Attachment 4
Dry Bulk Density Estimation

Dry bulk density ("BD") refers to the amount of sediment mass present in a specific volume of sediments. BD is important to the EA for two reasons. First, to estimate the mass of sediments resuspended during the HDP, the volume of dredged material (m^3) must be converted to a dry mass (kg dry mass). The bulk density (BD, kg/m^3) is the conversion factor. Second, the particle tracking model calculates the dispersion and subsequent redeposition of this mass of material in units of kg dry mass/m^2 of sediments. To calculate the depth of the redeposited material on the flats of Newark Bay, it is necessary to convert this mass of deposited sediment (kg dry mass/m^2) into a depth value (m). The depth of deposition (D_{DM}) is calculated using the computed mass of deposited sediment (M_{DM}, in units of kg/m^2) and the dry bulk density value:

$$D_{DM} = \frac{M_{DM}}{BD}$$

The bulk densities of HDP and O&M material were calculated using data collected within the respective areas to be dredged. BD values for HDP and O&M material were calculated independently, because O&M dredging generally removes recently deposited, less consolidated sediments, while the HDP will also remove older, more consolidated material. Measured bulk densities in surface sediments throughout the bay were used to calculate the depth of deposition.

Bulk Density of HDP dredged material

The mass of resuspended solids was estimated using field measurements of the bulk density of sediments to be dredged, using sediment cores collected by USACE for geotechnical characterization of the channels and side slopes of Newark Bay prior to dredging. There were two sources of data:

- Samples collected in 1998 and 2001 and reported in Table 24 of Appendix F of the Limited Reevaluation Report (USACE 2004).
- Samples collected in 1998 and reported in the plans and specifications for the Kill van Kull and Arthur Kill dredging contracts.

The field measurements for these samples consisted of moisture content (r_w, units of lb water/lb solids) and moist unit weight (r_s, units of lb total/ft^3). These were analyzed as follows to compute BD[1]:

$$BD = \frac{r_s}{1 + r_w} conv$$

[1] Note that lb water + lb solids = lb total mass, and BD is in units of kg solids / m^3 total volume.

where:

conv = conversion factor (16 [kg/m^3] / [lb/ft^3])

The dry bulk density data are presented in Table 1. In most cases, more than one sample was measured per core; core-specific values are presented in Table 2. Also indicated in Table 1 is the geomorphic area in which each core was collected: channel vs. slope. The average BD for the three channel samples was 1,600 kg/m^3. The average for slope samples was 1,100 kg/m^3.

A weighted average of the channel and slope values was used to calculate the overall BD of the dredged material. Approximately 15% of the dredged material is expected to originate on the slopes, based upon estimates available for dredge contract area S-NB-1. Using this as a weighting factor, the overall average BD is computed to be 1,500 kg/m^3. This value was used to represent the BD of HDP material.

Bulk Density of additional dredged material

To represent O&M and additional dredged sediments, the NBSA Phase 1 data collected in the channels, on the side slopes and along the industrial waterfront were used. These data are available for sediments within the top one to three feet and thus are probably representative of recently deposited material that would be removed during O&M dredging. Field measurements of percent moisture were converted to bulk density using as follows:

$$m_w = \frac{\text{percent moisture}}{100}$$

$$m_s = 1 - m_w$$

$$BD = \frac{m_s}{\frac{m_s}{\rho_s} + \frac{m_w}{\rho_w}}$$

where:

m_s = mass proportion of solids in the sample (kg solids/kg sample)
ρ_s = density of solids (2,650 kg solids/m^3 solids)
m_w = mass proportion of water in the sample (kg water/kg sample)
ρ_w = density of water (1,000 kg water/m^3 water)

Length-weighted BD values were computed for each core. The individual core values are presented in Table 1. BD was similar throughout the study area; an analysis of variance indicated no significant variation among the regions. The overall average BD for all areas was 800 kg/m^3; this value was used to represent the BD of O&M material for all regions.

Bulk Density of Surface Sediments

The dry bulk density of the newly deposited dredged material was set equal to the dry bulk density of the surface sediments. This is reasonable, given that the newly deposited dredged material, along with material deposited from other sources, will be mixed into the active layer of the sediment bed, thus taking on the characteristics of the surface layer of the bay.

The dry bulk density of surface sediments was calculated using the 6-inch surface slices of the NBSA Phase 1 data. Calculations were performed based upon the percent moisture data, as described above. The resulting dry bulk densities are presented in Table 3. The overall average BD for surface sediments in Newark Bay in the NBSA Phase 1 data set was 750 kg/m^3. This value was used in the calculation of the effects of deposition on surface sediment contaminant concentrations in Newark Bay.

Reference

USACE, 2004. Limited Reevaluation Report. Appendix F: Geotechnical

Table 1. Dry Bulk Density Data for Dredged Materia

Source	Geomorphic Area	Area	Sample ID	Moisture Content kg water /kg solids * 100	Moist Unit Weight lb/ft3	Dry density kg/m3
URS 1999	Channel/slopes	E	E-98-15	31.7	121.5	1477.7
URS 1999	Channel/slopes	E	E-98-15	38.8	116.7	1346.8
URS 1999	Channel/slopes	E	E-98-15	37.1	117.6	1374.0
URS 1999	Channel/slopes	PN	PN-98-06	21.6	131.1	1726.9
URS 1999	Channel/slopes	PN	PN-98-06	18.5	134.7	1820.8
URS 1999	Channel/slopes	PN	PN-98-06	17.1	138.0	1887.7
URS 1999	Channel/slopes	SE	SE-98-3	38.0	118.7	1377.8
URS 1999	Channel/slopes	SE	SE-98-3	30.2	123.7	1521.8
URS 1999	Channel/slopes	SE	SE-98-3	24.5	128.5	1653.3
URS 1999	Channel/slopes	AK	AK-98-4	45.0	109.7	1211.8
URS 1999	Channel/slopes	AK	AK-98-4	13.5	141.9	2002.6
USACE 2004	Channel/slopes	AK	AK-01-SF1-5	62.0	101.3	1001.6
USACE 2004	Channel/slopes	AK	AK-98-3	99.0	90.0	724.4
USACE 2004	Channel/slopes	AK	AK-98-3	99.2	89.9	722.9
USACE 2004	Channel/slopes	AK	AK-98-3	99.9	89.3	715.6
USACE 2004	Channel/slopes	AK	AK-98-3	86.5	93.7	804.8
USACE 2004	Channel/slopes	AK	AK-98-10	72.1	99.3	924.2
USACE 2004	Channel/slopes	AK	AK-98-10	69.4	103.4	977.7
USACE 2004	Channel/slopes	AK	AK-98-11A	102.0	91.5	725.6
USACE 2004	Channel/slopes	AK	AK-98-11A	108.1	90.7	698.1
USACE 2004	Channel/slopes	AK	AK-98-11A	99.0	91.0	732.5
USACE 2004	Channel/slopes	AK	AK-98-11A	110.9	88.4	671.4
USACE 2004	Channel/slopes	AK	AK-98-11A	120.1	87.3	635.3
USACE 2004	Channel/slopes	AK	AK-01-SFI-1	71.0	99.4	931.1
USACE 2004	Channel/slopes	AK	AK-01-SFI-2	75.0	96.7	885.1
USACE 2004	Channel/slopes	AK	AK-01-SFI-3	59.0	110.1	1109.2
USACE 2004	Channel/slopes	AK	AK-01-SFI-4	75.0	97.6	893.3
USACE 2004	Channel/slopes	AK	AK-01-SFI-6	71.0	99.6	933.0
USACE 2004	Channel/slopes	AK	AK-01-SFI-6	59.0	103.0	1037.6
USACE 2004	Channel/slopes	E	E-01-SFI-1	47.0	107.2	1168.1
USACE 2004	Channel/slopes	E	*E-01-SFI-1*	24.0	128.9	1665.1
USACE 2004	Channel/slopes	E	E-01-SFI-2	28.0	127.0	1589.3
USACE 2004	Channel/slopes	KVK	KVK-01-SFI-2	141	80.7	536.4
USACE 2004	Channel/slopes	KVK	KVK-01-SFI-6	45	107.3	1185.3
USACE 2004	Channel/slopes	KVK	KVK-01-SFI-6B	68	92.9	885.8
USACE 2004	Channel/slopes	NBN	NBN-01-SFI-2	22.0	133.3	1750.2
USACE 2004	Channel/slopes	NBN	NBN-01-SFI-2	27.0	126.4	1594.2
USACE 2004	Channel/slopes	NBN	NBN-01-SFI-3	26.0	127.1	1615.8
USACE 2004	Channel/slopes	NBN	NBN-01-SFI-3	40.0	110.6	1265.4
USACE 2004	Channel/slopes	NBN	NBN-01-SFI-4	94.0	90.1	743.9
USACE 2004	Channel/slopes	NBN	NBN-01-SFI-4	35.0	121.4	1440.4
USACE 2004	Channel/slopes	NBN	NBN-01-SFI-5	38.0	111.9	1298.8
USACE 2004	Channel/slopes	NBN	NBN-01-SFI-5B	30.0	122.0	1503.2
USACE 2004	Channel/slopes	SE	SE-01-SFI-01	35.0	118.4	1404.8
EPA NBSA Phase 1	Industrial Waterfront Area	AK	NB01SED002			1185
EPA NBSA Phase 1	Industrial Waterfront Area	AK	NB01SED068			557
EPA NBSA Phase 1	Southern Navigation Channels	AK	NB01SED001A			517
EPA NBSA Phase 1	Southern Navigation Channels	AK	NB01SED010A			918
EPA NBSA Phase 1	Transitional Slopes	AK	NB01SED011			1003
EPA NBSA Phase 1	Industrial Waterfront Area	E	NB01SED036			454
EPA NBSA Phase 1	Port Channels	E	NB01SED034A			600
EPA NBSA Phase 1	Port Channels	E	NB01SED035A			510
EPA NBSA Phase 1	Southern Navigation Channels	NB	NB01SED017			642
EPA NBSA Phase 1	Southern Navigation Channels	NB	NB01SED021			1240
EPA NBSA Phase 1	Southern Navigation Channels	NB	NB01SED027			1032
EPA NBSA Phase 1	Southern Navigation Channels	NB	NB01SED030			690
EPA NBSA Phase 1	Southern Navigation Channels	NB	NB01SED031			805
EPA NBSA Phase 1	Southern Navigation Channels	NB	NB01SED033A			703
EPA NBSA Phase 1	Transitional Slopes	NB	NB01SED016			803
EPA NBSA Phase 1	Transitional Slopes	NB	NB01SED029			783
EPA NBSA Phase 1	Industrial Waterfront Area	PN	NB01SED049			540
EPA NBSA Phase 1	Port Channels	PN	NB01SED047			677
EPA NBSA Phase 1	Port Channels	PN	NB01SED048			637
EPA NBSA Phase 1	Industrial Waterfront Area	SE	NB01SED025			690
EPA NBSA Phase 1	Port Channels	SE	NB01SED024			1025
EPA NBSA Phase 1	Port Channels	SE	NB01SED026			1557
EPA NBSA Phase 1	Industrial Waterfront Area	exclude	HR01SED067			564

Table 1. Dry Bulk Density Data for Dredged Materia

Source	Geomorphic Area	Area	Sample ID	Moisture Content kg water /kg solids * 100	Moist Unit Weight lb/ft3	Dry density kg/m3
EPA NBSA Phase 1	Industrial Waterfront Area	exclude	HR01SED069			1280
EPA NBSA Phase 1	Industrial Waterfront Area	exclude	NB01SED012			558
EPA NBSA Phase 1	Industrial Waterfront Area	exclude	NB01SED065			815
EPA NBSA Phase 1	Inter-tidal Area	exclude	NB01SED003			678
EPA NBSA Phase 1	Inter-tidal Area	exclude	NB01SED038			1416
EPA NBSA Phase 1	Inter-tidal Area	exclude	NB01SED058			710
EPA NBSA Phase 1	Northern Navigation Channels	exclude	NB01SED046			877
EPA NBSA Phase 1	Northern Navigation Channels	exclude	NB01SED052			610
EPA NBSA Phase 1	Northern Navigation Channels	exclude	NB01SED055			1148
EPA NBSA Phase 1	Northern Navigation Channels	exclude	NB01SED061			870
EPA NBSA Phase 1	Northern Navigation Channels	exclude	NB01SED063			864
EPA NBSA Phase 1	Northern Navigation Channels	exclude	NB01SED066			1447
EPA NBSA Phase 1	Southern Navigation Channels	exclude	NB01SED004			532
EPA NBSA Phase 1	Southern Navigation Channels	exclude	NB01SED006A			582
EPA NBSA Phase 1	Southern Navigation Channels	exclude	NB01SED008A			462
EPA NBSA Phase 1	Southern Navigation Channels	exclude	NB01SED043			878
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED005			673
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED007			753
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED009			727
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED013			1167
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED014			994
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED015			747
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED019			1340
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED020			843
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED022			639
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED023			854
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED028			687
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED032			603
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED037			728
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED039			1079
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED040			713
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED041			641
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED044			542
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED045			955
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED050			911
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED051			629
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED053			953
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED054			1296
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED056			624
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED057			580
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED059			854
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED060			686
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED062			640
EPA NBSA Phase 1	Sub-tidal Flats	exclude	NB01SED064			1770
EPA NBSA Phase 1	Transitional Slopes	exclude	NB01SED018			1627
EPA NBSA Phase 1	Transitional Slopes	exclude	NB01SED042			646

EPA data are length-weighted averages. Percent moisture values can be found in the EPA Phase 1 database.

Areas:

NB	Newark Bay
AK	Arthur Kill
PN	Port Newark Channel
E	Port Elizabeth Channel
SE	South Elizabeth Channel
KVK	Kill van Kull
exclude	Not located in HDP or O&M areas within the study area

Table 1. Dry Bulk Density Data for Dredged Material

Source	Geomorphic Area	Area	Sample ID	Moisture Content kg water /kg solids * 100	Moist Unit Weight lb/ft3	Dry density kg/m3

Table 2. Dry Bulk Density Measured by USACE - Average by core

Region	Region	Core ID	Number of Observations Per Core	Average	Standard Deviation	Channel	Slopes
AK	Arthur Kill	AK-98-4	2	1,607	559	1,607	
SE	South Elizabeth Channel	SE-98-3	3	1,518	138		1,518
E-	Elizabeth Channel	E-98-15	3	1,399	69	1,399	
PN	Port Newark	PN-98-06	3	1,812	81	1,812	
AK	Arthur Kill	AK-98-3	4	742	42		742
AK	Arthur Kill	AK-98-10	2	951	38		951
AK	Arthur Kill	AK-98-11A	5	693	40		693
AK	Arthur Kill	AK-01-SFI-1	1	931	N/A		931
AK	Arthur Kill	AK-01-SFI-2	1	885	N/A		885
AK	Arthur Kill	AK-01-SFI-3	1	1,109	N/A		1,109
AK	Arthur Kill	AK-01-SFI-4	1	893	N/A		893
AK	Arthur Kill	AK-01-SFI-6	2	985	74		985
E-	Elizabeth Channel	E-01-SFI-1	2	1,417	351		1,417
E-	Elizabeth Channel	E-01-SFI-2	1	1,589	N/A		1,589
KV	Kill van Kull	KVK-01-SFI-2	1	536	N/A		536
KV	Kill van Kull	KVK-01-SFI-6	1	1,185	N/A		1,185
KV	Kill van Kull	KVK-01-SFI-6B	1	886	N/A		886
NB	Newark Bay	NBN-01-SFI-2	2	1,672	110		1,672
NB	Newark Bay	NBN-01-SFI-3	2	1,441	248		1,441
NB	Newark Bay	NBN-01-SFI-4	2	1,092	493		1,092
NB	Newark Bay	NBN-01-SFI-5	1	1,299	N/A		1,299
NB	Newark Bay	NBN-01-SFI-5B	1	1,503	N/A		1,503
SE	South Elizabeth Channel	SE-01-SFI-01	1	1,405	N/A		1,405
AK	Arthur Kill	AK-01-SF1-5	1	1,002	N/A		1,002
			Average	1,190		1,606	1,130
			Std. Dev.	345		206	321
			Count	24		3	21
			Proportion of Dredge Material			0.85	0.15
			Weighted Average for HDP				**1,535**