APPENDIX 1

Assessment of Dredging-induced Deposition Patterns

U.S. Army Corps of Engineers
New York District

TABLE OF CONTENTS

List of Tables

List of Figures

ACRONYMS

2,3,7,8-TCDD - 2,3,7,8-tetrachlorodibenzo-p-dioxin
ADCP – Acoustic Doppler Current Profiler
AK-41/40 - Arthur Kill Channel 41/ 40 foot Federal Navigation Project
AOC - Administrative Order on Consent
BMP - Best Management Practice
CARP - Contaminant Assessment and Reduction Program
CDF – Confined Disposal Facility
CERCLA - Comprehensive Environmental Response, Compensation and Liability Act
CFR – Code of Federal Regulations
COC – Contaminant of Concern
CWA - Clean Water Act
DHI – Danish Hydraulic Institute
EA - Environmental Assessment
EIS - Environmental Impact Statement
EPA – U.S. Environmental Protection Agency
ERDC – U.S. Army Engineer Research and Development Center
HARS - Historic Area Remediation Site
HDP - NY and NJ Harbor Deepening Project 50' and the Arthur Kill 41/40' Project combined
HTRW - Hazardous, Toxic, and Radioactive Waste
KVK/NB-45 - Kill Van Kull and Newark Bay Channels 45 foot Federal Navigation Project
MIKE3 – Suite of three-dimensional numerical models developed by DHI
MLLW – Mean Lower Low Water
NEPA - National Environmental Policy Act
NBSA - Newark Bay Study Area
N.J.A.C. – New Jersey Administrative Code
NJDEP - New Jersey Department of Environmental Protection
NOAA - National Oceanic and Atmospheric Administration
NYD – New York District
NYSDEC - New York State Department of Environmental Conservation
O&M – Operations and Maintenance (Maintenance Dredging)
PA – Particle Analysis module (MIKE3)
PAH - polycyclic aromatic hydrocarbon
PCB - polychlorinated biphenyl
PCDD - polychlorinated dibenzo-p-dioxin
PCDF - polychlorinated dibenzofuran
PJ-41 - Port Jersey Channel 41 foot Federal Navigation Project
REMAP - Regional Environmental Monitoring and Assessment Program
RI/FS - Remedial Investigation and Feasibility Study
TEQ - Toxicity Equivalency Quotient
TSS - Total Suspended Solids
USACE - United States Army Corps of Engineers

USEPA – United States Environmental Protection Agency
U.S.C. – United States Code
WQC - Water Quality Certification

1 INTRODUCTION

The Newark Bay Environmental Assessment requires the identification of transport pathways and the determination of the transported quantities of resuspended sediments during dredging operations in the Newark Bay Study Area (NBSA) and the subsequent deposition of the resuspended sediments. To the extent that contaminants often move in the water column sorbed to resuspended sediments induced by dredging, the task then entails the assessment of dredging-induced plumes and deposition patterns of dredged sediments and associated contaminants. The contaminant distribution is shown at appendix 2. With recent advances in both computational hydraulics and computer technology, an efficient method to make the assessment is to use numerical models to predict these events within target areas over the life of the dredging project.

This appendix presents the approach for evaluating the sediment dredging resuspension, transport, and redeposition using readily available modeling technology for the Newark Bay EA. Section 2 describes the capabilities and basis of the MIKE3 Particle Analysis (PA) model, which is part of the MIKE3 suite of models developed by Danish Hydraulic Institute (DHI). This is followed by modeling strategy as outlined in Section 3. Section 4 summarizes the methods and results of model calibration and verification based on replicating the measured sediment plumes from field ADCP (Acoustic Doppler Current Profiler) deployments at two different Newark Bay dredging locations and times, as well as sensitivity tests on critical model parameters. Section 5 presents the model-predicted deposition patterns of resuspended sediments due to HDP dredging within Newark Bay. Section 6 presents deposition patterns due to other dredge activities in the bay which will occur simultaneously (but separately) with the HDP. Section 6 summarizes the cumulative 5-year impacts due to HDP dredging an other dredging activities in Newark Bay by geomorphic areas.

2 MODEL DESCRIPTION

The Particle Analysis (PA) model, which is part of the MIKE3modeling suite developed by Danish Hydraulic Institute (DHI), is used here to predict the resuspension and deposition of suspended sediments released by dredging operation within a body of water, in this case, the Newark Bay Study Area

2.1 Hydrodynamic Model

The advection and dispersion (movement) of particles are driven by the current fields in the NBSA model domain. The PA model is linked with and driven by a separate model describing the three-dimensional hydrodynamics of Newark Bay (water surface elevations and currents). The hydrodynamic model was constructed on the MIKE3 HD model platform, a general, non-hydrostatic model system which simulates unsteady flows due to the applied influences of bathymetry, water levels, meteorology, river flows, and other factors. The hydrodynamic model was originally developed for the Corps of Engineers New York/New Jersey Harbor Navigation Study (USACE 1999). The model was used to evaluate the hydrodynamic and water quality impacts associated with deepening the harbor navigation channels to 50 feet. For details on model development and calibration, please reference USACE, 1999. The model was adapted for the purposes for the Newark Bay EA, using the same hydrodynamic conditions evaluated in the 1999 FEIS.

The MIKE3 model domain encompasses the NY Bight, Long Island Sound, Raritan Bay, NY Harbor, Newark Bay, and the tidally-influences reaches of the Hudson, Passaic, and Hackensack Rivers. The model is composed of overlapping grids of variable resolution, using nested areas of higher resolution (See Figure 1). The model computes water level, current velocity, temperature, and salinity at each grid point in the model domain over time. Resolution at the offshore Atlantic Ocean boundary is 2025m between calculation grid points, while in Newark Bay the resolution is 75m between adjacent points, providing resolution of the navigation channels. Figure 2 displays a detailed view of the 75m model domain, which includes NY Harbor, Kill Van Kull, and Newark

Bay. The MIKE3 model is fully three-dimensional running in non-hydrostatic mode, with a vertical resolution of 2 meters. There are nearly 70,000 computational points within the 75m domain. The model includes the influences of tides, winds, salinity, temperature, and freshwater discharges (rivers and outfalls). The hydrodynamic solution used for the dredge resuspension modeling corresponds with the model calibration period, August-September, 1995.

2.2 Particle Analysis Model

A Lagrangian particle tracking model was utilized to model the material resuspended during dredge operations. A Lagrangian model follows the progress of individual particles in a water body as the parcels are pushed by hydrodynamic forces while an Eulerian model computes currents from a fixed location. The difference between the two models is the frame of reference. A Lagrangian approach is equivalent to an observer sitting a boat being pushed by currents in a river, while an Eulerian approach is equivalent to an observer sitting in one place and watching the river currents pass by. In the case of the Newark Bay model, the Lagrangian model allows the path of the particles in the Bay to be traced and recorded.

Resuspended sediments from a dredge bucket may be visualized as a cloud or plume of sediment particles in the water body. The cloud will move with the currents around the dredge, dispersing and thinning as sediment grains settle to the bottom and turbulence mixes the cloud. The modeling of millions individual sediment grains comprising the plume would require computing power and time well beyond the capabilities of modern desktop computers. It is therefore necessary to model the plume as a limited number of discrete "particles," where each particle represents an aggregation of a certain quantity of sediment. After the particles are released into the water body, the model records the path of each individual particle as it is advected (moved) by the currents relative to the hydrodynamic model grid described in Section 2.1. The particles will be transported by the currents until the settling velocity of the particle and attenuation of currents allows the particle to settle to the bottom. After the model is run for a given duration, the model calculates a map of the redistributed sediments by counting the number of particles that have accumulated in each grid cell.

2.2.1 Advection and Dispersion

The Particle Analysis (PA) model of the MIKE 21 & MIKE 3 modeling suite is based on the random walk technique where an ensemble of particles is followed instead of solving the Eulerian advection-diffusion equation. The particles move due to the advective current and due to turbulent fluctuations. The advective velocities are obtained from the MIKE3 HD hydrodynamic simulation whereas the turbulent contributions are controlled by the dispersion coefficients, which represent all of the mechanisms that cause mixing at scales smaller than those at which the mass transport equation is averaged. Sediments are represented by non-decaying (i.e. conservative) particles. The transport of a conservative substance in the MIKE3 PA model is based on the following time and space averaged equation (DHI, 2006):

$$\frac{\partial(ch)}{\partial t}+\frac{\partial(uch)}{\partial x}+\frac{\partial(vch)}{\partial y}=\frac{\partial}{\partial x}\left[hD_{xx}\frac{\partial c}{\partial x}+hD_{xy}\frac{\partial c}{\partial y}\right]+\frac{\partial}{\partial y}\left[hD_{yx}\frac{\partial c}{\partial x}+hD_{yy}\frac{\partial c}{\partial y}\right]$$

Where:

c(x,y,t) is the depth-integrated concentration

u(x,y,t) is the x component of depth-integrated velocity (from MIKE3 HD)

v(x,y,t) is the y component of depth-integrated velocity (from MIKE3 HD)

h(x,y,t) is the water depth (from MIKE3 HD)

D_{xx}, D_{xy}, D_{yx}, D_{yy} are dispersion coefficients to represent sub grid-scale mixing

Designed to simulate the surface and subsurface transport of a substance suspended in the water column, the model divides the substance into discrete particles and then assigns a set of spatial coordinates to each particle. It is assumed that these particles advect with the surrounding water body and diffuse as a result of random processes. In a random-walk model the transport of each particle at each time step is tracked by computing the movement due to the deterministic advective force as well as random component which approximates the random and/or chaotic characteristics of time-averaged tidal mixing. In the MIKE3 PA model, the position of each particle is described by the Langevin equation (DHI, 2006):

$$\frac{\partial \mathbf{x}}{\partial t} = A(\mathbf{x},t) + B(\mathbf{x},t)\xi(t)$$

Where:

x(t) is the position of the particle at time t

A(**x**,t) is a known vector representing the deterministic force acting on **x**(t) (advection)

B(**x**,t) is a known tensor that characterizes the random forces (dispersion)

ξ(t) is a vector composed of random numbers

In this way, which is characteristic of the Lagrangian Discrete Parcels Method, the sediment is represented by a large ensemble of small particles. The Lagrangian Discrete Parcel scheme calculates the displacement of each particle as the sum of an advective deterministic component and an independent, random Markovian component, which statistically approximates the random and/or chaotic nature of time-averaged tidal mixing.

The movement of each particle is affected by the physico-chemical processes. Once the particles are released in the water body, their discrete path and mass are followed and recorded as a function of time relative to the reference grid system fixed in space. Then the density distribution of the ensemble can be interpreted as the concentration of suspended sediment.

The computation of the concentration from the distribution of particles is done at the end of a time step. The horizontal position of a particle defines which grid cell it "belongs to", thus the number of particles in each grid cell can easily be found. The concentration is obtained by dividing the total mass of the particles in a grid cell by the volume of the water in the grid cell. This gives a depth integrated concentration. A similar approach applies to layers as opposed to the entire water column whereby only particles in a specified depth range are counted and the integrating is over the layer depth.

This relatively extensive account given above is meant to highlight that the PA model drives and tracks the movement of an ensemble of particles, or particle cloud/plume, rather than individual sediment grains. Particles are released at a specified constant number per computational time step, i.e., at a constant rate, which does not influence the model outcome in terms of sediment deposition except to impart a "smooth" look to the concentration field. For example, for a time step of 30 seconds, if 5 particles are released at each time step and a constant source flux of 5 kg/s is specified, then each released particle would represent a mass of 30 kg.

2.2.2 Sediment Processes

The particle tracking model simulates sedimentation processes by assigning sediment parameters to each released particle. The properties of the released particles are described by their settling velocity, either constant or specified as a distribution of velocities or grain sizes. Particles may settle to the bed if due to settling, provided the bed shear stress is low enough to permit sedimentation. The mass of the particle cloud can change due to sedimentation and resuspension. The model calculates the concentration field of the substance by tallying the number of particles in each grid cell.

Vertical velocity in the PA model is controlled by three processes: advective vertical velocity, settling velocity of the particles, and vertical dispersion. The advective component is determined by the vertical current velocity from the three-dimensional hydrodynamic model. Settling velocity of the particles is assigned by the model set up. Each particle in the Newark Bay MIKE3 PA model is assigned a constant settling velocity. Settling velocity may be assigned individually to each particle source in the model. Two setting velocities, one lower, one higher, were assigned to the model dredge release sources to represent fine-grained suspended material and aggregated (clumped) sediments, respectively. Dispersion is calculated as the contribution of turbulence. Change in vertical position per time step is calculated according to the following equation:

$$\Delta z = (w + V_{set})\Delta t_p + \Delta D_z$$

Where:

Δz is the change in vertical position

w is the vertical current velocity produced by MIKE3 HD

V_{set} is the particle settling velocity

ΔD_z is the vertical dispersion component

A particle will settle to the bed if the bed shear stress is less than the critical value. Shield's Parameter (K_s) is used define the critical shear stress:

$$K_s = \frac{\tau}{D_{65}(S_s - 1)\gamma}$$

Where:

τ is critical shear stress

D_{65} is the diameter which 65% of sediment material is less than

S_s is the density of surface material

γ is the unit weight of water

The MIKE3 PA manual quotes typical values of Shield's parameter as ranging from 0.045 for sand to 0.2 for clay. If the shear stress on the bed exceeds the critical Shield's Parameter, then a settled particle may be resuspended.

2.3 Model Limitations

The PA model provides a robust tool for simulating the release of dredge sediments. The Lagrangian solution allows for the tracking of sediments from a specific location within the model grid to the point where the particle settles to the bed. The model is set up to approximate sediment behavior. The individual particles are assigned a settling velocity and all particles may be resuspended if bottom shear stress is higher than the deposition threshold. However, there are sediment processes which the model does not account for, among these:

- Settling velocity as a function of concentration (flocculation) processes. The PA model assumed a settling velocity based on individual particles and does not account for changes in settling based on the concentration of suspended sediment. However, for concentrations less than 100 mg/L (as is typical in Newark Bay) this approximation is valid.

- Bed consolidation. The model assumes the particles which settle to the bed have a constant resuspension shear stress. In reality, sediments will consolidate over time and densities and critical shear stress will rise correspondingly.

3 MODELING PROTOCOL

In the PA module, a dredge is modeled as a point source of particles. At a given location, particles are released throughout the water column at a mass rate estimated to match the assumed loss rate for the dredge plant. The goals of the model assessment are twofold: 1) to assess overall sedimentation rates on the Newark Bay shoals due to dredge resuspension and 2) to identify the associated contaminant transport from the HDP project area to other areas of the bay.

The HDP contract areas that may influence the Newark Bay RI/FS (i.e., those contracts operational during the sampling) are: S-NB-1, S-NB-2, S-E-1, S-AK-1, and S-AK 2/3. To assess the transport of potentially contaminated sediments, it is important to trace the path of sediments resuspended from distinct parts of the bay. To that end, each contract area is further subdivided into 2-3 subareas where each subarea is modeled as an individual simulation in MIKE3 PA. Figure 3 shows the subdivision of the Bay. Subareas were selected based on similar geomorphic area or dredging type. For instance, the channel widening on the south side of South Elizabeth Channel (S-NB-2(B)) has been assigned its own area because this area is primarily new work, excavating an historic berth where sediments may have deposited during the last 50 years.

Each subarea is assigned a number of particle sources to approximate the variation in spatial release as the dredge moves over the HDP project area. The model is run for a predetermined amount of time to trace the movement of resuspended sediments due to normal tidal currents. A simulation is conducted for each subarea to trace the path of sediments released from the subarea. The model tracks where each particle released settles to the bed. The result of the simulations is a map of resuspended sediment mass deposited over Newark Bay due to dredging in one subarea of the Bay. To compute the overall estimated sedimentation due to the HDP contracts, the results of the individual simulations are added together.

The individual subarea simulations are used to assess distribution of contaminated sediments from areas of elevated concentration. Contaminate concentration within a subarea is based either on previous USACE composite samples or on EPA cores of bed sediments. If there are areas of elevated concentration within a subarea, a map of sediment deposited from that subarea may be produced and the significance of the contaminant release may be assessed (see Appendix 2 for further discussion of the contaminant assessment).

3.1 Model Assumptions and Parameters

The dredge resuspension modeling involves the following assumptions and ranges of values:

a) Tidal currents. The modeling assumes that tidal currents are the dominant force in mapping the path of resuspended suspended sediments from dredging activity. The effects of storm events, vessel resuspension, and other factors are excluded from the analysis.

b) Dredge resuspension fraction (loss rate). The amount of resuspension, reported as percent of in situ mass, has been the subject of numerous studies and publications. For mechanical dredging of silts and clays, the available literature reports release rates between 0.1% and 9% (Bolen, 1979; National Academy, 1997; Hayes and Wu, 2001; National Research Council, 2006). Enclosed clamshells are at the lower end of this range and are estimated to reduce release by a factor of 2 over open clamshells (NRC, 2006). Release estimates vary widely depending on type of dredge, type of sediments, rate of dredging, condition of substrate, location of measurements, and analytical methods. A conservative estimate of 3% (upper-end of estimated values for enclosed clamshells) was selected for implementation with the Newark Bay resuspension model.

c) Dredge types. Two mechanical dredge types are anticipated for the HDP dredging. An environmental clamshell shall be employed for recently deposited black silt. The black silt represents recently deposit material which is more likely to contain contamination and is designated for upland disposal. An excavator dredge shall be used for HARS-suitable clays, sands, and gravel. For the S-NB-1 contract area, approximately 1/3 of material will be removed with environmental clamshell, and 2/3 with an excavator dredge. There are also areas of rock to be drilled and blasted. The release rates from the excavator dredge are expected to be less than the environmental clamshell due to the high degree of consolidation of the in-situ sediment, even after taking into account the reduced sediment loss rate from an environmental clamshell. The release rates from the excavator dredge which dredges rock, gravel and the very highly consolidated Pleistocene clay are conservatively assumed to be the same as from enclosed clamshell dredging.

d) Sediment Volumes. US Army Corps of Engineers provided estimates of the expected volumes to be dredged in each contract area. Volumes for the corresponding model subareas were computed based on fractional area. Table 1 presents the expected dredge volumes for each subarea and the estimated volumes lost during dredging (3% loss rate).

Table 1: Projected Environmental Clamshell Dredging and Loss Volumes

Model Subarea	Total Environmental Clamshell Dredging (cy)	Modeled 3% Volume Loss (cy)
S-E-1(A)*	414,289	12,429
S-E-1(B)*	215,111	6,453
S-E-1 TOTAL	**629,400**	**18,882**
S-NB-1(A)*	143,164	4,295
S-NB-1(B)*	219,622	6,589
S-NB-1(C)*	214,514	6,435
S-NB-1 TOTAL	**577,300**	**17,319**
S-NB-2(A)*	129,138	3,874
S-NB-2(B)*	200,594	6,018
S-NB-2(C)*	97,068	2,912
S-NB-2 TOTAL	**426,800**	**12,804**
S-AK-1 TOTAL	**120,600**	**3,618**
S-AK-2 TOTAL	**59,100**	**1,773**
S-AK-3 TOTAL	**21,000**	**630**

* Values estimated based on proportion of total area
Total volume estimates provided by USACE

e) In situ sediment density. In situ density of sediments was based on cores collected by USACE and EPA in the channel dredge prism between 1998 and 2005. Cores results displayed distinct difference in density (albeit with significant scatter) between the recently deposited surficial sediments, the consolidated sediments of Newark Bay and Arthur Kill.

The in situ dry bulk density for the dredged areas was applied as follows: 1500 kg/m^3 for Newark Bay channels and Arthur Kill (NB, SE, E, and AK contract areas) HDP material and 800 kg/m^3 for maintenance dredging material (regardless of location) See Appendix 2 for detailed analysis of sediment cores.

f) Deposited density. Sediments which deposit due to dredge resuspension are assumed to have a dry bulk density equal to the surficial sediments within Newark Bay: 750 kg/m^3.

g) Sediment release mechanisms. The far-field distribution of resuspended sediments is dependent on the vertical release of sediment within the water column. As a clamshell bucket cycles through its motion, sediment may be released near-bottom, mid-depth, or on the surface. The model was set up to distribute the vertical release of sediment based on the vertical distribution reported in McClellan et al. (1989). The model follows a regular cycle of vertical release points as described in **Table 2**.

Table 2: Dredging Cycle Resuspension Release Rates and Depths

Release Depth (% of total depth)	Normalized Release Rate	Direction of Bucket
80%	1	Up
50%	0.5	Up
10%	0.2	Up
10%	0.1	Down
50%	0.1	Down

h) Settling behavior. The resuspended sediments are broken into two fractions with different settling velocities. One third of the sediment mass released was assumed to have a higher settling velocity represent aggregated sediment (clumps) or coarse-grained sediments released from the bucket, while for the balance two thirds, a smaller settling velocity appropriate for cohesive disaggregated fine-grained sediments was prescribed. This distribution of aggregated versus disaggregated sediments is based on the experience of US Army Engineer Research and Development Center (ERDC) from recent acoustic plume measurements of closed clamshell dredging operations (unpublished). Numeric values of settling velocity are discussed below in model calibration.

3.2 Model Set Up

The Newark Bay HDP project is anticipated to extend over 5 years (2007-2012). The dredging will be broken into six individual contract areas. Depending on the phase and season, a single dredge, multiple dredges, or no dredges may be operating in Newark Bay at any given time. It is impractical to explicitly simulate the full 5-years of dredging due to uncertainties in the number of dredges operating at a given time as well as limitations on speed of desktop computer simulation. Therefore, the dredge contract was modeled schematically, using a typical spring-neap tidal cycle to define the distribution of resuspended sediments from the dredges. The total impact of the HDP was assessed by extrapolating the results of the spring-neap simulations to represent the total volume of dredging reported in Table 1.

3.2.1 Hydrodynamics

The PA model was driven by three-dimensional hydrodynamic flows from the previously calibrated MIKE3 Hydrodynamics module (See Section 2).

3.2.2 Simulation Duration and Time Step

Each simulation consists of 2 weeks of simulation, encompassing a typical spring-neap cycle. The period simulated (tide, river discharge, and wind conditions) is 28 August to 11 September, 1995. This is the same period simulated for water quality calibration and hydrodynamic verification in the 1999 HDP EIS (USACE, 1999). The PA model uses a time step of 30 seconds. According to the application guidelines for the PA model, the time step should be sufficiently small that a particle will not move further than one grid cell. With a 30-second time step, a current velocity of up to 2.5 m/s may be resolved on a 75-meter grid (maximum currents observed during the simulation were 2.8 m/s, typical currents are much less).

3.2.3 Bathymetry

The base bathymetry (see Figure 2) represents conditions after completion of the S-KVK-2 and AK-2/3 contracts, i.e., KVK depths at 53 feet MLLW, AK depths at 43 feet MLLW, with Newark Bay depths representative of fall 2005 conditions.

3.2.4 Simulation Methodology

The entire dredging domain was divided spatially into 11 subareas as shown in Figure 3. Several particle release sources were specified within each subarea to represent discrete areas of dredge activity. Each source released particles at varying water depths on a regular cycle to simulate the vertical release distribution of a bucket cycle. The model traced the concentration of particles over the model grid as well as the location and number of particles which settle within each grid cell. Each source also "walks" during the simulation to neighboring grid cells (75m apart) at about 1.5 day intervals so that dredge sources spend an equal duration over each grid cell within the dredging subarea.

A separate spring-neap simulation was conducted for each subarea with the output of each simulation specifying the mass distribution over Newark Bay due to dredging in the subarea. The results of each 14-day simulation were then extrapolated (factoring of the particle tracking model results of suspended sediment to account for the total amount to be dredged for the HDP; not spatial extrapolation) to account for the anticipated volume of sediment from each area. See Table 1 for anticipated dredging volumes of each subarea.

3.2.5 Output

Output from the model was used to produce distribution maps of deposition thickness due to dredging over the duration of the HDP construction project in Newark Bay, which are used to create the composite deposition due to all the contracts or to trace deposition patterns due to dredging in one part of the bay.

4 MODEL CALIBRATION AND VERIFICATION

As described earlier the model simulates the fate of resuspended dredge sediments by tracing particles as they move through the water and ultimately deposit on the seabed. It is not practical to measure in the field the deposition due to a unique dredge source because the sediments become mixed with existing bottom sediments and other resuspension sources. Therefore, the only means of calibrating the model to actual dredge resuspension is by measuring total suspended sediments (TSS) in the vicinity of an operating dredge and compare measured TSS to the model predictions under similar hydrodynamic conditions. Two recent series of TSS data generated from field monitoring of dredging-induced plumes (See Appendix 3) in the project vicinity were available for model calibration and validation.

4.1 Model Calibration

The first TSS measurement was conducted near an operating dredge at Shooters Island corresponding to subarea AK-1 as shown in Figure 4. The measurement program consisted of a boat-mounted Acoustic Doppler Current Profiler (ADCP) to measure the flow field in three dimensions and the acoustic backscatter of suspended sediments. The ADCP instrument was calibrated with concurrent suspended sediment sampling for subsequent laboratory analysis of in-situ suspended sediment concentration and sediment gradation. The backscatter readings are then converted to TSS based on the regressed backscatter measurement and concurrent in-situ suspended sediment concentration relationship to yield time series of the variation in suspended sediment concentration with tide and dredging operation. This data was used to calibrate the model by varying the various input parameters to achieve a qualitatively good match in terms of depth-integrated concentration (See Appendix 3 for details of the TSS data collection and results). The model calibration criteria was that the majority of measurements should fall within the maximum and minimum modeled concentrations during the data collection period and over the spatial extent of the measured plume.

The dredge operating at the site was a Cable Arm bucket dredge with an 18 cubic yard bucket and an average production rate between 114.8 cubic yards per hour during the ebb phase and 257.7 cubic yards per hour during flood phase. The model was calibrated to reproduce the flood and ebb tide depth integrated measurements conducted over two hours on 19 June and 20 June 2006. The hydrodynamic model and particle tracking model were run during a period of similar tide range and phase (based on measurements for the tide gage at Bergen Point) to compare with the measurements..

Figure 5(a) illustrates the position of the dredge and the measured transects near Shooters Island in relation to the model grid bathymetry. One set of transects was taken at both flood and ebb tide, giving a snapshot of the dredge plume at one time during each tide condition.

Model results were extracted along a line parallel with the flood and ebb currents for comparison with the measured extents of the dredge plume. Figure 5(b) displays a transect section aligned with the currents was selected along the channel from the “upstream” side of the dredge to the “downstream” side. Comparison of the suspended solids concentration along this line forms the basis of the model calibration.

For the purposes of the calibration, the PA model was output at a resolution of 15m in the vicinity of the dredge to capture gradients in the near-field TSS concentrations.

Basic assumptions for the calibration were an in situ dry density of 1500 kg/m^3 for new work dredging and a 3% loss rate as discussed previously. The equivalent mass release rate under these assumptions is 2.4kg/s and 0.9kg/s for the flood and ebb phases, respectively.

Near-field concentrations were found to be relatively insensitive to variations in settling velocity, dispersion, and Shield’s parameter. The near-field concentration in the model is determined mainly by advective currents and dredge source strength. With the mass rate calculated above, a good match was achieved between modeled TSS concentration and measured TSS given the following modeling parameters:

a) Settling velocity of 0.5 mm/s and 1.5 cm/s for fines and aggregated fractions, respectively. Settling velocity was assigned based on typical grain sizes for the fine sediments of Newark Bay and typical values for aggregate sediments. For fines, the /settling velocity was initially set using curves for stokes law assuming free falling particles and adjusted to reproduce measured TSS concentrations. While this method does not account for concentration-related processes such as flocculation, concentrations are generally less than 100mg/L and therefore do not play a large roll in determining settling velocity.

b) Dispersion coefficients were specified as proportional to the fluxes. The model default relationship between longitudinal and transversal dispersion was applied. Table 3 presents the dispersion coefficients used in the model.

Table 3: Dispersion Coefficients

Direction	Proportionality Constant	Max (m^2/s)	Min (m^2/s)
Longitudinal	1.0	1.0	0.01
Transversal	0.1	0.1	0
Vertical	0.01	0.01	0

c) Critical Shields number: 0.1 – equivalent to a critical bottom shear stress of 0.1 N/m^2, a typical value for cohesive sediments. Higher bottom shear stress will resuspend settled particles. Typical values of Shield's parameter of incipient motion vary between 0.045 for sand and 0.2 for clay.

Model sensitivity to the three parameters above is presented in the next section.

Figure 6(a) and Figure 6(c) display the mean and maximum depth-integrated TSS concentration of the modeled dredge plume during the 2-hour flood data collection period. Figure 6(b) displays the depth-integrated TSS concentration as measured by the ADCP (concentrations are adjusted to TSS over ambient, where ambient was estimated to be 6.6mg/L). Figure 7 displays the maximum, mean, and minimum modeled concentration along the section line compared to the measured data along the same line. TSS concentrations near the dredged were measured at about 191 mg/L while the mean modeled concentration during the flood measurements was 158 mg/L, with a maximum of 275 mg/L, which brackets the instantaneous measurement.

Figure 8(a) and Figure 8(c) displays the mean and maximum modeled depth-integrated TSS during the ebb phase, while Figure 8(c) displays the measured depth-integrated TSS transects. Figure 9 displays the maximum, mean, and minimum modeled concentration along the section line compared to the measured data along the same line. Peak concentrations near the dredge were lower due to the decreased production rate, 59 mg/L. The maximum model concentrations during the ebb phase were 66 mg/L with a mean value of 41 mg/L. Table 4 presents the peak near-field concentrations at the dredge source for both measured and modeled results.

Table 4: Peak Near-Field Depth-Integrated TSS Concentration at Dredge Source

Direction	Flood Tide Period	Ebb Tide Period
Measured	191 mg/L	59 mg/L
Maximum Model	275 mg/L	66 mg/L
Mean Model	158 mg/L	41 mg/L
Minimum Model	60 mg/L	27 mg/L

Due to variations in currents, the modeled plume is predicted to vary in concentrations and size over the two-hours of measurements. The model encompasses the range of measured concentrations observed in the plume and matches the spatial extent of the plume. The peak concentration near the dredge is well matched by the model. Both mean model concentration and measurements show a return to near-ambient concentration levels approximately 200m from the dredge. Due to differences in dredging rate, the concentrations measured during the ebb phase are substantially less than during the flood phase. The model matches this reduction in TSS. The mass in the water column and the extents of the plume are reasonably matched by the model, the model parameters (loss rate, settling velocity, shields parameter, and dispersion) are judged calibrated to represent dredge resuspension.

4.2 Sensitivity Tests

Model parameters were varied during calibration to examine effects on TSS concentration. Sensitivity tests for deposition patters were also conducted based on the calibration model parameters. The following discussion examine the model sensitivity to dispersion, Shield's parameter, and settling velocity in regards to predicted sedimentation patterns.

a) Dispersion coefficients: Dispersion can be specified either as constant or varying with the ambient currents, one coefficient in each spatial dimension: longitudinal, transverse, and vertical. To better reflect the sedimentary processes brought about by tidal dynamics, the latter option of varying with the currents has been adopted. Three different dredging sub-areas have been selected for representative tests: S-NB-1(B), S-NB-2(A), and S-NB-2(C) (See Figure 3). The sedimentation pattern refers to the deposited depth of sediment due to dredging resuspension computed using the surficial dry density of 800 kg/m^3.

Using the dredging sub-area S-NB-1(B), Figure 10 and Figure 11 show that the sedimentation pattern is not sensitive to an one-order increase in the value of the longitudinal dispersion coefficient from 1 to 10 (designated large) both in terms of the proportionality constant and the maximum value (in m^2/s).

Using the dredging sub-area S-NB-2(C), increasing the maximum value of the vertical dispersion coefficient from 0.001 m^2/s (small) to 0.01 m^2/s (average) and then to 0.1 m^2/s (large) while keeping the proportionality constant unchanged at 0.01, increases the sedimentation depth, especially in the vicinity of the dredge locations represented as sources with a correspondingly smaller spatial extent of the low values of the sedimentation depth. These changes are shown in Figure 12 to Figure 14.

The effect of the transverse dispersion coefficient can be gleaned from comparing Figure 12 (small vertical dispersion and average transverse dispersion coefficient of 0.1 m^2/s as the maximum) and Figure 15 obtained from a small but constant value for the vertical dispersion but large transverse dispersion coefficient of 0.5 m^2/s, and is found to be minor.

Based on the above analysis, the particle plumes and deposition patterns are not very sensitive to changes in the longitudinal dispersion coefficient and the transverse dispersion coefficient. The results, however, do evince more sensitivity to the vertical dispersion coefficient where the larger values lead to smaller plume and deposition extents and higher sedimentation depth. Also, smaller values of vertical dispersion coefficient tend to promote model stability.

For production runs, the three dispersion coefficients are specified through proportionality factors with their respective minimum and maximum values: longitudinal (1, 0.01 and 1.0 m^2/s), transverse (0.1, 0.0 and 0.1 m^2/s) and vertical (0.01, 0.0 and 0.01 m^2/s). It is to be noted that as a result of the Lagrangian approach, the resolution of the plume is not restricted by the grid size of the current field nor are the dispersion coefficients dependent on the grid size and time step. On the latter, the only restriction is that the particle should not move more than one grid space in one time step.

b) Shields Number: Based on the classical Shields diagram with subsequent amendment for the fine sediment range, the Shields number varies between 0.045 for sand (cohesionless) and 0.2 for mud (cohesive). For the case of low Shields number, changing the Shields number from 0.01 to 0.1 has practically no effect on the sedimentation pattern and thickness as seen from Figure 10 and Figure 16 for the dredging sub-area S-NB-1(B). For the case of high Shields number, increasing the value from 0.1 to 0.2 too does not result in any noticeable change as evident from Figure 13 and Figure 17 for the dredging sub-area S-NB-2(C).

Since the PA results are not sensitive to the Shields number within the recommended range, a value of 0.1 was assigned for all simulations.

c) Settling velocity: Both theoretical curves considering Stokes Law and measured curves as a function of sediment grain size and concentration levels are readily available and hence the settling velocities appropriate for the actual sediment grains obtained from field samples were used. The analysis done here is more to ensure that the changes in sedimentation pattern are consistent with the trend in the settling velocities.

Using the dredging sub-area S-NB-2(A), the changes in the sedimentation pattern for increasing values of the settling velocities are shown in Figure 18, Figure 19, and Figure 20. Small settling velocities refer to 0.5 mm/s for the fines and 1 cm/s for the sand fraction. The corresponding values for the average and large settling velocities are 1.5 mm/s and 1 cm/s, and 1.5 mm/s and 5 cm/s. There is a noticeable trend toward larger sedimentation depths at the vicinity of the dredging locations (sources) for increasing settling velocities as more sediments are prone to settling out but the effects are spatially constrained to the dredging locations. Far-field deposition extents (outside of the channels) are not sensitive to changes in settling velocity.

In summary, for the cases shown in Figure 10 to Figure 21, overall sedimentation patterns are similar although there are some changes consistent with the trend in the parameter values. Parameter values selected for the model production runs represent the median values from the sensitivity analysis.

4.2 Model Validation

The calibration of the model is validated by comparing the model results to a second, independent dredge event without changing model parameters. The second measurement program was conducted at a South Elizabeth Channel berth area over three ebb periods (July 10-11, 2006). The purpose of the dredging operation was maintenance dredging for a berth along the South Elizabeth Channel. The first ebb period was selected as the verification period, and occurred over 2 hours on July 10, 2006. Figure 21 displays the measured transects around the location of the dredge. The overall average production rate was 238.6 cubic yards per hour. An in situ dry density of 800 kg/m^3 was assumed for the dredged sediments, consistent with density encountered during maintenance dredging operations. Again the measured tidal range at Bergen Point during the measurement is used to select the appropriate time period of the hydrodynamic output to drive the PA model with the values of the calibrated parameters remaining unchanged but at a revised mass release rate (1.2 kg/s) consistent with the average production rate stated above. Figure 21 also displays two section lines used for comparison between model and measurements.

Figure 22(a) and Figure 22(b) displays the maximum and mean TSS concentration of the modeled dredge plume during the 2-hour data collection period. Figure 22(c) displays the TSS concentration as measured by the ADCP (concentrations are adjusted to TSS over ambient, where ambient was estimated to be 6.6mg/L). The measured transects cover a much smaller area than is predicted by the model plume. The model shows a large variation in plume concentration over the measurement period. Figure 23(a) and Figure 23(b) present the maximum, mean, and minimum modeled concentration along the section lines compared to the measured data along the same lines. The mean model concentration matches the measured near field concentrations. However, the model shows a secondary peak over the adjacent shoals and predicts a plume extending more than 500m from the dredge at certain times during the 2 hour measurements. The measurement transects did not extend over the adjacent shoals far enough from the dredge to verify the presence of this secondary plume. This secondary plume is a result of resuspension of particles which settled on the shoals and are resuspended as current velocity increases. Nevertheless, the model is deemed to have reproduced the measured near-field TSS, both in terms of point values and the spread of the plume reasonably well[1], using the calibrated parameters.

[1] In the context of the modeling effort "reasonably well" was defined as a majority of the measured data points that fell within the maximum and minimum concentrations predicted by the model during the plume measurement period. Modeled data is summarized and presented as minimum, mean and maximum within the two-hour window. The fact that the measured data fall within the temporal variability of the model led to the determination that the model is reasonably representing the extent and behavior of the measured plume.

5 HARBOR DEEPENING PROJECT DEPOSITION PATTERNS

The calibrated dredge resuspension model was run for each of the eleven dredging subareas. Each subarea was simulated for a two-week spring-neap cycle corresponding to 28 August 1995 – 10 September 1995. The model tracks the release of particles (both aggregated and disaggregate sediments) and the eventual deposition of the bottom. The model output is given in kg/m^2 over the domain of the model grid. The model output for each subarea is scaled to represent the total mass of dredging in the subarea estimated for the HDP. The redeposited mass is then converted to depth using the dry density of newly deposited sediments in Newark Bay.

The dry density is defined as the mass of solids in the bulk mixture of solids and water. The average dry density reported by EPA (2006) for the top six inches of Newark Bay surface sediment was 750 kg/m^3. It is necessary to compute the depth based on dry density to account for the fact that the deposited solids comprise only a fraction of the sediment layer they form. The remaining volume is taken up by water. Dry density computations on the EPA data may be found in Appendix 2.

Figure 24 thru Figure 35 present the predicted deposited depth of sediment due to dredging resuspension over Newark Bay and the adjacent channels and rivers for each of the 11 subareas. The deposition scale reports deposited sediments of 2mm or greater, which is the practical limit of detection of sedimentation by the most sensitive sediment monitoring technology. Note that the majority of sediment released is predicted to deposit on the channel bottoms in the vicinity of the dredge areas. There are two mechanisms at work which cause the deposition on channel bottoms: 1) the sediments which have a higher settling velocity (aggregated sediments) or are released close to the bottom will have a tendency to deposit near the source and 2) the depth of the channels in many cases prevents suspended sediments from rising over the banks and the sediments remain confined in the channels. Only fine sediments released high in the water column will deposit in the shallows of the bay.

Examining the sedimentation figures, Elizabeth Channel (Figure 24 subarea S-E1(A)) experiences some of the largest sedimentation depths (50-60 mm). Currents in Elizabeth Channel are very small and therefore resuspended sediments tend to deposit in the immediate vicinity of the dredge. The other area with higher sedimentation, on the order of 80mm (Figure 30), is the southern edge of South Elizabeth Channel (S-NB-2(B)). This area is a zone of channel widening, where large amounts of sediment are dredged over a relatively small area; therefore the near field deposition is greater than in areas where existing depths are closer to the 50-ft project depth.

Figure 35 displays the overall sedimentation predicted due to resuspension of sediments during the HDP in Newark Bay, produced by summing the deposition due to each subarea. Sedimentation greater than 2 mm is generally found immediately adjacent to the channel boundaries, and the nearby shoals (between South Elizabeth Channel and Arthur Kill, and over the Newark Bay CDF). Otherwise sedimentation occurs mainly on the channel bottoms, with sediment deposits found in the Kill van Kull and farther north into Newark Bay.

The deposition of resuspended sediments may be summarized by looking at three designated geomorphic area in Newark Bay: the channel bottoms, transitional zones between channels and undredged flats, and the shallow flats. Table 5 summarizes the mean, minimum, and maximum predicted depths in each geomorphic zone. Mean deposition on the channel bottoms was 10.0mm with variability between 0.0mm and 82.3mm. Mean deposition in the transition between channels and flats was 7.7mm with variability between 0.0mm and 60.9mm. Mean deposition on the Newark Bay flats was 0.8mm with variability between 0.0mm and 44.0mm.

Table 5 Deposited Sediment Depths from HDP by Geomorphic Area

Geomorphic Area	Deposited Sediment Depth		
	Minimum (mm)	Mean (mm)	Maximum (mm)
Channel Bottoms	0.0	10.0	82.3
Transition Zones	0.0	7.7	60.9
Flats	0.0	0.8	44.0

6 OTHER DREDGING PROJECT DEPOSITION PATTERNS

Maintenance dredging of existing channels and other new work dredging projects outside of the HDP may also resuspend sediments in Newark Bay. Other dredging and maintenance dredging will occur concurrently with the HDP. Estimates of other dredging, including maintenance, over the 5-year HDP to be conducted both by USACE and PANYNJ were prepared as described in Section 5.4 of the main EA document. Table 6 presents the estimated maintenance and other dredge volumes by project area. Several of these projects are anticipated to occur outside the limits of the HDP channels. Figure 36 shows the areas used in the resuspension model of these other dredging including maintenance.

Table 6. 5-year Dredge Volume Estimates for Other Dredging Including Maintenance

Dredge Area	Area (yd2)	USACE Dredging (yd^3)	PANYNJ Dredging (yd^3)	Total Volumes (yd^3)
Port Newark Channels	362,314	195,000	122,600	317,600
S-AK-1	321,506	-	-	-
S-AK-2	400,838	-	-	-
S-AK-3	354,185	117,000	75,995	192,995
S-E-1(A)	544,356	65,000	118,234	183,234
S-E-1(B)	298,296	-	64,790	64,790
S-NB-1(A)	284,313	30,000	-	30,000
S-NB-1(B)	383,928	-	-	-
S-NB-1(C)	647,677	20,250	140,675	160,925
S-NB-2(A)	471,760	14,750	102,466	117,216
S-NB-2(B)	148,509	-	-	-
S-NB-2(C)	385,651	-	-	-

Several simulations were conducted to investigate the contribution to sedimentation due to other dredging and maintenance dredging to be conducted during the 5-year HDP duration. Figure 37 presents the projected sedimentation depth associated with resuspended sediments during other dredging and maintenance dredging. The highest sediment accumulation is observed in the Port Newark channels intersections where the large cross sectional area reduces current velocities. The maximum sedimentation depth in the channels is 61mm (2.4 inches), while the maximum sedimentation outside the channel areas is 7mm (0.3 inches) over the Newark Bay CDF. Sedimentation outside of the channel areas is minimal.

7 CUMULATIVE 5-YEAR DEPOSITION

Figure 38 presents the cumulative deposition predicted by the combined effects of the HDP and other dredging including maintenance. The deposited thickness is higher in the areas where both the HDP and other dredging are predicted to have relatively high sedimentation, namely the Elizabeth Channel where it intersects the Port Newark Pierhead Channel. Table 7 presents the cumulative sediment depths by geomorphic area. In general, the contribution of other dredging including maintenance to resuspended sediment depth is less than half that of the HDP.

Table 7 Deposited Sediment Depths from HDP by Geomorphic Area

	Deposited Sediment Depth		
Geomorphic Area	Minimum (mm)	Mean (mm)	Maximum (mm)
Channel Bottoms	0.0	13.1	127.5
Transition Zones	0.0	9.1	70.1
Flats	0.0	0.9	49.4

8 FINDINGS AND SUMMARY

A numerical modeling framework was implemented to track the deposition of sediment resuspended by dredging activity in Newark Bay. The model used the MIKE3 particle tracking model (PA) to predict the transport and deposition of sediments released by environmental (closed) clamshell dredges. The model was calibrated and validated to reproduce the measured near-field TSS concentrations around dredges operating in Newark Bay in June-July 2006.

The model used a conservative 3% ratio of dredged material lost to resuspension in the water column and tracks the concomitant sediment movement and deposition. Dredge volumes for each contract area were evaluated based on USACE design estimates and associated mass was calculated using a typical dry density for consolidated channel sediments. The output of the model is a map of the distribution of deposited sediment mass density.

The model predicted the deposition patterns and mass distribution of sediments resuspended during the dredging of harbor deepening contracts S-E1, S-NB-1, S-NB-2, S-AK-1, and S-AK-2/3. Sediment deposit thickness is reported for the Newark Bay channels, transition areas, and shoal areas based on a surface in situ dry density of 750 kg/m^3. In addition, resuspended sediment deposits were estimated due to maintenance and other dredging in Port Newark Channel and PANYNJ berths during the 5 year HDP.

All model simulations demonstrate that the majority of resuspended sediment deposits in the immediate vicinity of the dredge, with smaller amounts deposited on channels outside of the dredge contract areas and in the shallows of the bay. The modeled cumulative sedimentation due to HDP dredging and maintenance dredging was minimal for the 5-year project lifetime. The predicted sedimentation depths were used to assess impact to the chemical analysis of the RI/FS. Details of the chemical analysis are found in Appendix 2.

9 REFERENCES

Bohlen, W.F., Cundy, D.F., Tramontano, J.M. (1978), "Suspended Material Distributions in the Wake of Estuarine Channel Dredging Operations," *Estuarine and Coastal Marine Science*, 9, pp. 699-711.

Danish Hydraulic Institute. (2005). MIKE21 & MIKE3 PA/SA: Particle Analysis and Oil Spill Analysis Module User Guide.

EPA (2006) Newark Bay Study Area Phase 1 Database. www.ourpassaic.org.

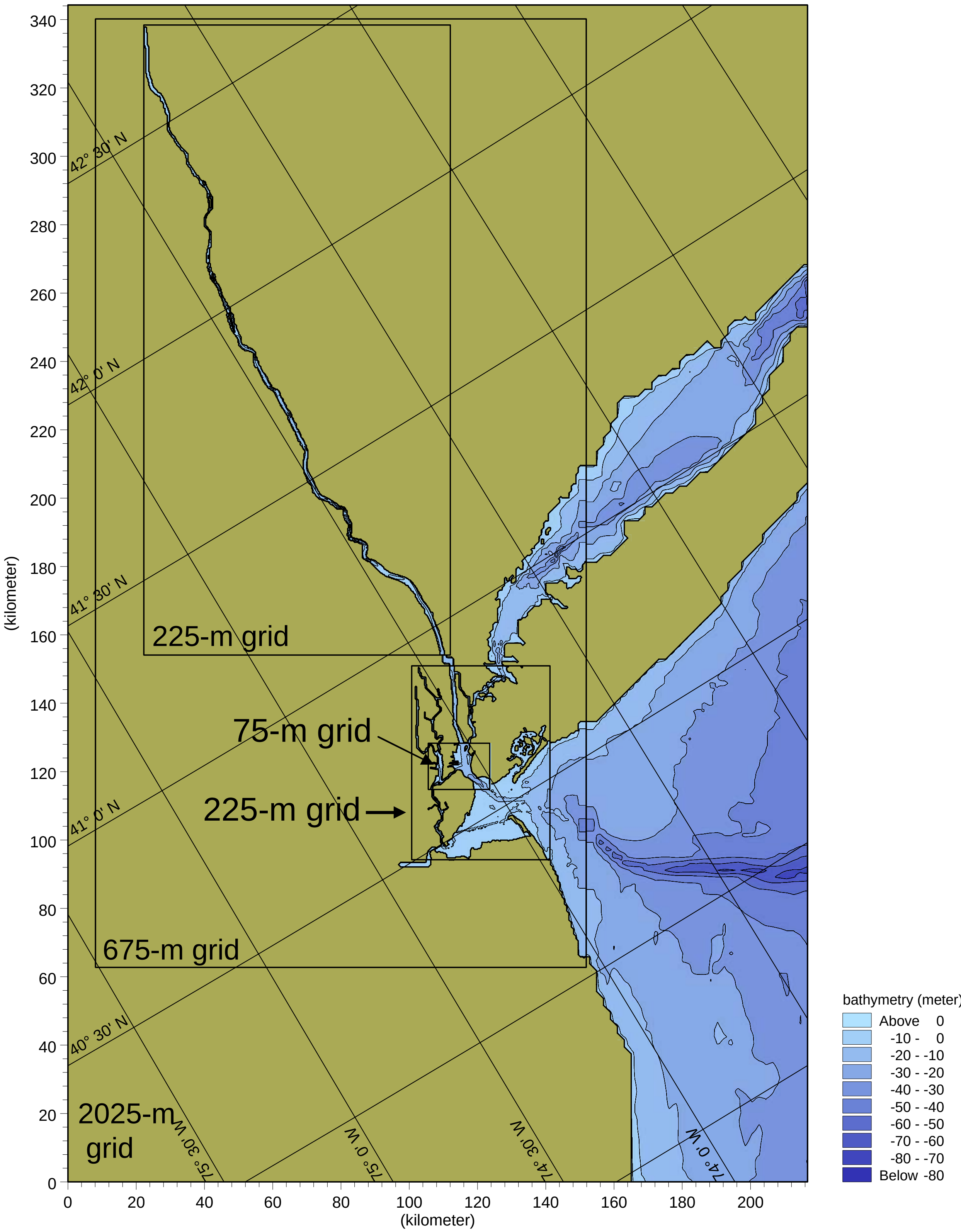
Hayes, D., Wu, P. (2001). "Simple Approach to TSS Source Strength Estimates," *WEDA Proceedings*, WEDA XXI, Houston, June 15 -27

McClellan, T.N., Havis, R.N., Hayes, D.F. and G.L. Raymond. (1989). Field Studies of Sediment Resuspension Characteristics of Selected Dredges. Technical Report HL-89-9, Environmental Laboratory, Waterways Experiment Station, Vicksburg.

National Research Council (2001). "A Risk-Management Strategy for PCB-Contaminated Sediments," Committee on Remediation of PCB-Contaminated Sediments, Board on Environmental Studies and Toxicology, Division on Life and Earth Studies, National Academy Press, Washington, DC.

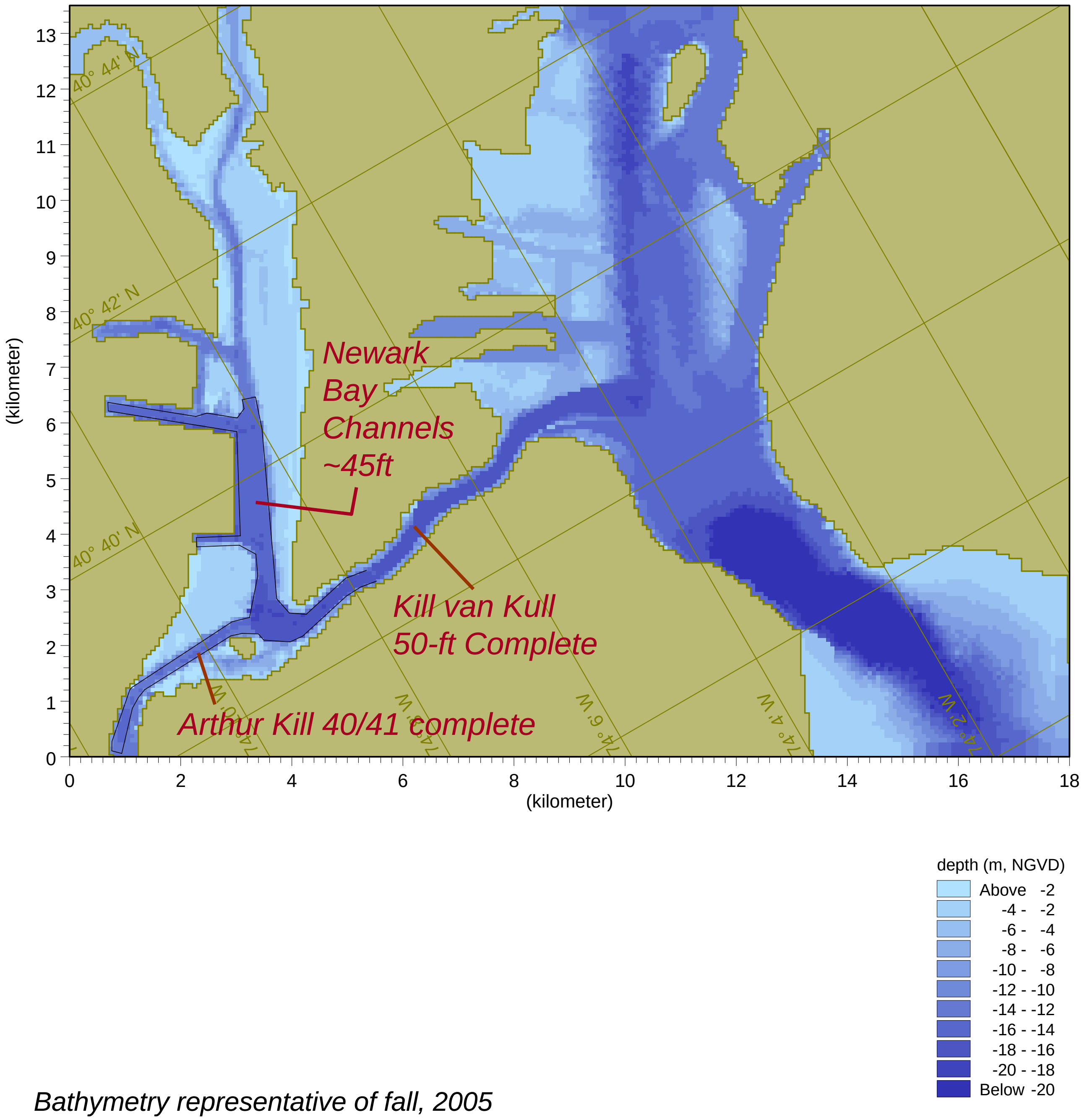
US Army Corps of Engineers (2006). "Suspended Sediment Plumes Associated with Navigation Dredging in the Arthur Kill Waterway, New Jersey," August 2006.

US Army Corps of Engineers (1999), NY District and NY/NJ Harbor Partnership, "New York/New Jersey Harbor Navigation Study, Hydrodynamic and Water Quality Modeling, Model Calibration, Verification, & Application," December.



US Army Corps of Engineers
New York District

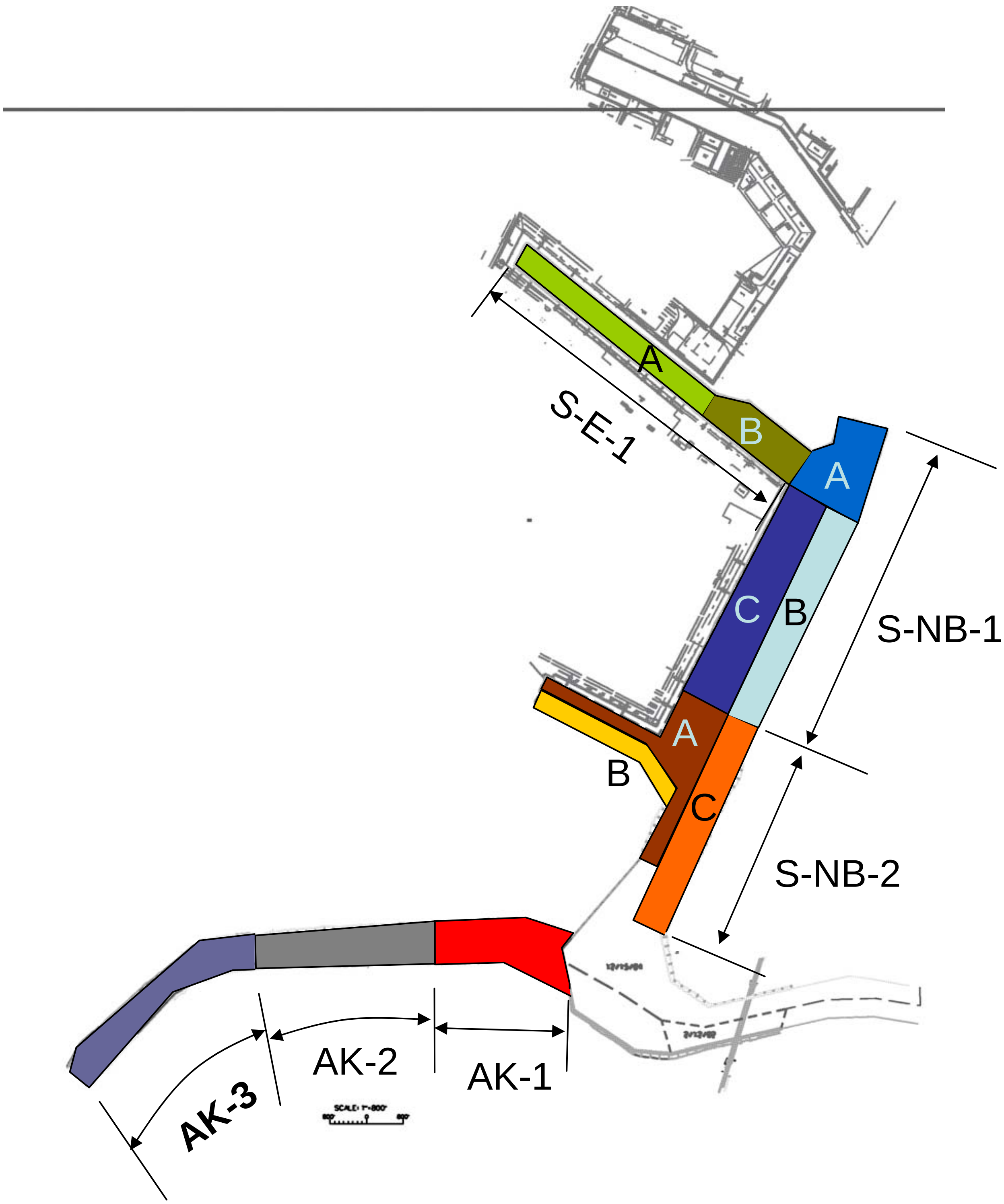
Figure 1
Hydrodynamic Model Domain



Bathymetry representative of fall, 2005

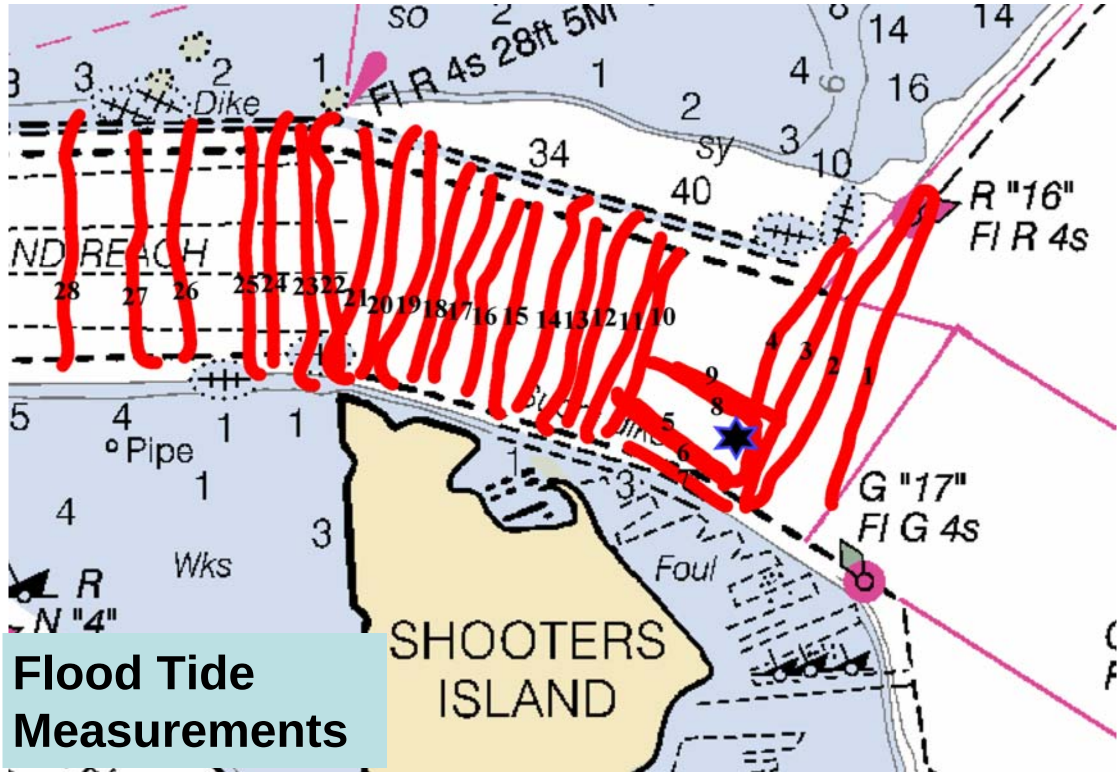
US Army Corps of Engineers
New York District

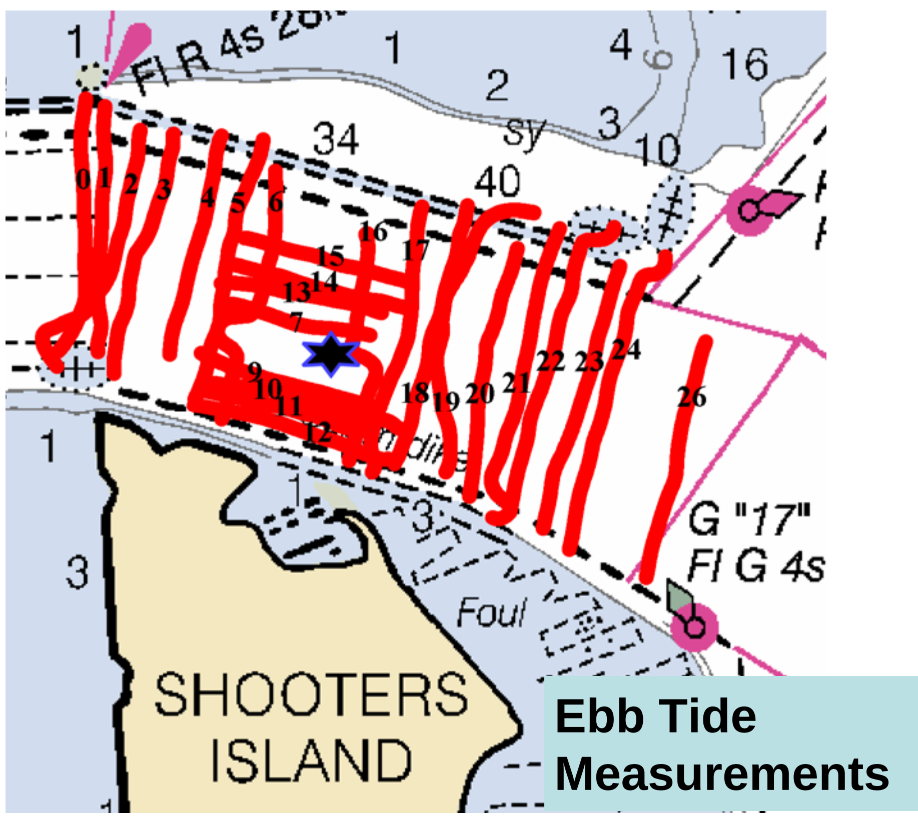
Figure 2
75m Grid and Bathymetry
For Newark Bay



US Army Corps of Engineers
New York District

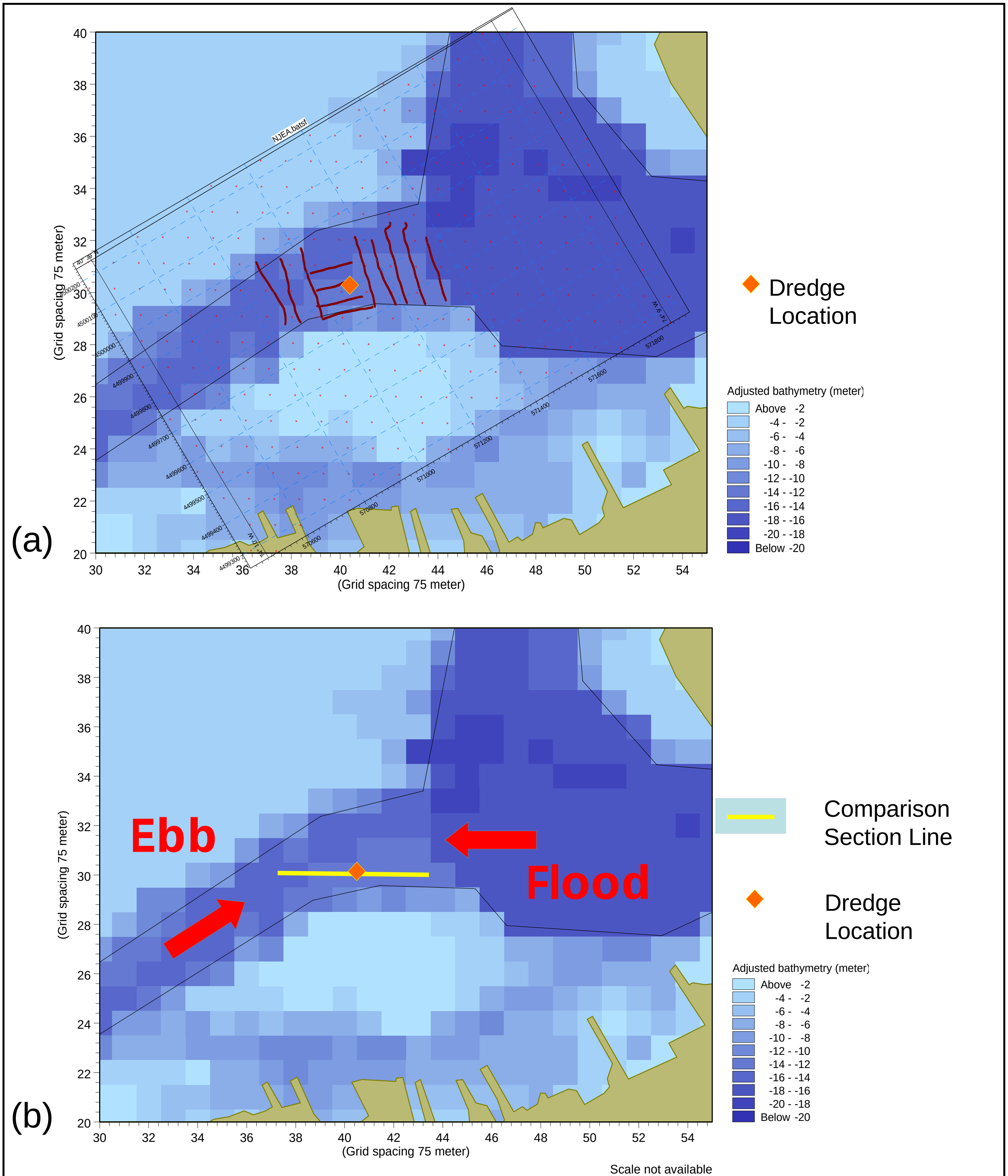
Figure 3
Dredge Model Subareas





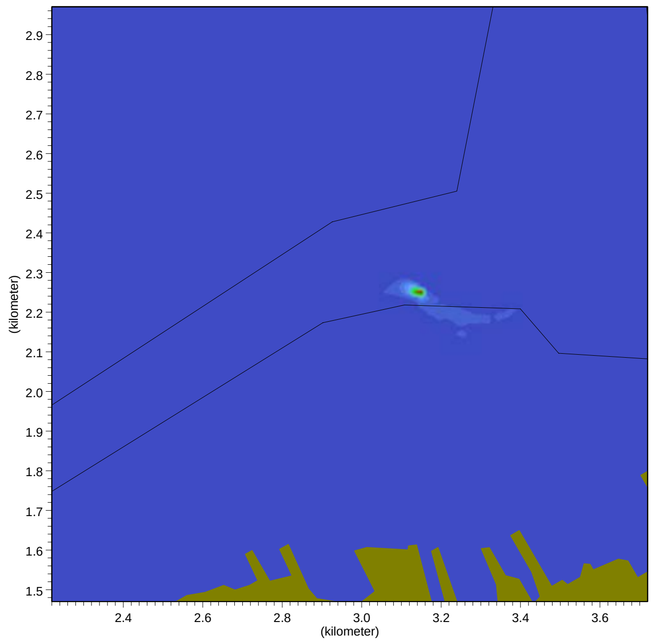
US Army Corps of Engineers
New York District

Figure 4
Measured TSS Transects
Arthur Kill Channel

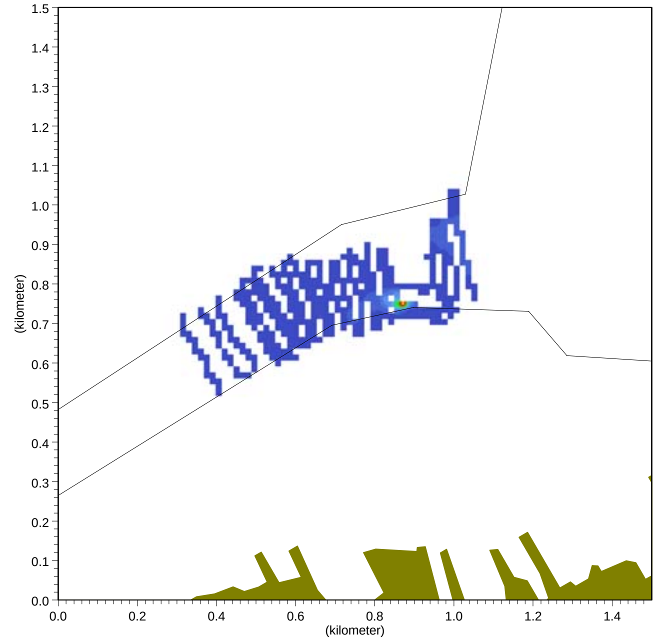


US Army Corps of Engineers
New York District

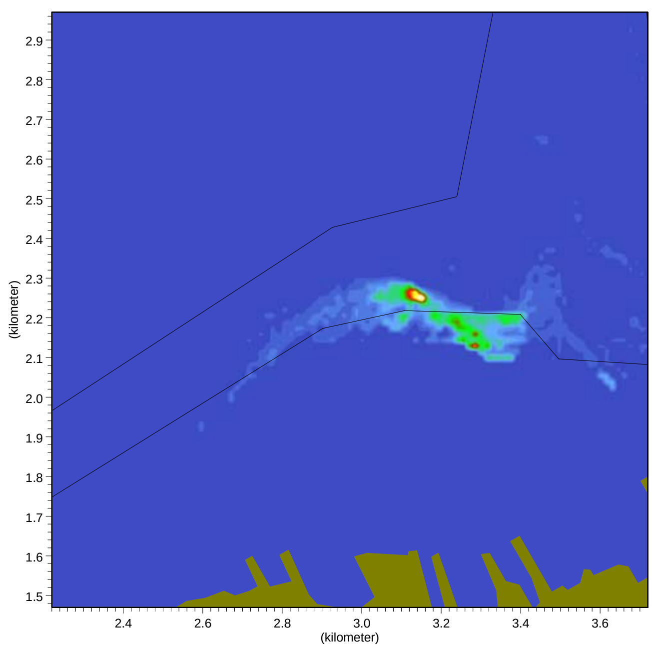
Figure 5
Selected Model Grid Locations for TSS Comparison – Arthur Kill



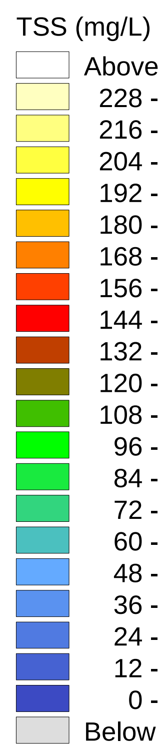
(a) Model (2hr Mean)



(b) Measured Transects

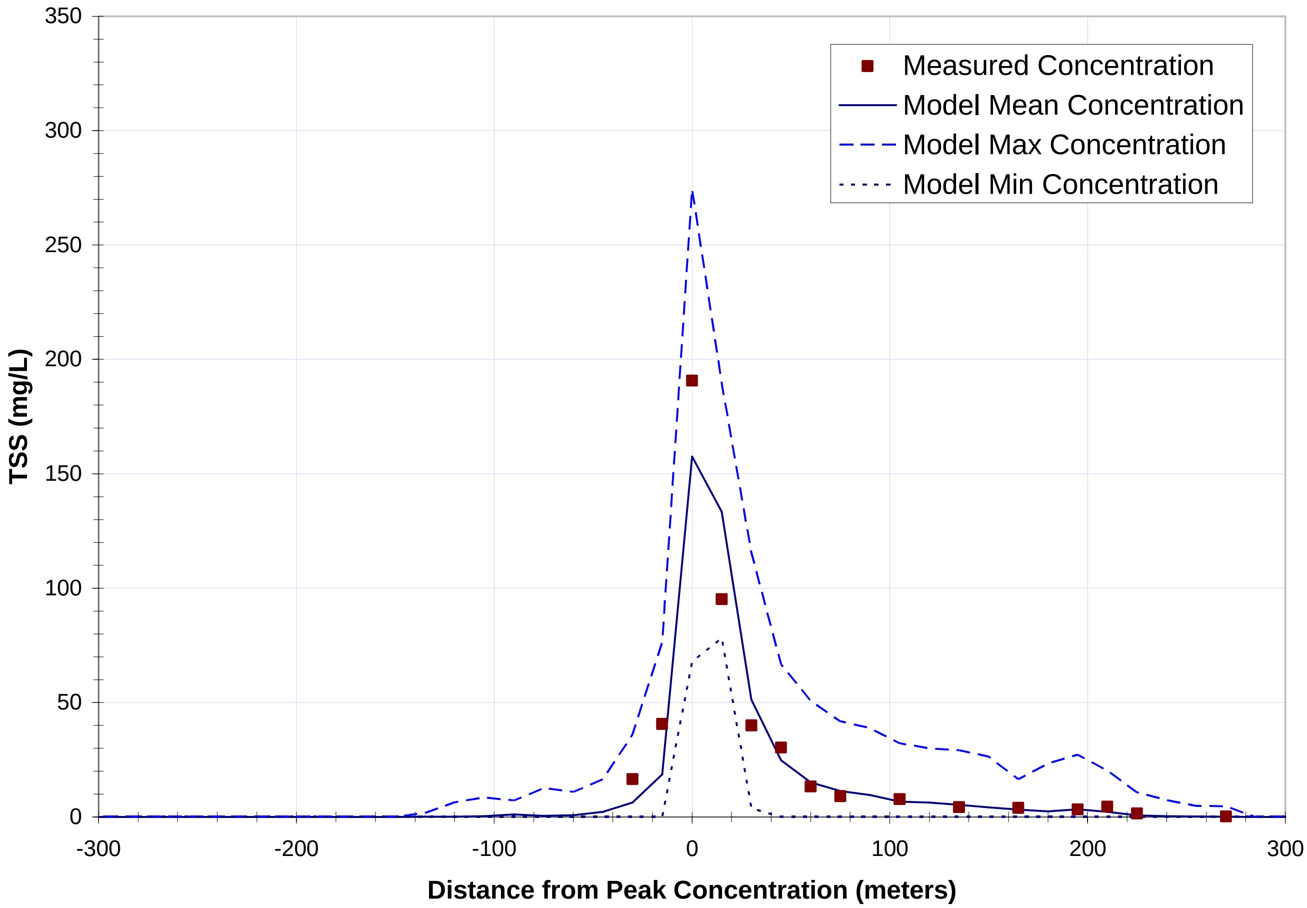


(c) Model (2hr Max)



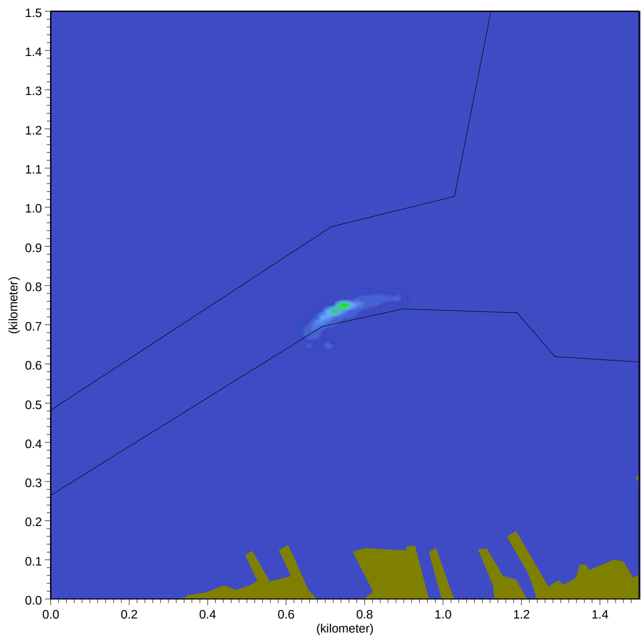
US Army Corps of Engineers
New York District

Figure 6
Flood Plume Concentration and Extent
Arthur Kill

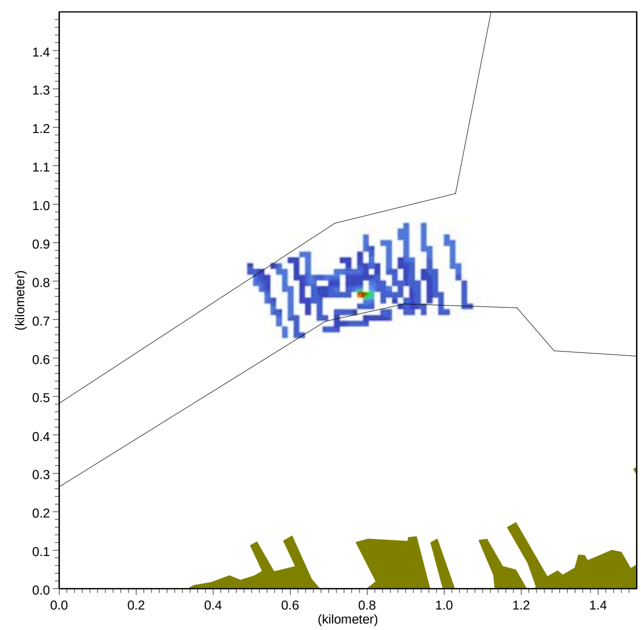


US Army Corps of Engineers
New York District

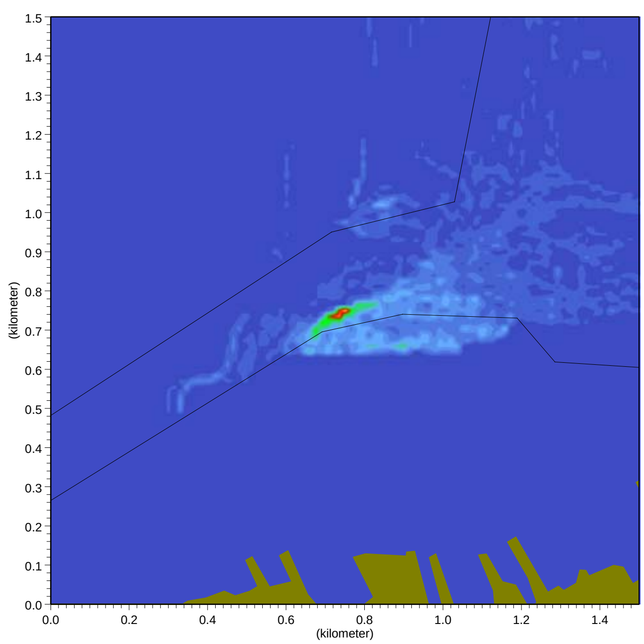
Figure 7
Flood Calibration Section Line
Arthur Kill



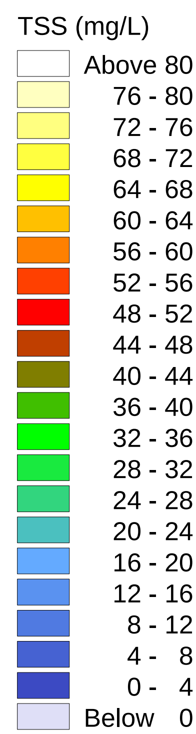
(a) Model (2hr Mean)



(b) Measured Transects

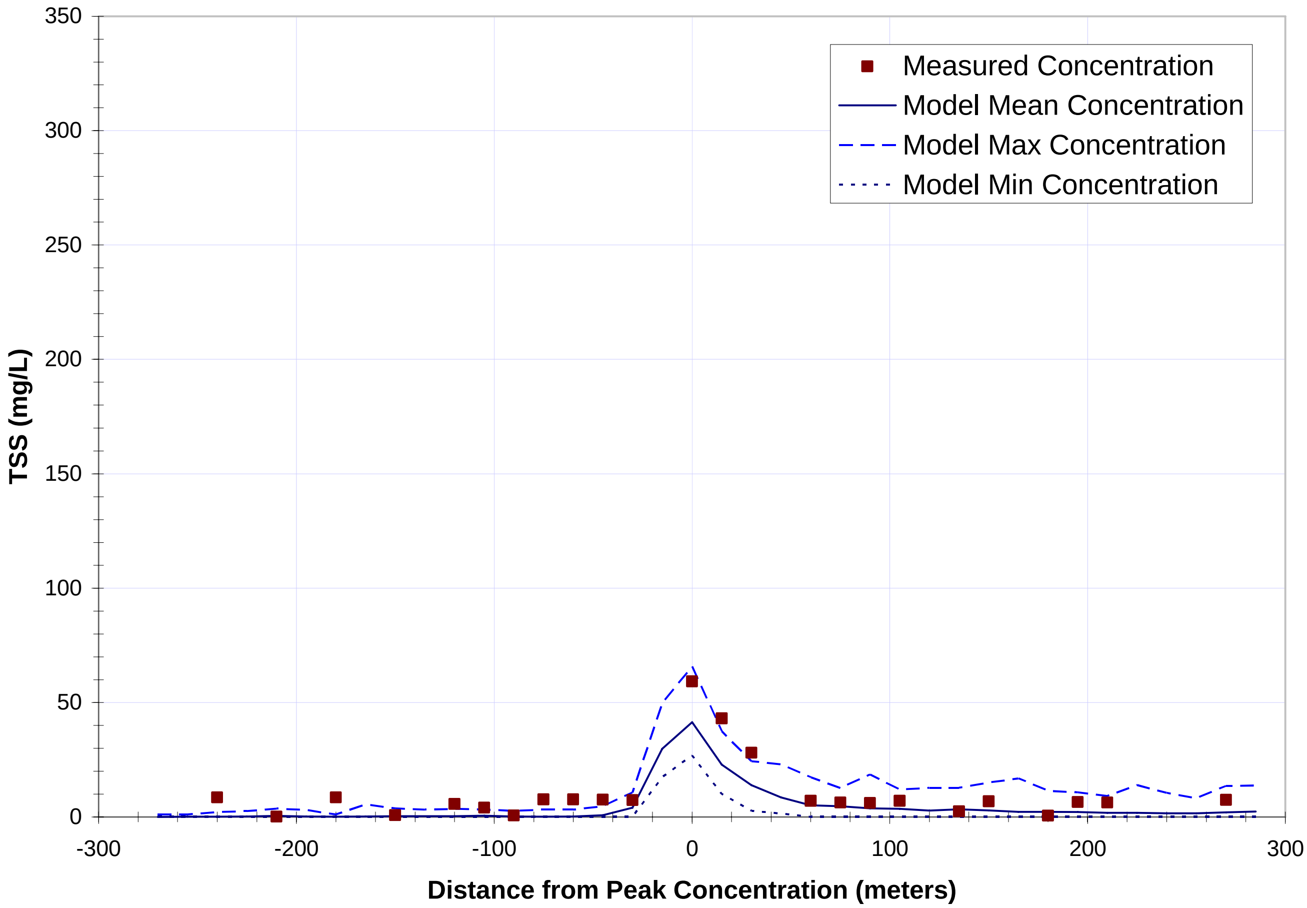


(c) Model (2hr Max)



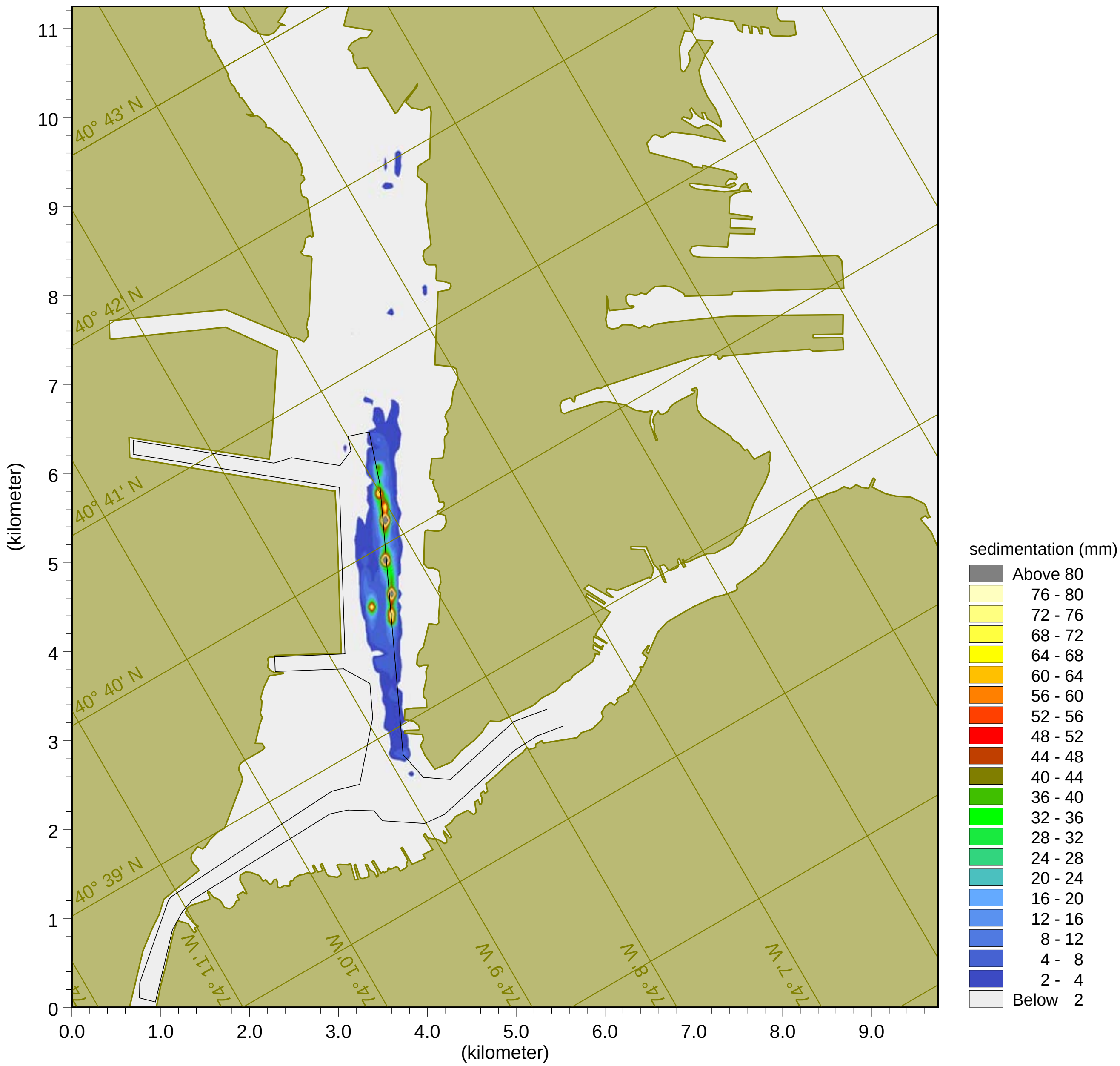
US Army Corps of Engineers
New York District

Figure 8
Ebb Plume Concentration and Extent
Arthur Kill



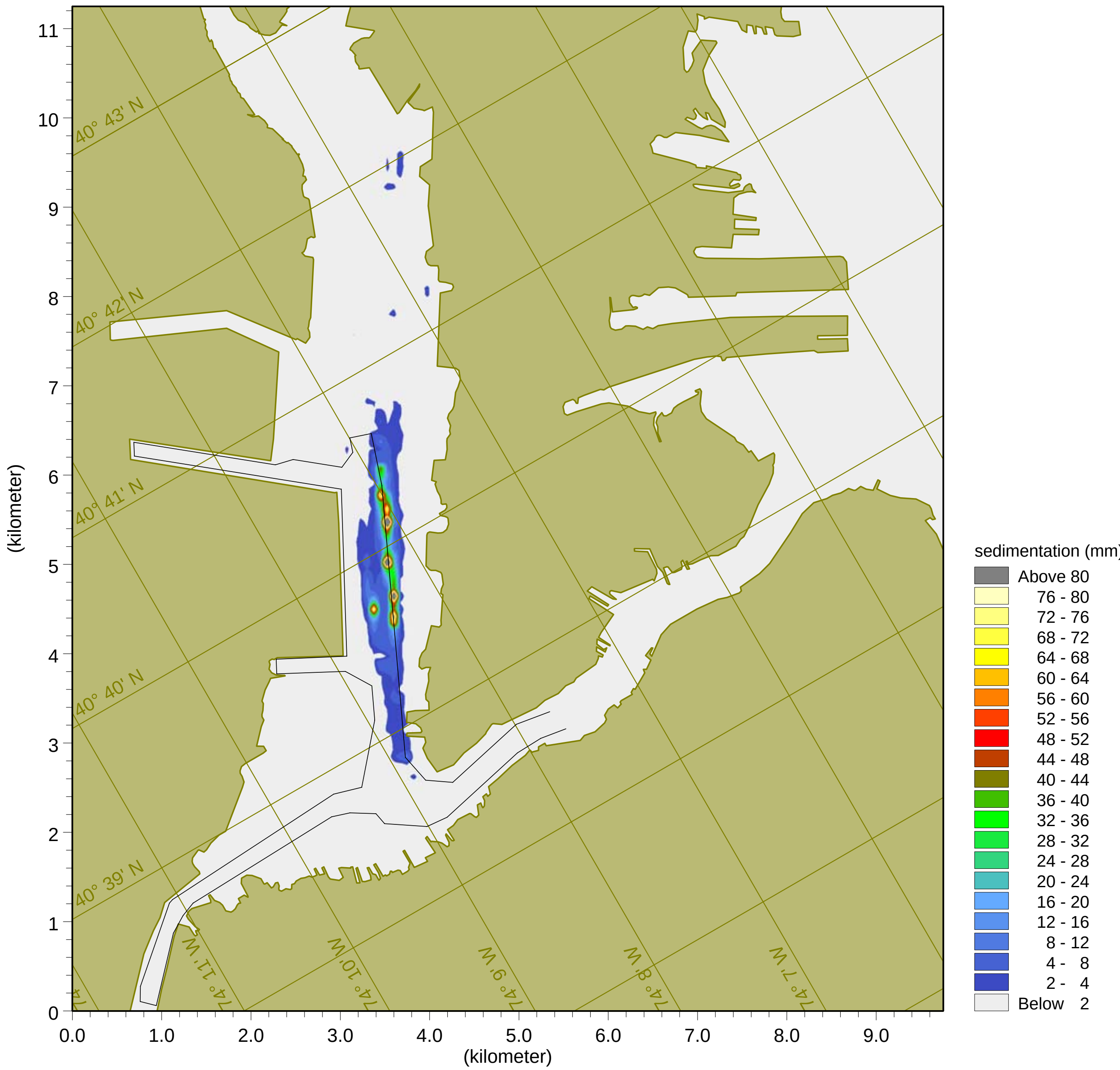
US Army Corps of Engineers
New York District

Figure 9
Ebb Calibration Section Line
Arthur Kill



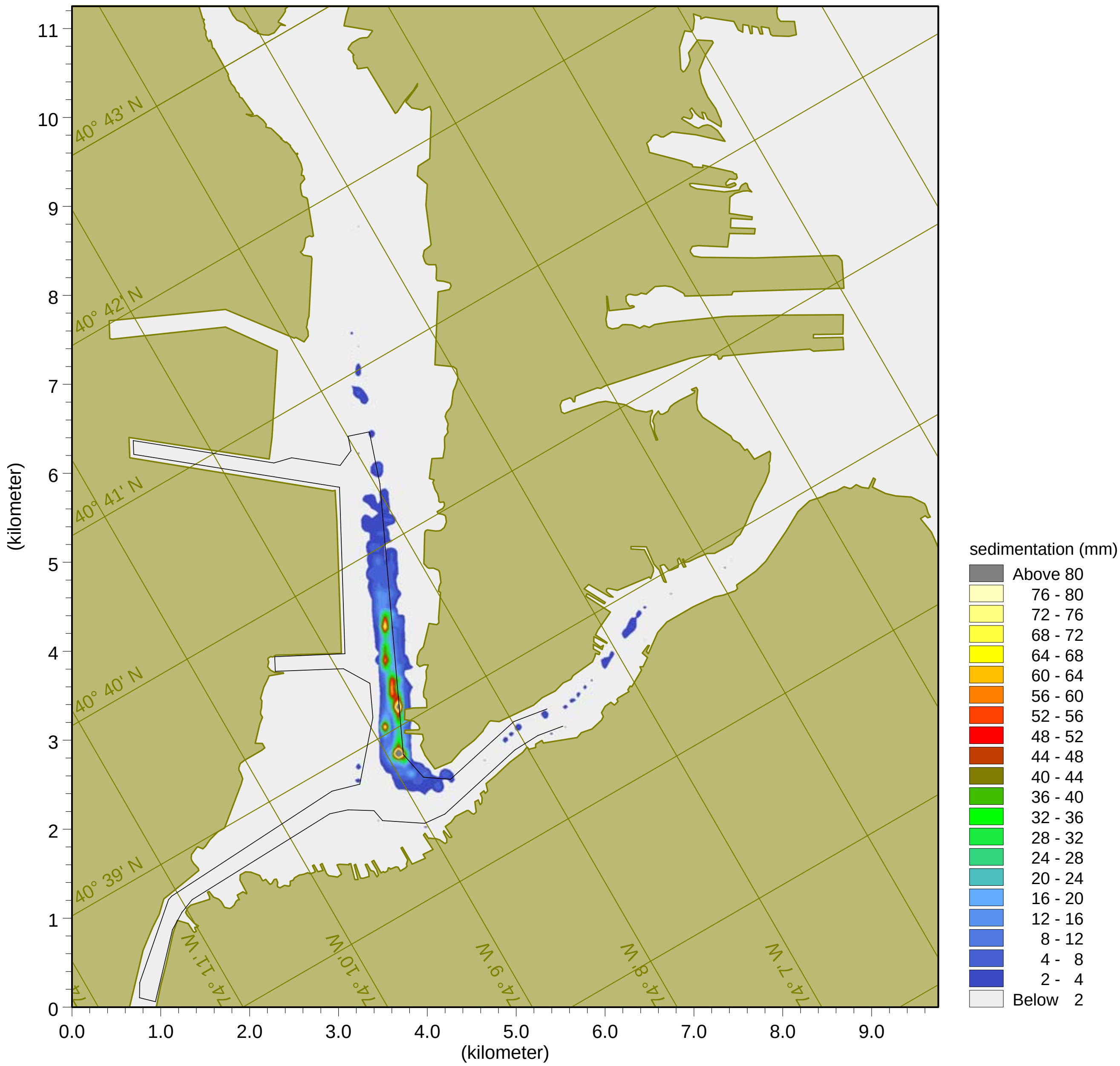
US Army Corps of Engineers
New York District

Figure 10 Sensitivity Test: Sedimentation – S-NB-1(B) Longitudinal Dispersion = 1.0 m^2/s



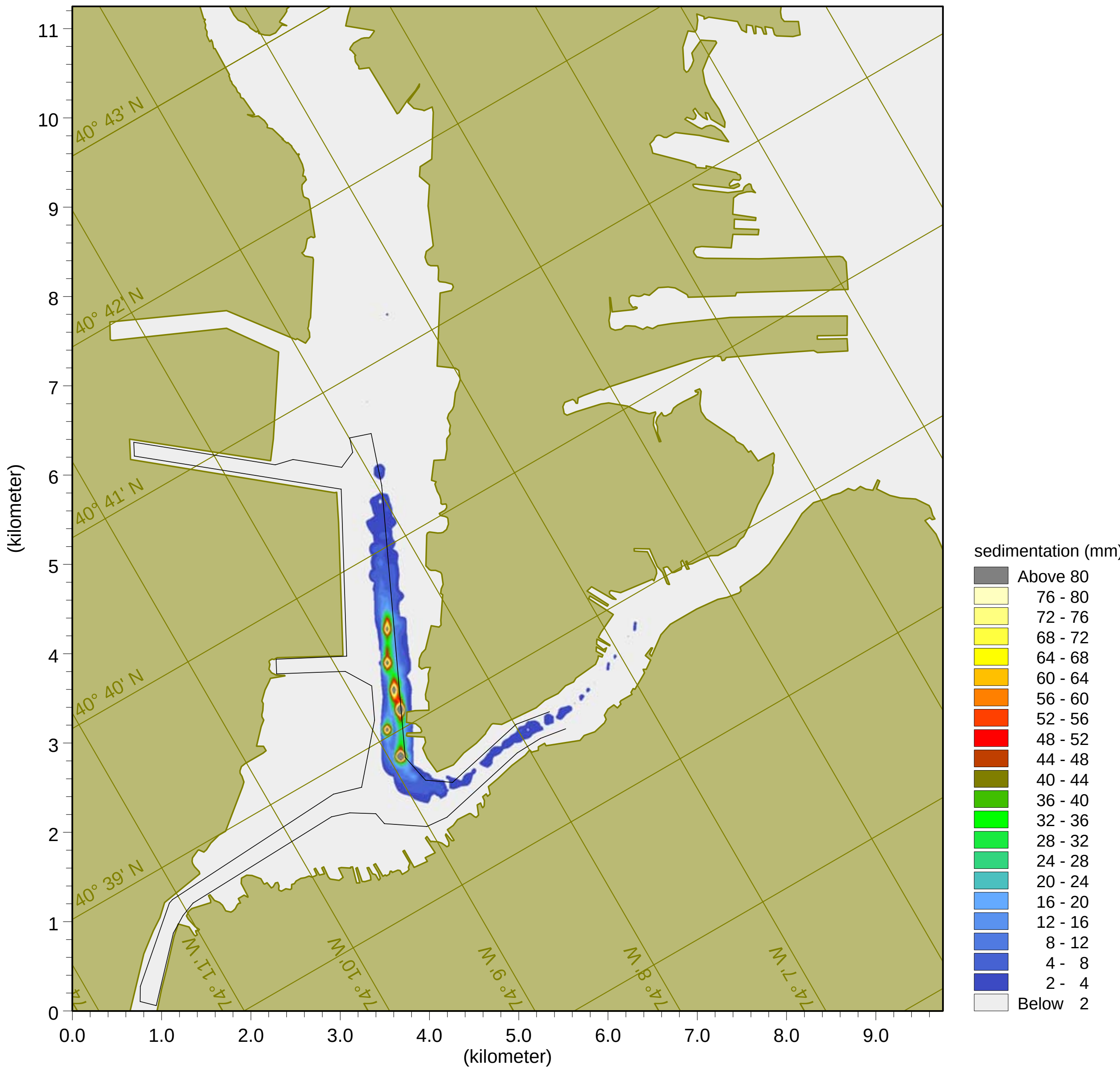
US Army Corps of Engineers
New York District

Figure 11 Sensitivity Test: Sedimentation – S-NB-1(B) Longitudinal Dispersion = 10 m^2/s



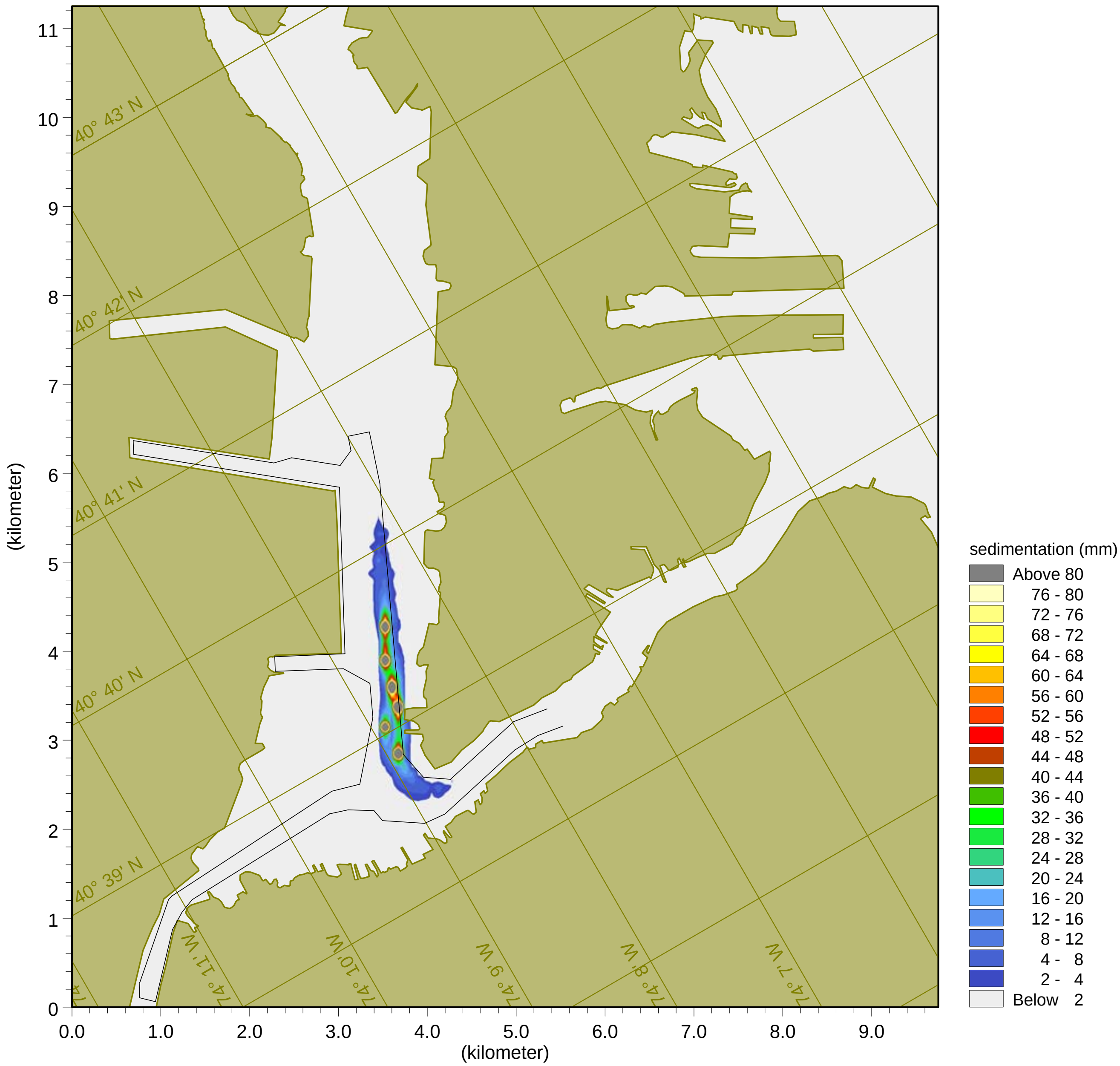
US Army Corps of Engineers
New York District

Figure 12 Sensitivity Test: Sedimentation – S-NB-2(C) Vertical Dispersion = 0.001 m²/s



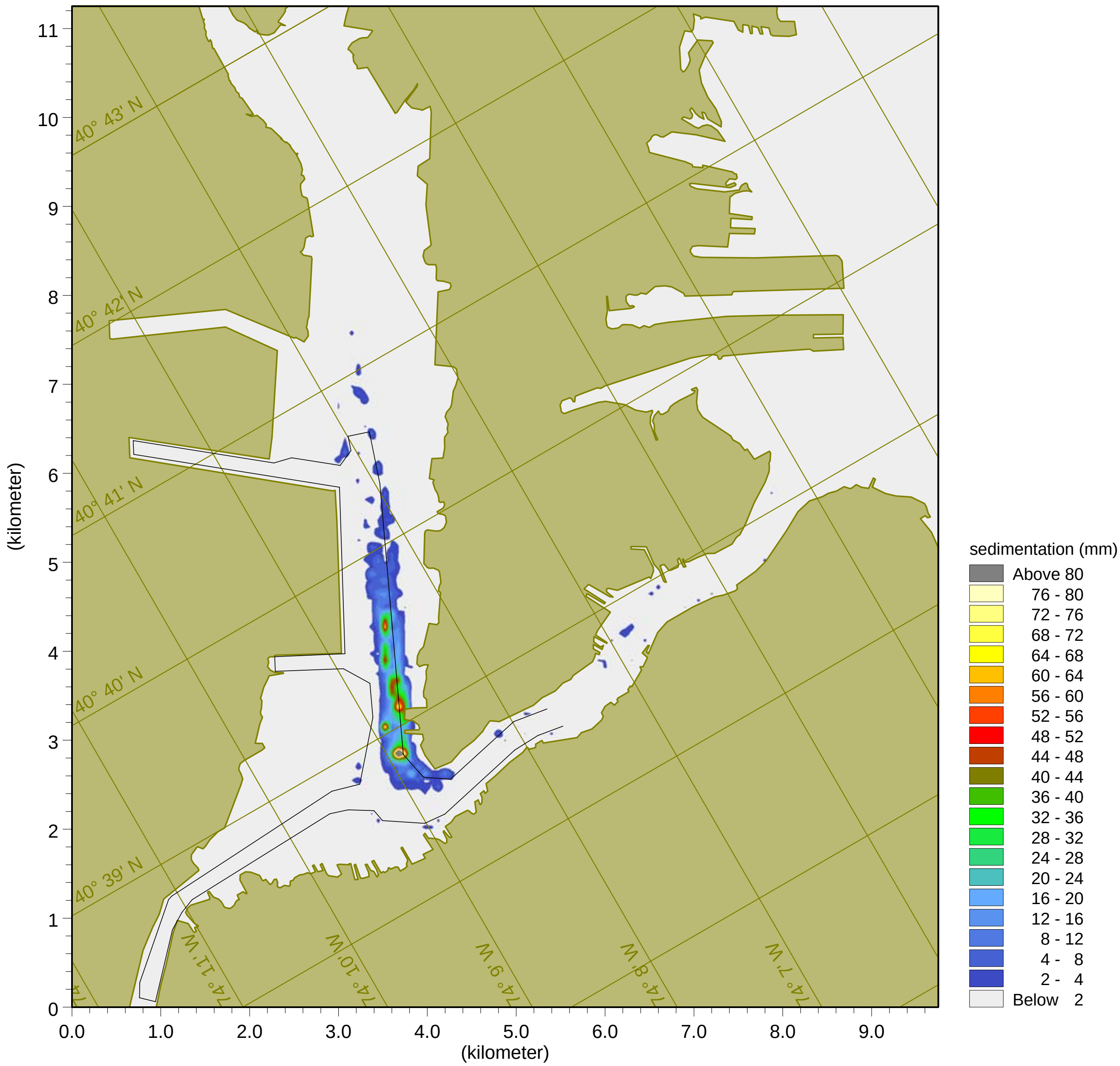
US Army Corps of Engineers
New York District

Figure 13 Sensitivity Test: Sedimentation – S-NB-2(C) Vertical Dispersion = 0.01 m^2/s



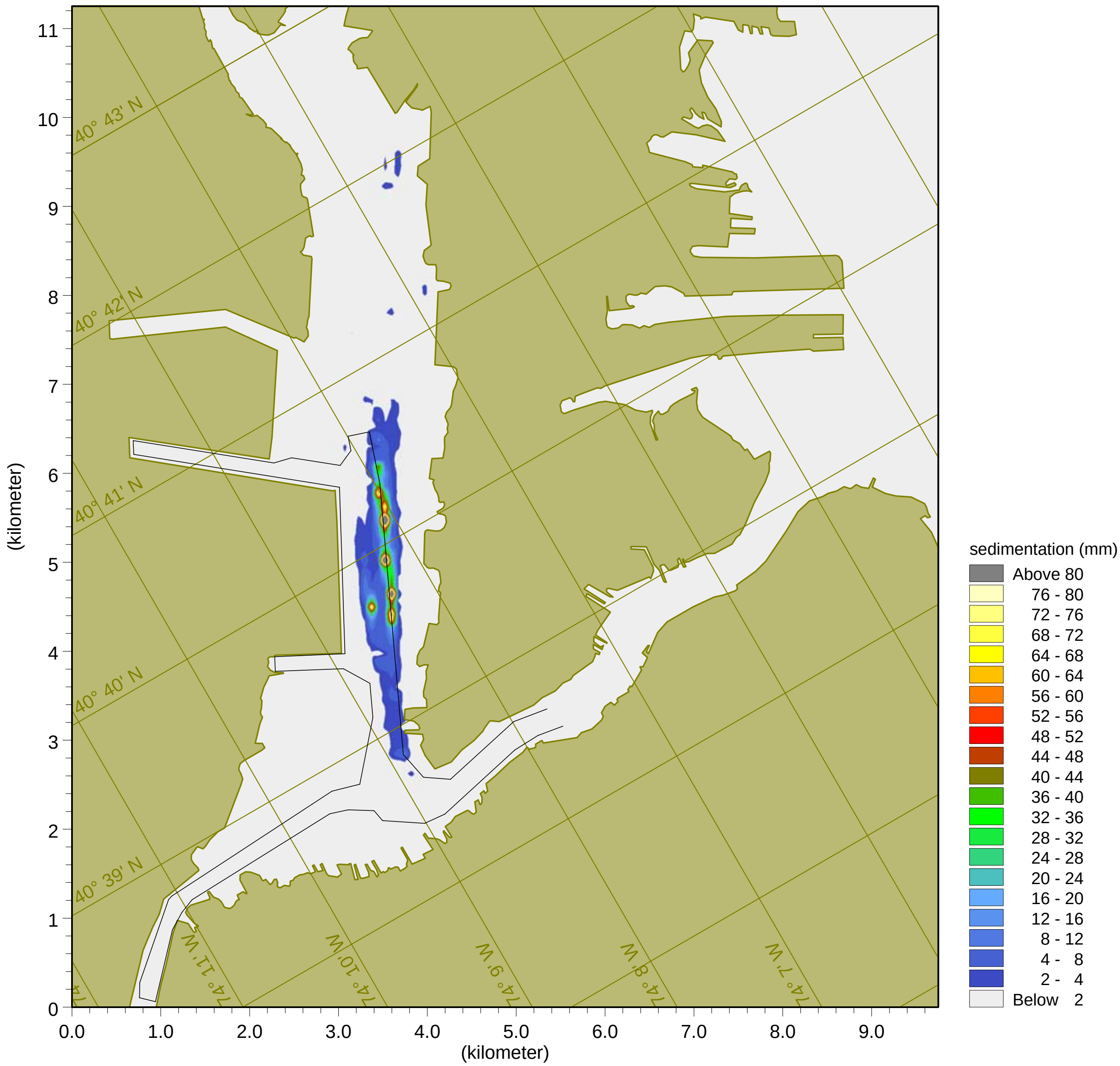
US Army Corps of Engineers
New York District

Figure 14 Sensitivity Test: Sedimentation – S-NB-2(C) Vertical Dispersion = 0.1 m^2/s



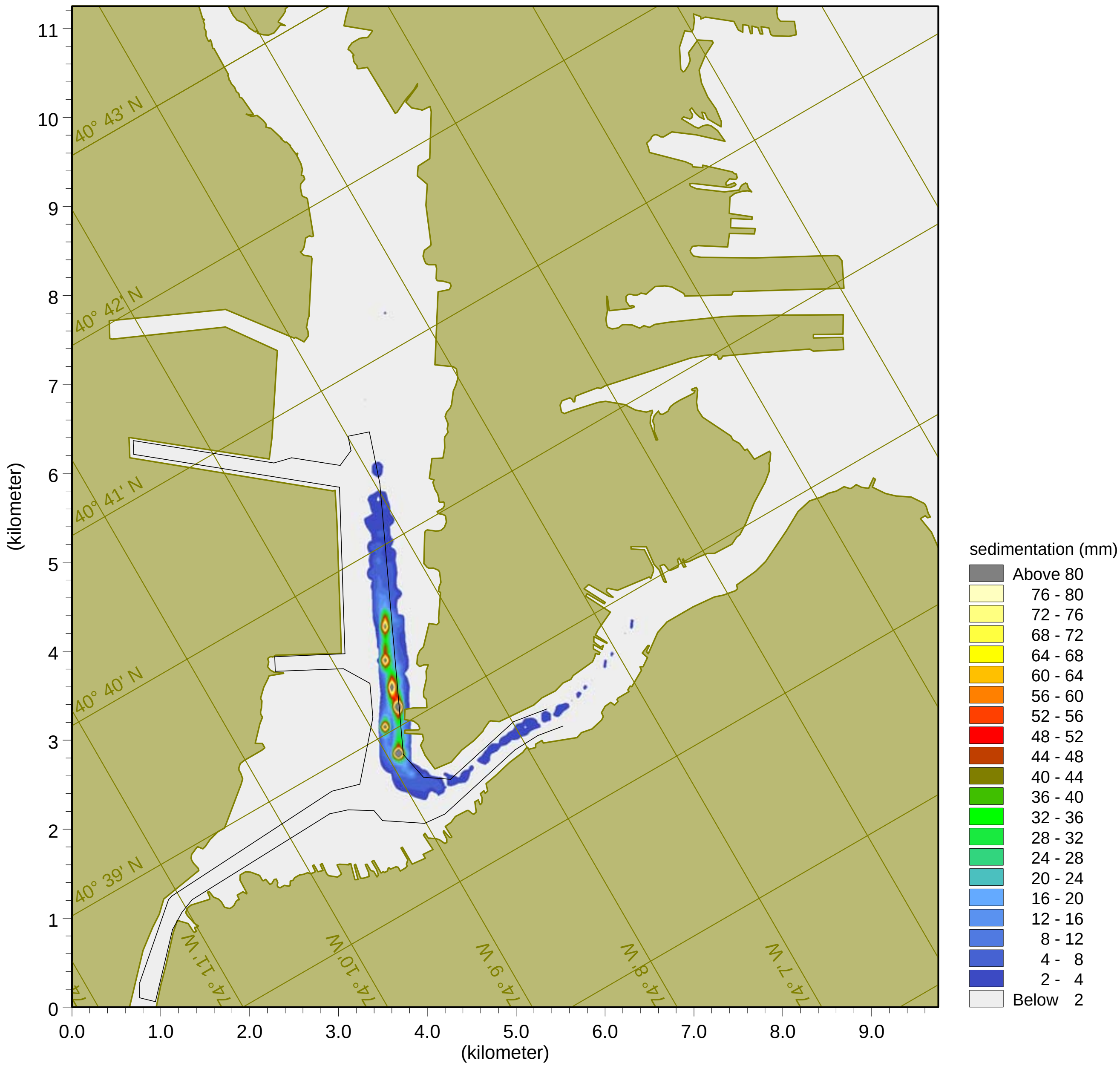
US Army Corps of Engineers
New York District

Figure 15 Sensitivity Test:
Sedimentation – S-NB-2(C)
Transverse Dispersion = 0.05 m^2/s



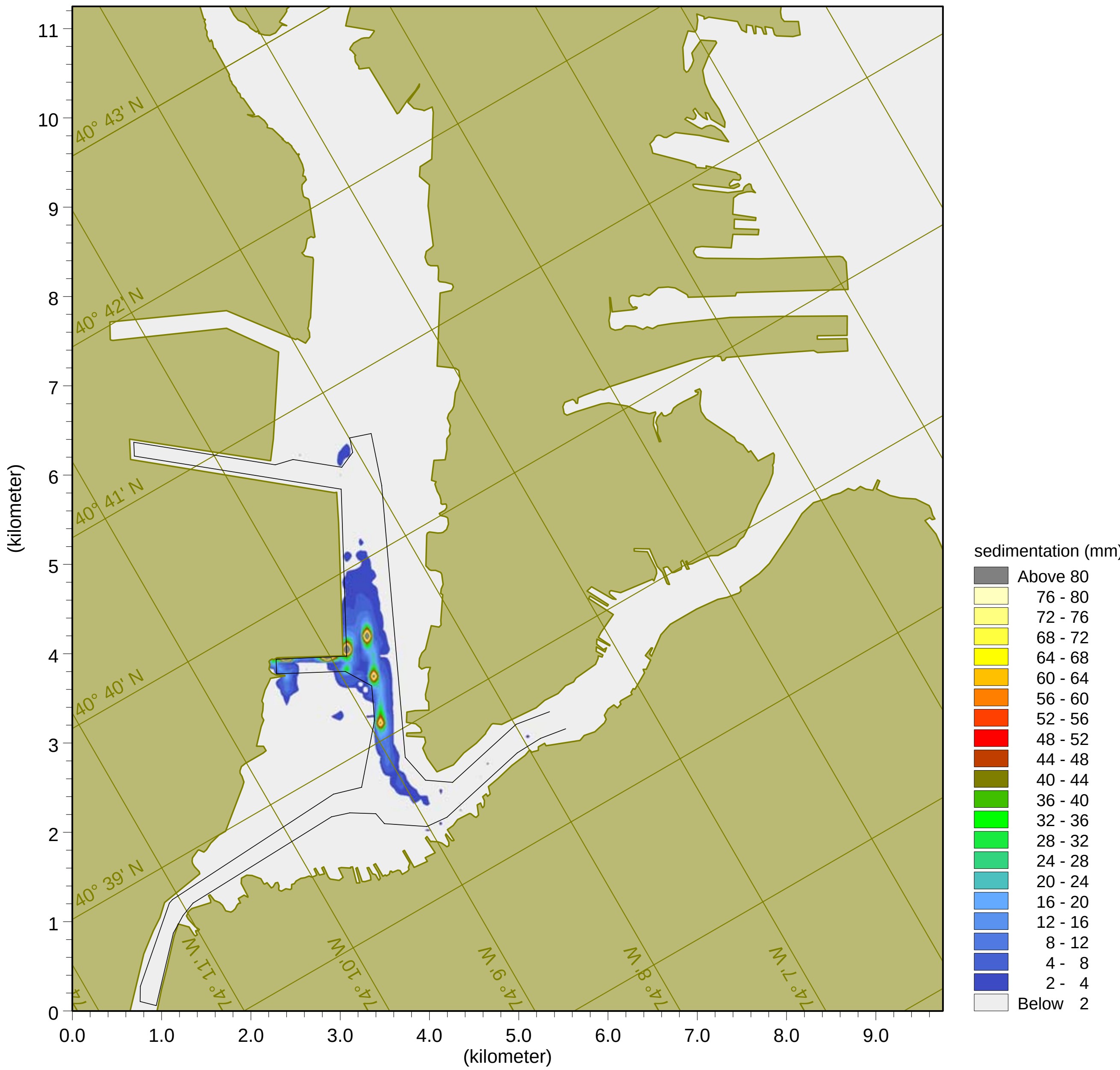
US Army Corps of Engineers
New York District

Figure 16 Sensitivity Test: Sedimentation – S-NB-1(B) Shields Number = 0.01



US Army Corps of Engineers
New York District

Figure 17 Sensitivity Test: Sedimentation – S-NB-2(C) Shields Number = 0.2 m^2/s

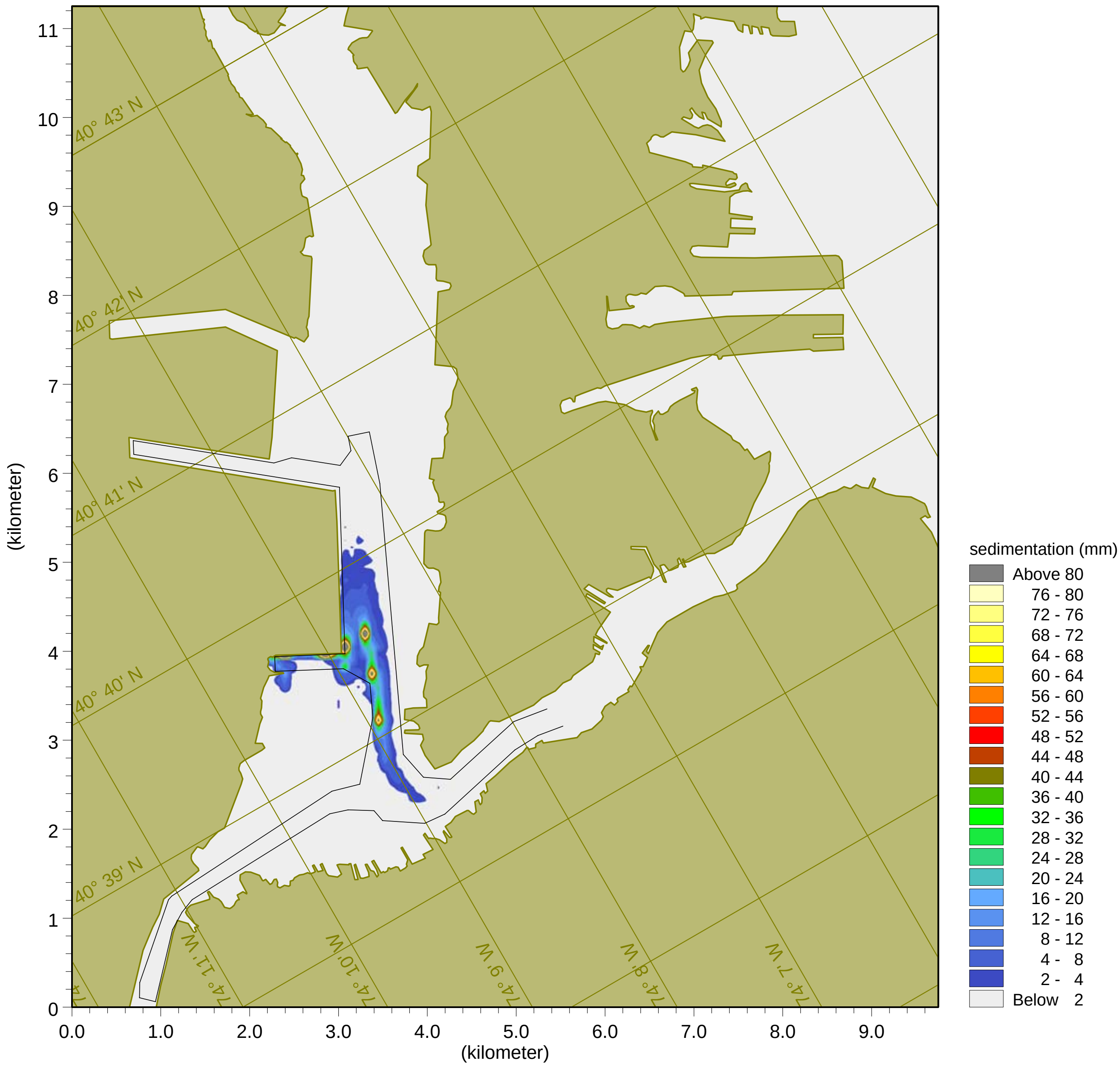


Settling Velocity – Fines: 0.5 mm/s

Settling Velocity – Coarse: 1.0 cm/s

US Army Corps of Engineers
New York District

Figure 18 Sensitivity Test: Sedimentation – S-NB-2(A) Small Settling Velocities

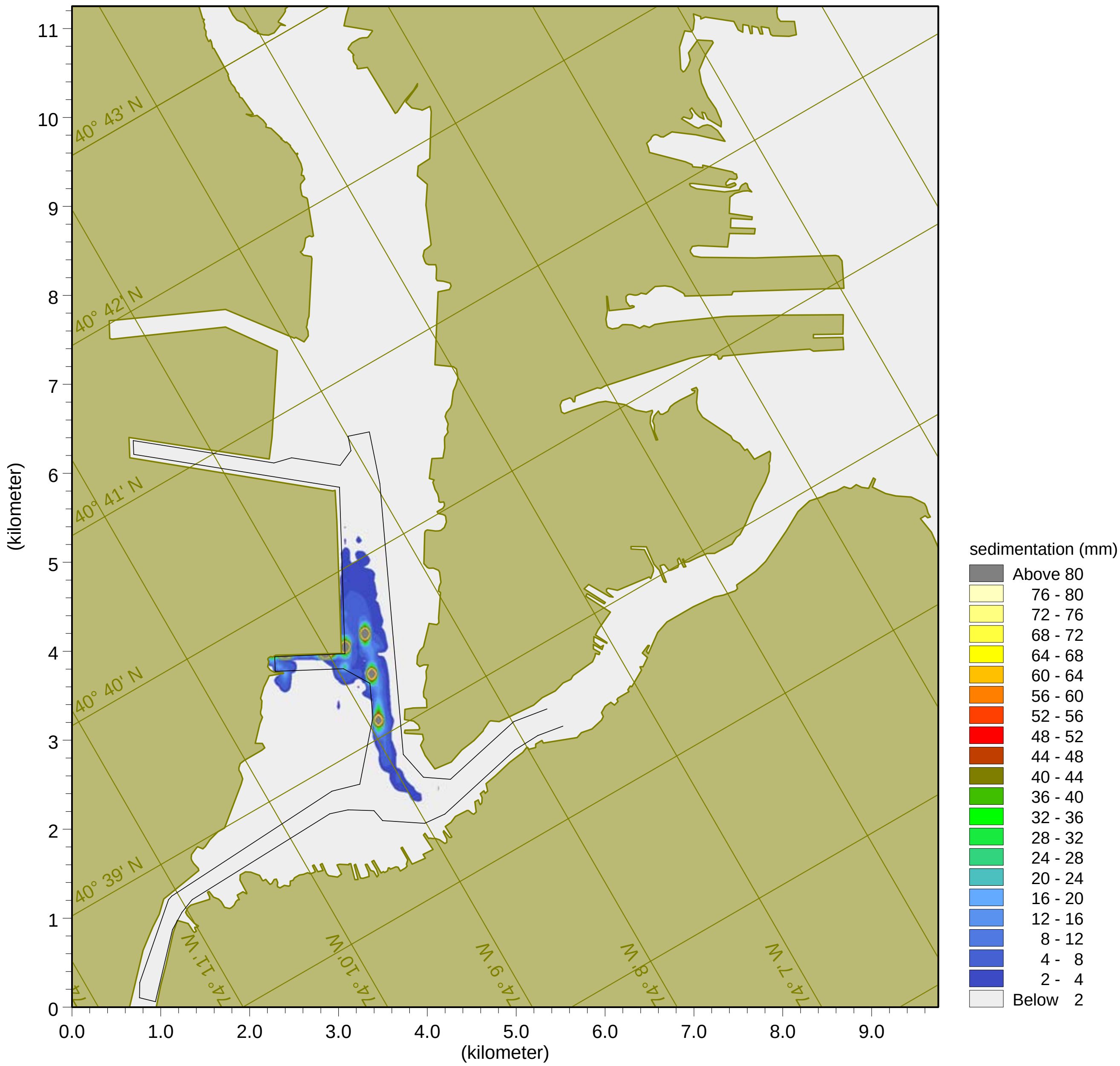


Settling Velocity – Fines: 1.5 mm/s

Settling Velocity – Coarse: 1.0 cm/s

US Army Corps of Engineers
New York District

Figure 19 Sensitivity Test: Sedimentation – S-NB-2(A) Medium Settling Velocities

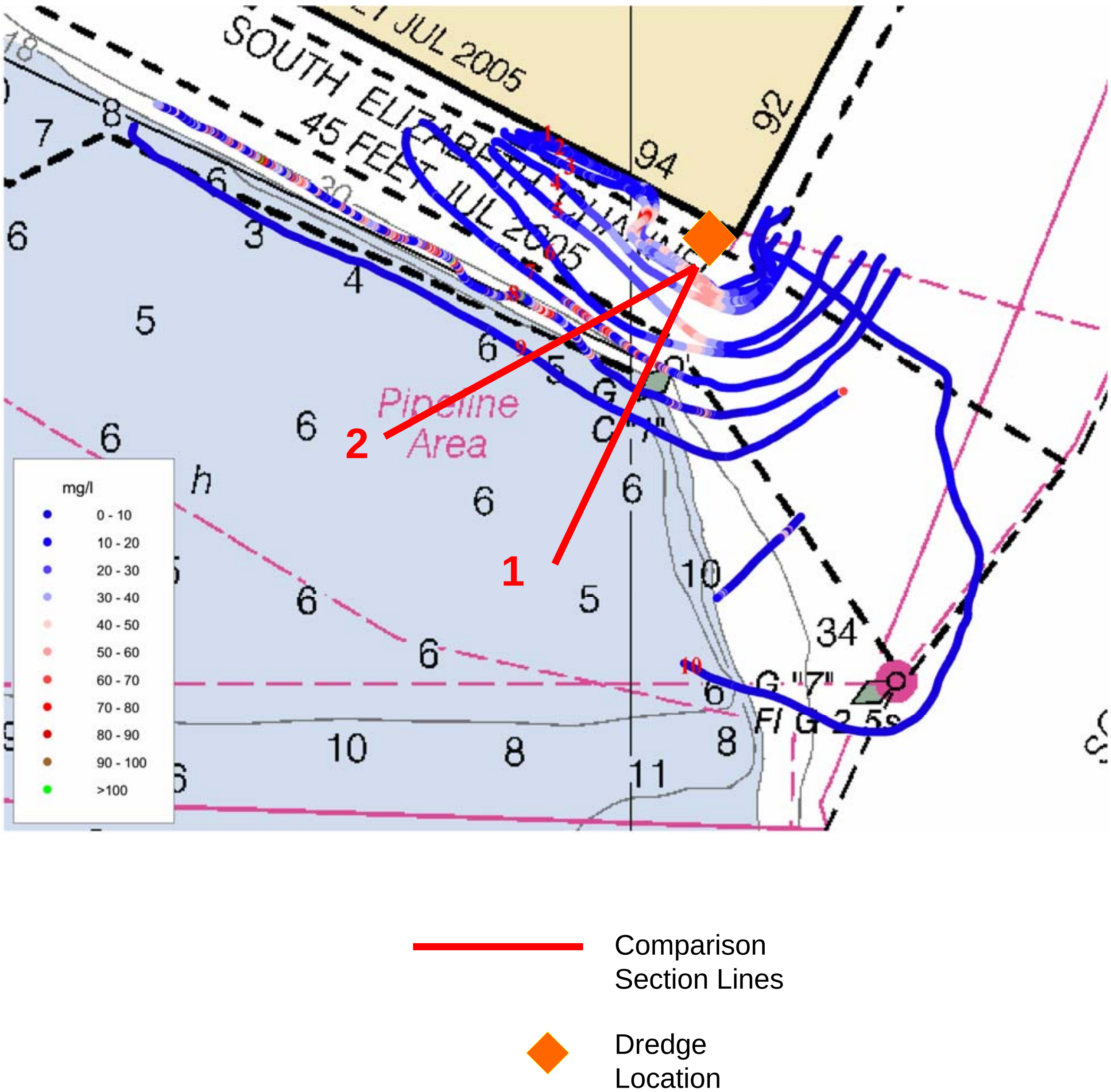


Settling Velocity – Fines: 1.5 mm/s

Settling Velocity – Coarse: 5.0 cm/s

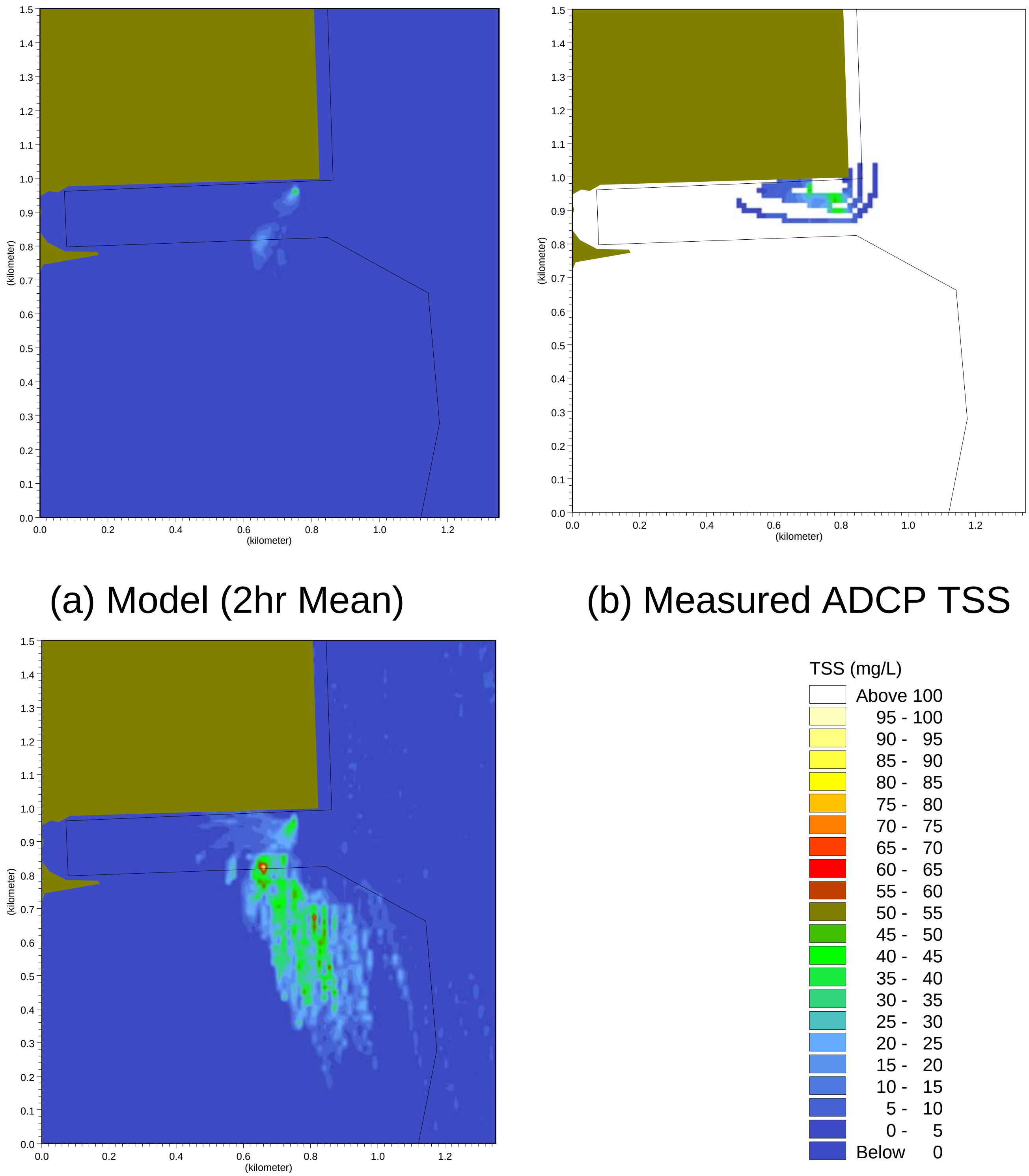
US Army Corps of Engineers
New York District

Figure 20 Sensitivity Test: Sedimentation – S-NB-2(A) Large Settling Velocities



US Army Corps of Engineers
New York District

Figure 21
Measured TSS transects
South Elizabeth Channel



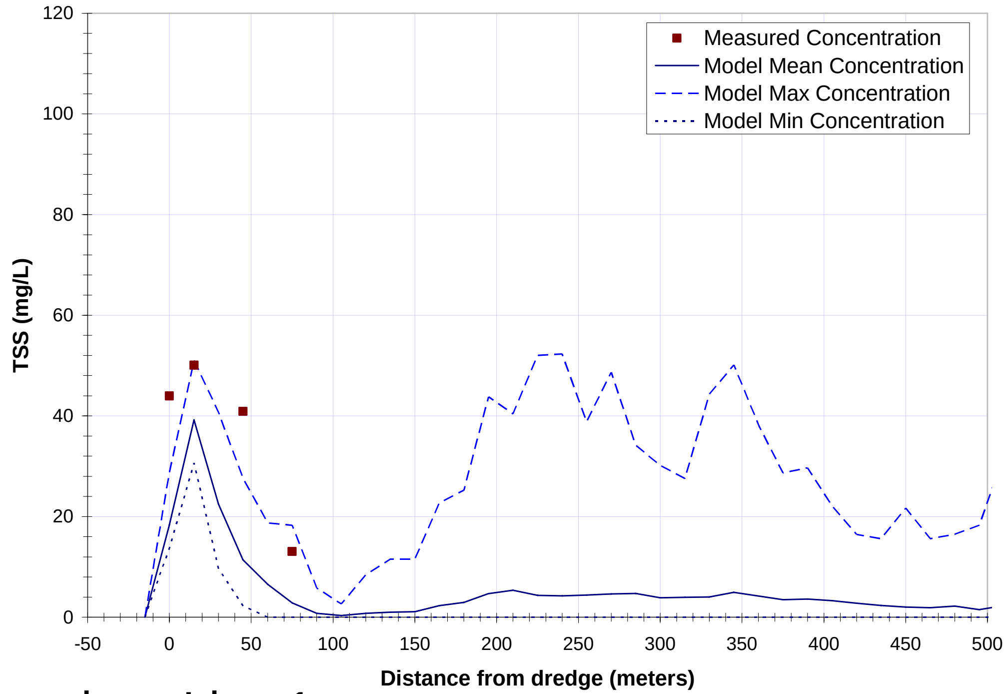
(a) Model (2hr Mean)

(b) Measured ADCP TSS

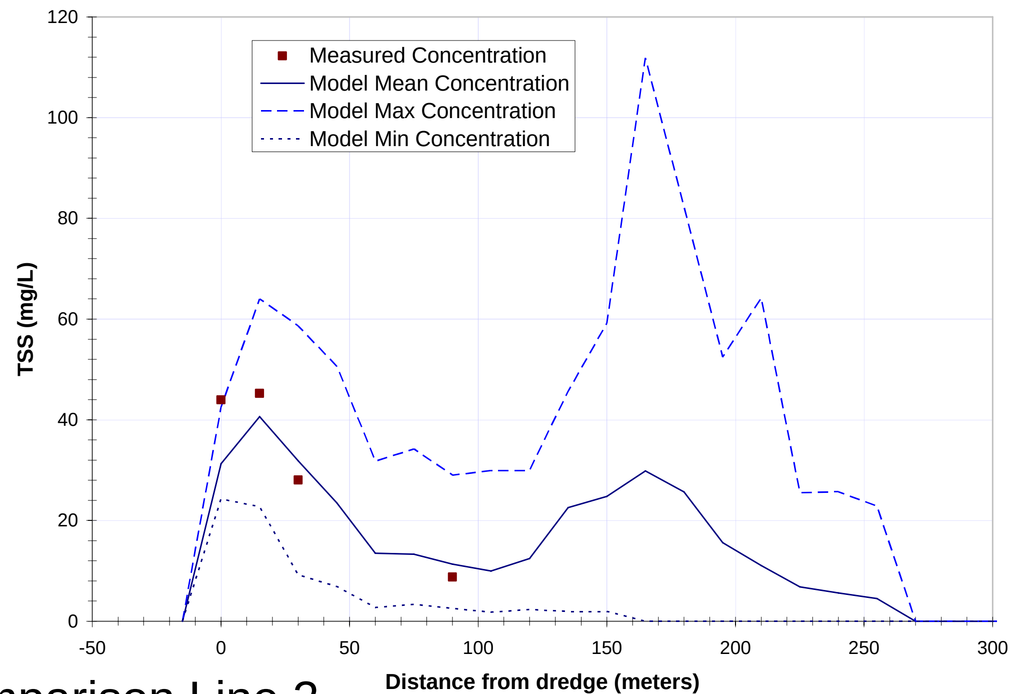
(c) Model (2hr Max)

US Army Corps of Engineers
New York District

Figure 22
Plume Concentration and Extent
South Elizabeth Channel



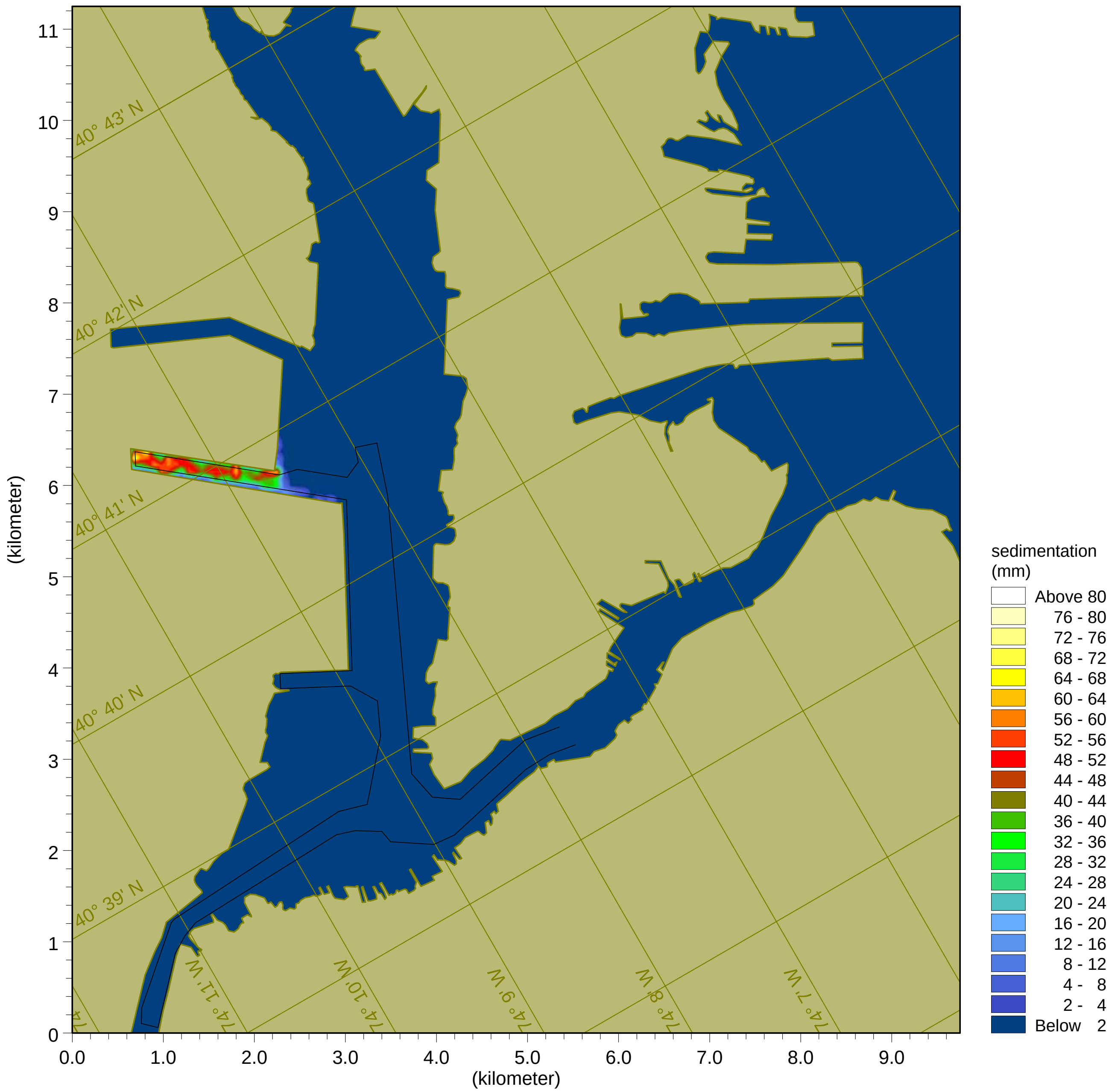
(a) Comparison Line 1



(b) Comparison Line 2

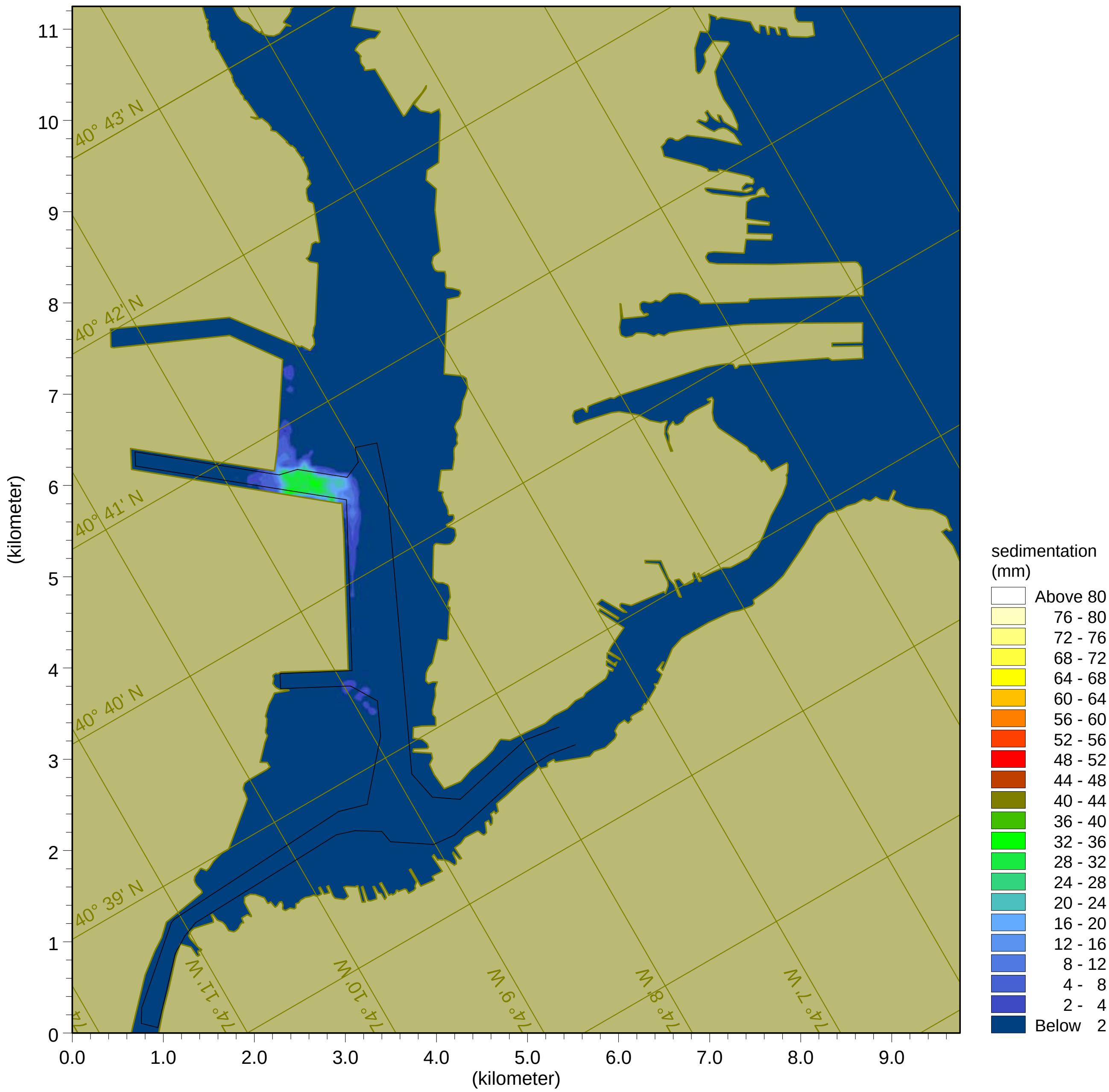
US Army Corps of Engineers
New York District

Figure 23
Validation Plume Section Concentration
South Elizabeth Channel



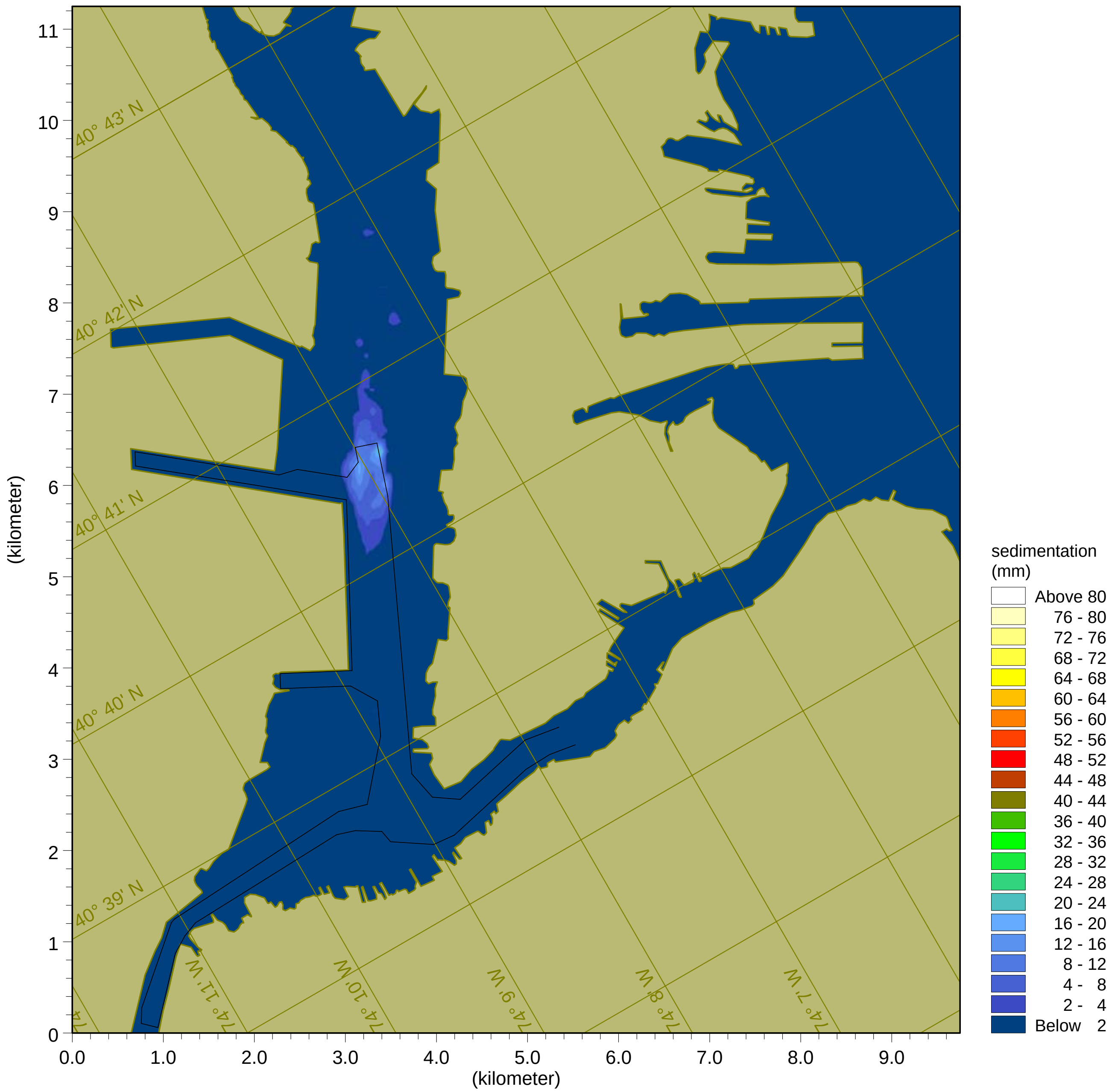
US Army Corps of Engineers
New York District

Figure 24
Dredge Resuspension Induced Sedimentation – Area S-E-1(A)



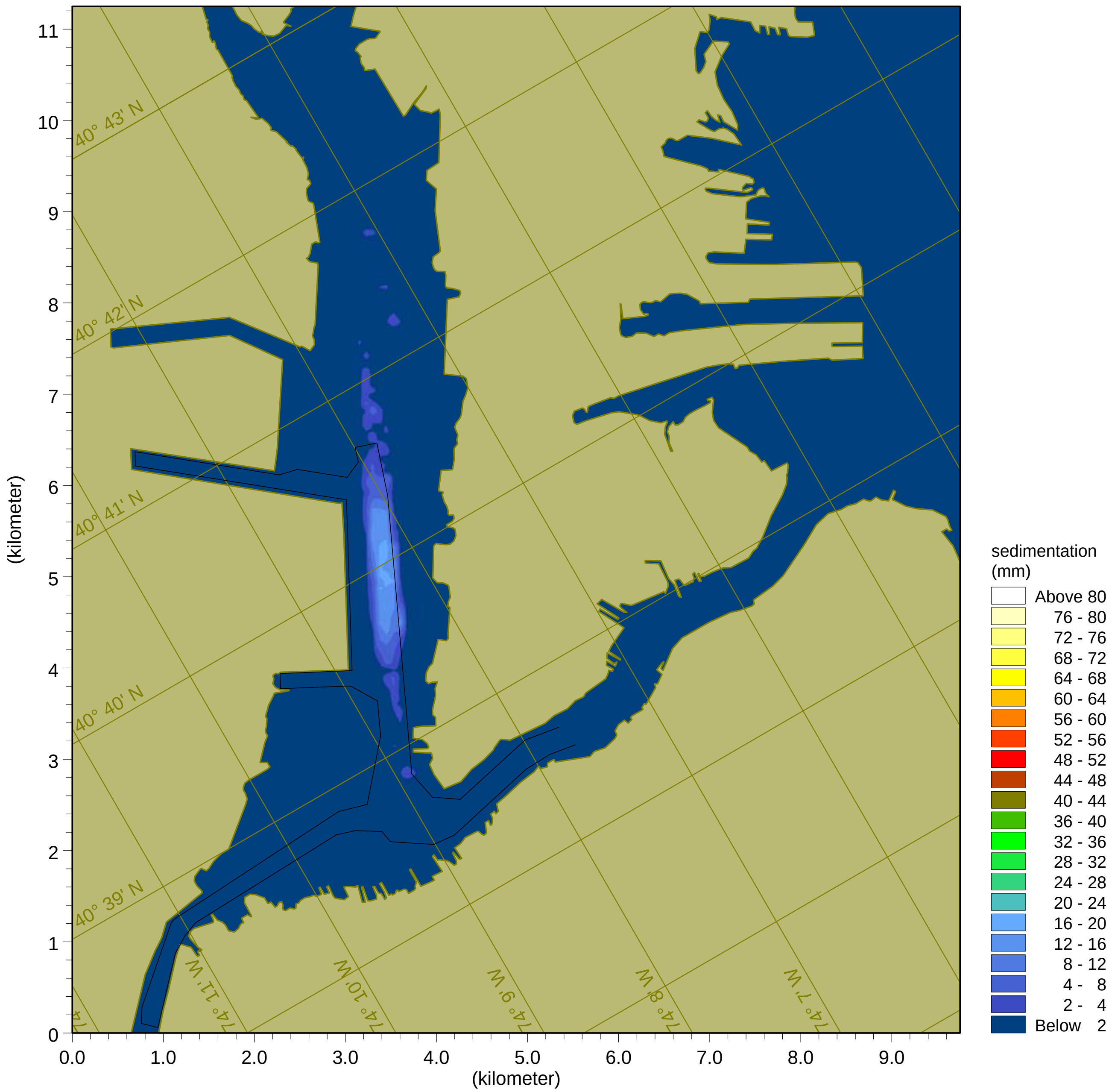
US Army Corps of Engineers
New York District

Figure 25
Dredge Resuspension Induced Sedimentation – Area S-E-1(B)



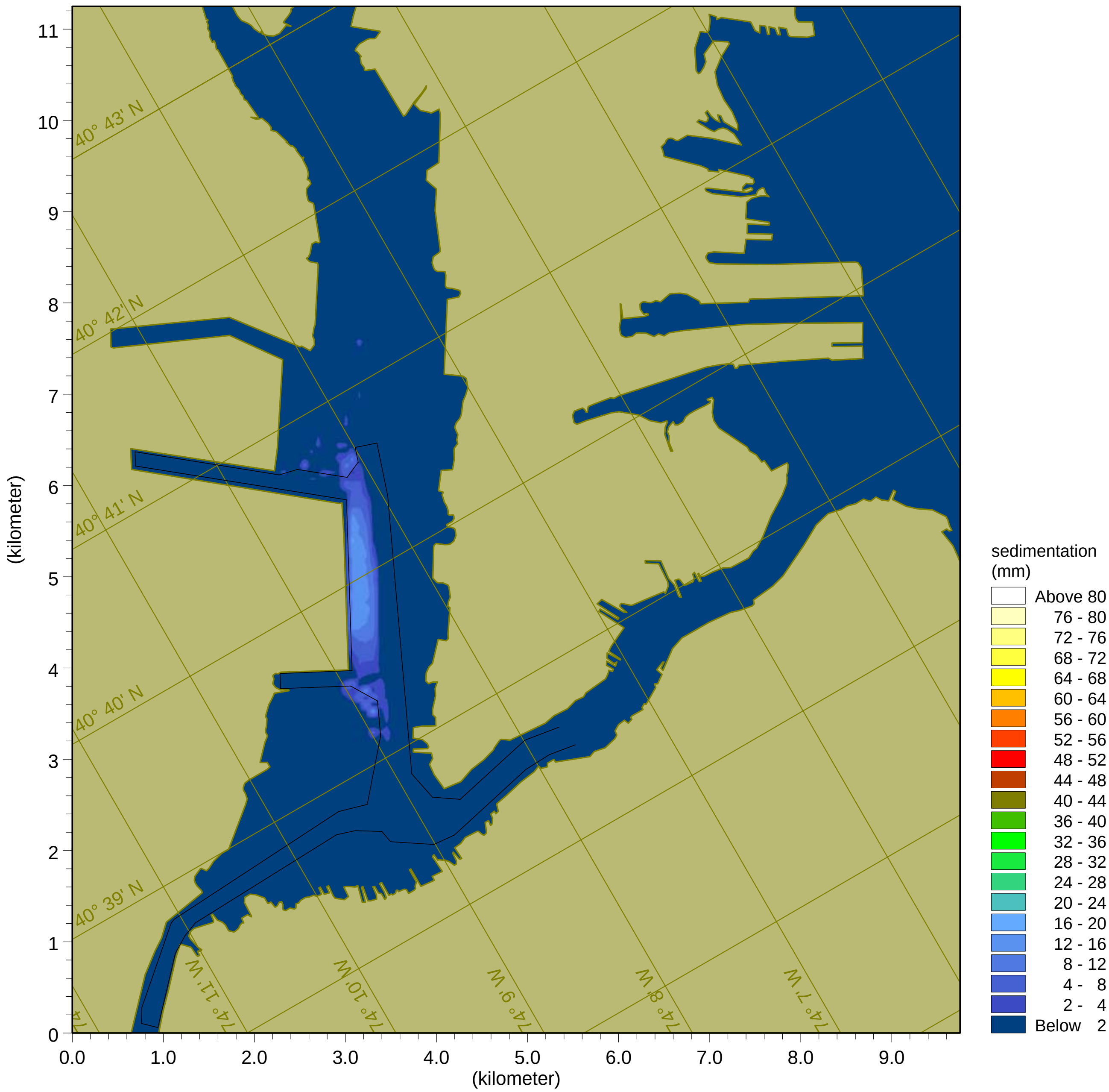
US Army Corps of Engineers
New York District

Figure 26
Dredge Resuspension Induced Sedimentation – Area S-NB-1(A)



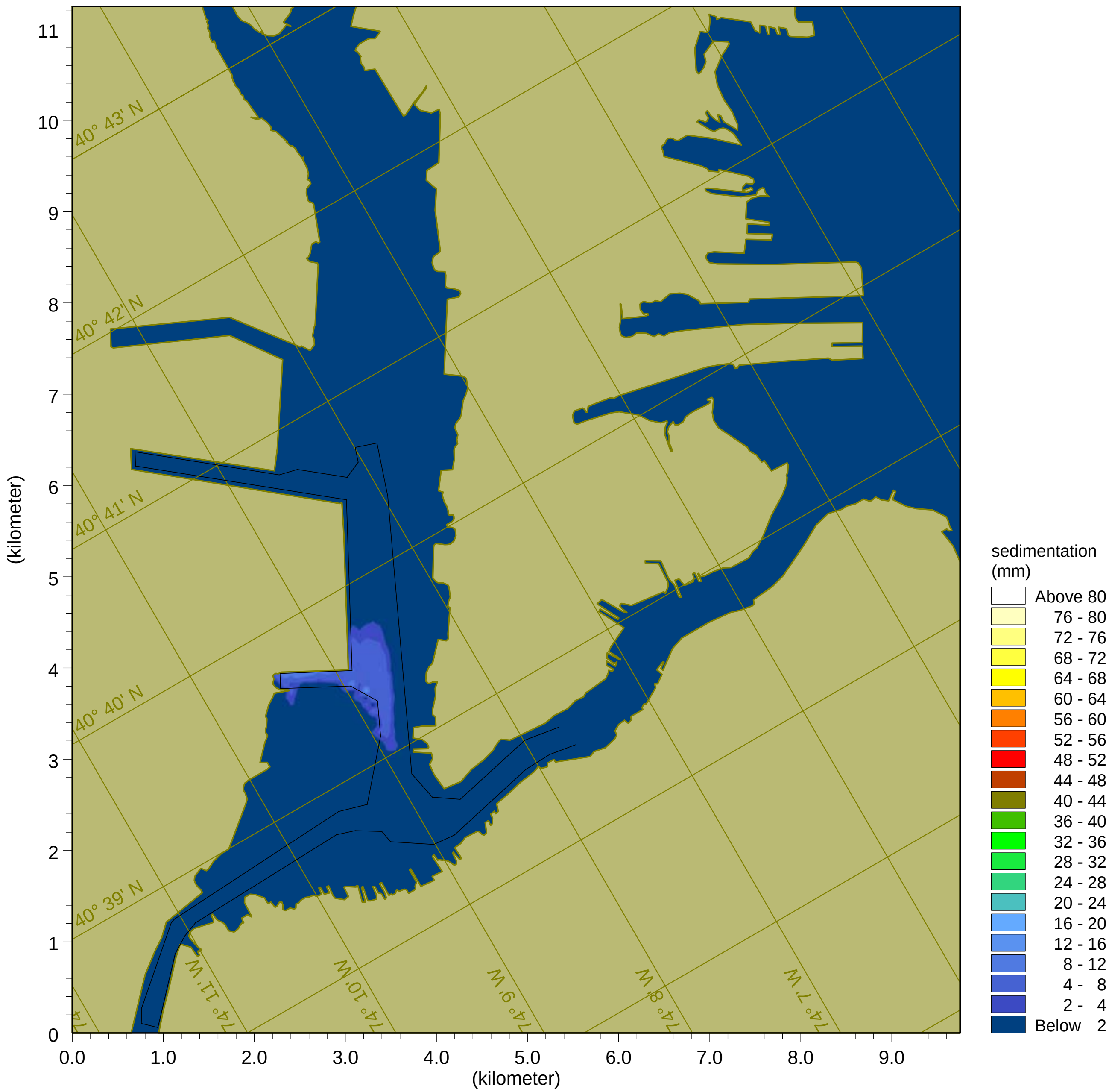
US Army Corps of Engineers
New York District

Figure 27
Dredge Resuspension Induced Sedimentation – Area S-NB-1(B)



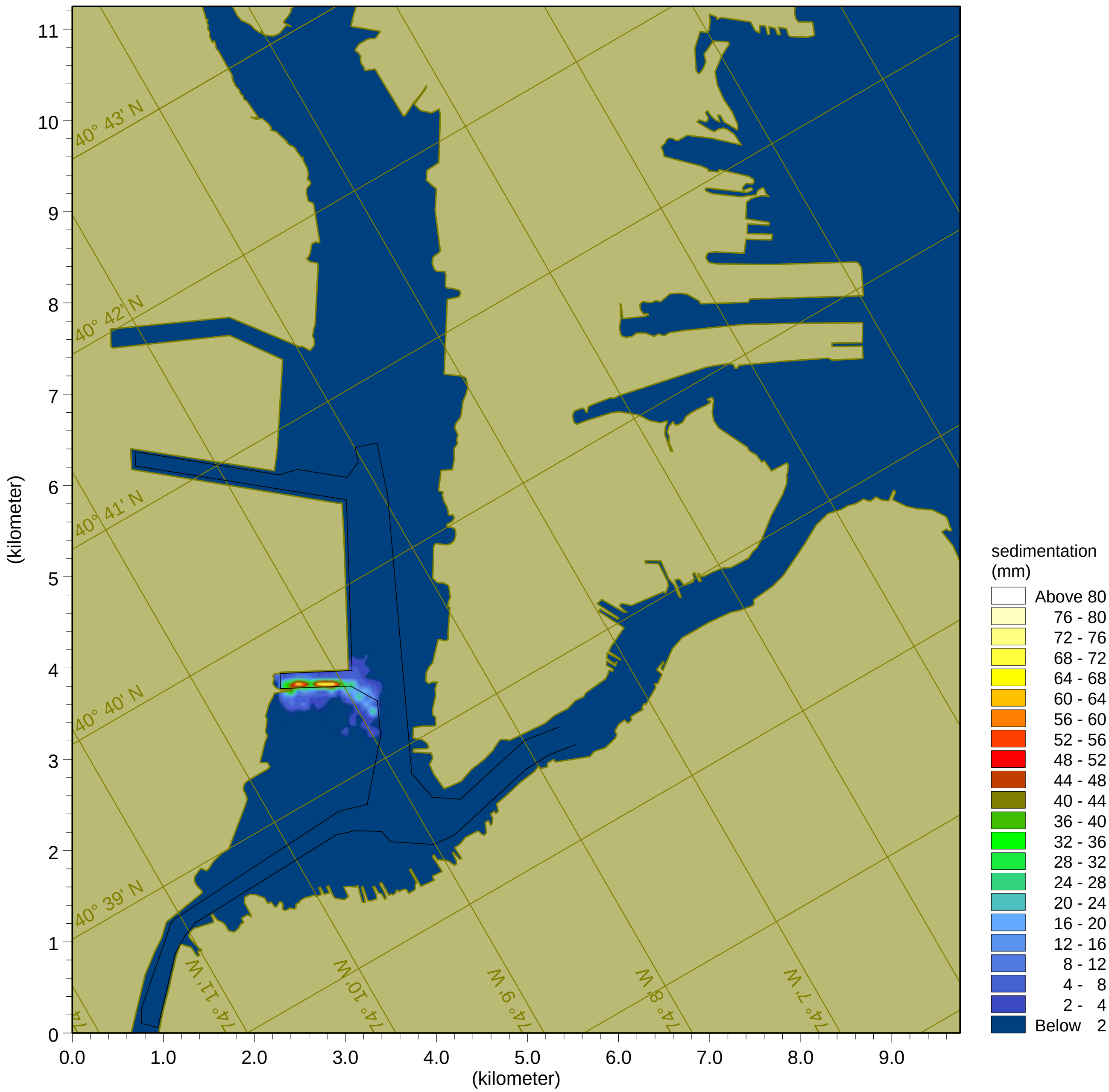
US Army Corps of Engineers
New York District

Figure 28
Dredge Resuspension Induced Sedimentation – Area S-NB-1(C)



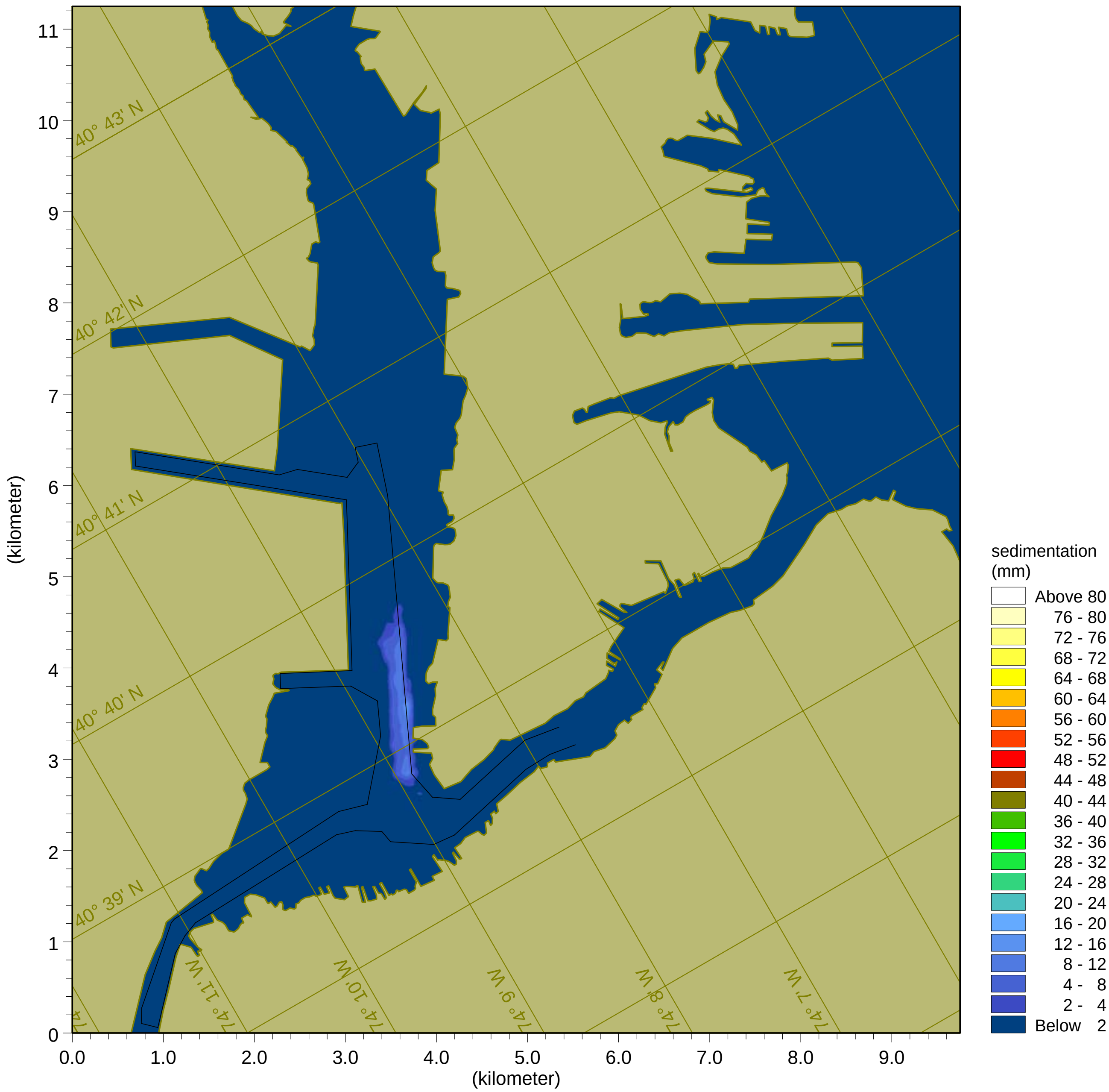
US Army Corps of Engineers
New York District

Figure 29
Dredge Resuspension Induced Sedimentation – Area S-NB-2(A)



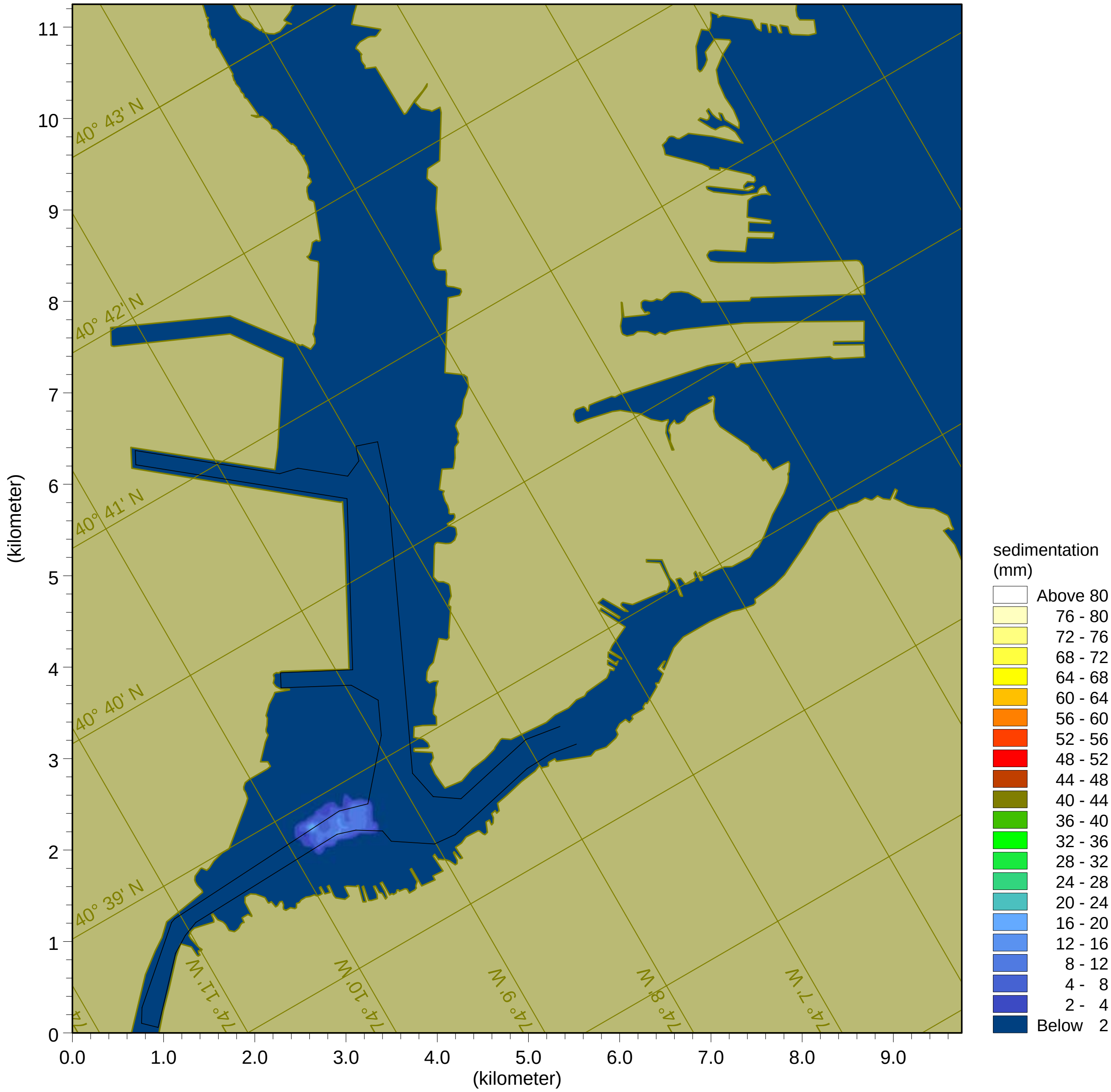
US Army Corps of Engineers
New York District

Figure 30
Dredge Resuspension Induced Sedimentation – Area S-NB-2(B)



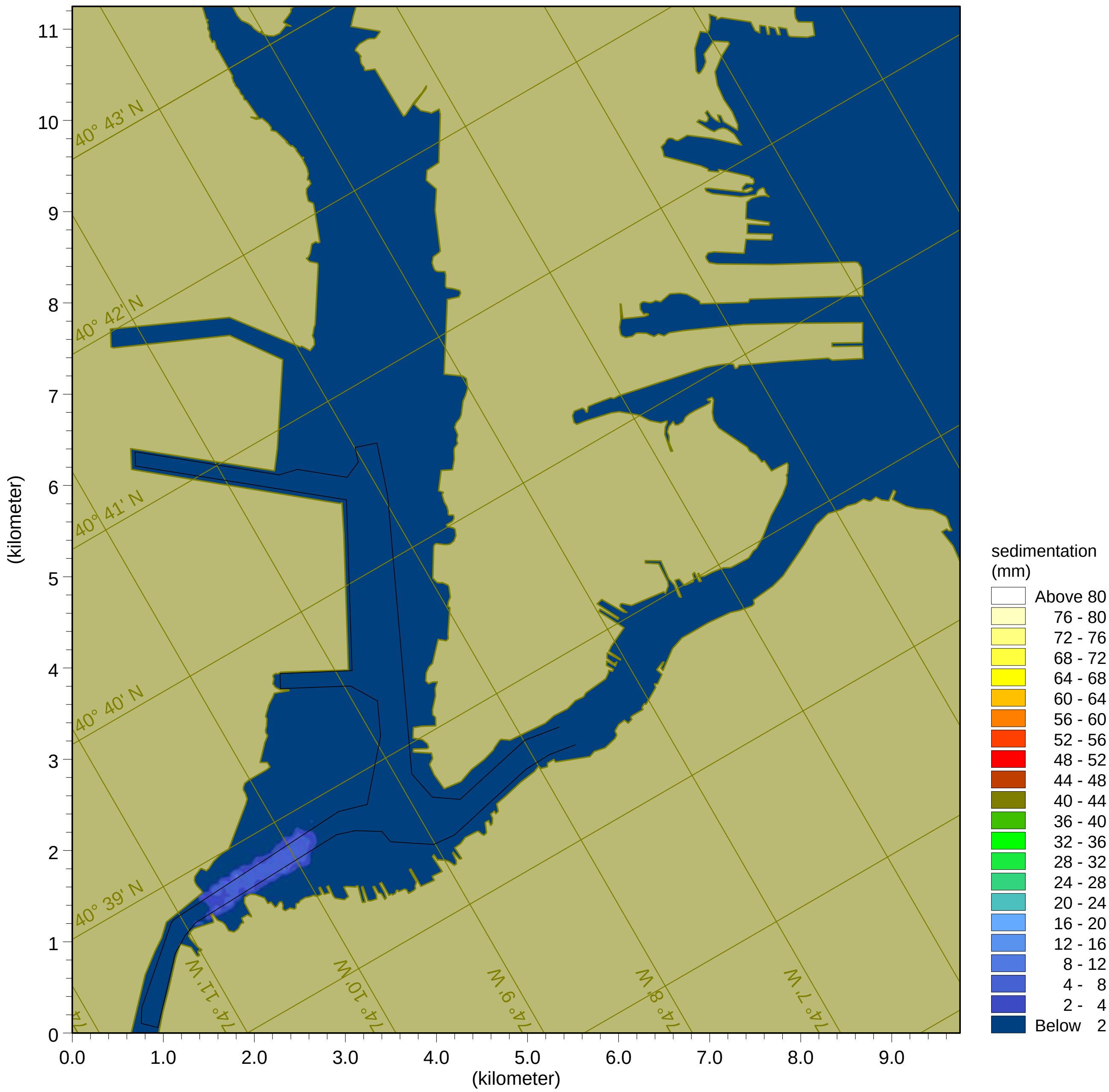
US Army Corps of Engineers
New York District

Figure 31
Dredge Resuspension Induced Sedimentation – Area S-NB-2(C)



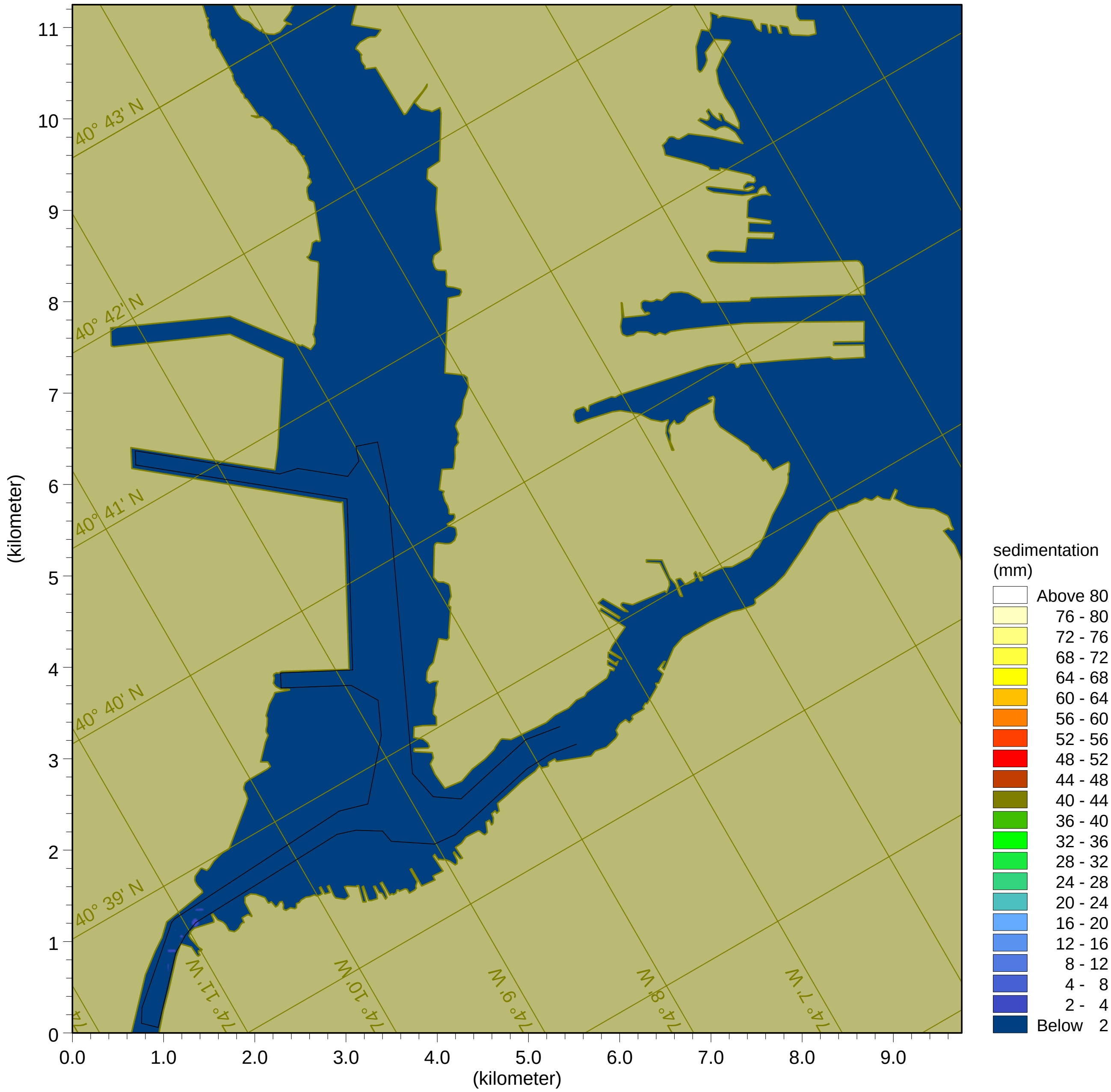
US Army Corps of Engineers
New York District

Figure 32
Dredge Resuspension Induced Sedimentation – Area AK-1



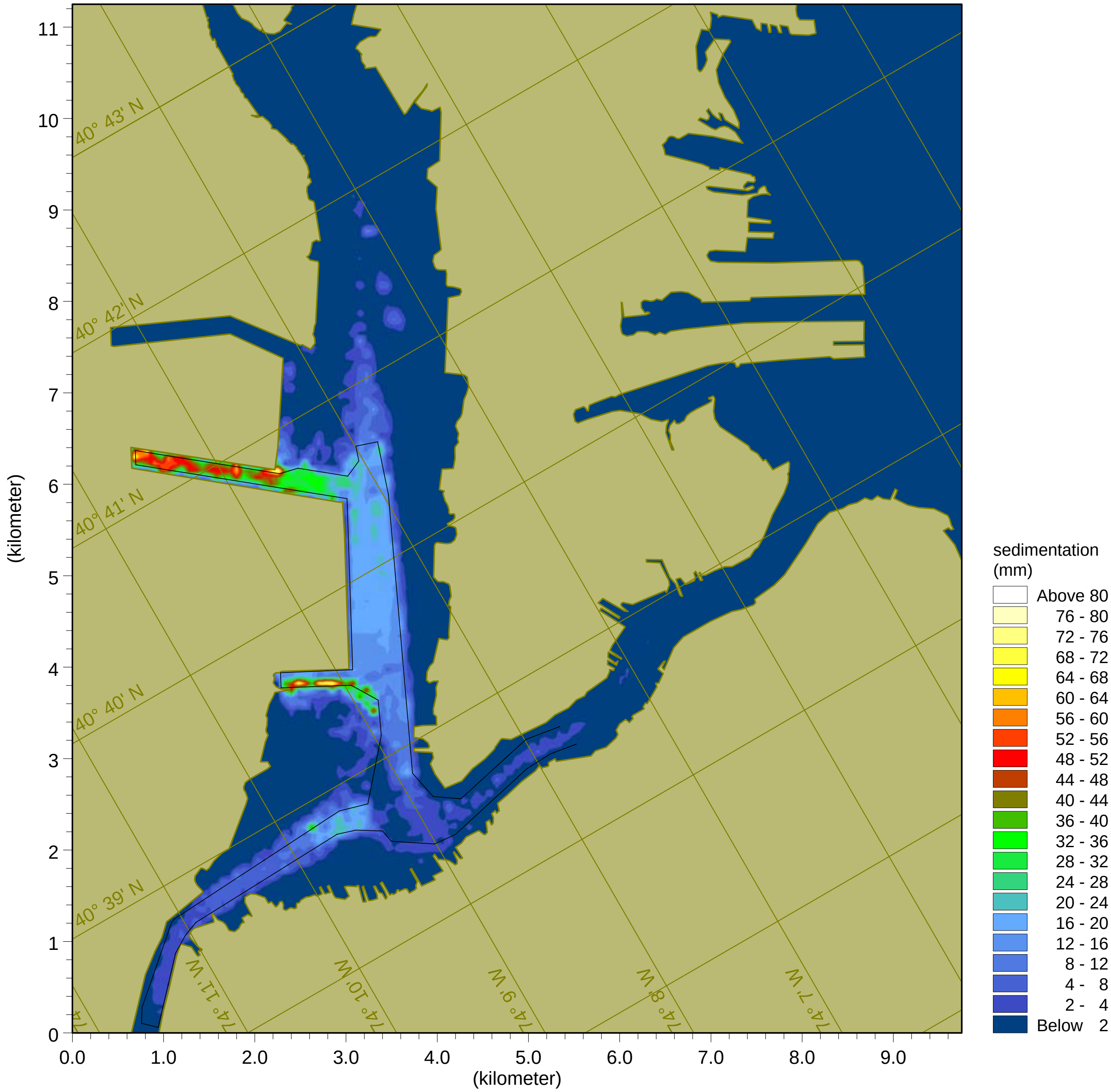
US Army Corps of Engineers
New York District

Figure 33
Dredge Resuspension Induced Sedimentation – Area AK-2



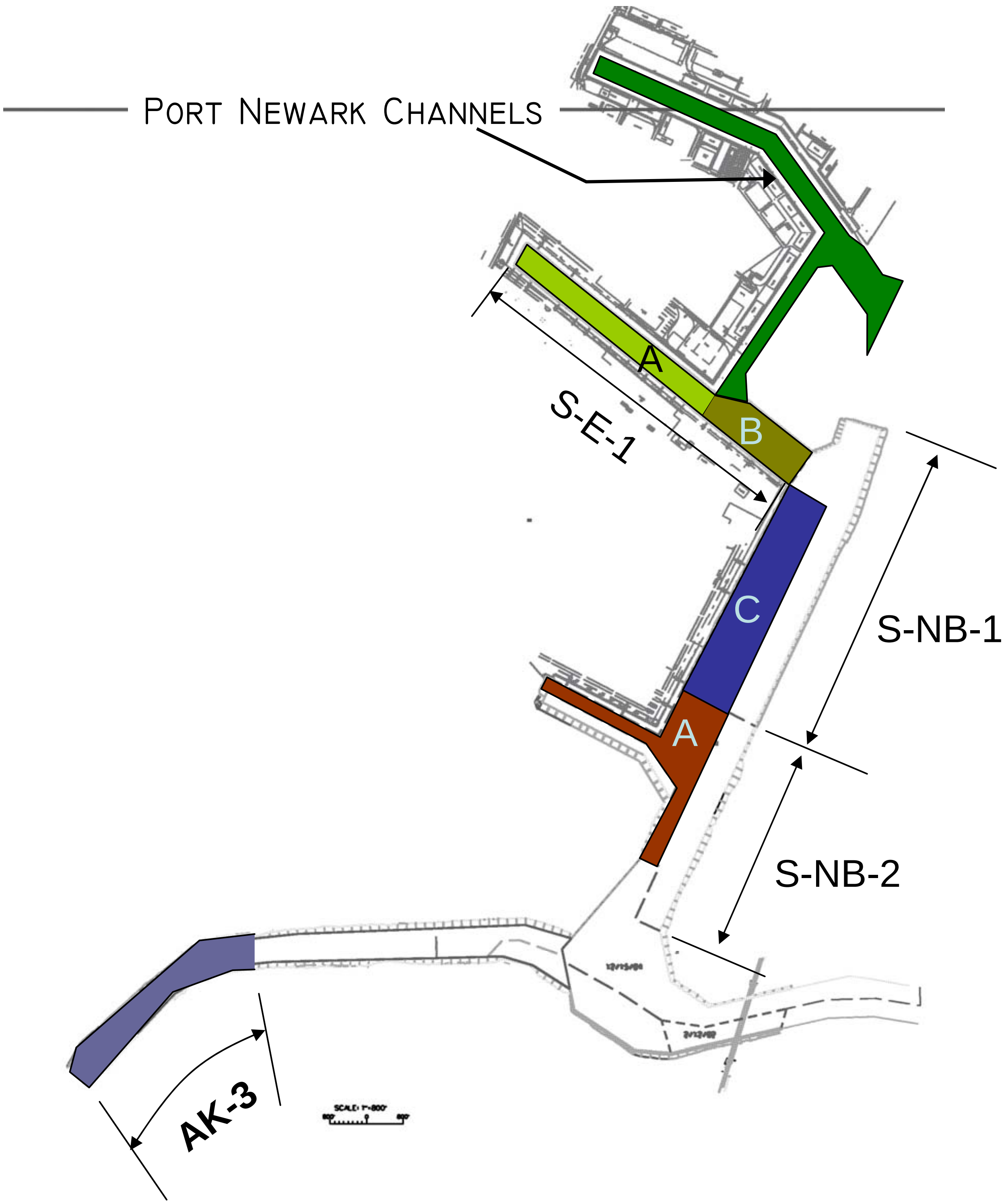
US Army Corps of Engineers
New York District

Figure 34
Dredge Resuspension Induced Sedimentation – Area AK-3



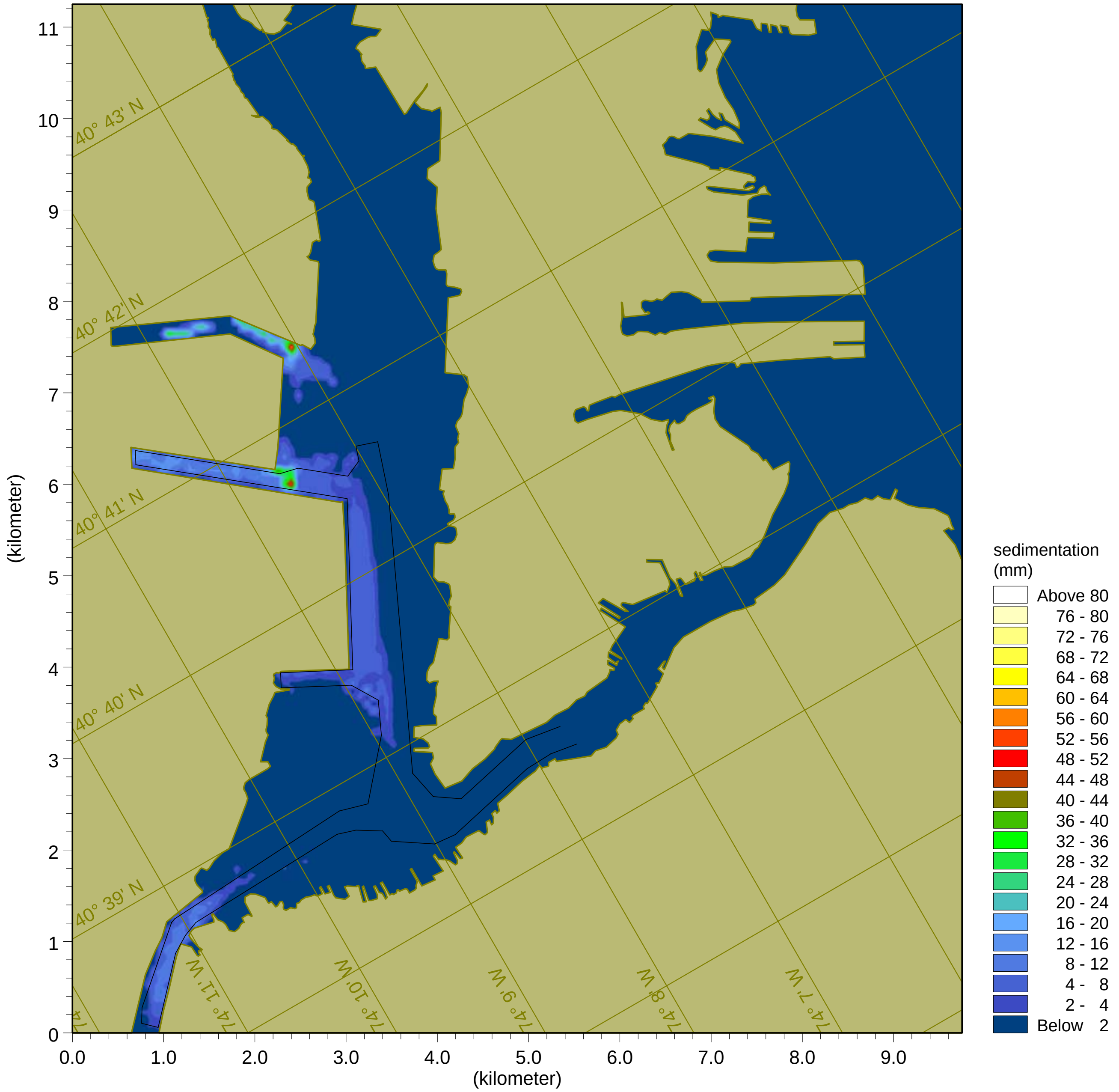
US Army Corps of Engineers
New York District

Figure 35
5-year Sedimentation Caused by HDP Resuspension



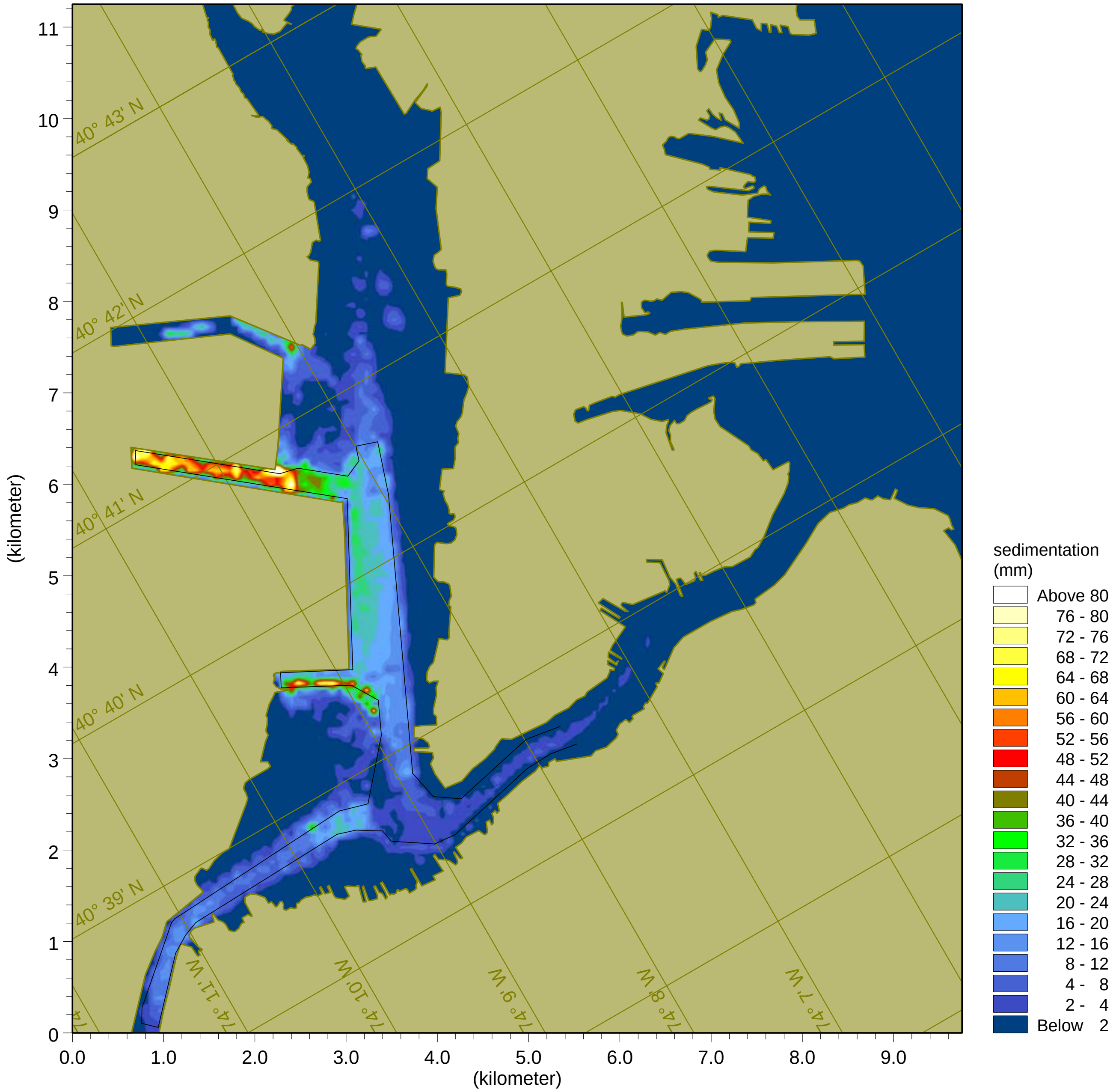
US Army Corps of Engineers
New York District

Figure 36
Dredge Model Subareas for Other Dredging Including Maintenance



US Army Corps of Engineers
New York District

Figure 37
Sedimentation Due to Maintenance and Other Dredging Resuspension



US Army Corps of Engineers
New York District

Figure 38
Cumulative 5-year Sedimentation Due to HDP and Other Dredging Resuspension