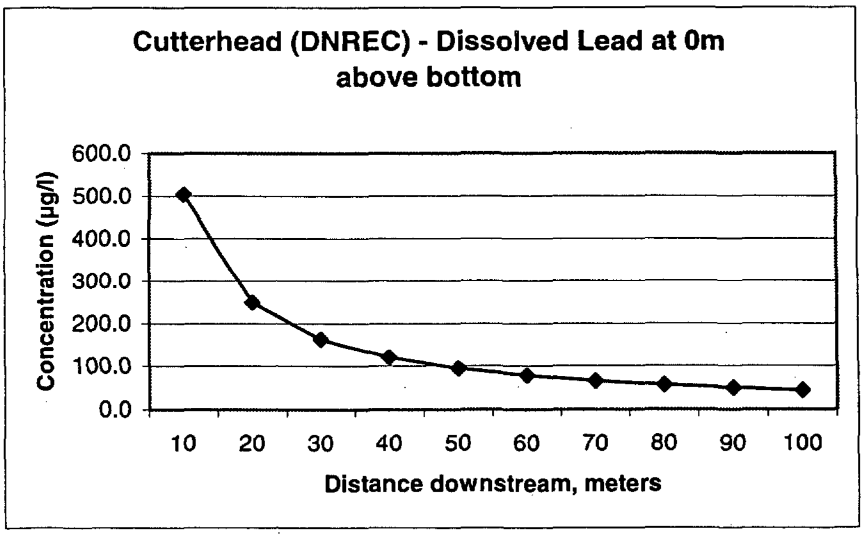

Cutterhead - Dissolved TSS at 0m above bottom
Concentration (mg/l)
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
10 20 30 40 50 60 70 80 90 100
Distance downstream, meters

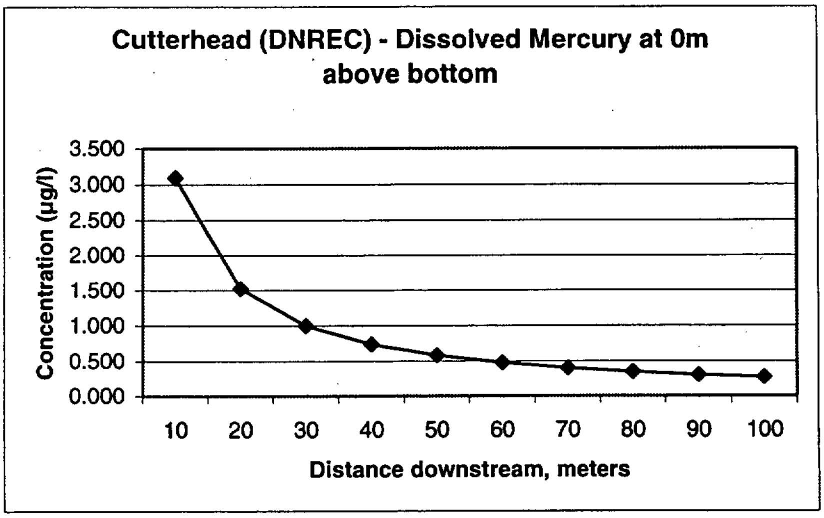

Cutterhead (DNREC) - Dissolved Arsenic at 0m above bottom
Concentration (µg/l)
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
10 20 30 40 50 60 70 80 90 100
Distance downstream, meters

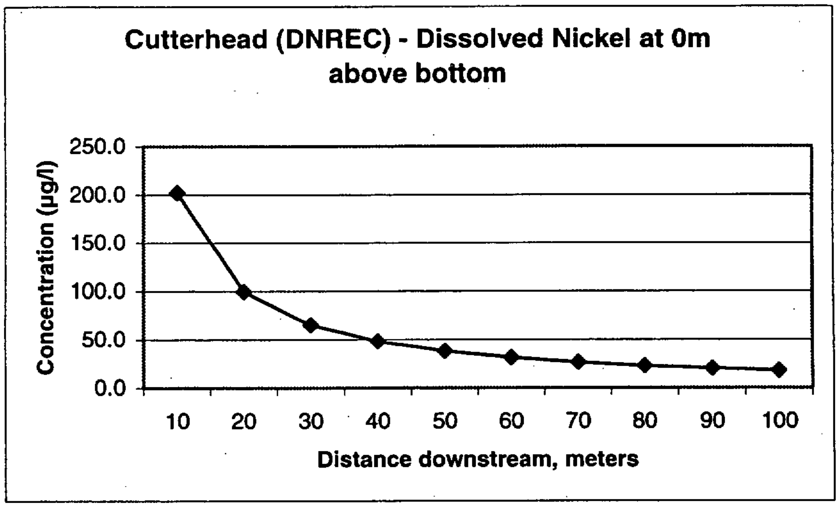

Cutterhead (DNREC) - Dissolved Cadmium at 0m above bottom
Concentration (µg/l)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
10 20 30 40 50 60 70 80 90 100
Distance downstream, meters

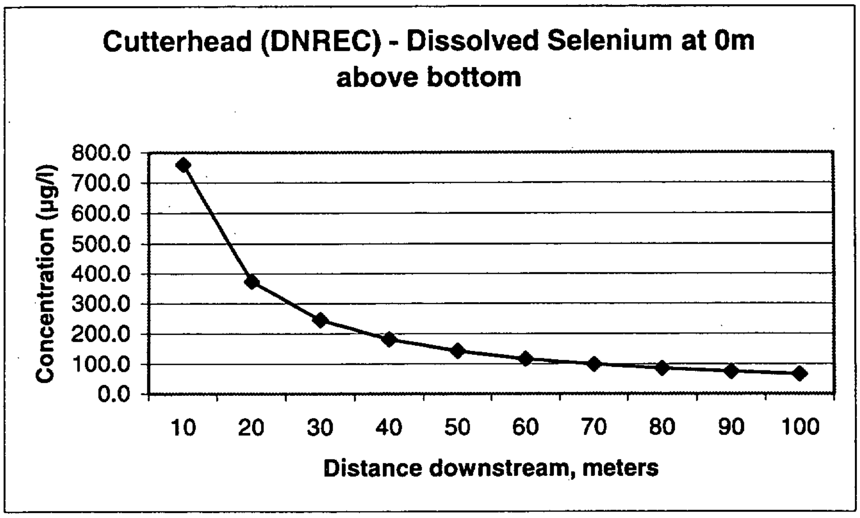

Cutterhead (DNREC) - Dissolved Chromium at 0m above bottom
Concentration (µg/l)
500.0
400.0
300.0
200.0
100.0
0.0
10
20
30
40
50
60
70
80
90
100
Distance downstream, meters

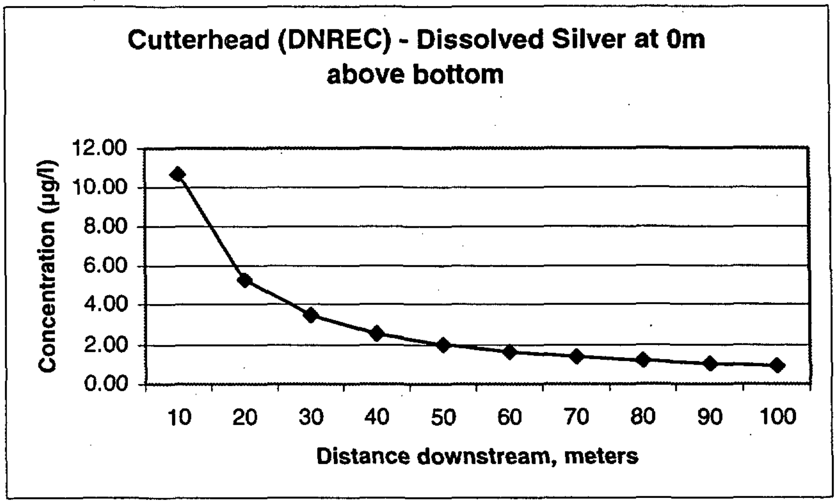

Cutterhead (DNREC) - Dissolved Copper at 0m above bottom
Concentration (µg/l)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
10
20
30
40
50
60
70
80
90
100
Distance downstream, meters

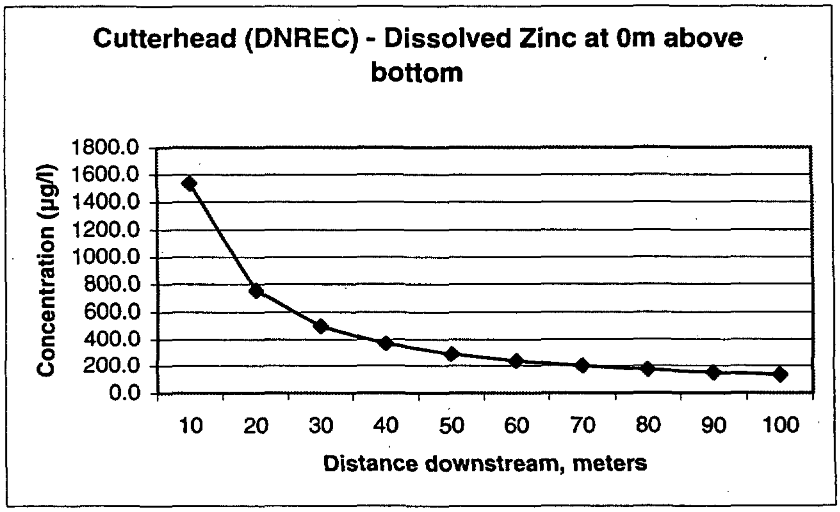

Cutterhead (DNREC) - Dissolved Lead at 0m above bottom
Concentration (µg/l)
600.0
500.0
400.0
300.0
200.0
100.0
0.0
10
20
30
40
50
60
70
80
90
100
Distance downstream, meters


Cutterhead (DNREC) - Dissolved Mercury at 0m above bottom
Concentration (µg/l)
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
10 20 30 40 50 60 70 80 90 100
Distance downstream, meters


Cutterhead (DNREC) - Dissolved Nickel at 0m above bottom
Concentration (µg/l)
250.0
200.0
150.0
100.0
50.0
0.0
10 20 30 40 50 60 70 80 90 100
Distance downstream, meters


Cutterhead (DNREC) - Dissolved Selenium at 0m above bottom
Concentration (µg/l)
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
10 20 30 40 50 60 70 80 90 100
Distance downstream, meters


Cutterhead (DNREC) - Dissolved Silver at 0m above bottom
Concentration (µg/l)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
10
20
30
40
50
60
70
80
90
100
Distance downstream, meters


Cutterhead (DNREC) - Dissolved Zinc at 0m above bottom
Concentration (µg/l)
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
10
20
30
40
50
60
70
80
90
100
Distance downstream, meters

Method : DNREC Equilibrium Equation										
Dredge Type : Cutterhead										
Near-Field Model : TGU Method, conservative parameters										
Far-Field Model : Kuo's Model, conservative parameters										
Resuspended Material Selected : Arsenic at bottom, µg/l										
Maxiumum sediment concentration:				18.4						
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
-50	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.4
-40	0.0	0.0	0.0	0.2	0.4	0.6	0.9	1.1	1.2	1.4
-30	0.0	0.2	0.9	1.7	2.3	2.8	3.1	3.2	3.3	3.3
-20	0.8	4.7	7.2	8.0	8.1	7.9	7.5	7.0	6.6	6.2
-10	33.7	31.0	25.0	20.5	17.2	14.7	12.8	11.2	10.0	9.0
0	117.5	57.8	38.0	28.0	22.1	18.1	15.3	13.1	11.5	10.2
10	33.7	31.0	25.0	20.5	17.2	14.7	12.8	11.2	10.0	9.0
20	0.8	4.7	7.2	8.0	8.1	7.9	7.5	7.0	6.6	6.2
30	0.0	0.2	0.9	1.7	2.3	2.8	3.1	3.2	3.3	3.3
40	0.0	0.0	0.0	0.2	0.4	0.6	0.9	1.1	1.2	1.4
50	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.4
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Method : DNREC Equilibrium Equation

Dredge Type : Cutterhead

Near-Field Model : TGU Method, conservative parameters

Far-Field Model : Kuo's Model, conservative parameters

Resuspended Material Selected : Cadmium at bottom, µg/l

Maxiumum sediment concentration: 4

distance from dredge in meters

	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
-40	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3
-30	0.0	0.0	0.2	0.4	0.5	0.6	0.7	0.7	0.7	0.7
-20	0.2	1.0	1.6	1.7	1.8	1.7	1.6	1.5	1.4	1.3
-10	7.3	6.7	5.4	4.5	3.7	3.2	2.8	2.4	2.2	2.0
0	25.6	12.6	8.3	6.1	4.8	3.9	3.3	2.9	2.5	2.2
10	7.3	6.7	5.4	4.5	3.7	3.2	2.8	2.4	2.2	2.0
20	0.2	1.0	1.6	1.7	1.8	1.7	1.6	1.5	1.4	1.3
30	0.0	0.0	0.2	0.4	0.5	0.6	0.7	0.7	0.7	0.7
40	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Method	:	DNREC Equilibrium Equation								
Dredge Type	:	Cutterhead								
Near-Field Model	:	TGU Method, conservative parameters								
Far-Field Model	:	Kuo's Model, conservative parameters								
Resuspended Material Selected :			Chromium at bottom, µg/l							
Maxiumum sediment concentration:				63.7						
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-60	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4
-50	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.9	1.2	1.5
-40	0.0	0.0	0.2	0.7	1.4	2.2	3.0	3.7	4.3	4.8
-30	0.0	0.7	3.1	5.8	8.0	9.6	10.6	11.1	11.4	11.4
-20	2.7	16.4	24.8	27.8	28.1	27.2	25.9	24.4	22.8	21.4
-10	116.6	107.2	86.6	71.0	59.5	50.8	44.2	38.9	34.6	31.1
0	406.9	200.3	131.4	97.0	76.4	62.6	52.8	45.5	39.8	35.3
10	116.6	107.2	86.6	71.0	59.5	50.8	44.2	38.9	34.6	31.1
20	2.7	16.4	24.8	27.8	28.1	27.2	25.9	24.4	22.8	21.4
30	0.0	0.7	3.1	5.8	8.0	9.6	10.6	11.1	11.4	11.4
40	0.0	0.0	0.2	0.7	1.4	2.2	3.0	3.7	4.3	4.8
50	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.9	1.2	1.5
60	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Method	:	DNREC Equilibrium Equation								
Dredge Type	:	Cutterhead								
Near-Field Model	:	TGU Method, conservative parameters								
Far-Field Model	:	Kuo's Model, conservative parameters								
Resuspended Material Selected :			Copper at bottom, µg/l							
Maxiumum sediment concentration:				38.4						
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-60	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2
-50	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.7	0.9
-40	0.0	0.0	0.1	0.4	0.8	1.3	1.8	2.3	2.6	2.9
-30	0.0	0.4	1.9	3.5	4.9	5.8	6.4	6.7	6.9	6.9
-20	1.7	9.9	15.0	16.7	16.9	16.4	15.6	14.7	13.8	12.9
-10	70.3	64.6	52.2	42.8	35.8	30.7	26.6	23.5	20.9	18.8
0	245.3	120.7	79.2	58.5	46.0	37.8	31.8	27.4	24.0	21.3
10	70.3	64.6	52.2	42.8	35.8	30.7	26.6	23.5	20.9	18.8
20	1.7	9.9	15.0	16.7	16.9	16.4	15.6	14.7	13.8	12.9
30	0.0	0.4	1.9	3.5	4.9	5.8	6.4	6.7	6.9	6.9
40	0.0	0.0	0.1	0.4	0.8	1.3	1.8	2.3	2.6	2.9
50	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.7	0.9
60	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Method	: DNREC Equilibrium Equation									
Dredge Type	: Cutterhead									
Near-Field Model	: TGU Method, conservative parameters									
Far-Field Model	: Kuo's Model, conservative parameters									
Resuspended Material Selected :	Lead at bottom, µg/l									
Maxiumum sediment concentration:				78.9						
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
-60	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.5
-50	0.0	0.0	0.0	0.0	0.2	0.4	0.8	1.1	1.5	1.9
-40	0.0	0.0	0.2	0.8	1.7	2.8	3.8	4.6	5.3	5.9
-30	0.0	0.9	3.8	7.2	10.0	11.9	13.1	13.8	14.1	14.2
-20	3.4	20.4	30.7	34.4	34.8	33.7	32.0	30.2	28.3	26.5
-10	144.4	132.8	107.3	87.9	73.7	63.0	54.7	48.2	42.9	38.5
0	504.1	248.0	162.7	120.1	94.6	77.8	65.4	56.3	49.3	43.7
10	144.4	132.8	107.3	87.9	73.7	63.0	54.7	48.2	42.9	38.5
20	3.4	20.4	30.7	34.4	34.8	33.7	32.0	30.2	28.3	26.5
30	0.0	0.9	3.8	7.2	10.0	11.9	13.1	13.8	14.1	14.2
40	0.0	0.0	0.2	0.8	1.7	2.8	3.8	4.6	5.3	5.9
50	0.0	0.0	0.0	0.0	0.2	0.4	0.8	1.1	1.5	1.9
60	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.5
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Method : DNREC Equilibrium Equation										
Dredge Type : Cutterhead										
Near-Field Model : TGU Method, conservative parameters										
Far-Field Model : Kuo's Model, conservative parameters										
Resuspended Material Selected : Mercury at bottom, µg/l										
Maxiumum sediment concentration:				0.484						
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
-60	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.003
-50	0.000	0.000	0.000	0.000	0.001	0.003	0.005	0.007	0.009	0.012
-40	0.000	0.000	0.001	0.005	0.011	0.017	0.023	0.028	0.033	0.036
-30	0.000	0.005	0.023	0.044	0.061	0.073	0.080	0.085	0.087	0.087
-20	0.021	0.125	0.189	0.211	0.213	0.207	0.196	0.185	0.173	0.162
-10	0.886	0.814	0.658	0.539	0.452	0.386	0.336	0.296	0.263	0.236
0	3.092	1.522	0.998	0.737	0.580	0.476	0.401	0.346	0.302	0.268
10	0.886	0.814	0.658	0.539	0.452	0.386	0.336	0.296	0.263	0.236
20	0.021	0.125	0.189	0.211	0.213	0.207	0.196	0.185	0.173	0.162
30	0.000	0.005	0.023	0.044	0.061	0.073	0.080	0.085	0.087	0.087
40	0.000	0.000	0.001	0.005	0.011	0.017	0.023	0.028	0.033	0.036
50	0.000	0.000	0.000	0.000	0.001	0.003	0.005	0.007	0.009	0.012
60	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.003
70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Method : DNREC Equilibrium Equation										
Dredge Type : Cutterhead										
Near-Field Model : TGU Method, conservative parameters										
Far-Field Model : Kuo's Model, conservative parameters										
Resuspended Material Selected : Nickel at bottom, µg/l										
Maxiumum sediment concentration:				31.6						
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2
-50	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.6	0.8
-40	0.0	0.0	0.1	0.3	0.7	1.1	1.5	1.9	2.1	2.4
-30	0.0	0.4	1.5	2.9	4.0	4.8	5.3	5.5	5.7	5.7
-20	1.4	8.2	12.3	13.8	13.9	13.5	12.8	12.1	11.3	10.6
-10	57.8	53.2	43.0	35.2	29.5	25.2	21.9	19.3	17.2	15.4
0	201.9	99.3	65.2	48.1	37.9	31.1	26.2	22.6	19.7	17.5
10	57.8	53.2	43.0	35.2	29.5	25.2	21.9	19.3	17.2	15.4
20	1.4	8.2	12.3	13.8	13.9	13.5	12.8	12.1	11.3	10.6
30	0.0	0.4	1.5	2.9	4.0	4.8	5.3	5.5	5.7	5.7
40	0.0	0.0	0.1	0.3	0.7	1.1	1.5	1.9	2.1	2.4
50	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.6	0.8
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Method :	DNREC Equilibrium Equation									
Dredge Type :	Cutterhead									
Near-Field Model :	TGU Method, conservative parameters									
Far-Field Model :	Kuo's Model, conservative parameters									
Resuspended Material Selected :	Selenium at bottom, µg/l									
Maxiumum sediment concentration:			119							
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
-60	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.7
-50	0.0	0.0	0.0	0.1	0.3	0.6	1.1	1.7	2.3	2.9
-40	0.0	0.0	0.3	1.2	2.6	4.2	5.7	7.0	8.1	8.9
-30	0.0	1.3	5.8	10.9	15.0	17.9	19.8	20.8	21.3	21.4
-20	5.1	30.7	46.4	51.9	52.5	50.8	48.3	45.5	42.7	39.9
-10	217.8	200.2	161.8	132.6	111.1	95.0	82.5	72.7	64.7	58.1
0	760.2	374.1	245.5	181.2	142.6	117.0	98.7	85.0	74.3	65.9
10	217.8	200.2	161.8	132.6	111.1	95.0	82.5	72.7	64.7	58.1
20	5.1	30.7	46.4	51.9	52.5	50.8	48.3	45.5	42.7	39.9
30	0.0	1.3	5.8	10.9	15.0	17.9	19.8	20.8	21.3	21.4
40	0.0	0.0	0.3	1.2	2.6	4.2	5.7	7.0	8.1	8.9
50	0.0	0.0	0.0	0.1	0.3	0.6	1.1	1.7	2.3	2.9
60	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.7
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

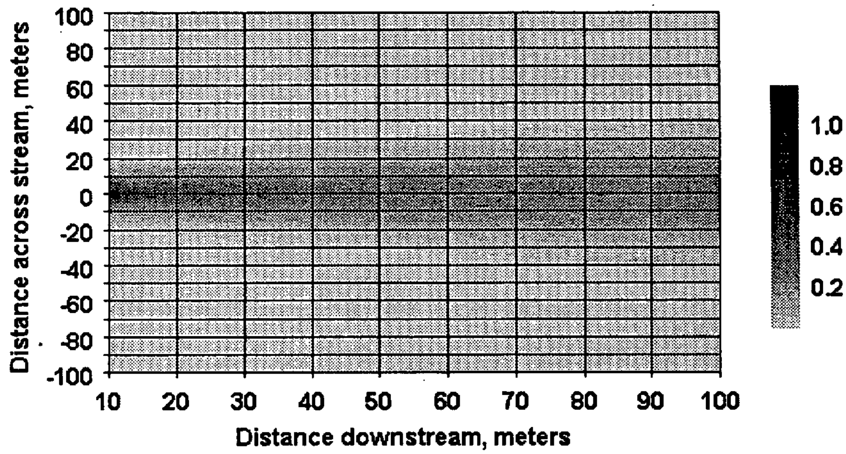
Method	:	DNREC Equilibrium Equation								
Dredge Type	:	Cutterhead								
Near-Field Model	:	TGU Method, conservative parameters								
Far-Field Model	:	Kuo's Model, conservative parameters								
Resuspended Material Selected :			Silver at bottom, µg/l							
Maxiumum sediment concentration:				1.67						
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
-50	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.04
-40	0.00	0.00	0.00	0.02	0.04	0.06	0.08	0.10	0.11	0.13
-30	0.00	0.02	0.08	0.15	0.21	0.25	0.28	0.29	0.30	0.30
-20	0.07	0.43	0.65	0.73	0.74	0.71	0.68	0.64	0.60	0.56
-10	3.06	2.81	2.27	1.86	1.56	1.33	1.16	1.02	0.91	0.82
0	10.67	5.25	3.44	2.54	2.00	1.64	1.38	1.19	1.04	0.92
10	3.06	2.81	2.27	1.86	1.56	1.33	1.16	1.02	0.91	0.82
20	0.07	0.43	0.65	0.73	0.74	0.71	0.68	0.64	0.60	0.56
30	0.00	0.02	0.08	0.15	0.21	0.25	0.28	0.29	0.30	0.30
40	0.00	0.00	0.00	0.02	0.04	0.06	0.08	0.10	0.11	0.13
50	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.03	0.04
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Method : DNREC Equilibrium Equation										
Dredge Type : Cutterhead										
Near-Field Model : TGU Method, conservative parameters										
Far-Field Model : Kuo's Model, conservative parameters										
Resuspended Material Selected : Zinc at bottom, µg/l										
Maxiumum sediment concentration:				240						
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3
-60	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	1.0	1.5
-50	0.0	0.0	0.0	0.1	0.6	1.3	2.3	3.4	4.7	5.8
-40	0.0	0.0	0.6	2.5	5.3	8.4	11.4	14.1	16.2	18.0
-30	0.0	2.7	11.6	21.9	30.3	36.2	39.9	42.0	43.0	43.1
-20	10.3	61.9	93.5	104.7	105.8	102.5	97.4	91.7	86.0	80.6
-10	439.3	403.8	326.3	267.3	224.1	191.6	166.5	146.6	130.5	117.2
0	1533.2	754.5	495.0	365.4	287.7	235.9	199.0	171.4	149.9	132.8
10	439.3	403.8	326.3	267.3	224.1	191.6	166.5	146.6	130.5	117.2
20	10.3	61.9	93.5	104.7	105.8	102.5	97.4	91.7	86.0	80.6
30	0.0	2.7	11.6	21.9	30.3	36.2	39.9	42.0	43.0	43.1
40	0.0	0.0	0.6	2.5	5.3	8.4	11.4	14.1	16.2	18.0
50	0.0	0.0	0.0	0.1	0.6	1.3	2.3	3.4	4.7	5.8
60	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	1.0	1.5
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

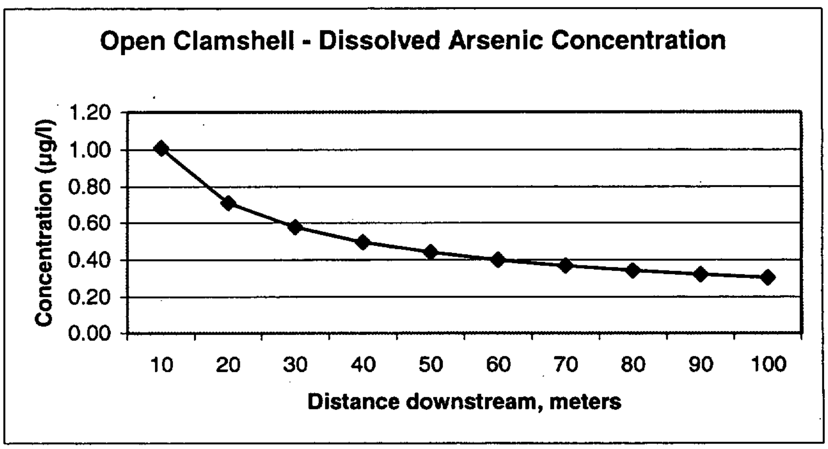
APPENDIX E

Model Results of Bucket Dredging in the Sun Marcus Hook Berthing Area of the Delaware River, using the DREDGE model with Equilibrium Partitioning Coefficients

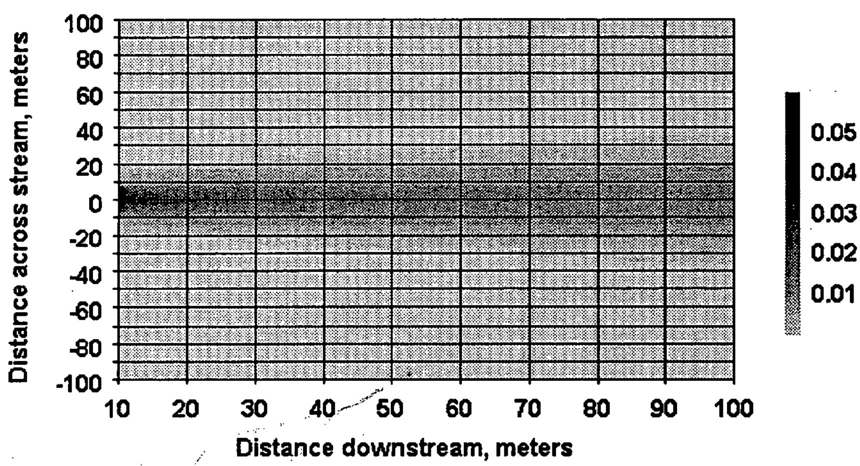
Open Clamshell Arsenic



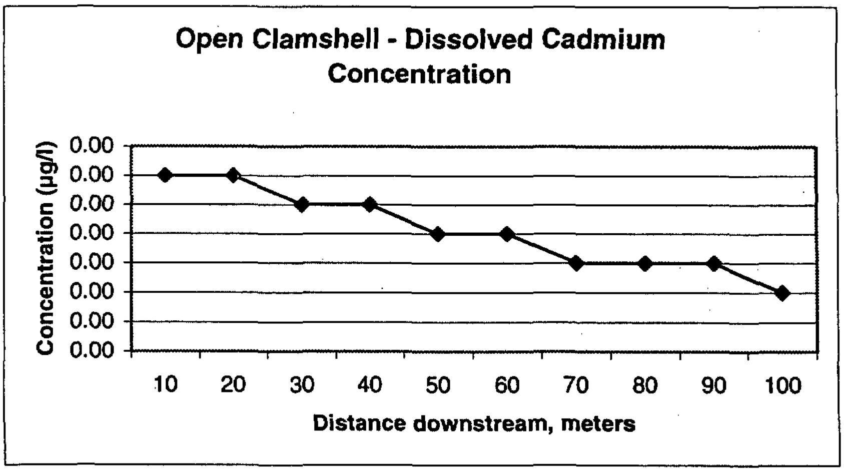
Open Clamshell Dissolved Arsenic



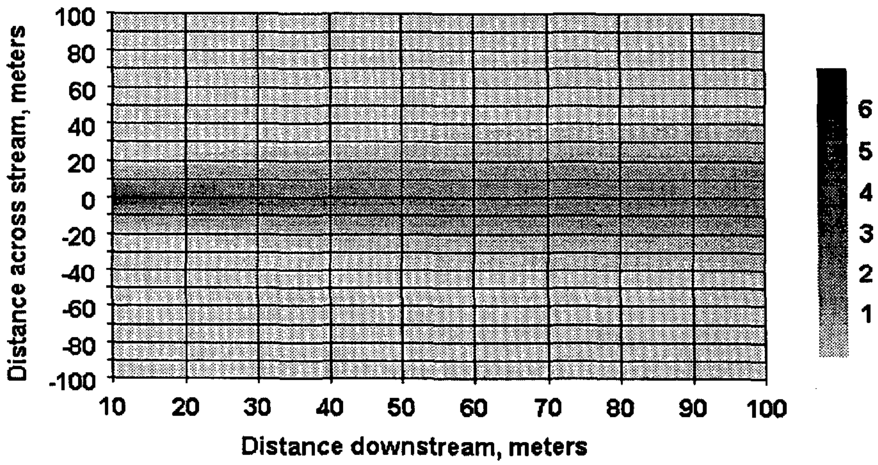
Open Clamshell Cadmium



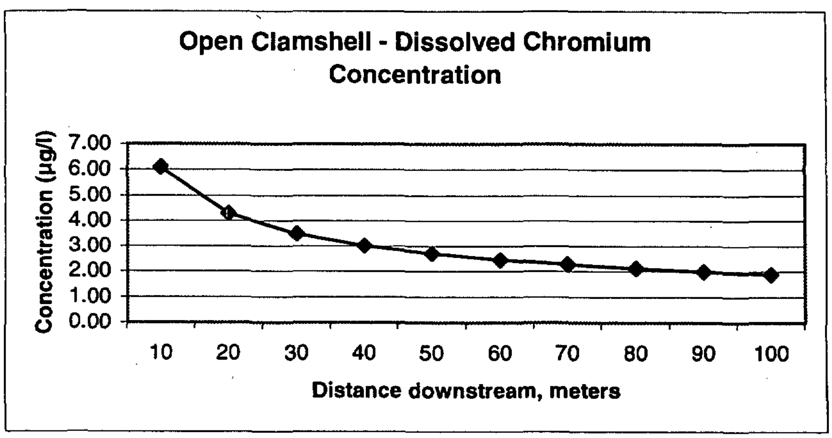
Open Clamshell Dissolved Cadmium



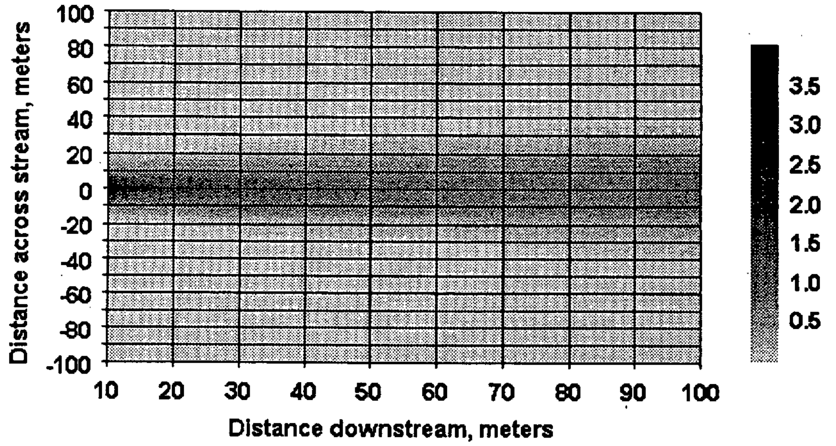
Open Clamshell Chromium



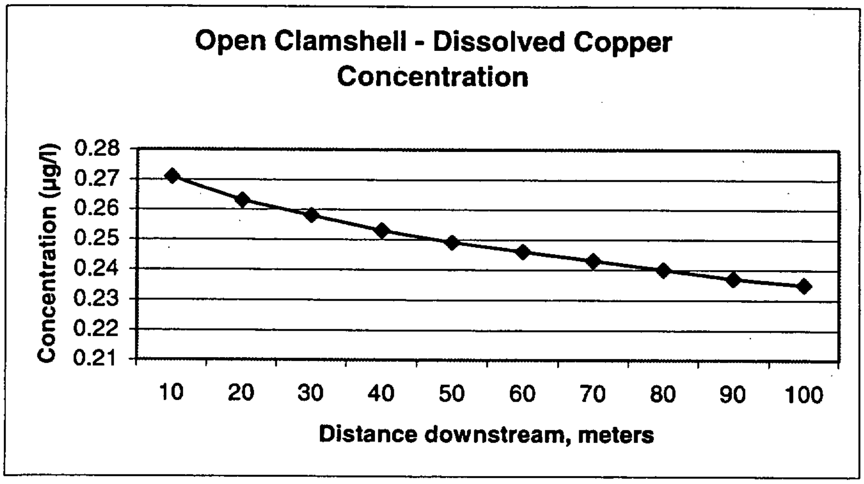
Open Clamshell Dissolved Chromium



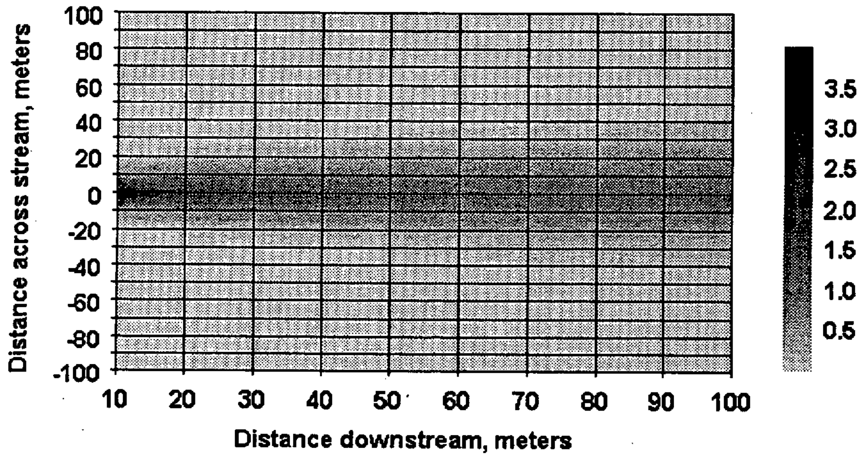
Open Clamshell Copper



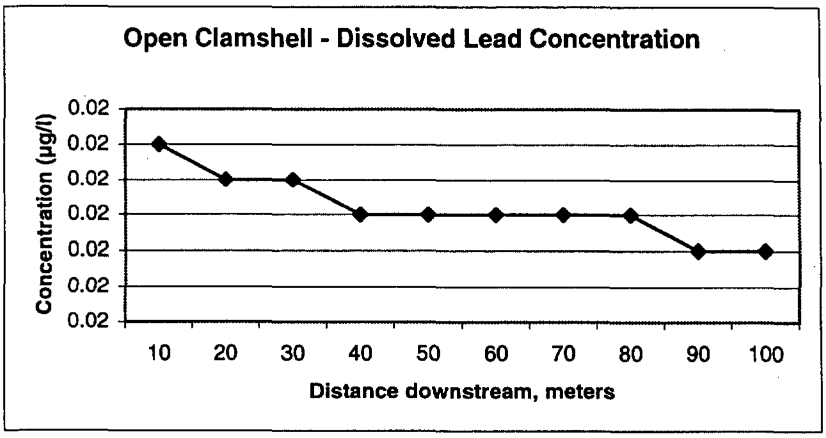
Open Clamshell Dissolved Copper



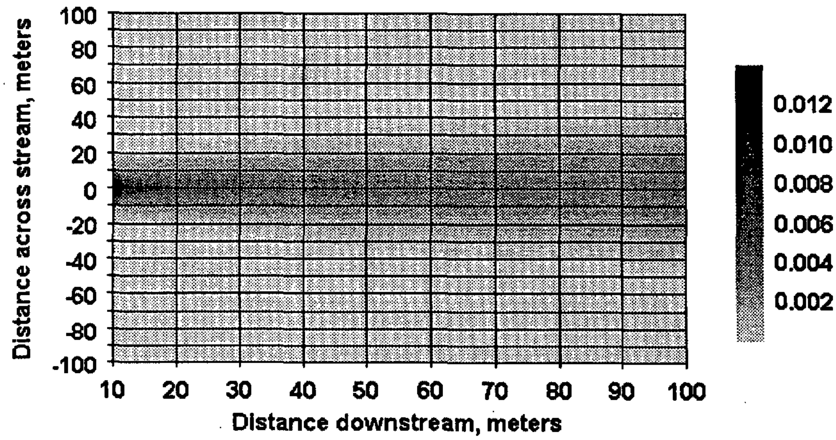
Open Clamshell Lead



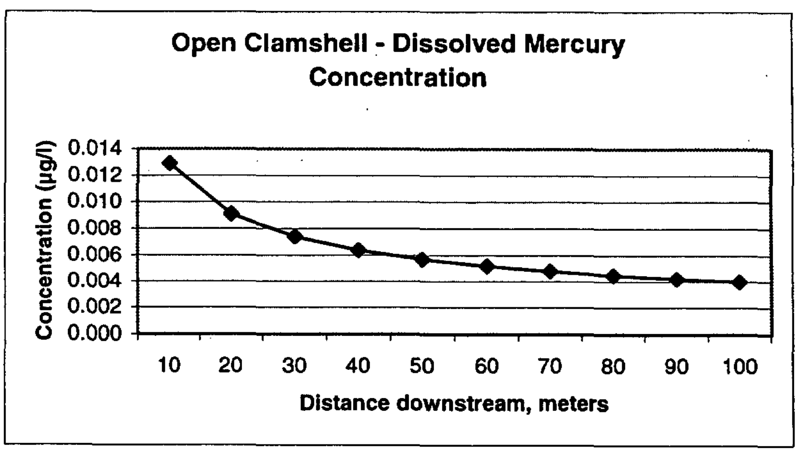
Open Clamshell Dissolved Lead



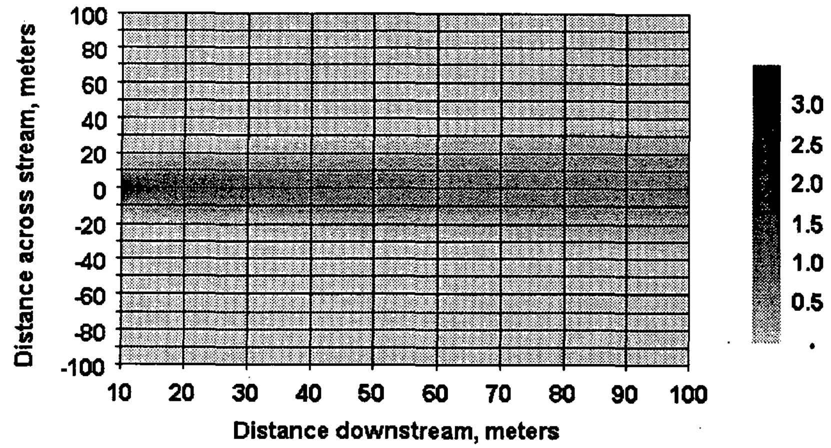
Open Clamshell Mercury



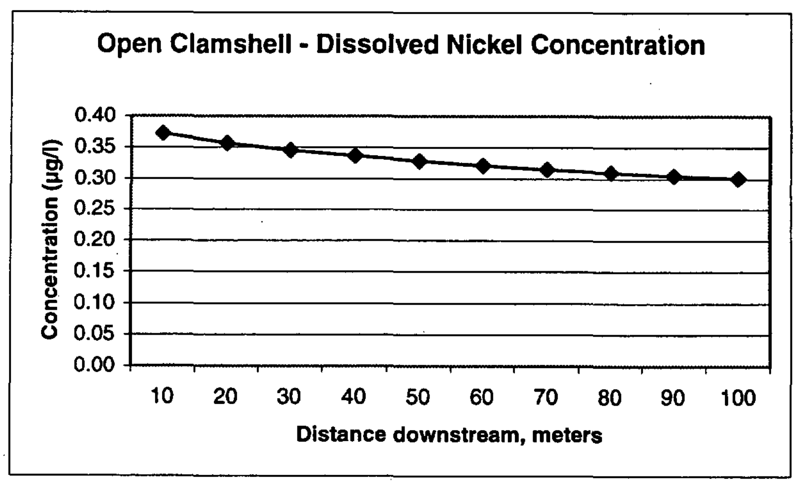
Open Clamshell Dissolved Mercury



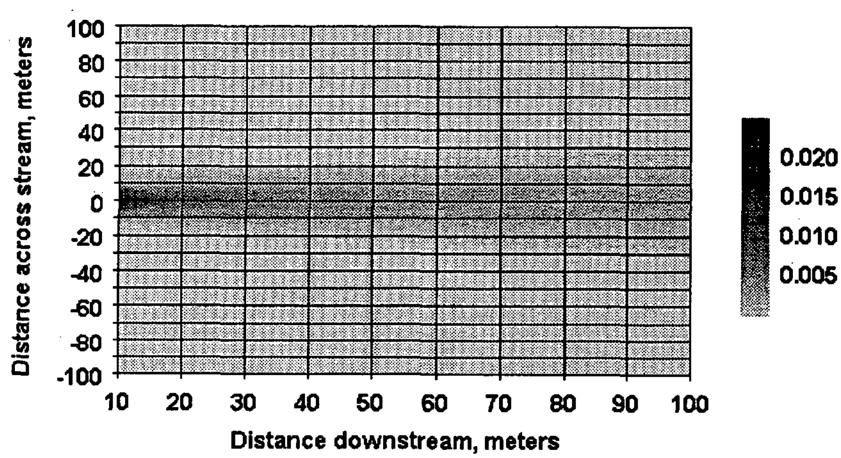
Open Clamshell Nickel



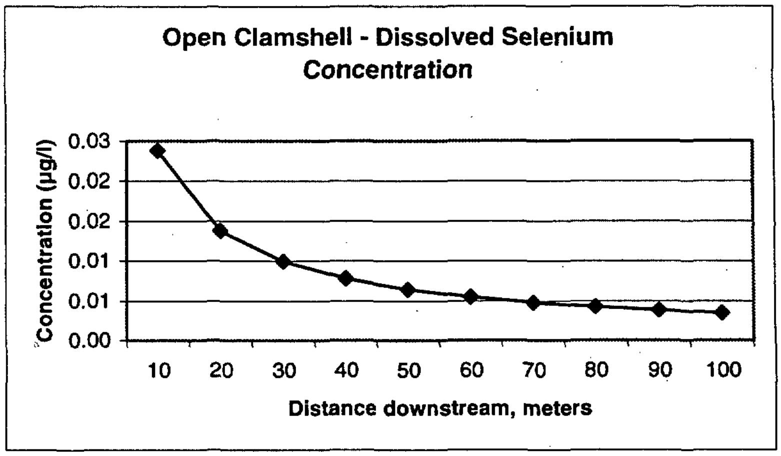
Open Clamshell Dissolved Nickel



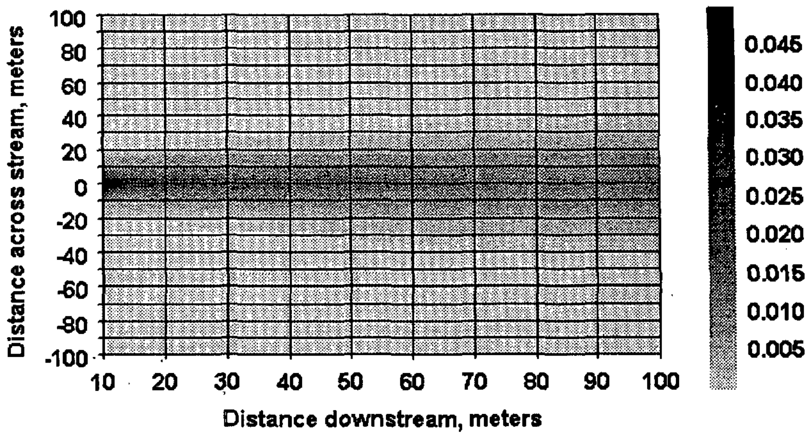
Open Clamshell Selenium



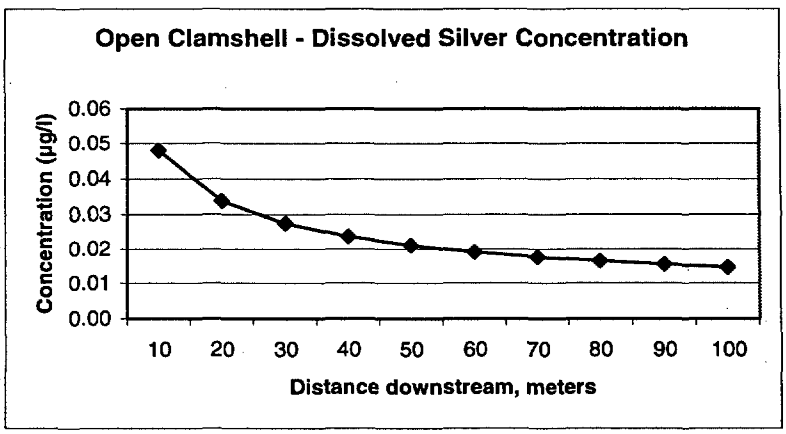
Open Clamshell Dissolved Selenium



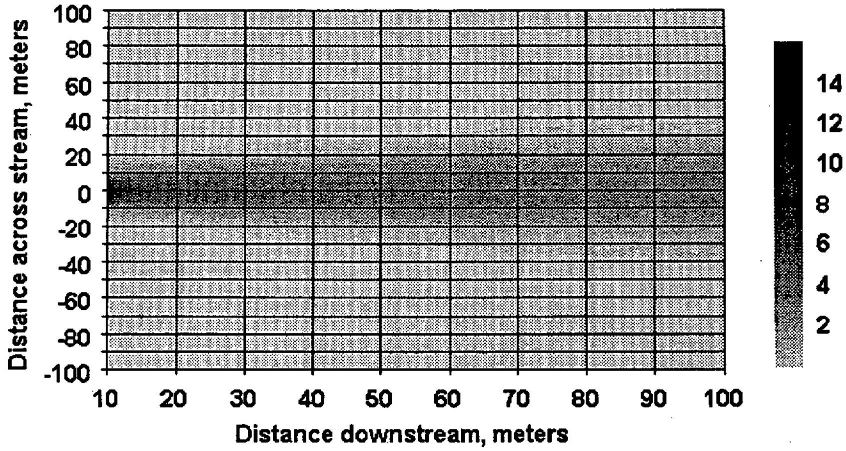
Open Clamshell Silver



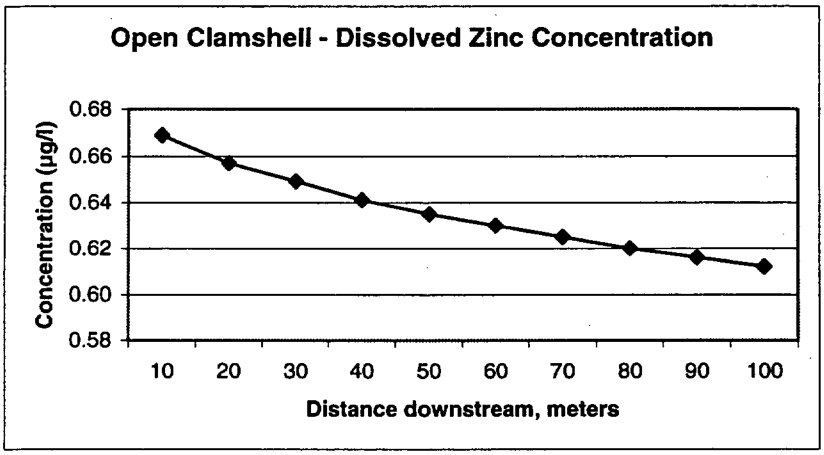
Open Clamshell Dissolved Silver



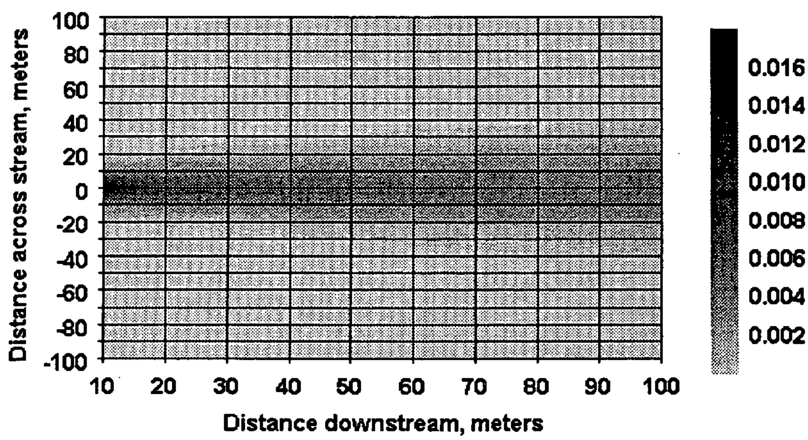
Open Clamshell Zinc



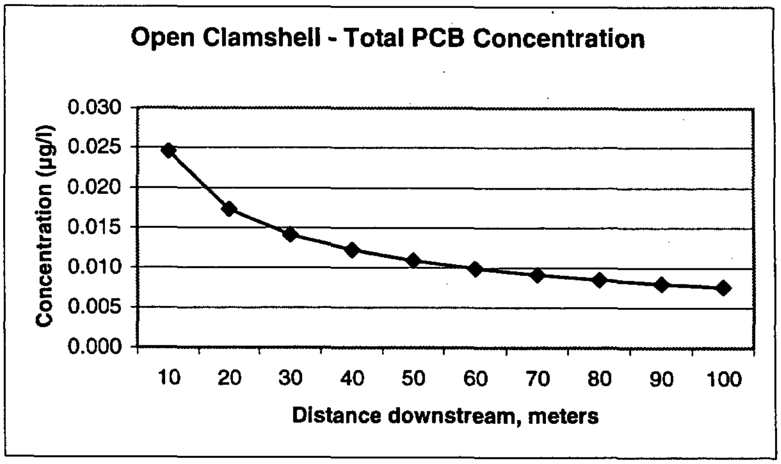
Open Clamshell Dissolved Zinc



Open Clamshell PCBs



Open Clamshell Total PCBs



Dredge Type : Open Clamshell

Near-Field Model : TGU Method

Far-Field Model : Kuo's Model

Resuspended Material Selected : Dissolved Arsenic, µg/l

	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
-40	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.03
-30	0.00	0.00	0.01	0.02	0.04	0.05	0.06	0.07	0.08	0.09
-20	0.00	0.05	0.10	0.13	0.15	0.17	0.17	0.18	0.18	0.18
-10	0.28	0.37	0.37	0.36	0.34	0.32	0.31	0.29	0.28	0.27
0	1.01	0.71	0.58	0.50	0.44	0.40	0.37	0.34	0.32	0.30
10	0.28	0.37	0.37	0.36	0.34	0.32	0.31	0.29	0.28	0.27
20	0.00	0.05	0.10	0.13	0.15	0.17	0.17	0.18	0.18	0.18
30	0.00	0.00	0.01	0.02	0.04	0.05	0.06	0.07	0.08	0.09
40	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.03
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type :	Open Clamshell									
Near-Field Model :	TGU Method									
Far-Field Model :	Kuo's Model									
Resuspended Material Selected :	Dissolved Cadmium, µg/l									
	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type :	Open Clamshell									
Near-Field Model :	TGU Method									
Far-Field Model :	Kuo's Model									
Resuspended Material Selected :			Dissolved Chromium, µg/l							
	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
-50	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.08
-40	0.00	0.00	0.00	0.01	0.04	0.08	0.12	0.17	0.21	0.25
-30	0.00	0.01	0.08	0.18	0.28	0.37	0.45	0.51	0.57	0.61
-20	0.03	0.35	0.65	0.86	0.99	1.06	1.11	1.13	1.14	1.14
-10	1.74	2.29	2.30	2.21	2.10	1.99	1.90	1.81	1.73	1.66
0	6.09	4.29	3.50	3.02	2.70	2.45	2.27	2.12	1.99	1.88
10	1.74	2.29	2.30	2.21	2.10	1.99	1.90	1.81	1.73	1.66
20	0.03	0.35	0.65	0.86	0.99	1.06	1.11	1.13	1.14	1.14
30	0.00	0.01	0.08	0.18	0.28	0.37	0.45	0.51	0.57	0.61
40	0.00	0.00	0.00	0.01	0.04	0.08	0.12	0.17	0.21	0.25
50	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.08
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type : Open Clamshell

Near-Field Model : TGU Method

Far-Field Model : Kuo's Model

Resuspended Material Selected : Dissolved Copper, μg/l

	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
-50	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.05
-40	0.00	0.00	0.00	0.01	0.03	0.05	0.07	0.08	0.10	0.11
-30	0.00	0.01	0.05	0.08	0.11	0.13	0.15	0.16	0.16	0.17
-20	0.02	0.13	0.17	0.19	0.20	0.21	0.21	0.21	0.21	0.21
-10	0.23	0.24	0.24	0.24	0.24	0.24	0.24	0.23	0.23	0.23
0	0.27	0.26	0.26	0.25	0.25	0.25	0.24	0.24	0.24	0.24
10	0.23	0.24	0.24	0.24	0.24	0.24	0.24	0.23	0.23	0.23
20	0.02	0.13	0.17	0.19	0.20	0.21	0.21	0.21	0.21	0.21
30	0.00	0.01	0.05	0.08	0.11	0.13	0.15	0.16	0.16	0.17
40	0.00	0.00	0.00	0.01	0.03	0.05	0.07	0.08	0.10	0.11
50	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.05
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type : Open Clamshell

Near-Field Model : TGU Method

Far-Field Model : Kuo's Model

Resuspended Material Selected : Dissolved Lead, µg/l

	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
-50	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
-40	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02
-30	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02
-20	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
-10	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
0	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
10	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
20	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
30	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02
40	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02
50	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type : Open Clamshell										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Mercury, µg/l										
	10	20	30	40	50	60	70	80	90	100
-100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
-30	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001
-20	0.000	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002
-10	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004
0	0.013	0.009	0.007	0.006	0.006	0.005	0.005	0.004	0.004	0.004
10	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004
20	0.000	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002
30	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Dredge Type :	Open Clamshell									
Near-Field Model :	TGU Method									
Far-Field Model :	Kuo's Model									
Resuspended Material Selected :			Dissolved Nickel, µg/l							
	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
-50	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04
-40	0.00	0.00	0.00	0.01	0.03	0.05	0.06	0.08	0.10	0.11
-30	0.00	0.01	0.04	0.08	0.12	0.14	0.16	0.17	0.18	0.19
-20	0.02	0.14	0.20	0.23	0.24	0.25	0.25	0.25	0.26	0.26
-10	0.29	0.32	0.32	0.31	0.31	0.31	0.30	0.30	0.29	0.29
0	0.37	0.36	0.35	0.34	0.33	0.32	0.32	0.31	0.31	0.30
10	0.29	0.32	0.32	0.31	0.31	0.31	0.30	0.30	0.29	0.29
20	0.02	0.14	0.20	0.23	0.24	0.25	0.25	0.25	0.26	0.26
30	0.00	0.01	0.04	0.08	0.12	0.14	0.16	0.17	0.18	0.19
40	0.00	0.00	0.00	0.01	0.03	0.05	0.06	0.08	0.10	0.11
50	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type :	Open Clamshell									
Near-Field Model :	TGU Method									
Far-Field Model :	Kuo's Model									
Resuspended Material Selected :			Dissolved Selenium, µg/l							
	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type : Open Clamshell										
Near-Field Model : TGU Method										
Far-Field Model : Kuo's Model										
Resuspended Material Selected : Dissolved Silver, µg/l										
	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-20	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
-10	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
0	0.05	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01
10	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
20	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type : Open Clamshell

Near-Field Model : TGU Method

Far-Field Model : Kuo's Model

Resuspended Material Selected : Dissolved Zinc, μg/l

	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.05
-50	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.10	0.13	0.17
-40	0.00	0.00	0.01	0.05	0.11	0.17	0.23	0.28	0.31	0.34
-30	0.00	0.04	0.16	0.28	0.36	0.41	0.44	0.46	0.48	0.49
-20	0.09	0.40	0.50	0.53	0.55	0.56	0.56	0.57	0.57	0.57
-10	0.61	0.63	0.63	0.62	0.62	0.62	0.61	0.61	0.61	0.60
0	0.67	0.66	0.65	0.64	0.64	0.63	0.63	0.62	0.62	0.61
10	0.61	0.63	0.63	0.62	0.62	0.62	0.61	0.61	0.61	0.60
20	0.09	0.40	0.50	0.53	0.55	0.56	0.56	0.57	0.57	0.57
30	0.00	0.04	0.16	0.28	0.36	0.41	0.44	0.46	0.48	0.49
40	0.00	0.00	0.01	0.05	0.11	0.17	0.23	0.28	0.31	0.34
50	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.10	0.13	0.17
60	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.05
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Dredge Type : Open Clamshell

Near-Field Model : TGU Method

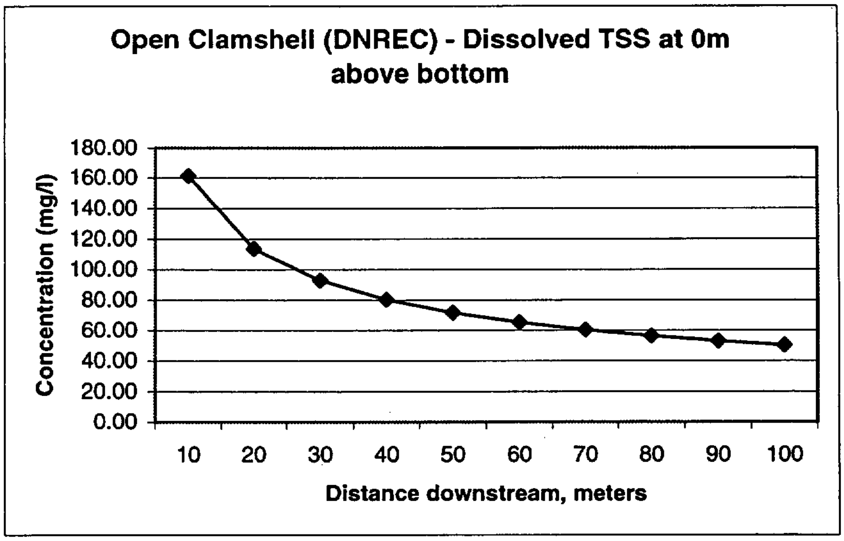
Far-Field Model : Kuo's Model

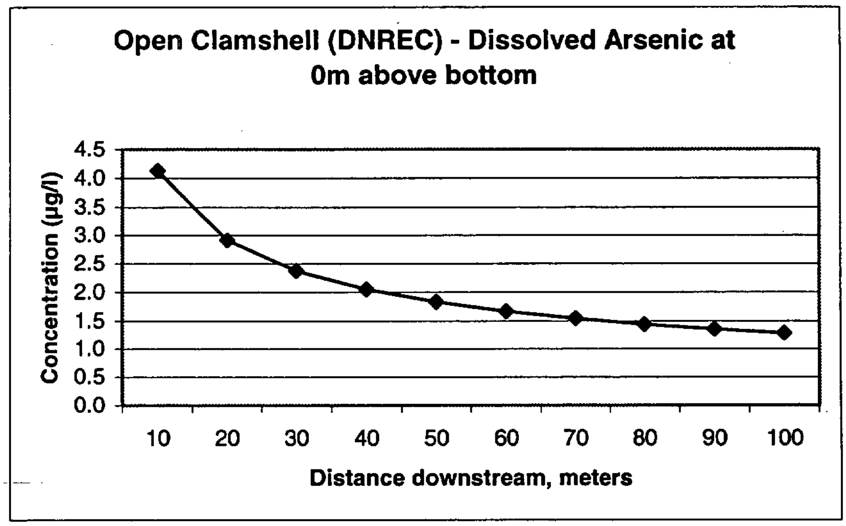
Resuspended Material Selected : Dissolved PCBs, µg/l

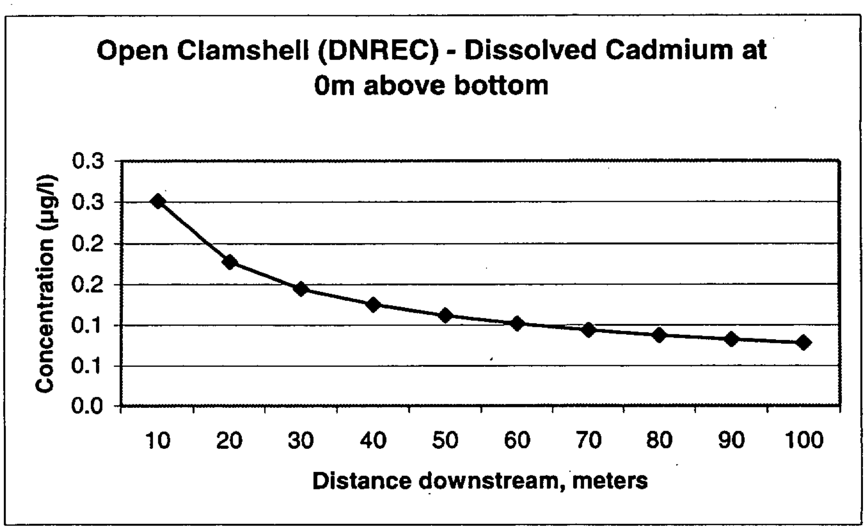
	10	20	30	40	50	60	70	80	90	100
-100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
-30	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001
-20	0.000	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002
-10	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002
0	0.007	0.005	0.004	0.004	0.003	0.003	0.003	0.003	0.002	0.002
10	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002
20	0.000	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002
30	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

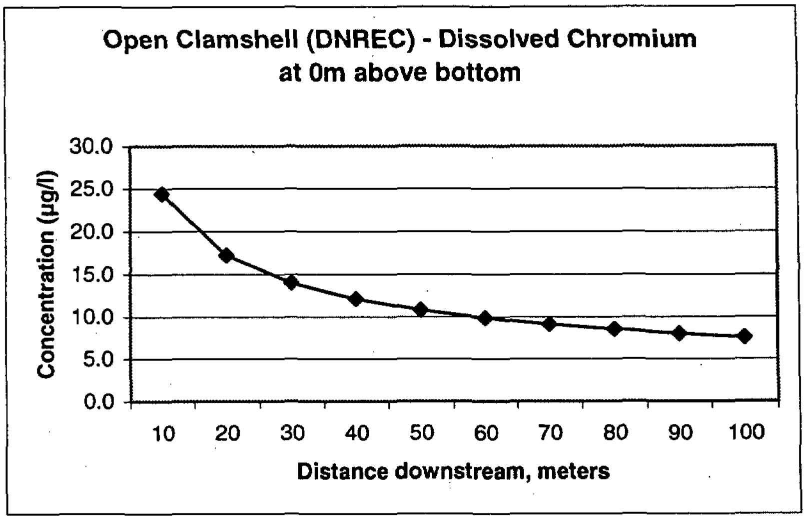
APPENDIX F

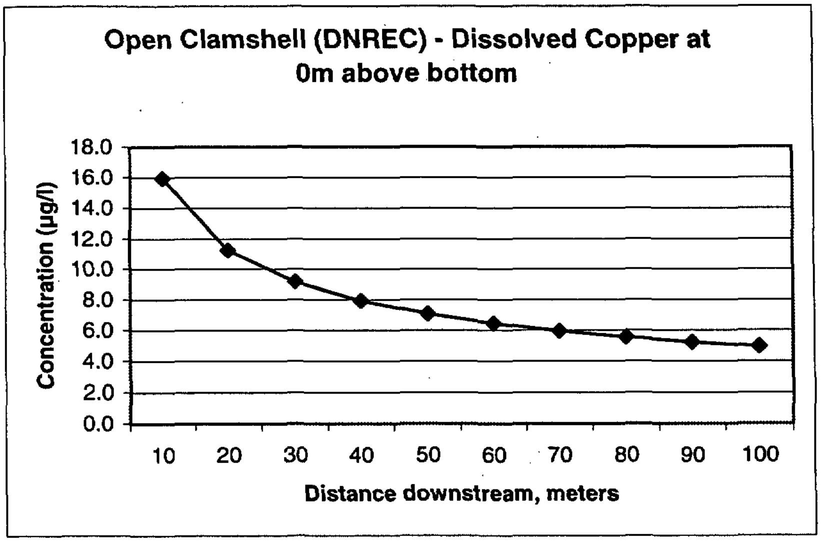
Model Results of Bucket Dredging in the Sun Marcus Hook Berthing Area of the Delaware River, using DNREC Equilibrium Partitioning Method for Metals

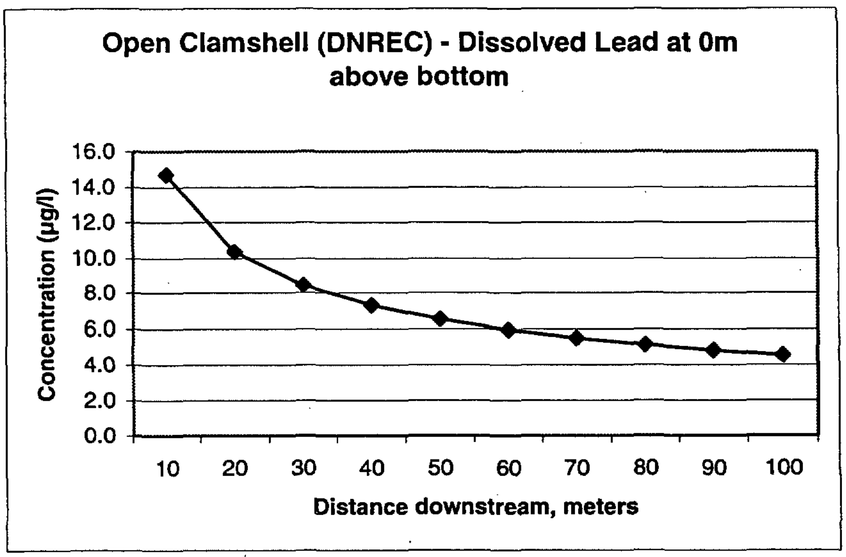

Open Clamshell (DNREC) - Dissolved TSS at 0m above bottom
Concentration (mg/l)
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
10 20 30 40 50 60 70 80 90 100
Distance downstream, meters

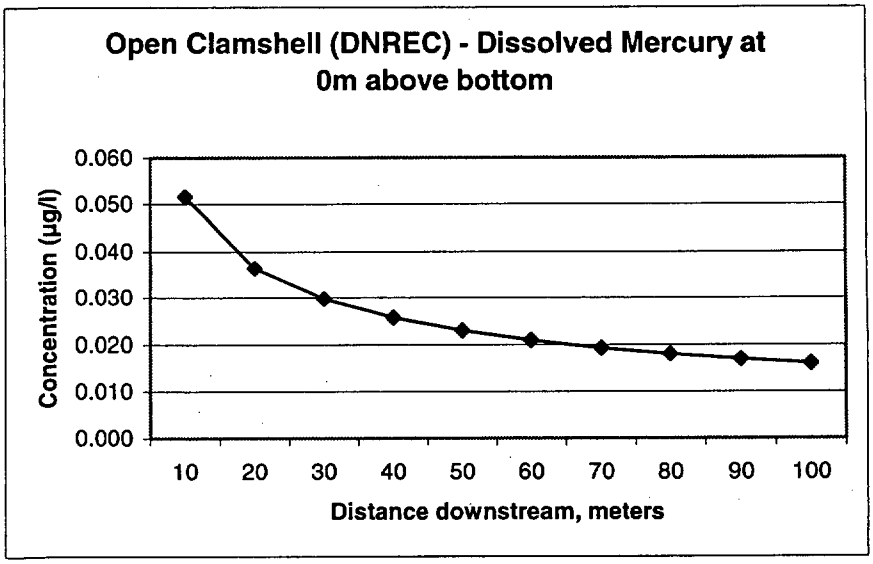

Open Clamshell (DNREC) - Dissolved Arsenic at 0m above bottom
Concentration (µg/l)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10 20 30 40 50 60 70 80 90 100
Distance downstream, meters

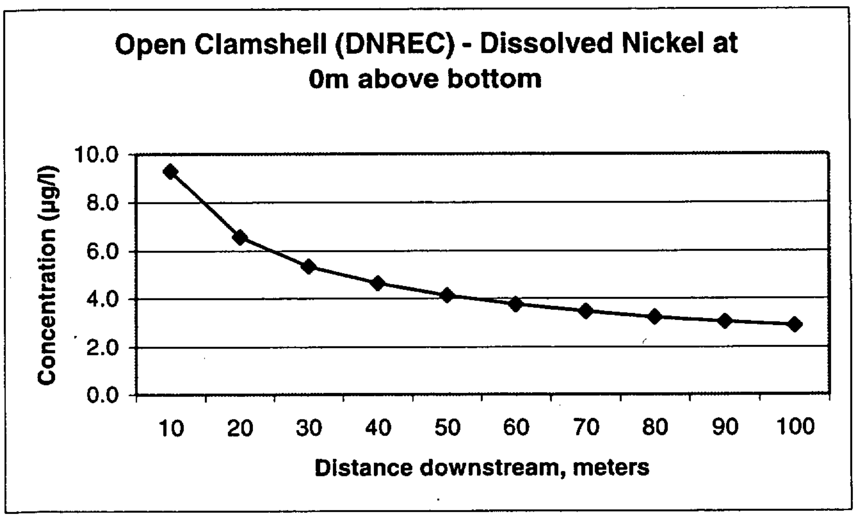

Open Clamshell (DNREC) - Dissolved Cadmium at 0m above bottom
Concentration (µg/l)
0.3
0.3
0.2
0.2
0.1
0.1
0.0
10 20 30 40 50 60 70 80 90 100
Distance downstream, meters

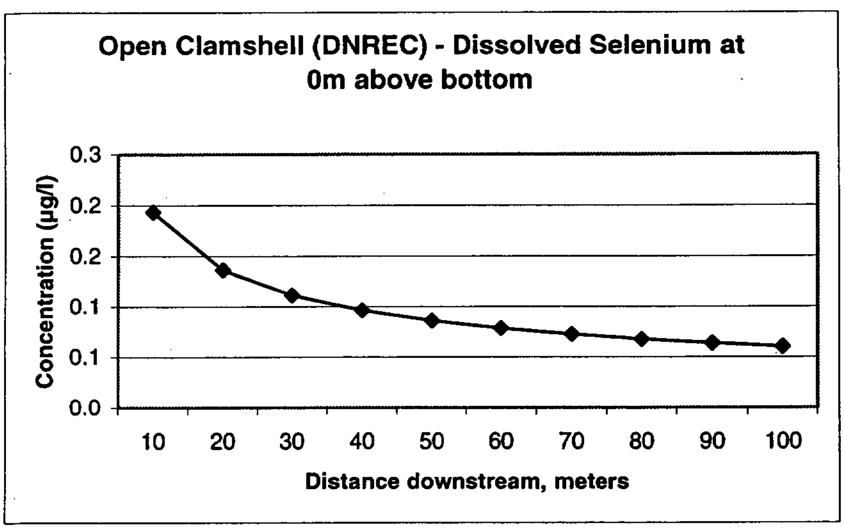

Open Clamshell (DNREC) - Dissolved Chromium at 0m above bottom
Concentration (µg/l)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
10 20 30 40 50 60 70 80 90 100
Distance downstream, meters

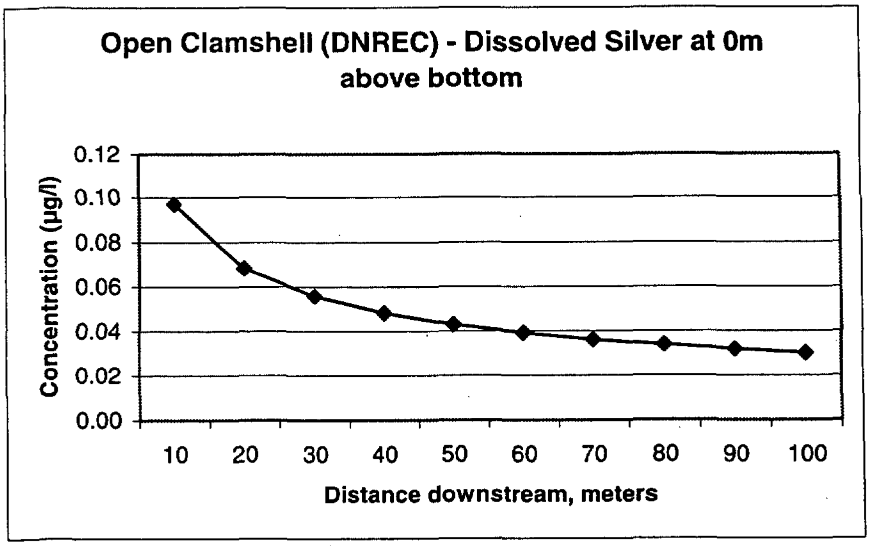

Open Clamshell (DNREC) - Dissolved Copper at 0m above bottom
Concentration (µg/l)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
10 20 30 40 50 60 70 80 90 100
Distance downstream, meters


Open Clamshell (DNREC) - Dissolved Lead at 0m above bottom
Concentration (µg/l)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
10 20 30 40 50 60 70 80 90 100
Distance downstream, meters


Open Clamshell (DNREC) - Dissolved Mercury at
0m above bottom
Concentration (µg/l)
0.060
0.050
0.040
0.030
0.020
0.010
0.000
10
20
30
40
50
60
70
80
90
100
Distance downstream, meters


Open Clamshell (DNREC) - Dissolved Nickel at
0m above bottom
Concentration (µg/l)
10.0
8.0
6.0
4.0
2.0
0.0
10
20
30
40
50
60
70
80
90
100
Distance downstream, meters


Open Clamshell (DNREC) - Dissolved Selenium at
0m above bottom
Concentration (µg/l)
0.3
0.2
0.2
0.1
0.1
0.0
10
20
30
40
50
60
70
80
90
100
Distance downstream, meters


Open Clamshell (DNREC) - Dissolved Silver at 0m above bottom
Concentration (µg/l)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
10
20
30
40
50
60
70
80
90
100
Distance downstream, meters

Method : DNREC Equilibrium Equation										
Dredge Type : Open Clamshell										
Near-Field Model : TGU Method, conservative parameters										
Far-Field Model : Kuo's Model, conservative parameters										
Resuspended Material Selected : TSS, mg/l										
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.11
-60	0.00	0.00	0.00	0.00	0.01	0.04	0.10	0.20	0.36	0.56
-50	0.00	0.00	0.00	0.03	0.14	0.36	0.69	1.13	1.64	2.20
-40	0.00	0.01	0.12	0.54	1.31	2.32	3.46	4.61	5.73	6.77
-30	0.00	0.41	2.18	4.81	7.54	9.99	12.06	13.77	15.14	16.24
-20	1.09	9.34	17.51	22.95	26.31	28.31	29.46	30.07	30.32	30.35
-10	46.20	60.90	61.11	58.61	55.69	52.89	50.34	48.05	46.00	44.15
0	161.25	113.78	92.70	80.12	71.51	65.14	60.18	56.18	52.85	50.03
10	46.20	60.90	61.11	58.61	55.69	52.89	50.34	48.05	46.00	44.15
20	1.09	9.34	17.51	22.95	26.31	28.31	29.46	30.07	30.32	30.35
30	0.00	0.41	2.18	4.81	7.54	9.99	12.06	13.77	15.14	16.24
40	0.00	0.01	0.12	0.54	1.31	2.32	3.46	4.61	5.73	6.77
50	0.00	0.00	0.00	0.03	0.14	0.36	0.69	1.13	1.64	2.20
60	0.00	0.00	0.00	0.00	0.01	0.04	0.10	0.20	0.36	0.56
70	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.11
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Method : DNREC Equilibrium Equation

Dredge Type : Open Clamshell

Near-Field Model : TGU Method, conservative parameters

Far-Field Model : Kuo's Model, conservative parameters

Resuspended Material Selected : Arsenic, µg/l

Maximum sediment concentration: 6.4

distance from dredge in meters

	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-40	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2
-30	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.4	0.4
-20	0.0	0.2	0.4	0.6	0.7	0.7	0.8	0.8	0.8	0.8
-10	1.2	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1
0	4.1	2.9	2.4	2.1	1.8	1.7	1.5	1.4	1.4	1.3
10	1.2	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1
20	0.0	0.2	0.4	0.6	0.7	0.7	0.8	0.8	0.8	0.8
30	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.4	0.4
40	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Method	:	DNREC Equilibrium Equation								
Dredge Type	:	Open Clamshell								
Near-Field Model	:	TGU Method, conservative parameters								
Far-Field Model	:	Kuo's Model, conservative parameters								
Resuspended Material Selected :		Cadmium, µg/l								
Maximum sediment concentration:				0.39						
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-10	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
0	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
10	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Method : DNREC Equilibrium Equation										
Dredge Type : Open Clamshell										
Near-Field Model : TGU Method, conservative parameters										
Far-Field Model : Kuo's Model, conservative parameters										
Resuspended Material Selected : Chromium, µg/l										
Maximum sediment concentration:				37.8						
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
-50	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3
-40	0.0	0.0	0.0	0.1	0.2	0.4	0.5	0.7	0.9	1.0
-30	0.0	0.1	0.3	0.7	1.1	1.5	1.8	2.1	2.3	2.5
-20	0.2	1.4	2.6	3.5	4.0	4.3	4.5	4.5	4.6	4.6
-10	7.0	9.2	9.2	8.9	8.4	8.0	7.6	7.3	7.0	6.7
0	24.4	17.2	14.0	12.1	10.8	9.8	9.1	8.5	8.0	7.6
10	7.0	9.2	9.2	8.9	8.4	8.0	7.6	7.3	7.0	6.7
20	0.2	1.4	2.6	3.5	4.0	4.3	4.5	4.5	4.6	4.6
30	0.0	0.1	0.3	0.7	1.1	1.5	1.8	2.1	2.3	2.5
40	0.0	0.0	0.0	0.1	0.2	0.4	0.5	0.7	0.9	1.0
50	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Method : DNREC Equilibrium Equation										
Dredge Type : Open Clamshell										
Near-Field Model : TGU Method, conservative parameters										
Far-Field Model : Kuo's Model, conservative parameters										
Resuspended Material Selected : Copper, µg/l										
Maximum sediment concentration:				24.7						
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-50	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2
-40	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.5	0.6	0.7
-30	0.0	0.0	0.2	0.5	0.7	1.0	1.2	1.4	1.5	1.6
-20	0.1	0.9	1.7	2.3	2.6	2.8	2.9	3.0	3.0	3.0
-10	4.6	6.0	6.0	5.8	5.5	5.2	5.0	4.7	4.5	4.4
0	15.9	11.2	9.2	7.9	7.1	6.4	5.9	5.6	5.2	4.9
10	4.6	6.0	6.0	5.8	5.5	5.2	5.0	4.7	4.5	4.4
20	0.1	0.9	1.7	2.3	2.6	2.8	2.9	3.0	3.0	3.0
30	0.0	0.0	0.2	0.5	0.7	1.0	1.2	1.4	1.5	1.6
40	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.5	0.6	0.7
50	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Method : DNREC Equilibrium Equation										
Dredge Type : Open Clamshell										
Near-Field Model : TGU Method, conservative parameters										
Far-Field Model : Kuo's Model, conservative parameters										
Resuspended Material Selected : Lead, µg/l										
Maximum sediment concentration:				22.8						
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
-50	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2
-40	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6
-30	0.0	0.0	0.2	0.4	0.7	0.9	1.1	1.3	1.4	1.5
-20	0.1	0.9	1.6	2.1	2.4	2.6	2.7	2.7	2.8	2.8
-10	4.2	5.6	5.6	5.3	5.1	4.8	4.6	4.4	4.2	4.0
0	14.7	10.4	8.5	7.3	6.5	5.9	5.5	5.1	4.8	4.6
10	4.2	5.6	5.6	5.3	5.1	4.8	4.6	4.4	4.2	4.0
20	0.1	0.9	1.6	2.1	2.4	2.6	2.7	2.7	2.8	2.8
30	0.0	0.0	0.2	0.4	0.7	0.9	1.1	1.3	1.4	1.5
40	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6
50	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Method : DNREC Equilibrium Equation										
Dredge Type : Open Clamshell										
Near-Field Model : TGU Method, conservative parameters										
Far-Field Model : Kuo's Model, conservative parameters										
Resuspended Material Selected : Mercury, µg/l										
Maximum sediment concentration: 0.08										
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
-40	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002
-30	0.000	0.000	0.001	0.002	0.002	0.003	0.004	0.004	0.005	0.005
-20	0.000	0.003	0.006	0.007	0.008	0.009	0.009	0.010	0.010	0.010
-10	0.015	0.019	0.020	0.019	0.018	0.017	0.016	0.015	0.015	0.014
0	0.052	0.036	0.030	0.026	0.023	0.021	0.019	0.018	0.017	0.016
10	0.015	0.019	0.020	0.019	0.018	0.017	0.016	0.015	0.015	0.014
20	0.000	0.003	0.006	0.007	0.008	0.009	0.009	0.010	0.010	0.010
30	0.000	0.000	0.001	0.002	0.002	0.003	0.004	0.004	0.005	0.005
40	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002
50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Method : DNREC Equilibrium Equation										
Dredge Type : Open Clamshell										
Near-Field Model : TGU Method, conservative parameters										
Far-Field Model : Kuo's Model, conservative parameters										
Resuspended Material Selected : Nickel, µg/l										
Maximum sediment concentration: 14.43										
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
-40	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.4
-30	0.0	0.0	0.1	0.3	0.4	0.6	0.7	0.8	0.9	0.9
-20	0.1	0.5	1.0	1.3	1.5	1.6	1.7	1.7	1.8	1.8
-10	2.7	3.5	3.5	3.4	3.2	3.1	2.9	2.8	2.7	2.5
0	9.3	6.6	5.4	4.6	4.1	3.8	3.5	3.2	3.1	2.9
10	2.7	3.5	3.5	3.4	3.2	3.1	2.9	2.8	2.7	2.5
20	0.1	0.5	1.0	1.3	1.5	1.6	1.7	1.7	1.8	1.8
30	0.0	0.0	0.1	0.3	0.4	0.6	0.7	0.8	0.9	0.9
40	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.4
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Method : DNREC Equilibrium Equation										
Dredge Type : Open Clamshell										
Near-Field Model : TGU Method, conservative parameters										
Far-Field Model : Kuo's Model, conservative parameters										
Resuspended Material Selected : Selenium, µg/l										
Maximum sediment concentration:				0.3						
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-10	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
0	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
10	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Method : DNREC Equilibrium Equation										
Dredge Type : Open Clamshell										
Near-Field Model : TGU Method, conservative parameters										
Far-Field Model : Kuo's Model, conservative parameters										
Resuspended Material Selected : Silver, µg/l										
Maximum sediment concentration: 0.15										
distance from dredge in meters										
	downstream------>									
across	10	20	30	40	50	60	70	80	90	100
-100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-30	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
-20	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
-10	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
0	0.10	0.07	0.06	0.05	0.04	0.04	0.04	0.03	0.03	0.03
10	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
20	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
30	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Method : DNREC Equilibrium Equation

Dredge Type : Open Clamshell

Near-Field Model : TGU Method, conservative parameters

Far-Field Model : Kuo's Model, conservative parameters

Resuspended Material Selected : Zinc, µg/l

Maximum sediment concentration: 98.6

distance from dredge in meters

downstream------>

across	10	20	30	40	50	60	70	80	90	100
-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2
-50	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.4	0.6	0.9
-40	0.0	0.0	0.0	0.2	0.5	0.9	1.4	1.8	2.3	2.7
-30	0.0	0.2	0.9	1.9	3.0	3.9	4.8	5.4	6.0	6.4
-20	0.4	3.7	6.9	9.1	10.4	11.2	11.6	11.9	12.0	12.0
-10	18.2	24.0	24.1	23.1	22.0	20.9	19.9	19.0	18.1	17.4
0	63.6	44.9	36.6	31.6	28.2	25.7	23.7	22.2	20.8	19.7
10	18.2	24.0	24.1	23.1	22.0	20.9	19.9	19.0	18.1	17.4
20	0.4	3.7	6.9	9.1	10.4	11.2	11.6	11.9	12.0	12.0
30	0.0	0.2	0.9	1.9	3.0	3.9	4.8	5.4	6.0	6.4
40	0.0	0.0	0.0	0.2	0.5	0.9	1.4	1.8	2.3	2.7
50	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.4	0.6	0.9
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0