Short-Term Risks Associated with Confined Aquatic Disposal of Contaminated Dredged Material at Piaçaguera Canal, Brazil.

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Outline

- **Dredged Material and Cap Loss From Ships**
  - Ship-Induced Shear Stress
  - Erosion Characterization
  - Ship-Induced Erosion Predictions
- **Dredged Material Loss During Placement**
  - Sediment Properties and Processes
  - Loss Predictions During Placement
- **Far-Field Transport of Loss Terms**
  - Lagrangian Particle Tracking (SSFATE)

Quantifying Loss Term from Ship Passage

- **Ship passage produces stress on sediment bed**
  - Advanced ship hydrodynamic models developed by ERDC for both propeller and bow wake dynamics
  - Predict time series of bottom stress (τ) due to ship passage
- **Erosion of Mixed Sediments**
  - Site-specific mixed sediment experiments required
  - Develop site-specific algorithms for erosion vs. density (ρ), τ
  - Develop site-specific algorithms for density vs. depth (d)
- **Erosion Due to Ship Passage**
  - Incorporate site-specific erosion algorithms into ship passage model to quantify losses due to ships

Ship-Induced Shear Stress

- **Complex ship hydrodynamic model developed at ERDC after years of research and data collection**
- **Time/spatially variable shear stress predicted for various vessels that use the channel**
  - Bulk Carrier Ships
  - Tugs
  - Hopper Dredge
- **Time Series Shear Stress Estimates Depend on:**
  - Ship Properties (dimensions, displacement, speed, etc)
  - Propeller Properties (dimensions, pitch, rpm, etc)
  - Distance from Centerline (Y)
  - Water Depth (D)

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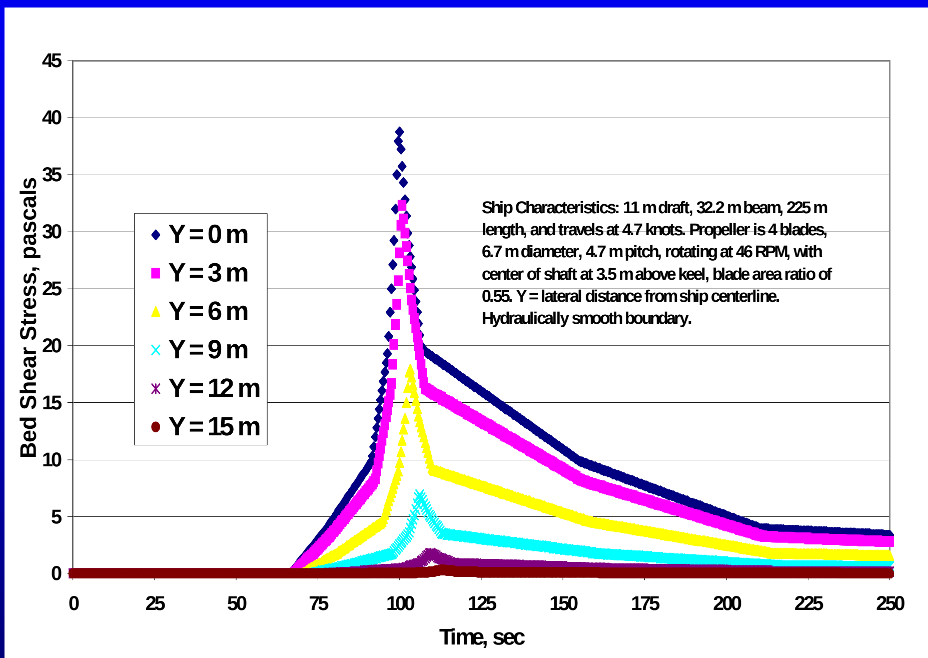
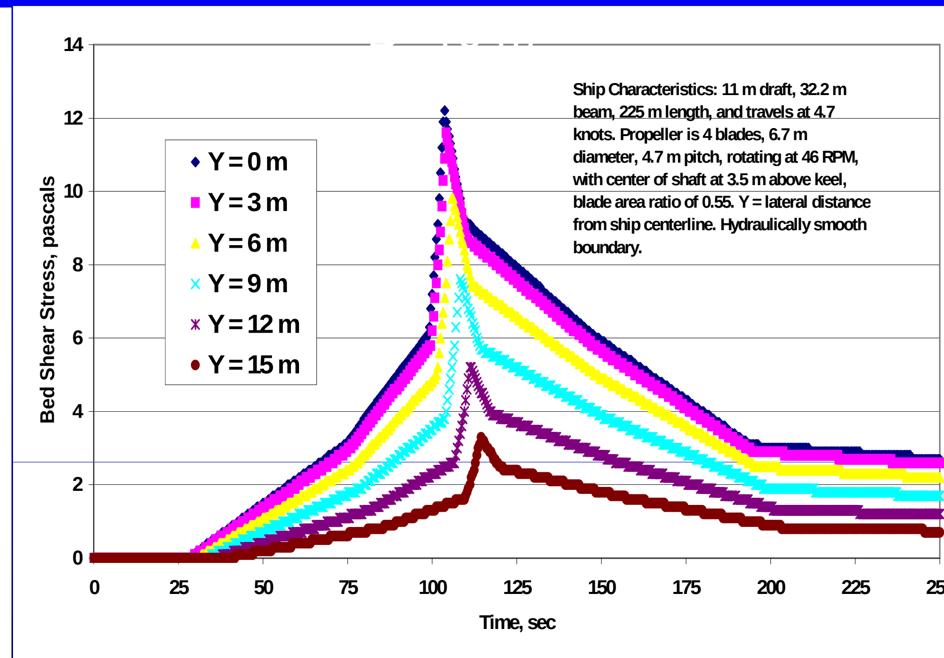
Ship Model Predictions
Bed Shear at D=13 and 16 m





Peak bed shear decreases about 30% for every extra meter in depth

Peak bed shear stress occurs for only short time period

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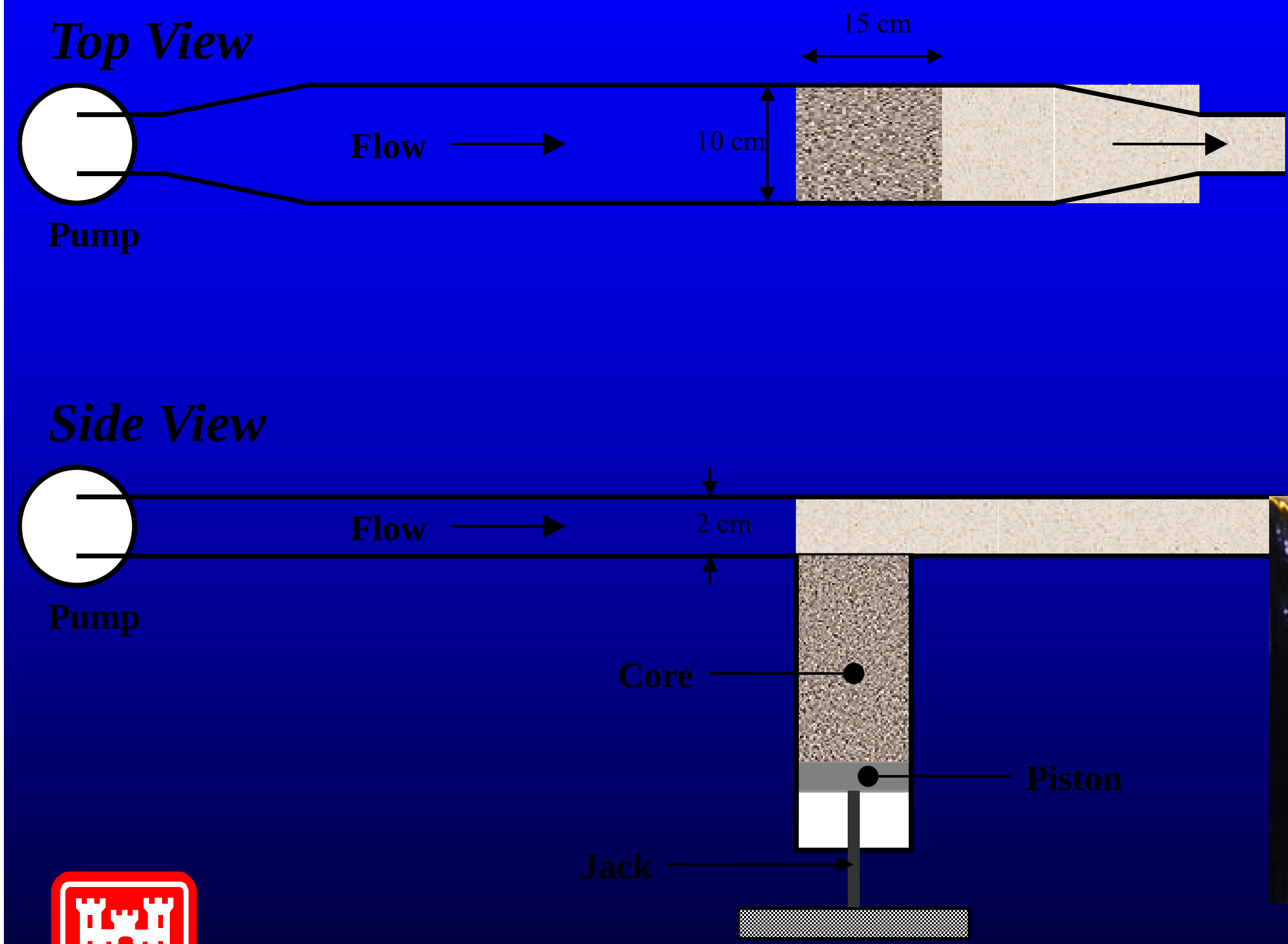
Site-Specific Erosion Algorithms

- **Why Quantify Site-Specific Erosion ?**
  - Erosion rates known for sand as function of τ, GSD
  - Mixed sediments are cohesive and erosion depends on multiple properties, including τ, GSD, ρ, OC, salinity, etc
  - Quantitative relationships between properties and processes are unknown. Therefore, site-specific erosion algorithm parameterization required
  - Couple these erosion data with site-specific consolidation data to determine erosion variation with depth, time
- **Site Specific Erosion Algorithms Developed Using Sedflume**

Sedflume Schematic



Method for Applying Sedflume

- **Create Cores for Erosion Testing**
  - Cores created for cap material and dredged material
  - Material slurried (simulating dredging process) and poured into coring tubes
  - Slurry of varying density used so that consolidation with time is quantified under different conditions
- **Erosion Experiments performed on each core**
  - Cap or dredged material
  - Varying consolidation times
  - Measure erosion rates at varying ρ, τ for cap and DM

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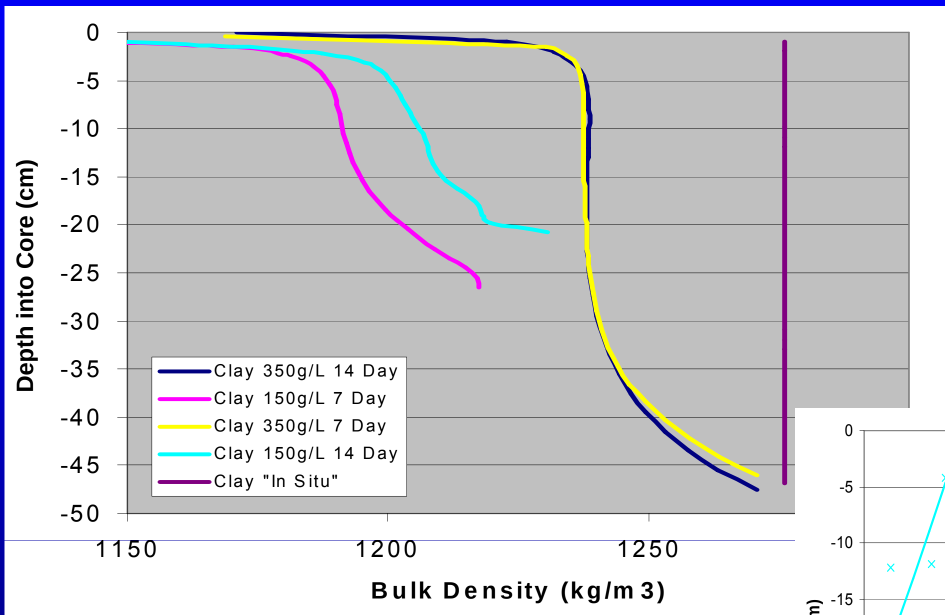
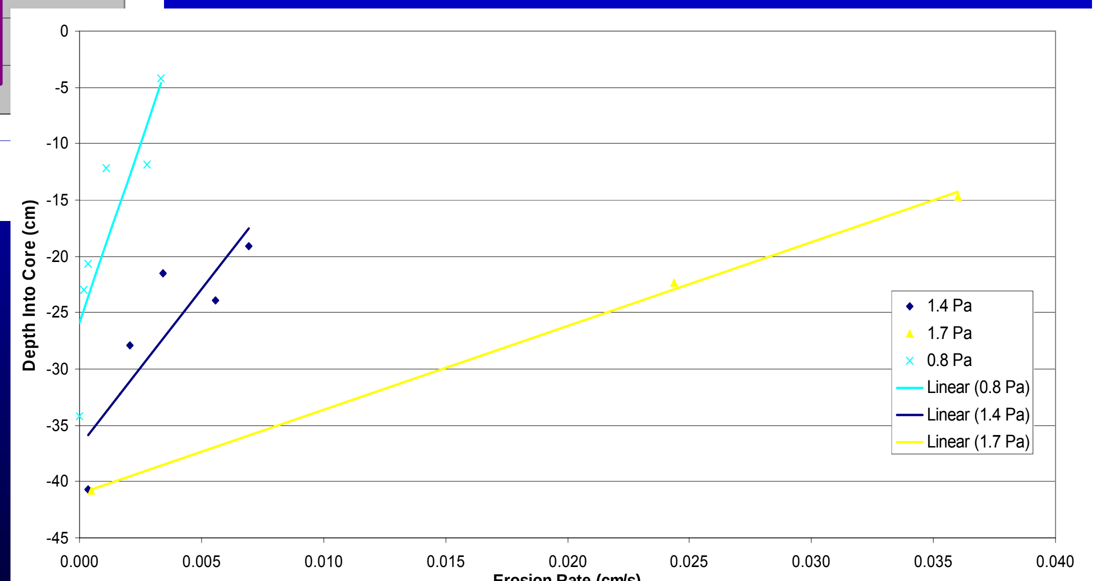
Density and Erosion vs. Depth

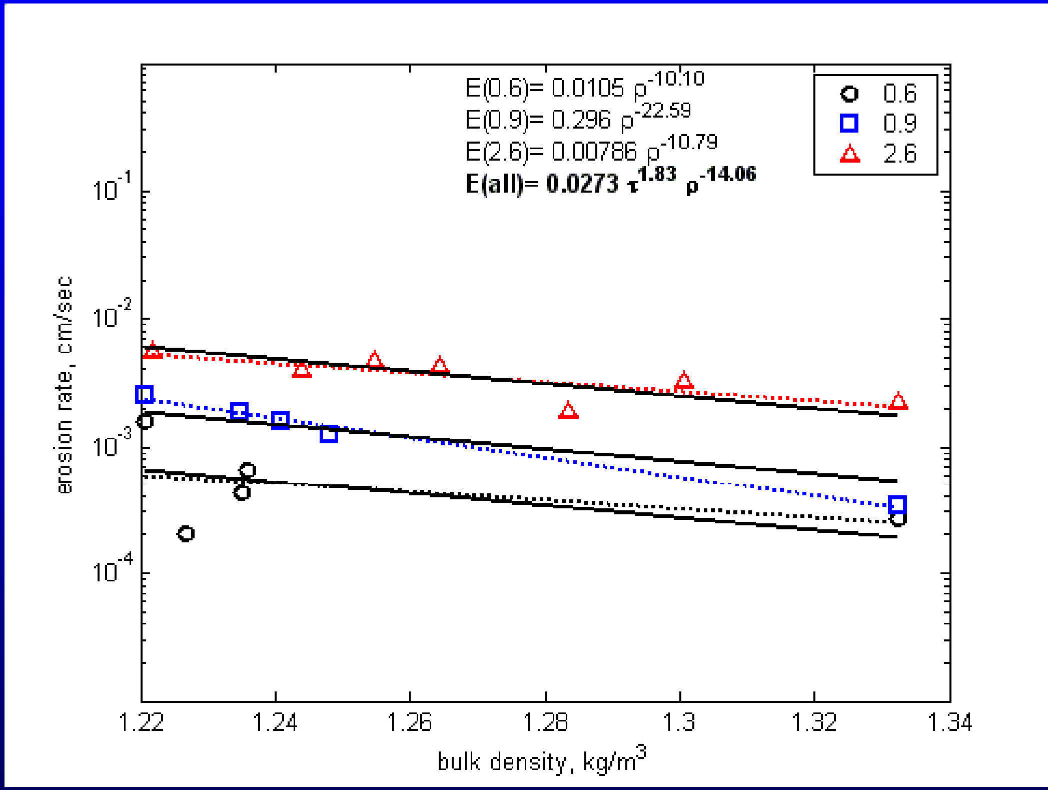


These studies performed for both cap and dredged material

Provides density vs. time, density vs. depth and erosion vs. depth/density relationships



Dredged Material and Cap Erosion Relationships



Erosion Rate vs. Density Evaluated for Various Applied Shear Stresses

Erosion Rate vs. Shear and Density and Density vs. Depth and Time Correlated

Quantify erosion as a function of depth/density, consolidation time, and applied shear stress (all known quantities from ship model, consolidation tests, and Sedflume)

$E = A \tau^{n} \rho^{m}$, where A, n, m are sediment-specific parameters

Separate A, n, and m parameterization for Cap and DM

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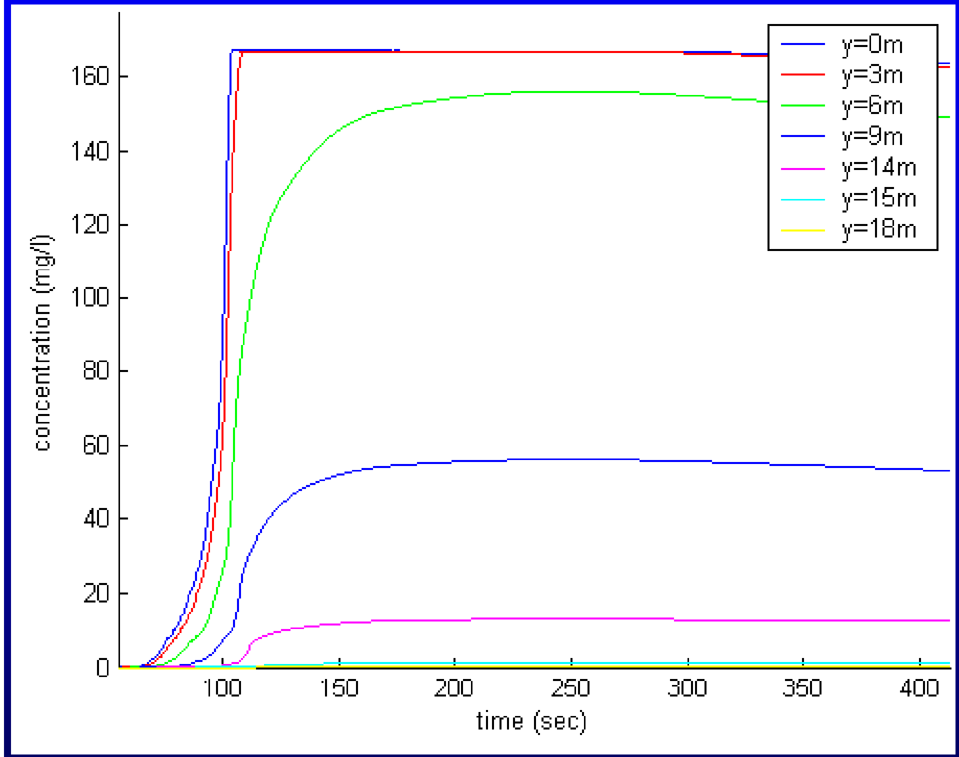
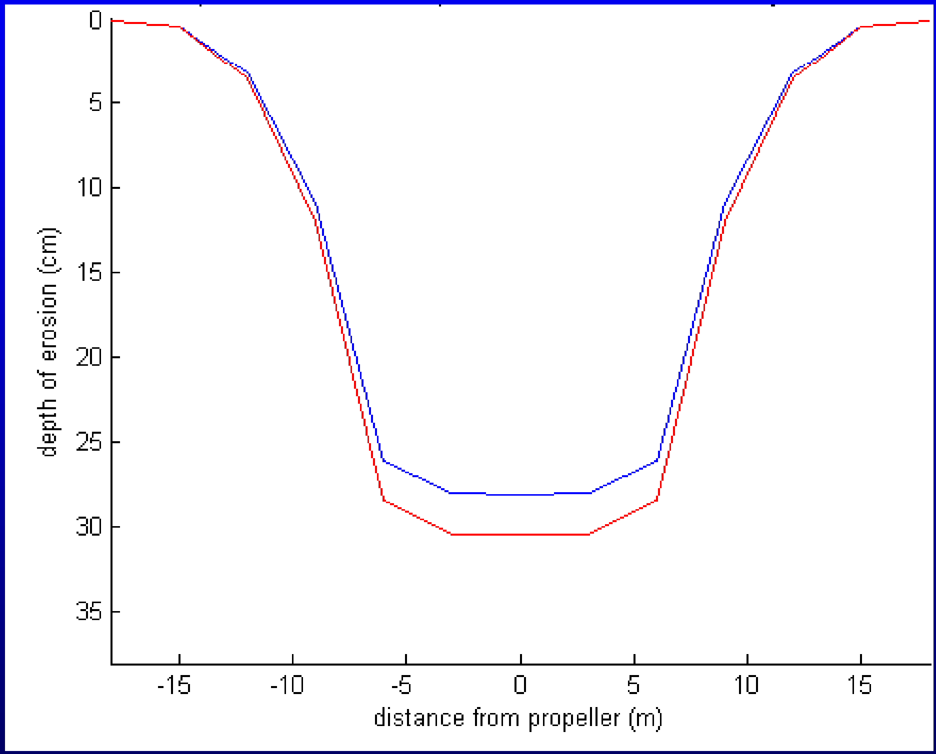
Ship Erosion Predictions

D=14 m





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Ship Erosion Predictions

- Erosion predictions shown for initial ship passage
- Erosion from subsequent ship passages will be less because of increased ρ
- Most of suspended sediment remains in lower water column (especially sand fraction)
- Most will settle back within the CAD cell
- Sediment that exits channel is considered ship-induced loss term for far-field fate modeling

Quantifying Disposal Loss Term

- Physical models (scaled laboratory experiments)
  - Hopper disposal
  - Mechanical dredge and disposal
  - Submerged pipeline
  - Submerged diffuser
- STFATE numerical model for hopper disposal

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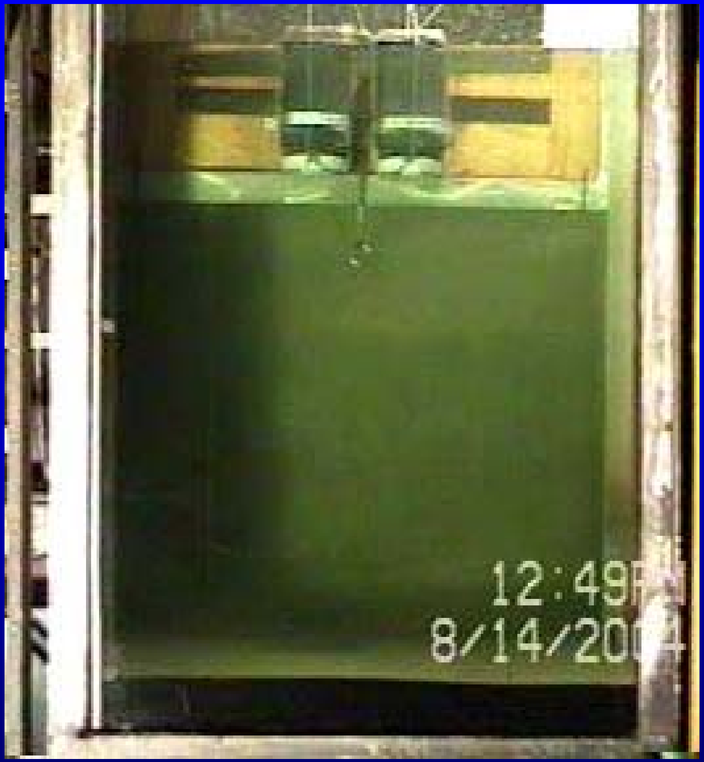
Physical Models

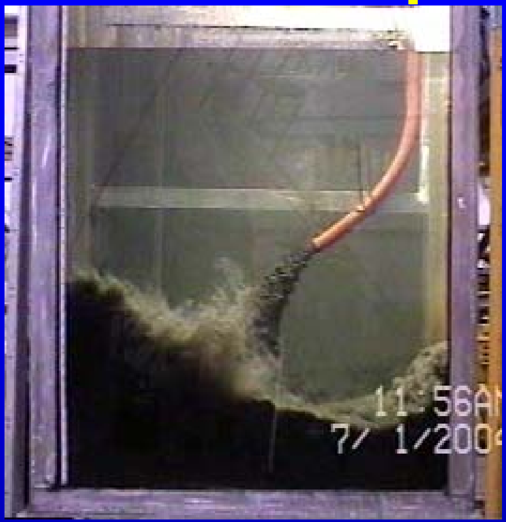


Hopper/Barge Disposal

100 to
300 mg/L

5 to 10
mg/L

Pipeline Disposal



10 to 40 mg/L

150 to
200 mg/L

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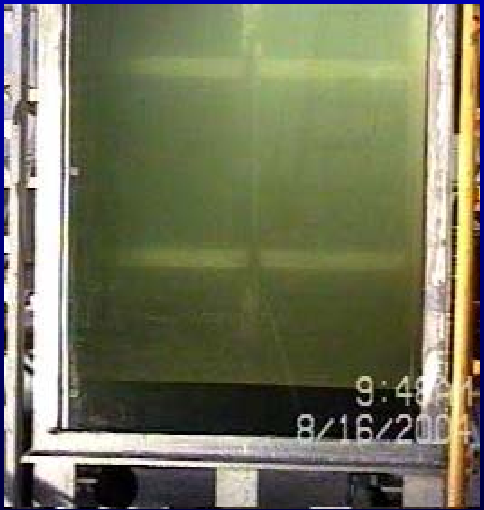
Submerged Diffuser



2 to 50 mg/L

Physical Models Results

Test	Upper 50% of Water Column % of total mass	Overall Water Column % of total mass
Test 1- Bottom dumping of mechanically dredged material	0.2	1
Test 1b (Rep 2) - Bottom dumping of mechanically dredged material	0.4	2
Test 2 - Slurry discharge from a submerged diffuser	0.003	0.06
Test 2b (Rep 2)- Slurry discharge from a submerged diffuser	0.08	0.2
Test 3 - Slurry discharge from a pipeline	0.04	0.4
Test 4 - Bottom dumping of hydraulically dredged material	0.3	1

STFATE Modeling

- Models instantaneous discharges from hoppers and barges
- Predicts losses to water column and their distribution, dense slurry composition on bottom, deposition and surge

Percent Stripped Inside and Outside CAD Cell					
Case	Location	Coarse Silt	Fine Silt	Clay	Overall
25% Full	Above CAD	2.9	2.6	4.6	3.4
25% Full	In CAD	9.2	8.1	16.7	11.2
50% Full	Above CAD	5.7	5.2	9.4	6.7
50% Full	In CAD	6.7	5.8	11.9	8.0

Far-Field Fate Modeling of Loss Terms

- Lagrangian particle tracking models used to define far-field fate of dredged material
- Post-processing of Lagrangian particle transport used to evaluate time history of TSS and Sedimentation over the entire estuary
- Use ship-induced loss estimates and disposal loss estimates as sources to particle tracker

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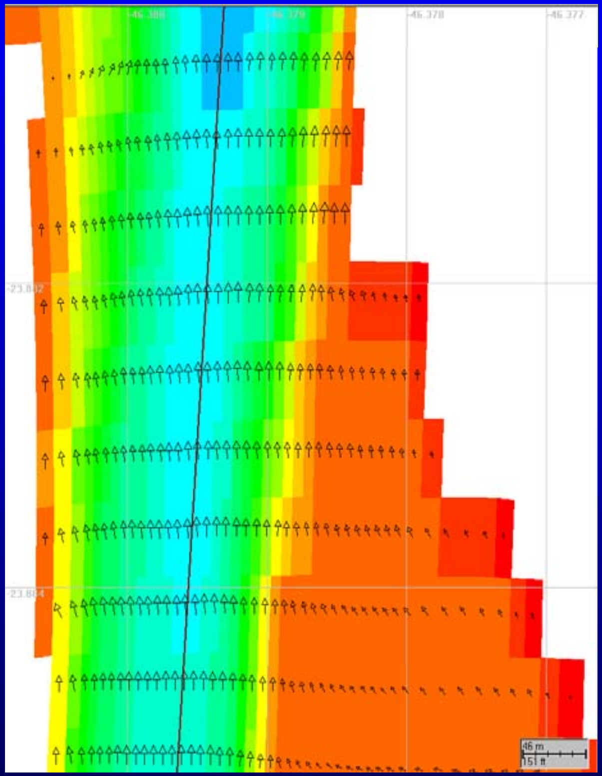
SSFATE Model Input

- Hydrodynamic Input
  - Estuary bathymetry
  - 3D Time-Varying Current field
- Sediment loss term input
  - Particle classes: clay, fine silt, coarse silt, fine sand, coarse sand
  - Source types: vertically and temporally varying point or line
  - Loss rate defined from dredging and ship models
  - Settling velocity and other sediment properties user defined



POM output used to drive SSFATE

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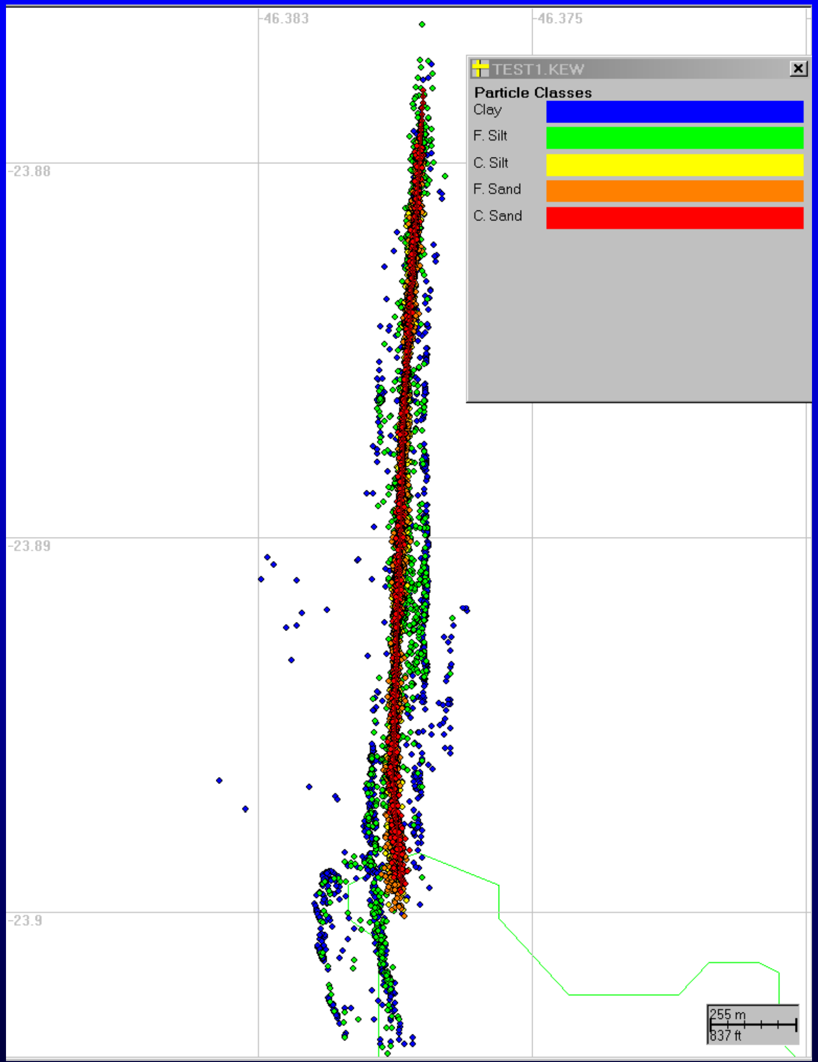
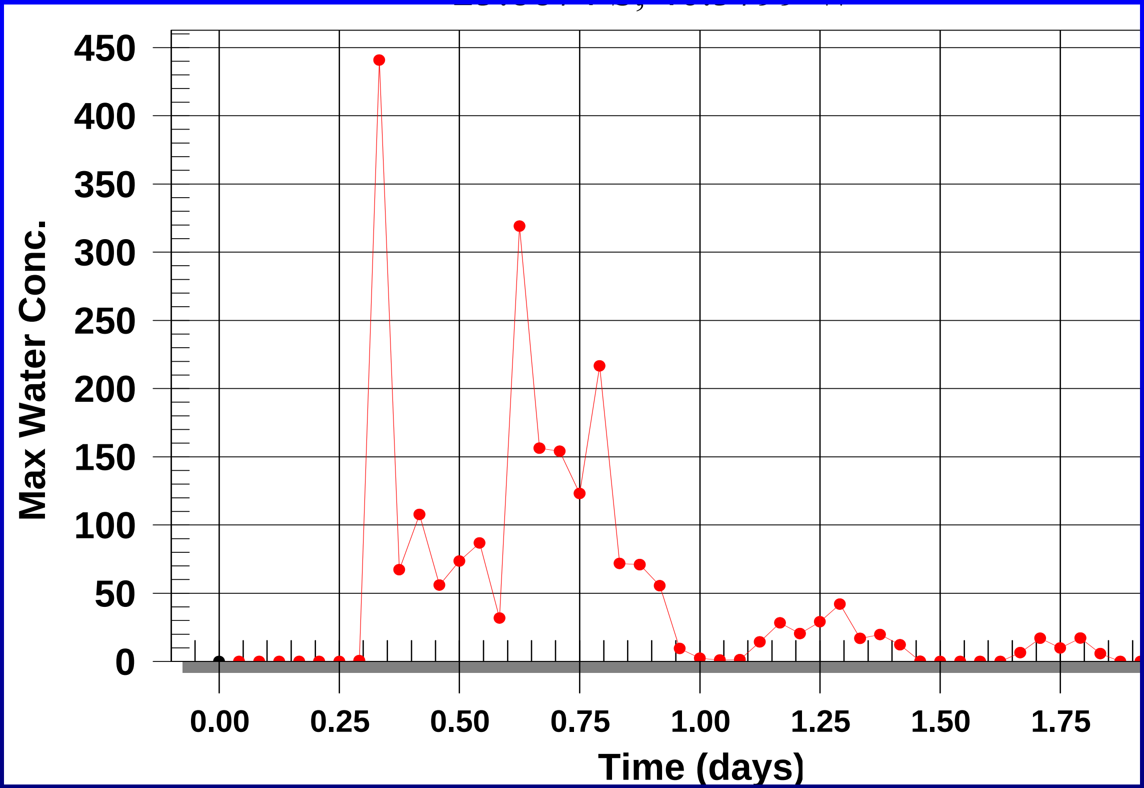
Example SSFATE Results

- SSFATE tracks particles from release location(s) as a function of sediment properties and hydrodynamic conditions
- Defined particle properties can be different for distinct particle classes
- Particle quantities and classes defined by loss term models
- This example is a hopper dredge loss (2 days after release)

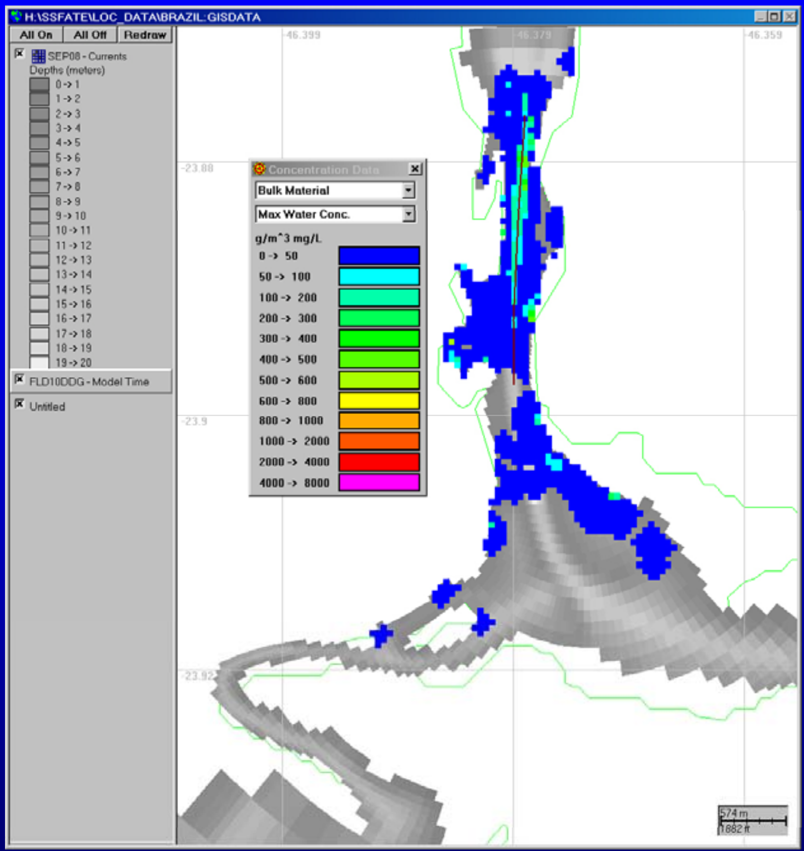


SSFATE- Data Analysis

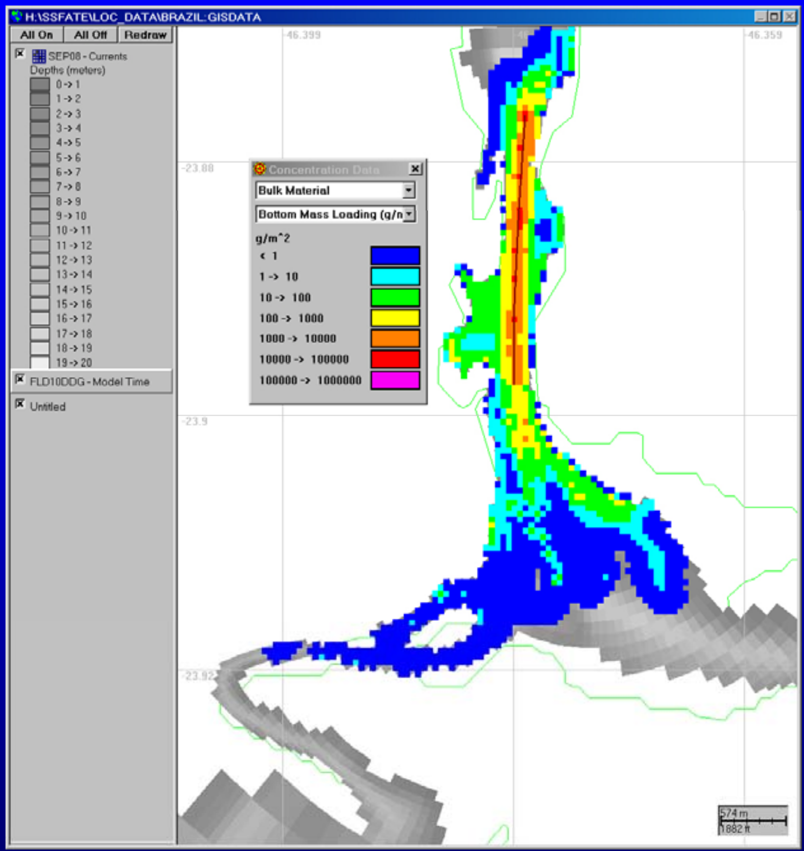


Maximum concentration at a specified point in the domain during 2 day simulation (24 hours of disposal cycles and 24 hours post-disposal)

Hopper Placement Results



TSS during placement



Sedimentation after placement

Solids Losses

Day of Operation	Height (meters)	Water Depth (meters)	Daily Solids Loss from Hopper Disposal (metric tons)	Daily Solids Loss from Ship Passage (metric tons)
0	0	25	70	0
3	3.5	21.5	350	0.1
6	5	20	700	0.5
11	7	18	1100	3
14.5	8	17	1400	9
18	9	16	1700	23
22	10	15	2000	70
24	10.5	14.5	2100	120

Dredging Losses: 80 metric tons per day or 0.5%

Controls

- Main source of loss is during placement
- Mechanical dredging and disposal would:
  - Increase density of disposed material
  - Reduce placement loss term
  - Increase settling rates
  - Reduce ship-induced losses (higher density material)
  - Reduce CAD pit storage needs (due to high density)
- Reduce losses by placing at bottom of CAD cell
  - Pipeline pump-out or submerged diffuser
- Limit height of dredged material fill
  - Increase CAD cell size
  - Slower placement to allow consolidation

Questions?

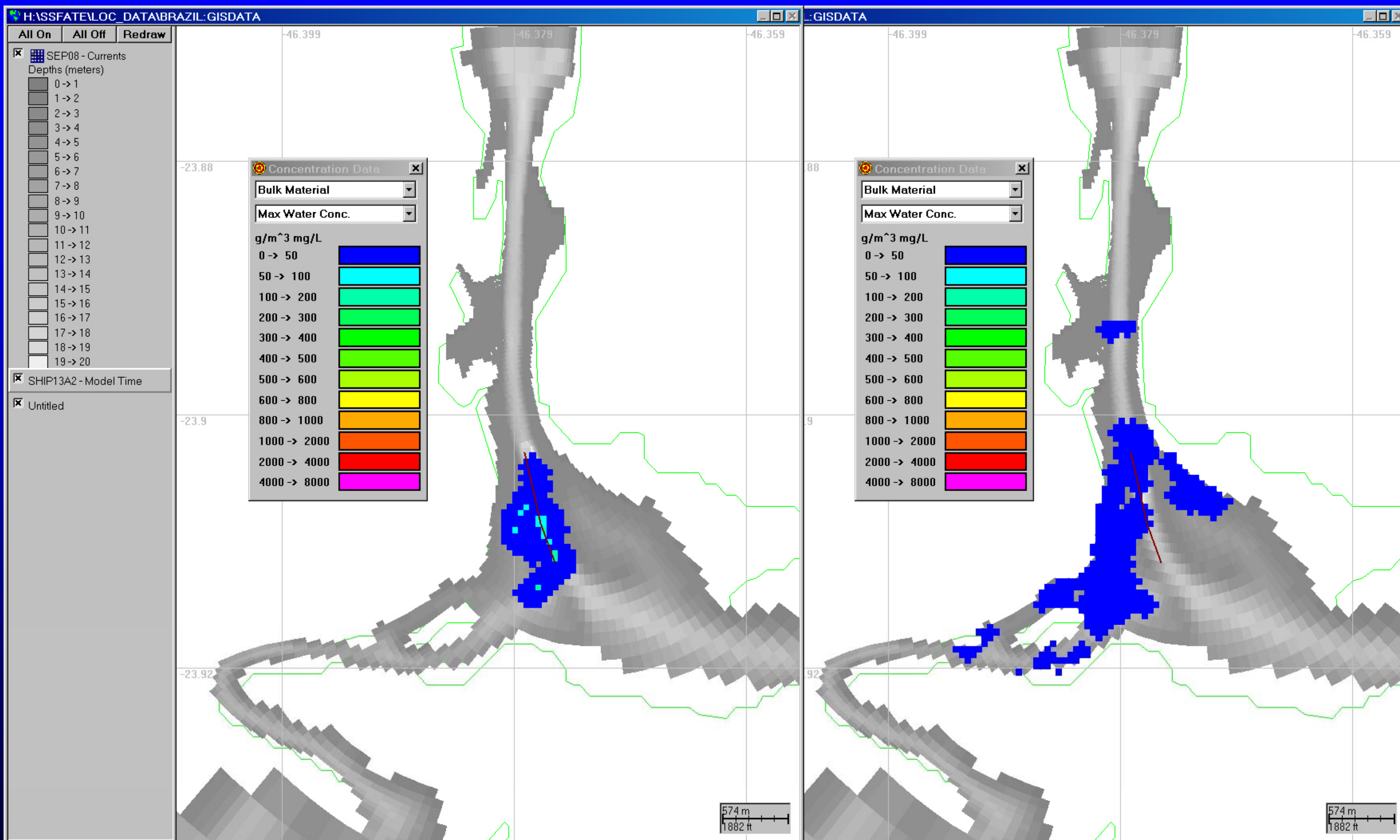
Solid Losses from Hopper Dredging

- Average Hopper Dredging Losses about 0.5% (80 metric tons per day)
- The TSS concentrations generally increase by less than 50 mg/L outside of the channel, and 100 mg/L in the channel.
- Increases in TSS are predicted predominantly in the area within 4 km of the Cubatao harbor.
- Deposition of 8 cm in the channel, about 1 cm near the channel, and up to 1 mm away from the channel.

Fate of Sediment Loss During Ship Passage

- Average ship passage losses about 0.2% of total suspended (30 metric tons per day)
- SSFATE results: The TSS concentrations generally increase by less than 50 mg/L outside of the channel, and by less than 100 mg/L in the channel.
- Increases in TSS are predicted predominantly in the area near the CAD cell.
- Deposition of 3 cm in the channel, about 3 mm near the channel, and very little away from the channel.
- SSFATE results would change with validated hydrodynamic model (more transport to east)

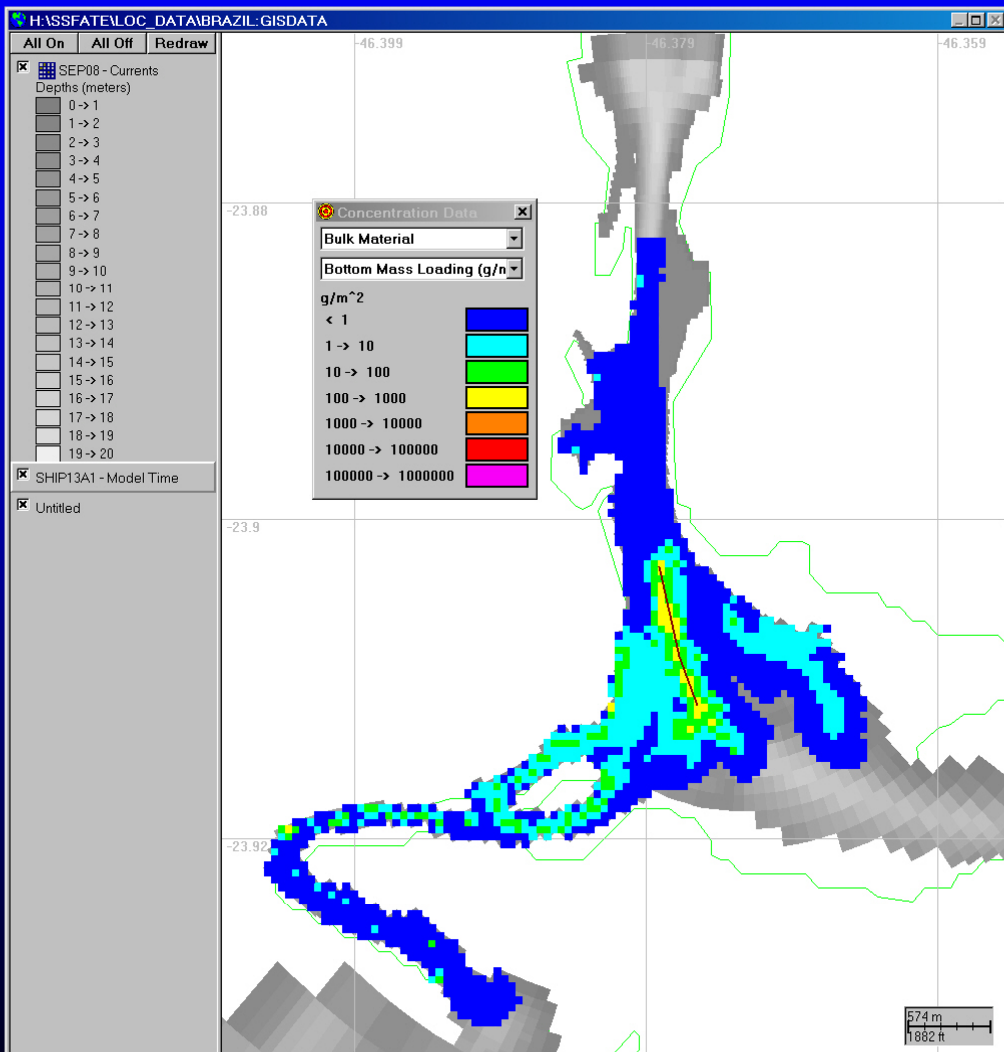
Ship Passage Results - TSS



3 hours

24 hours

Ship Passage Results - Sedimentation



$1000\ g/m^2 = 1\ cm$

Majority of loss term deposition in channel

Deposition $<10\ g/m^2$ (0.1 mm) outside the channel, in sensitive habitat

Solid Losses from Hopper Dredging

- Average Hopper Dredging Losses about 0.5% (80 metric tons per day)
- The TSS concentrations generally increase by less than 50 mg/L outside of the channel, and 100 mg/L in the channel.
- Increases in TSS are predicted predominantly in the area within 4 km of the Cubatao harbor.
- Deposition of 8 cm in the channel, about 1 cm near the channel, and up to 1 mm away from the channel.

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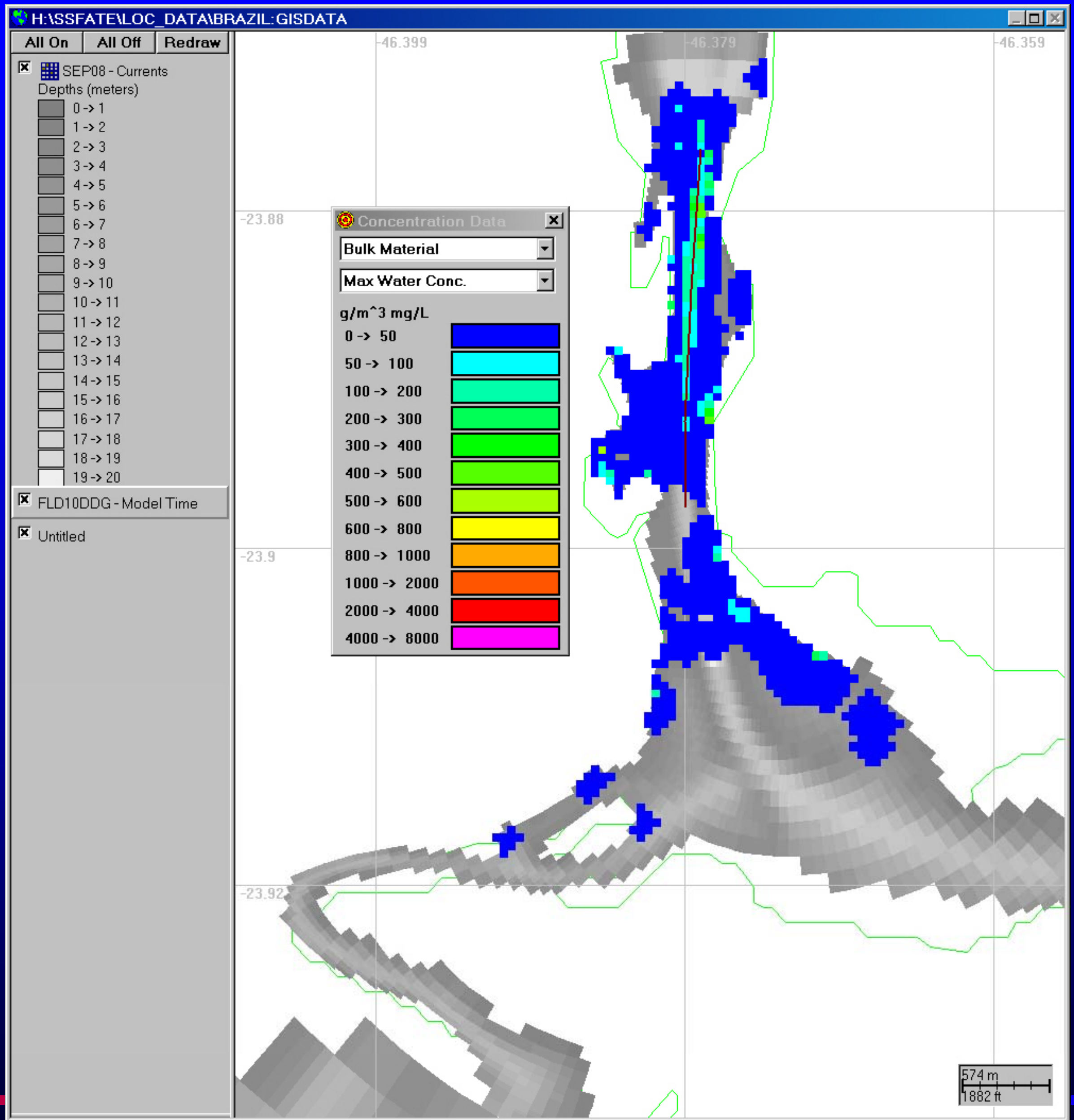
Hopper Dredging Losses



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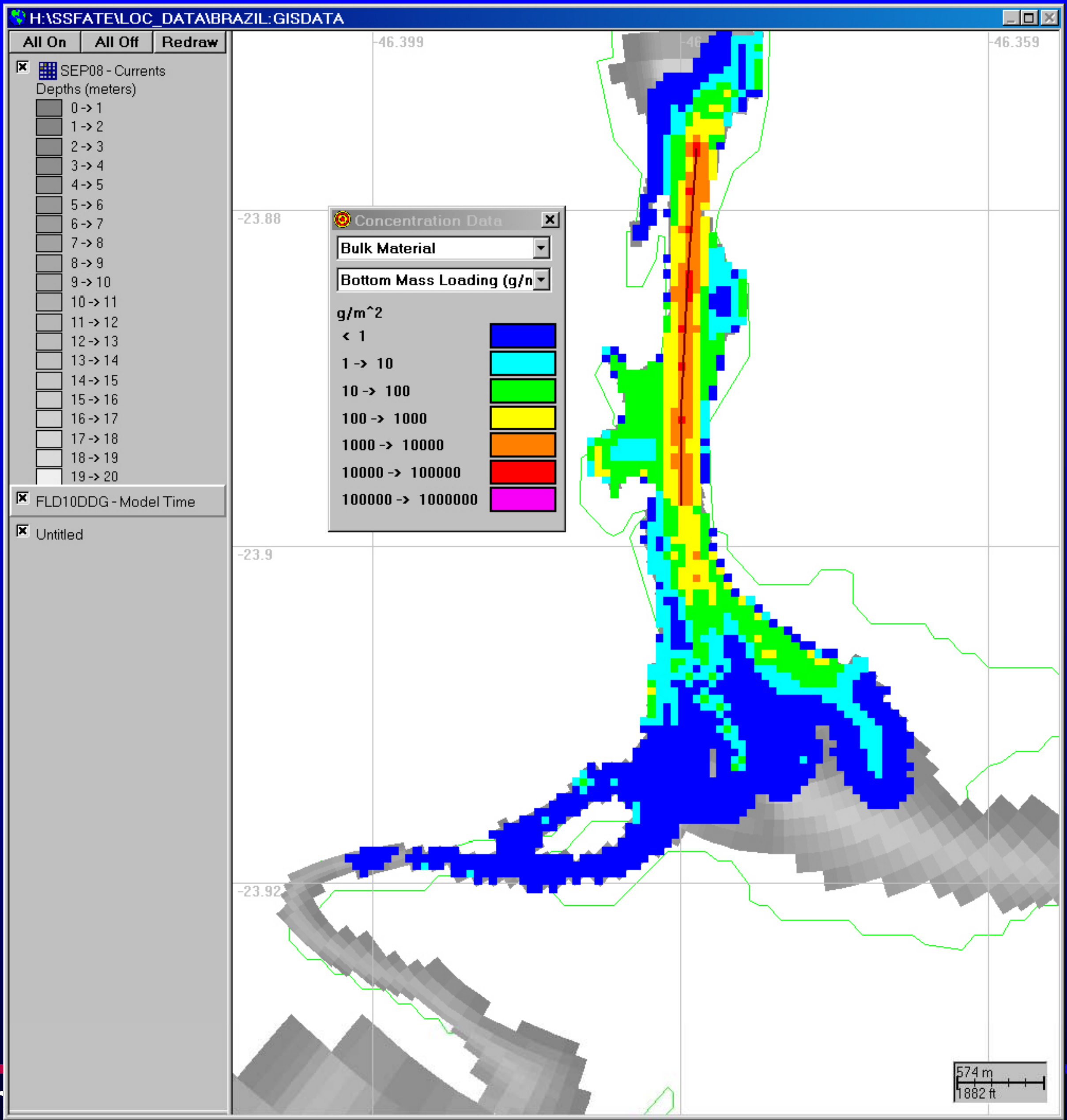
Hopper Dredging Losses

$1000 \text{ g/m}^2 = 1 \text{ cm}$



Solids Losses

Day of Operation	Height (meters)	Water Depth (meters)	Daily Solids Loss from Hopper Disposal (metric tons)	Daily Solids Loss from Ship Passage (metric tons)
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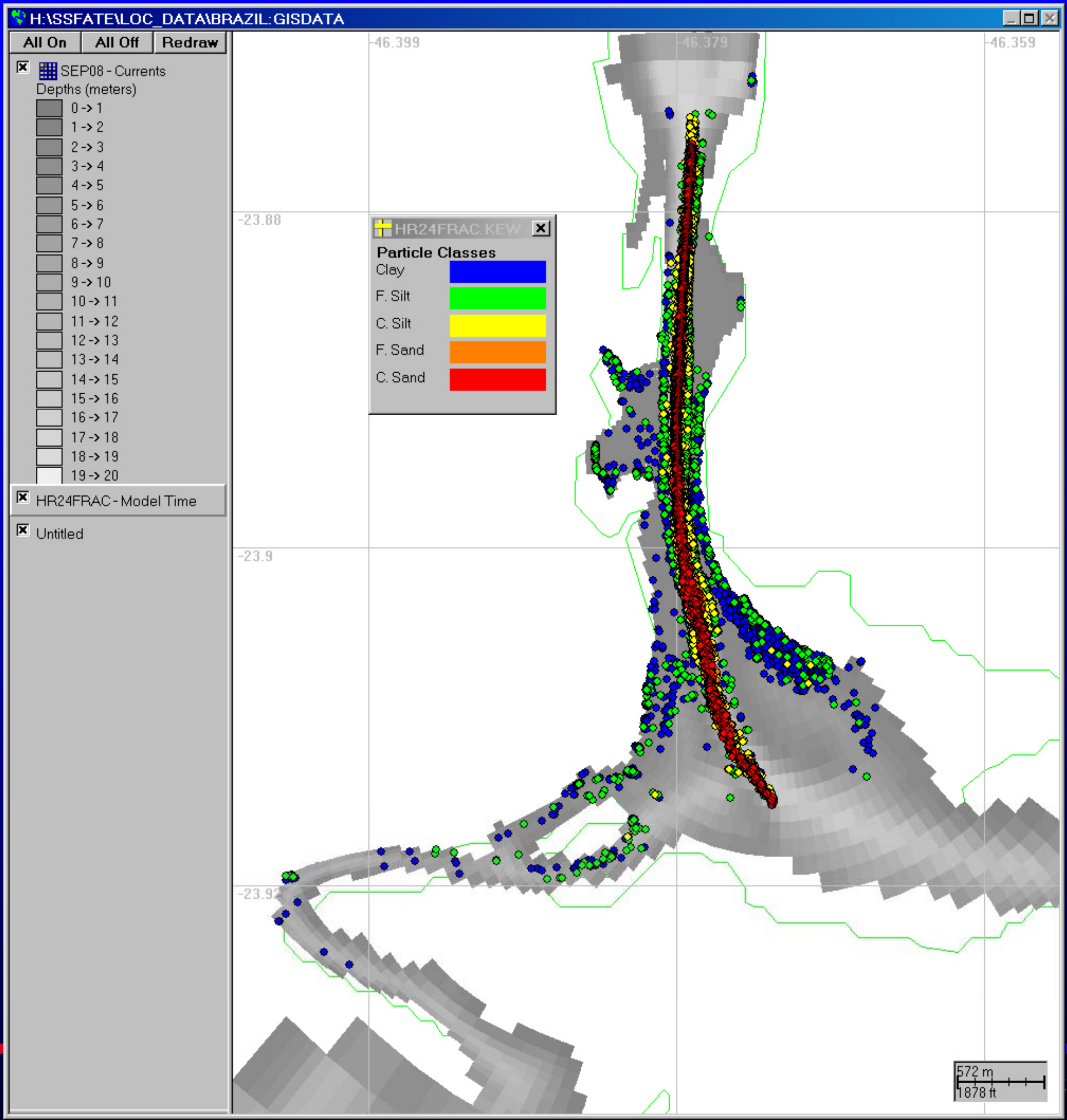
14.5	8	17	1400	9
18	9	16	1700	23
22	10	15	2000	70
24	10.5	14.5	2100	120

Dredging Losses: 80 metric tons per day or 0.5%

Solid Losses from Hopper Disposal

- Average Hopper Disposal Losses about 7% (1200 metric tons per day)
- The TSS concentrations generally increase by about 50 mg/L to 75 mg/L outside of the channel, 200 mg/L near the channel and 400 mg/L above the CAD cell with isolated areas and depths increasing by 300 mg/L to 1000 mg/L.
- Near the end of disposal when the solids loss rate would be double the average rate, the TSS concentrations would be expected to be double the values under average conditions.
- Deposition of 40 cm in the channel, about 8 cm near the channel, and up to 1 cm away from the channel.
- Losses could be much higher if considering the suspended load from disposal.

10-day Deposition Pattern



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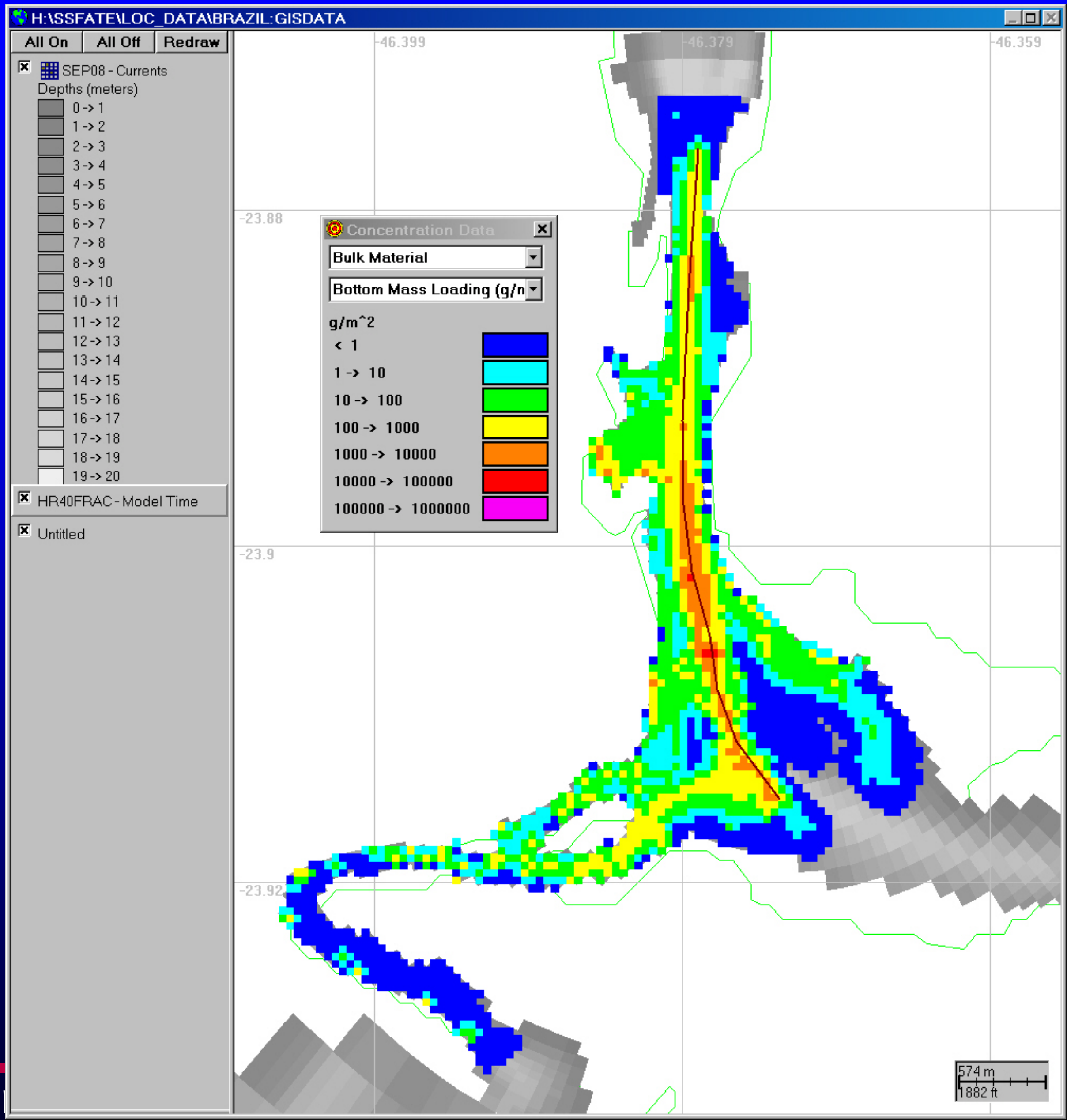
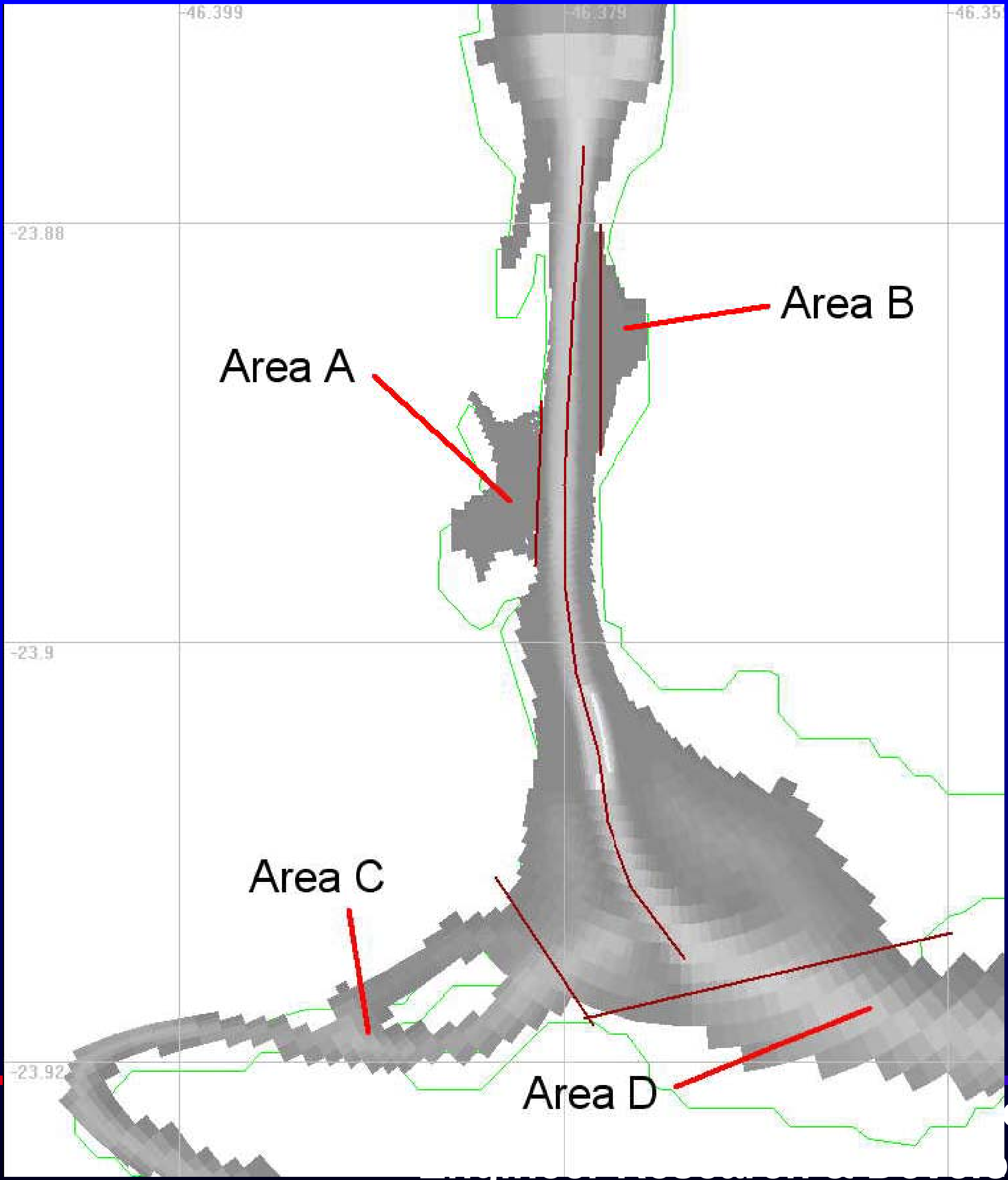
Deposition



1000 g/m² = 1 cm
for entire project



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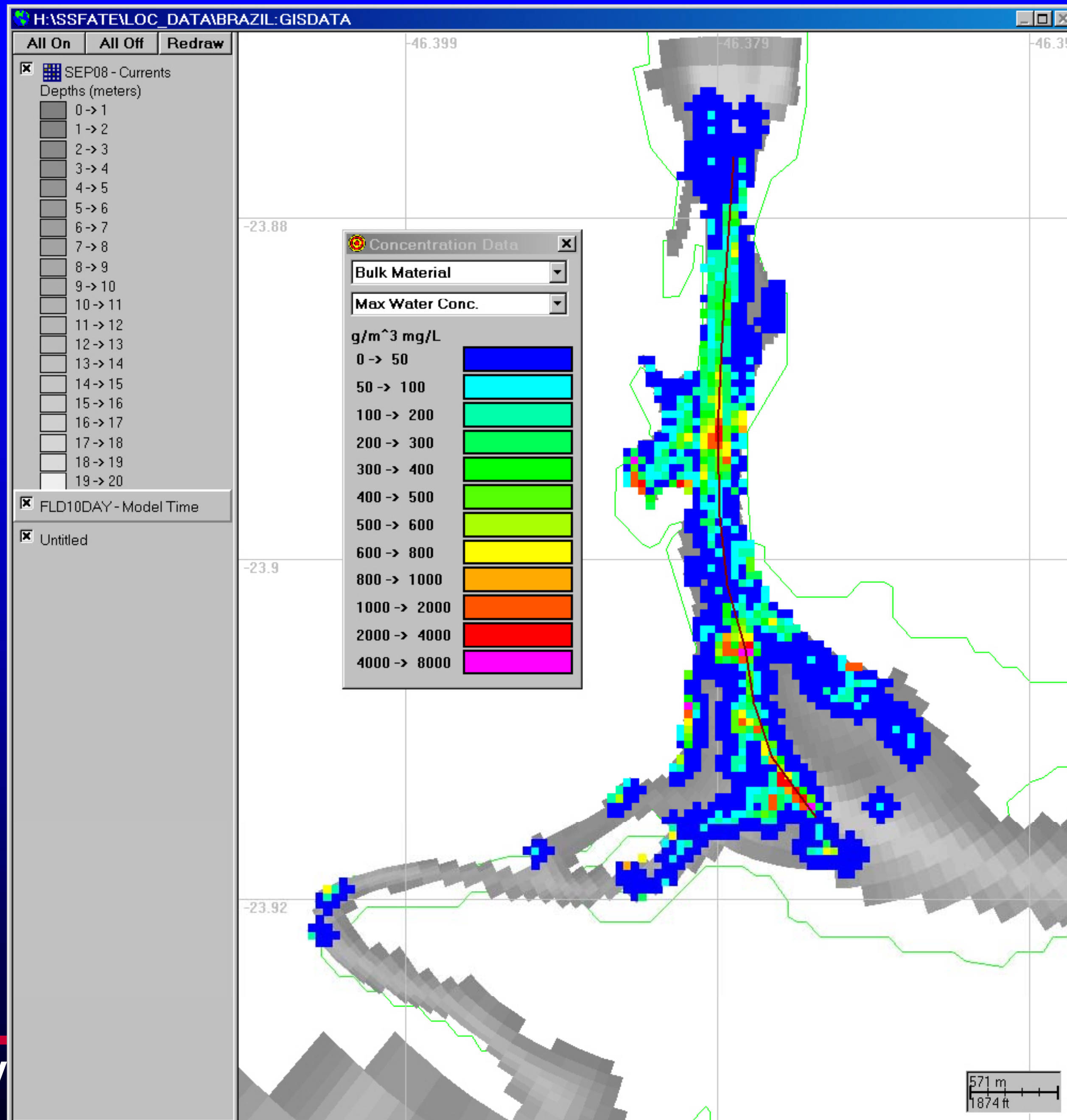
Solids Losses

	Day 1	Day 2	Day 5	Day 10
Total Deposits (metric tons)	860	1180	1240	1280
Total Suspended (metric tons)	480	160	100	60
Suspended Clay (metric tons)	270	140	100	60
Portion of Total Outside of Channel (centerline ± 100 m)	0.1%	5%	6%	6%
Portion of Total in Area A	< 0.1%	0.4%	1%	1%
Portion of Total in Area B	< 0.1%	< 0.1%	< 0.1%	< 0.1%
Portion of Total in Area C	< 0.1%	4%	4%	4%
Portion of Total in Area D	< 0.1%	< 0.1%	< 0.1%	< 0.1%

Water Quality



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Controls

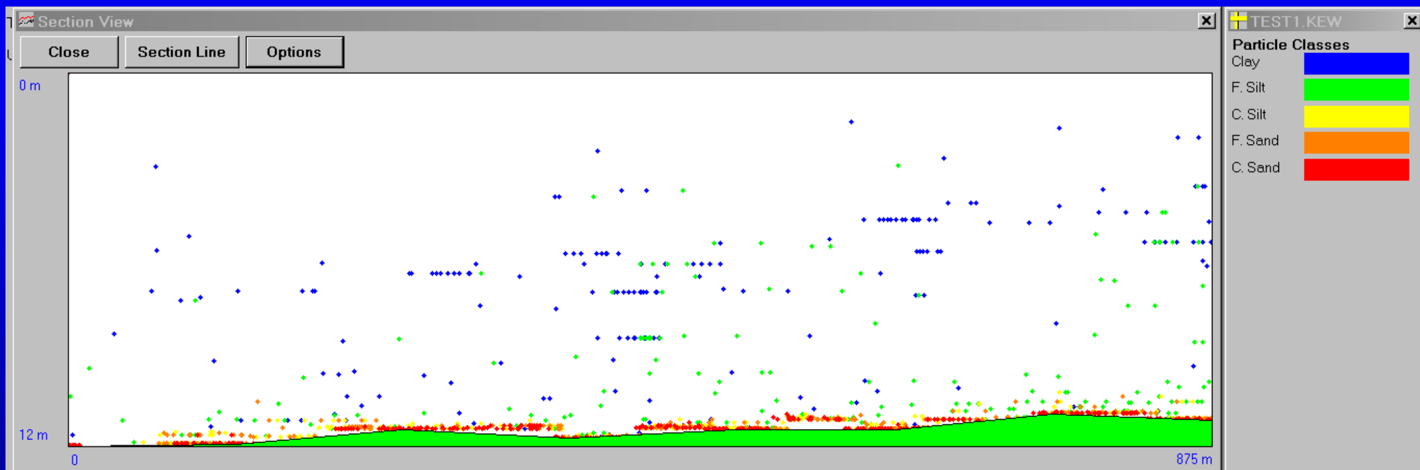
- Mechanical dredging and disposal would increase density of disposed material
- Increased density would reduce TSS losses to water column due to less entrainment of water and greater settling rates
- Increased density would reduce erosional losses
- Increased density would reduce storage needs and CAD pit size

Controls

- Disposed at the bottom of the CAD cell
- Limit the height of dredged material fill
  - Slow rate of disposal; extend period of disposal
  - Increase size of CAD cell
  - Limit quantity of dredged material

SSFATE- Data Analysis

Particle Data



Post-Processing Conversion to Concentration