Volume Calculation Methods

Reina Downing
Geologist / GIS Analyst
CSC Environmental Programs Group
Presented at the 2007 International ESRI Conference

Introduction:
Sediment Remediation Projects

- **Removal of contaminated sediments**
- **Estimate volume of sediment**
- **Contract as a measurement of achievement and payment**
- **Evaluate the results of kriging versus traditional methods used to calculate sediment volume**
- **Kriging depth of contamination and 3D visualization**

Traditional Methods to calculate volume:

1. Point to GRID – not interpolation

2. TINs (triangulated integrated network)

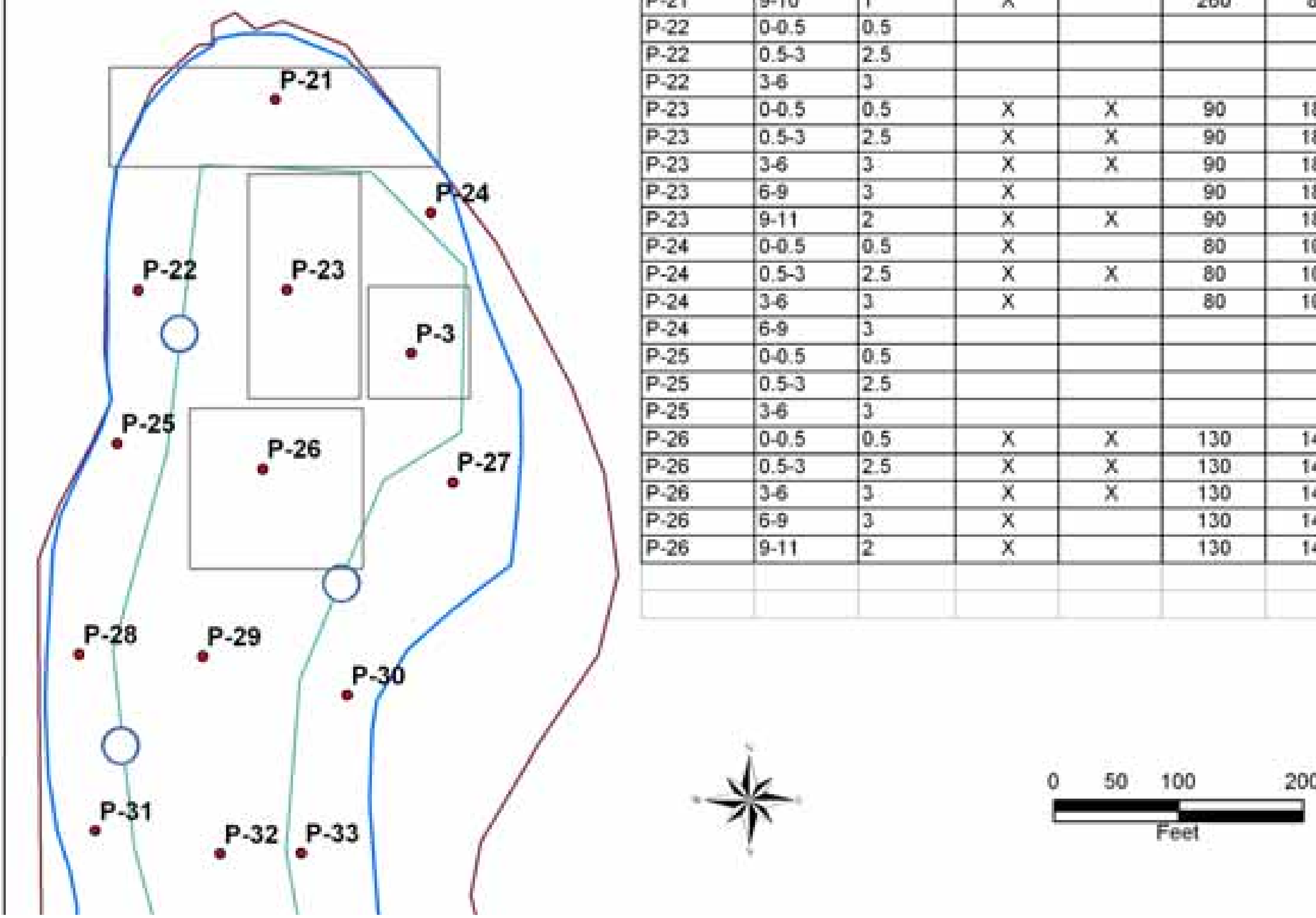
3. Interpolation Methods
   a) Inverse Distance Weighted
   b) Spline
   c) Kriging

Point to GRID

- In an engineering environment, design drawings and specifications are the traditional method of documenting and conveying volume calculations for the removal of contaminated sediments.
- Remedial investigations typically collect preliminary sediment depth data to provide an understanding of the site.
- The point data depths are then converted by a simple grid method.
- This method provides a rough calculation, based on the depth at the point inside the grid, which is extrapolated across a grid to calculate volume.

Point to Grid Method

Sample ID	Depth		Exceeds TEC	Exceeds PEC	Width (Feet)	Length (Feet)	Volume (CF)	Vol > TEC (CF)
P-03	0-0.5	0.5	X	X	80	90	3,600	3,600
P-21	0-0.5	0.5	X		260	80	10,400	10,400
P-21	0.5-3	2.5	X		260	80	52,000	52,000
P-21	3-6	3	X		260	80	62,400	62,400
P-21	6-9	3	X		260	80	62,400	62,400
P-21	9-10	1	X		260	80	20,800	20,800
P-22	0-0.5	0.5					0	0
P-22	0.5-3	2.5					0	0
P-22	3-6	3					0	0
P-23	0-0.5	0.5	X	X	90	180	8,100	8,100
P-23	0.5-3	2.5	X	X	90	180	40,500	40,500
P-23	3-6	3	X	X	90	180	48,600	48,600
P-23	6-9	3	X		90	180	48,600	48,600
P-23	9-11	2	X	X	90	180	32,400	32,400
P-24	0-0.5	0.5	X		80	100	4,000	4,000
P-24	0.5-3	2.5	X	X	80	100	20,000	20,000
P-24	3-6	3	X		80	100	24,000	24,000
P-24	6-9	3					0	0
P-25	0-0.5	0.5					0	0
P-25	0.5-3	2.5					0	0
P-25	3-6	3					0	0
P-26	0-0.5	0.5	X	X	130	140	9,100	9,100
P-26	0.5-3	2.5	X	X	130	140	45,500	45,500
P-26	3-6	3	X	X	130	140	54,600	54,600
P-26	6-9	3	X		130	140	54,600	54,600
P-26	9-11	2	X		130	140	36,400	36,400
							POND TOTAL:	2276500

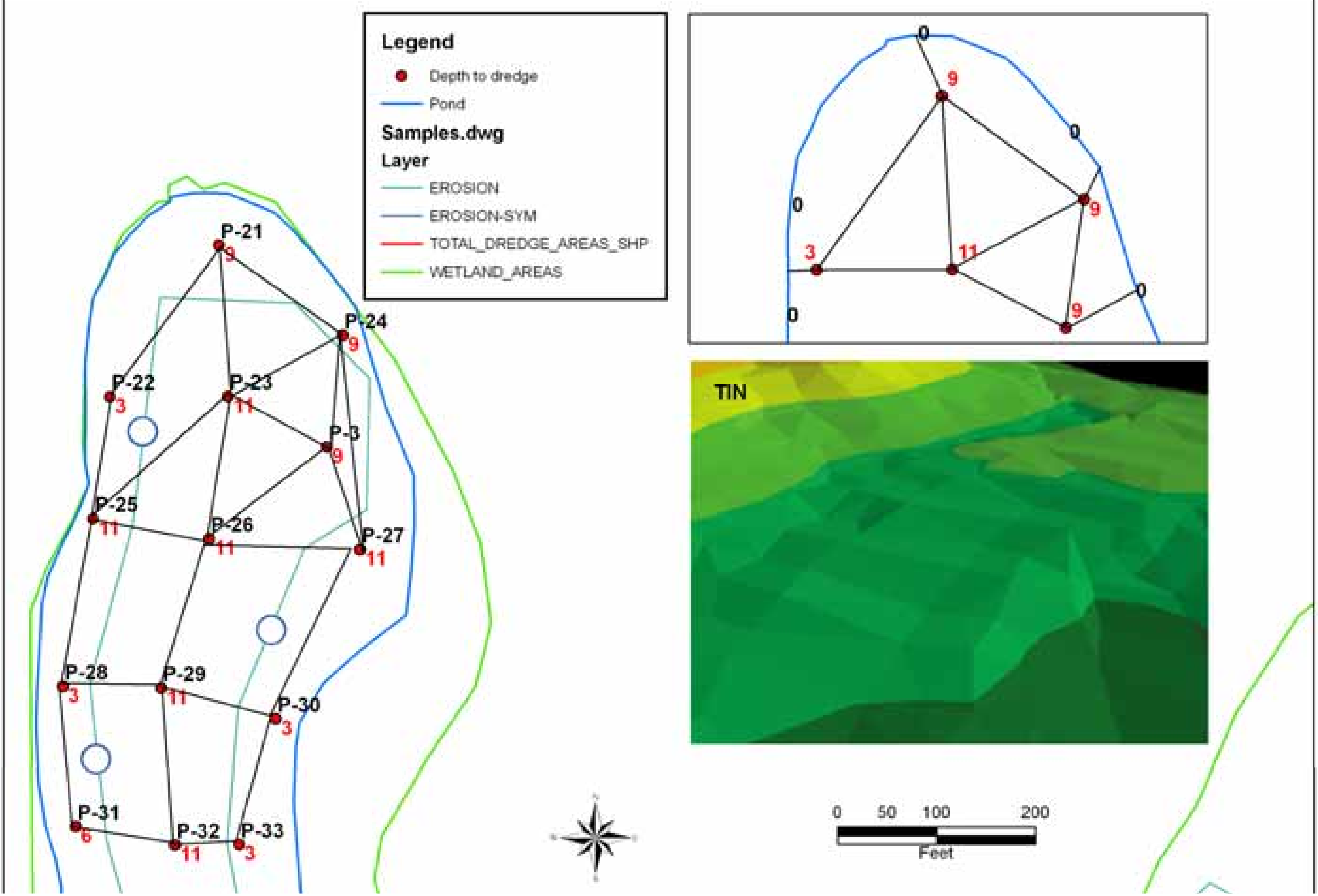


TINs

Triangulated integrated network (TIN)

While this method may produce a more accurate estimate of volume than the point to grid method, the assumption that there will be a straight line between data points is also going to result in a low bias estimate for volume.

Triangulated Integrated Network (TIN)



Other methods and data:

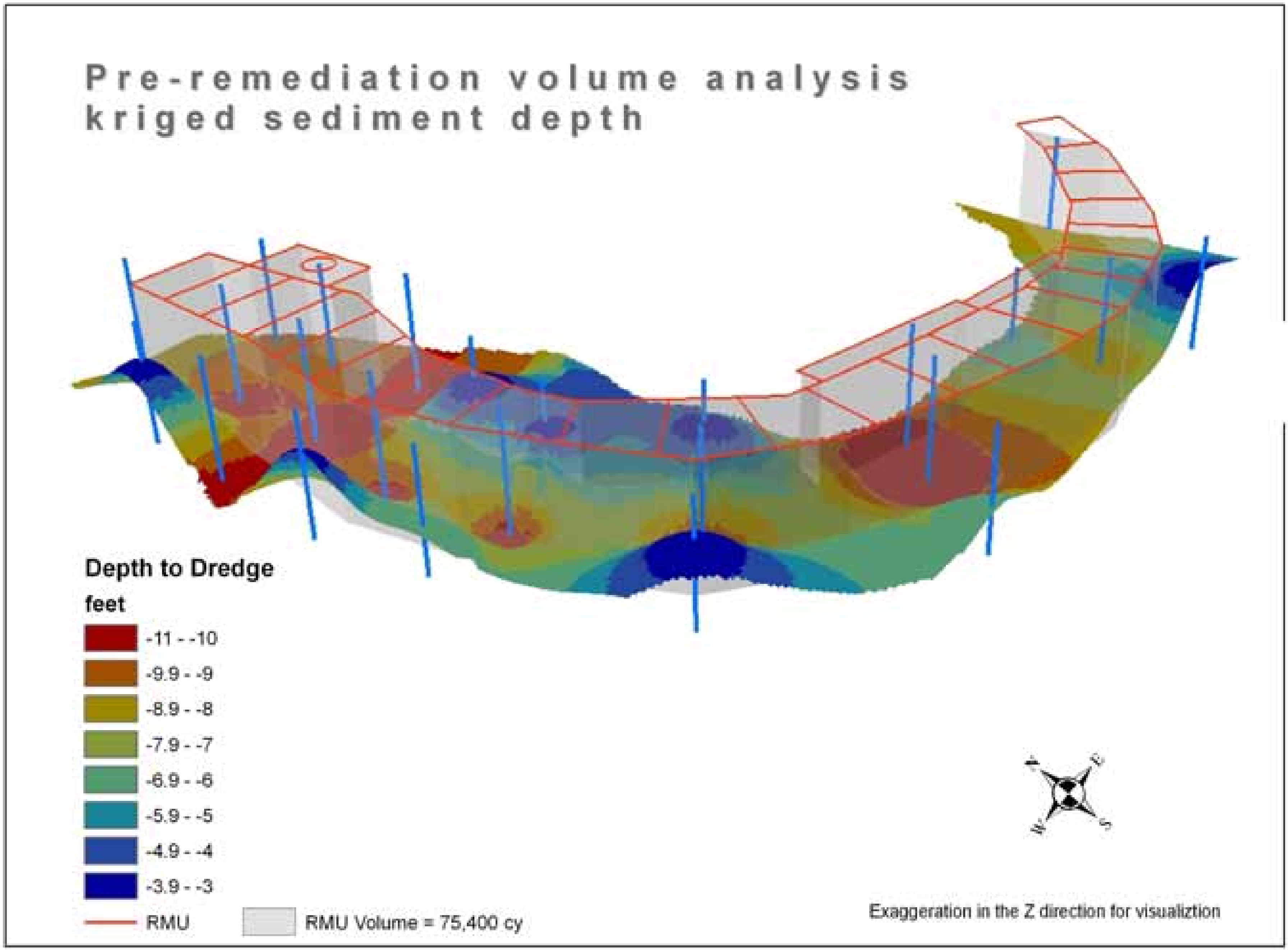
- **Bathymetric contours – pre and post provide an accurate estimate of volume** **(critical sediment angle of repose < ~ 37.5, or side slopes slump into basin)**
- **DEMs – not typically at the scale for calculating volume (~10 m)**
- **LIDAR – extremely accurate and expensive**

GIS Spatial & 3D Analyst Tools

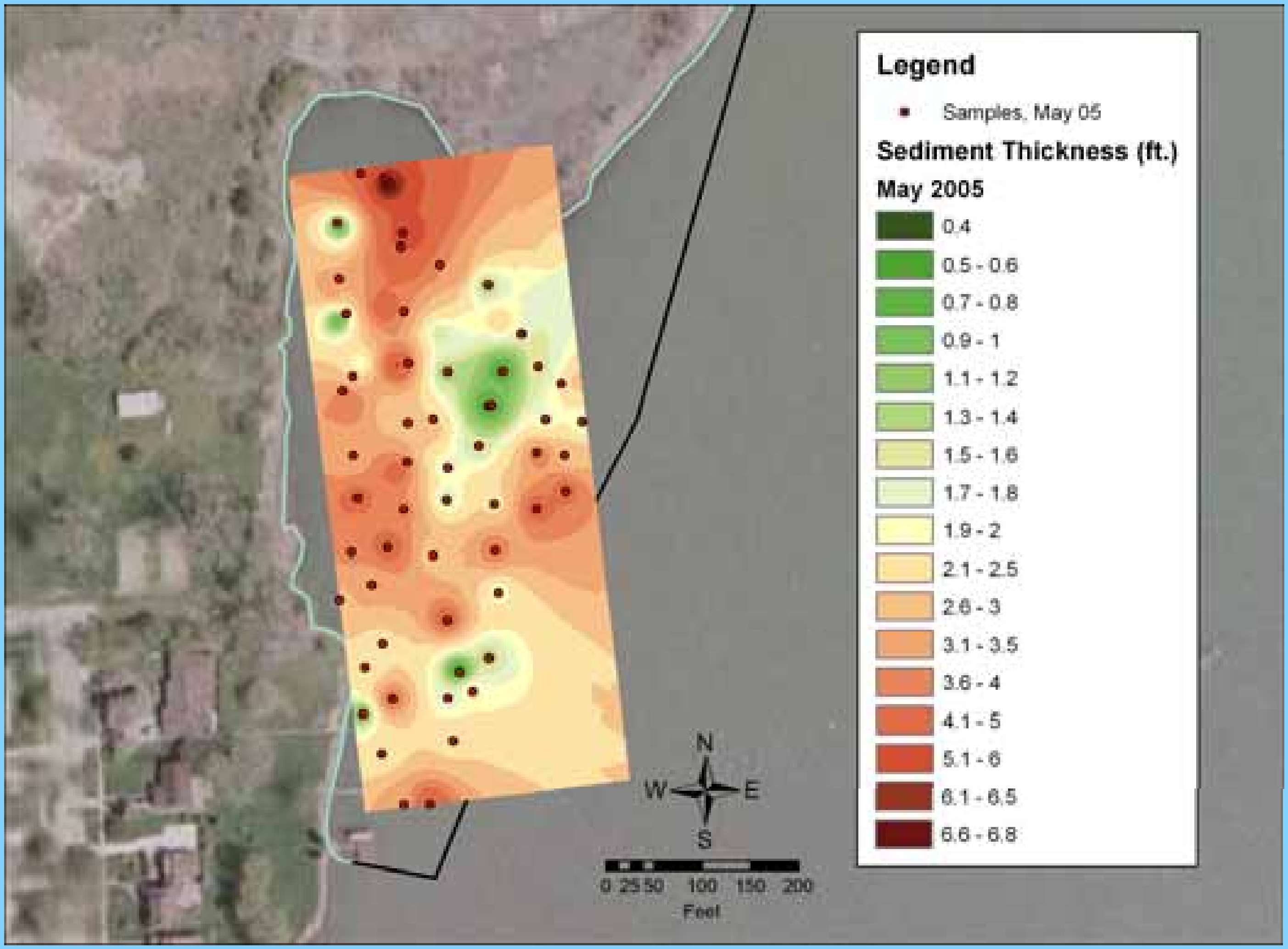
Interpolation methods:

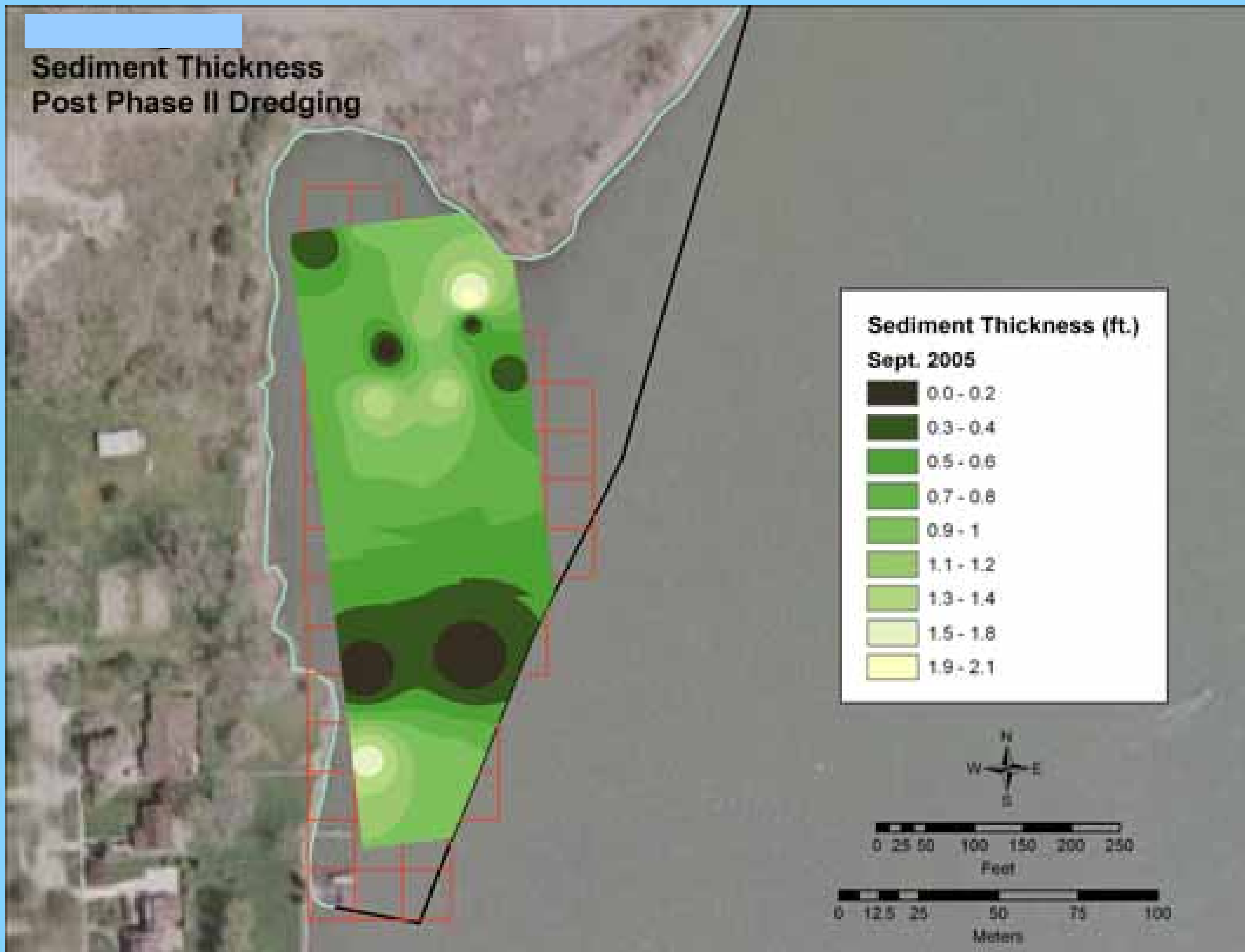
1. **Inverse Distance Weighting**
2. **Spline**
3. **Kriging**

Kriging uses an interpolation algorithm based on the geospatial distribution and variance of the data points. Kriging produces best linear unbiased estimates (BLUE), with a minimization of the estimation error.

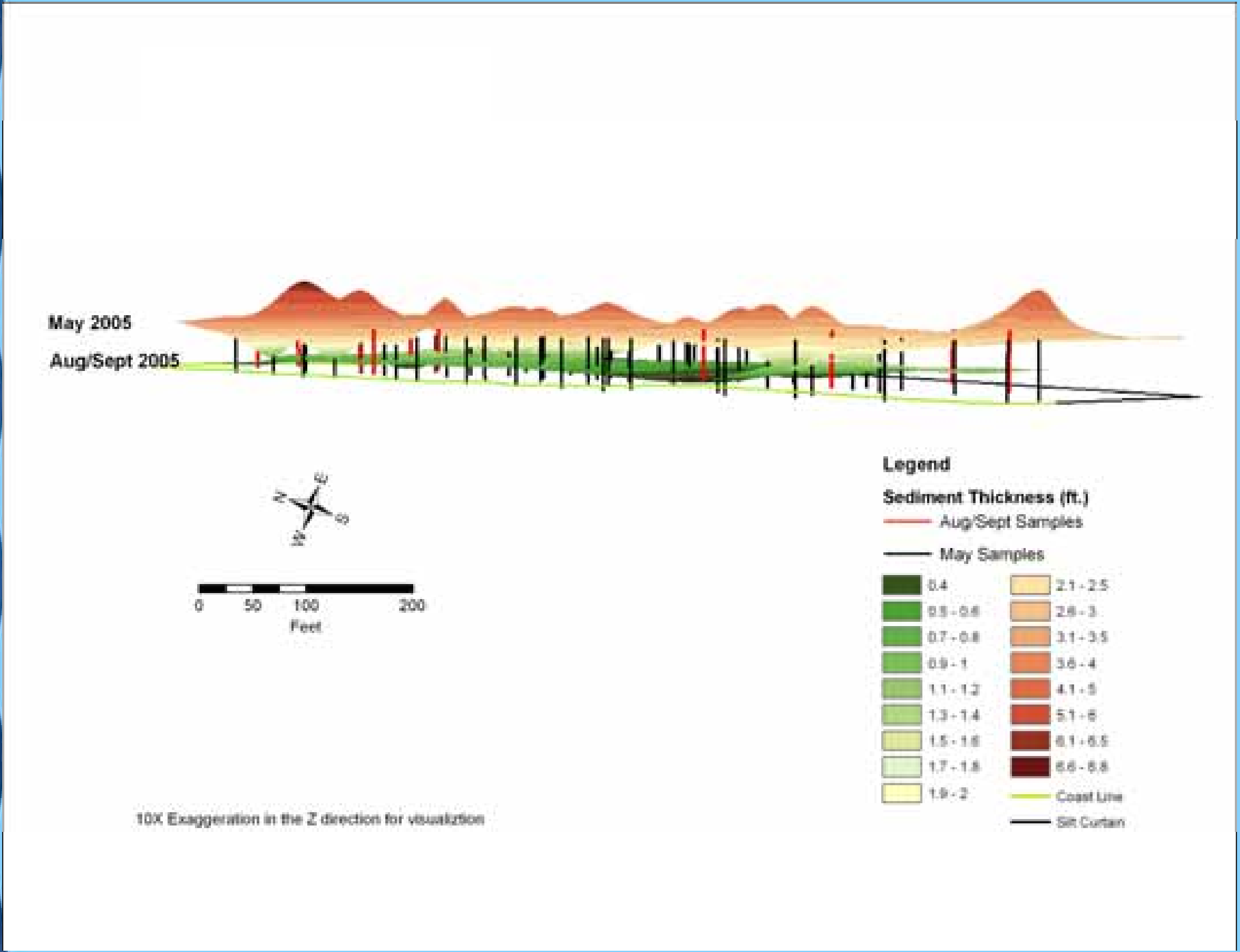

Pre-remediation volume analysis
kriged sediment depth
Depth to Dredge
feet
-11 - -10
-9.9 - -9
-8.9 - -8
-7.9 - -7
-6.9 - -6
-5.9 - -5
-4.9 - -4
-3.9 - -3
RMU
RMU Volume = 75,400 cy
Exaggeration in the Z direction for visualiztion
N
E
W
S

Conversion to grid linear kriging



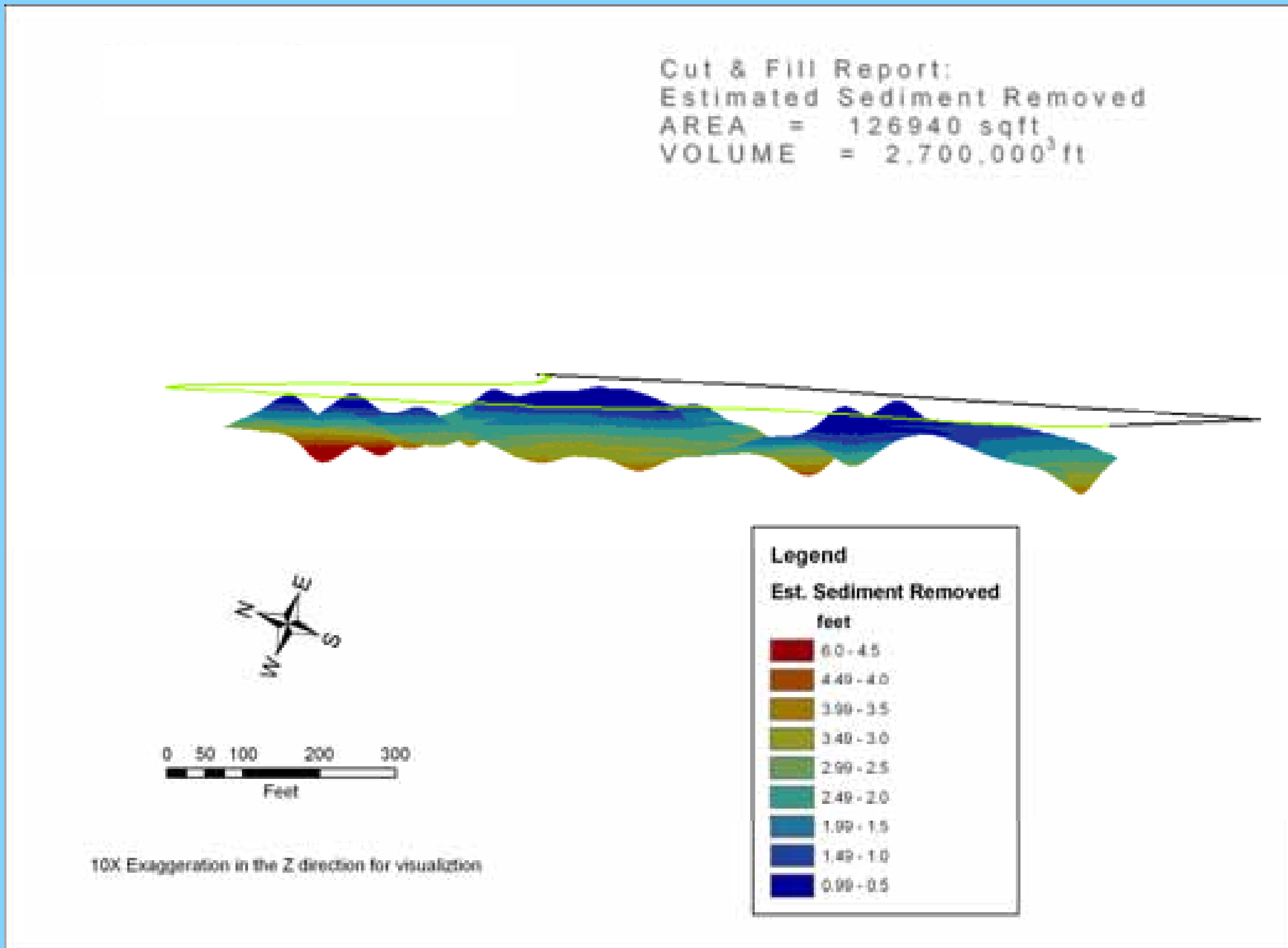

Sediment Thickness
Post Phase II Dredging
Sediment Thickness (ft.)
Sept. 2005
0.0 - 0.2
0.3 - 0.4
0.5 - 0.6
0.7 - 0.8
0.9 - 1
1.1 - 1.2
1.3 - 1.4
1.5 - 1.8
1.9 - 2.1
N
W
E
S
0 25 50 100 150 200 250
Feet
0 12.5 25 50 75 100
Meters

3-D Visualization



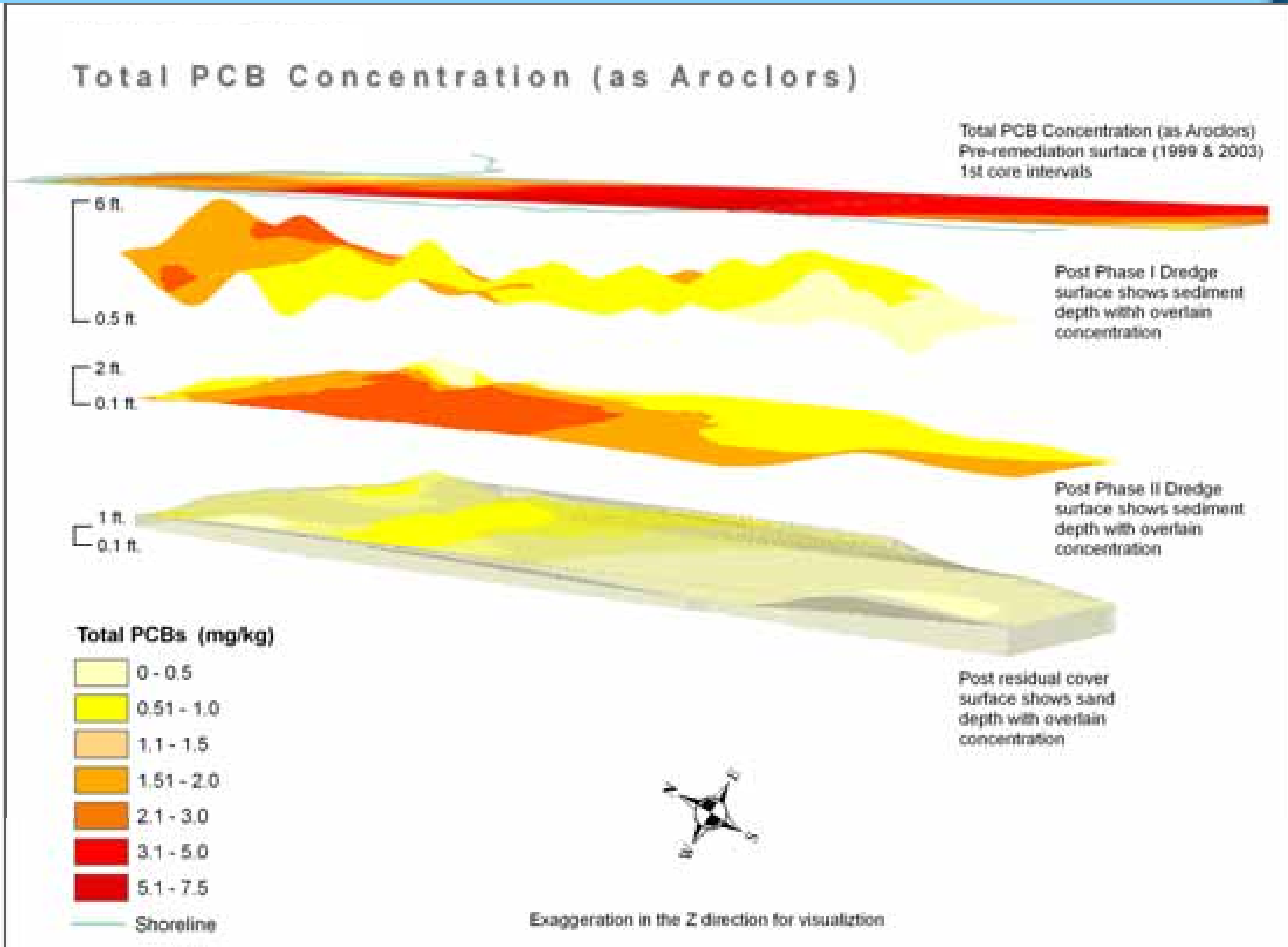
Calculations – Raster Math

- **Area**
- **Volume**



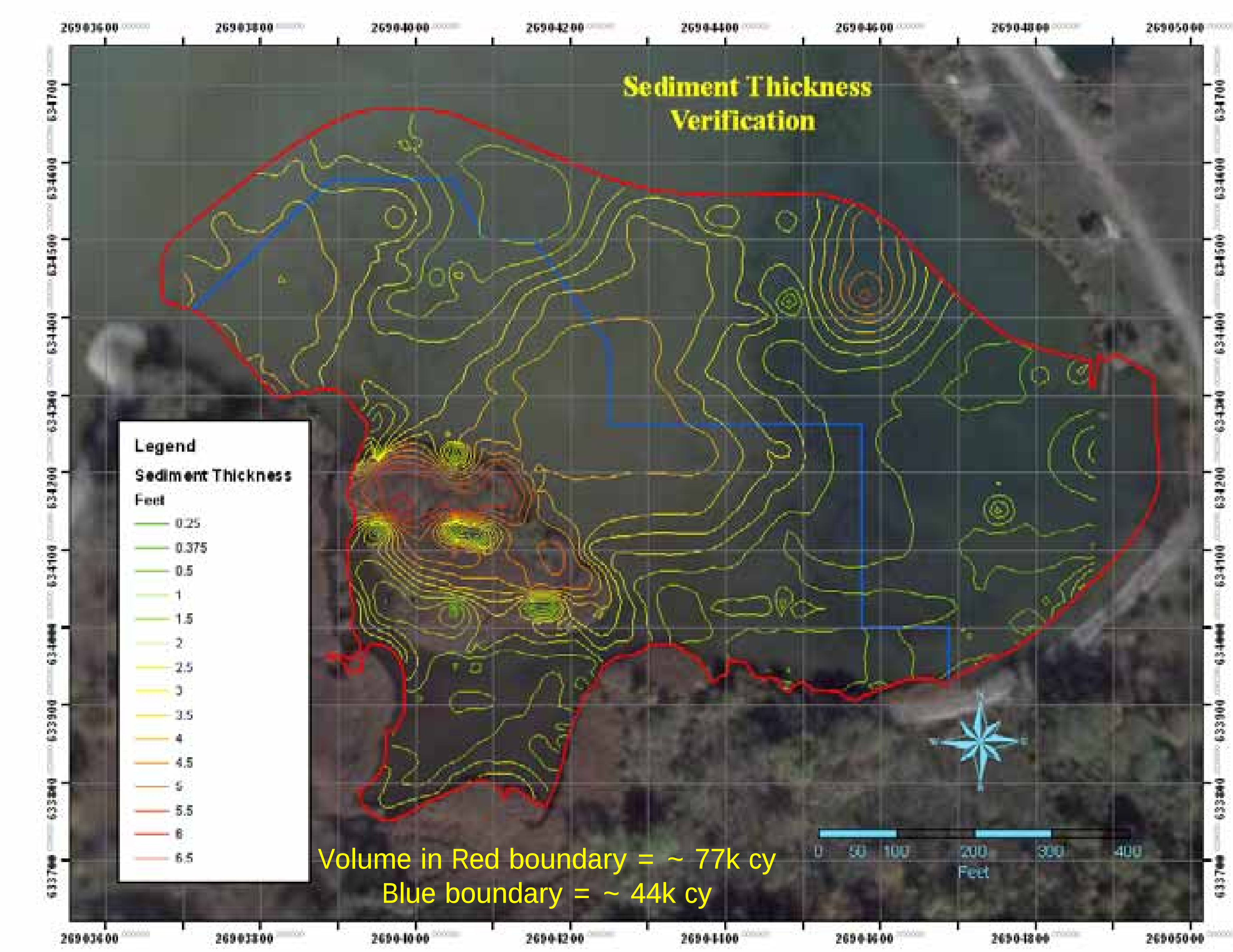
3-D surface of removed sediment from May to Sept, 2005

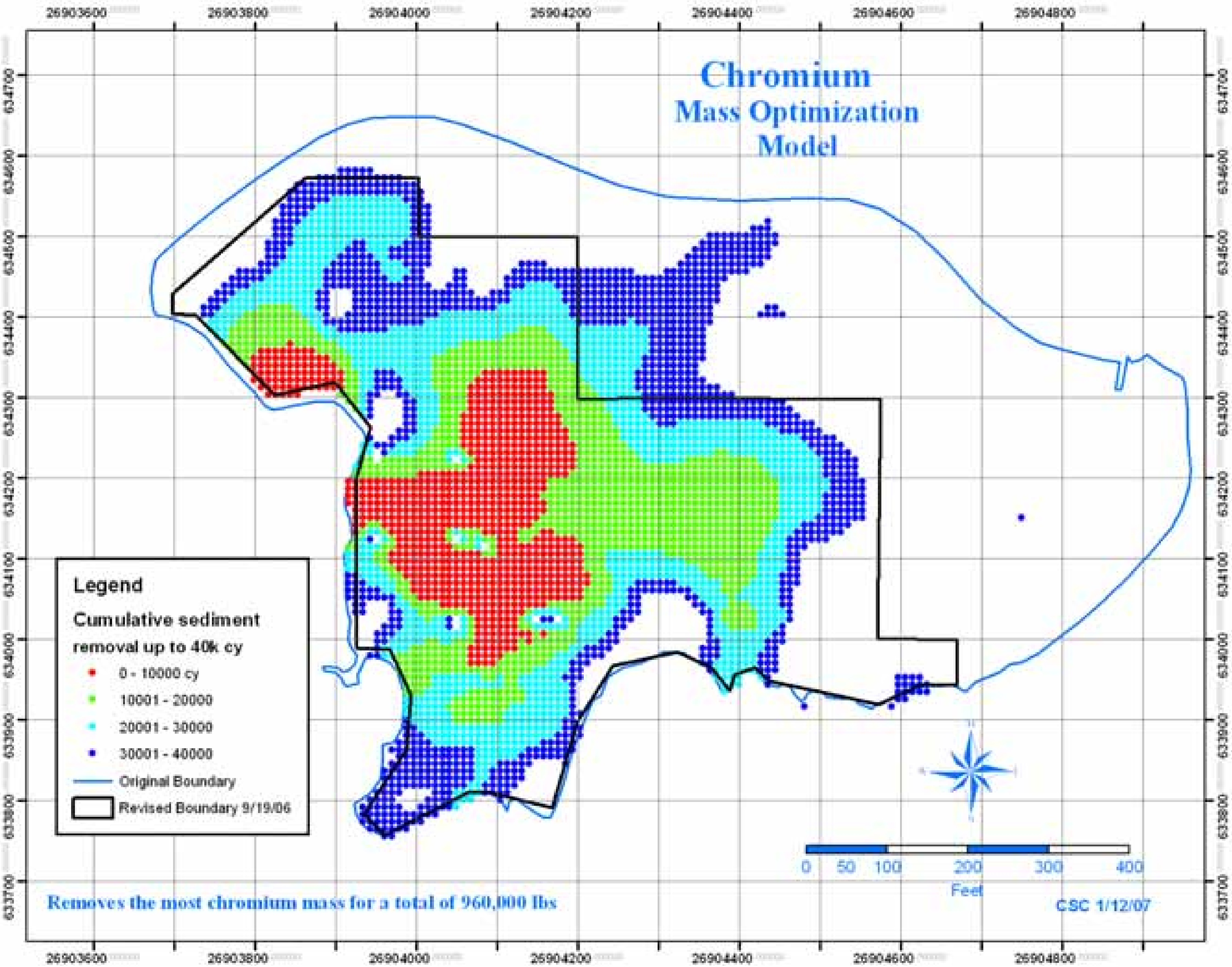
Sediment Depth with concentration data overlain



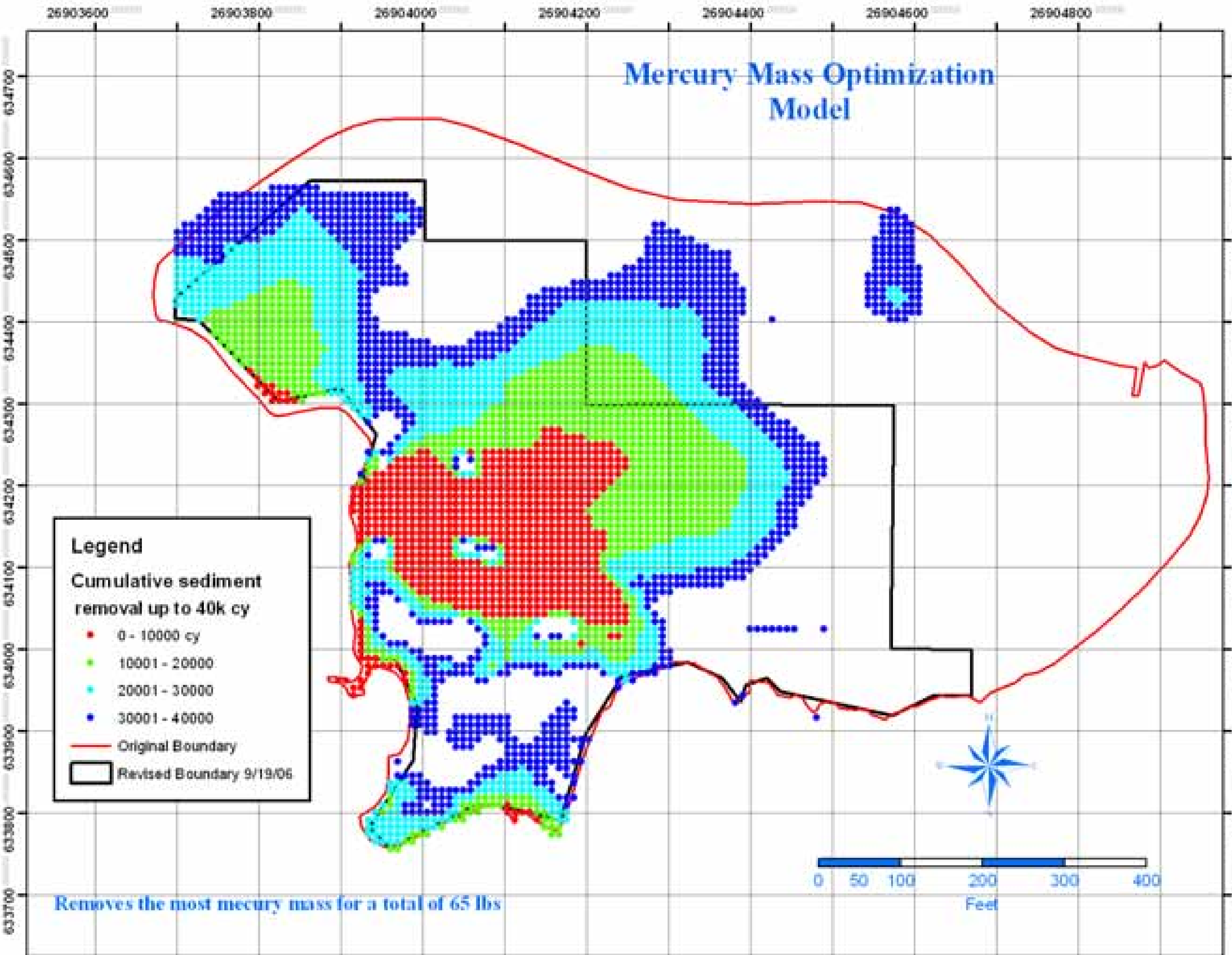
Mass removal model

1. linear kriging sediment survey data to calculate sediment thickness & volume
2. log kriging sediment contaminant concentration data
3. dividing the site into discrete three dimensional cells of 3’ * 3’ * sediment depth
4. estimating mass of contaminant for each cell based on log kriged concentration surface
5. sorting cells by mass of contaminant
6. integrating cumulative mass of contaminant removed until 40,000 cubic yards of sediment was reached
7. illustrating the optimized mass removal for each contaminant and estimating pounds of contaminant within the original and revised boundary at the site


Sediment Thickness
Verification
Legend
Sediment Thickness
Feet
0.25
0.375
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
Volume in Red boundary = ~ 77k cy
Blue boundary = ~ 44k cy
0 50 100 200 300 400
Feet



Chromium
Mass Optimization
Model
Legend
Cumulative sediment
removal up to 40k cy
0 - 10000 cy
10001 - 20000
20001 - 30000
30001 - 40000
Original Boundary
Revised Boundary 9/19/06
0 50 100 200 300 400
Feet
Removes the most chromium mass for a total of 960,000 lbs
CSC 1/12/07
26903600
26903800
26904000
26904200
26904400
26904600
26904800
634700
634600
634500
634400
634300
634200
634100
634000
633900
633800
633700



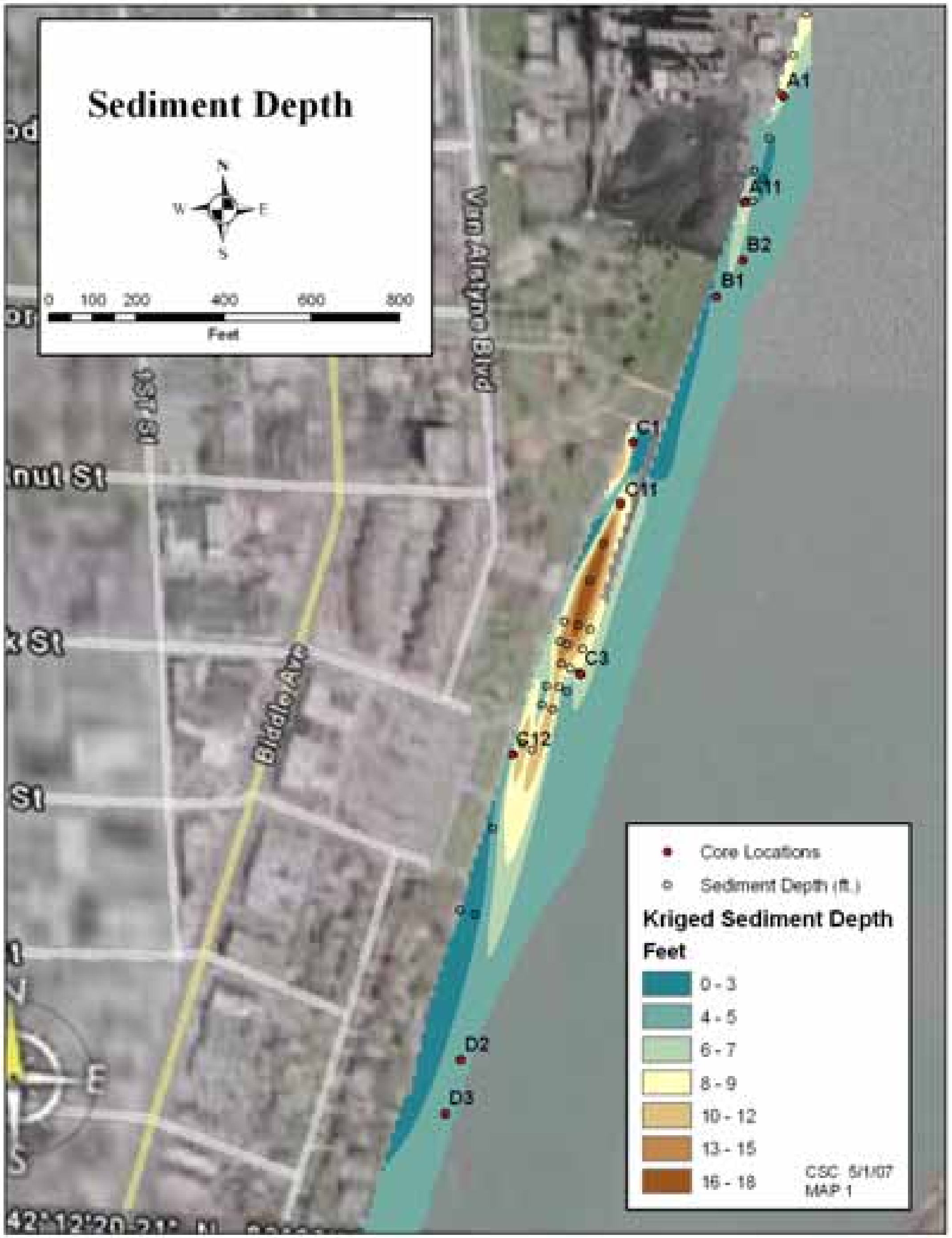
Mercury Mass Optimization Model
Legend
Cumulative sediment removal up to 40k cy
0 - 10000 cy
10001 - 20000
20001 - 30000
30001 - 40000
Original Boundary
Revised Boundary 9/19/06
Removes the most mecury mass for a total of 65 lbs
0 50 100 200 300 400
Feet
26903600
26903800
26904000
26904200
26904400
26904600
26904800
634700
634600
634500
634400
634300
634200
634100
634000
633900
633800
633700

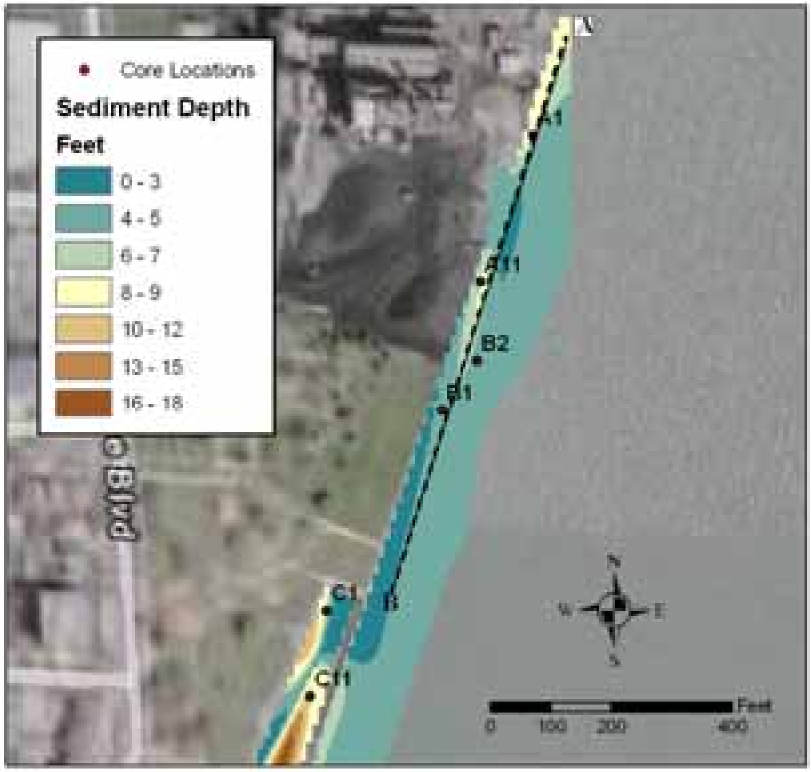
Mass optimization model results:

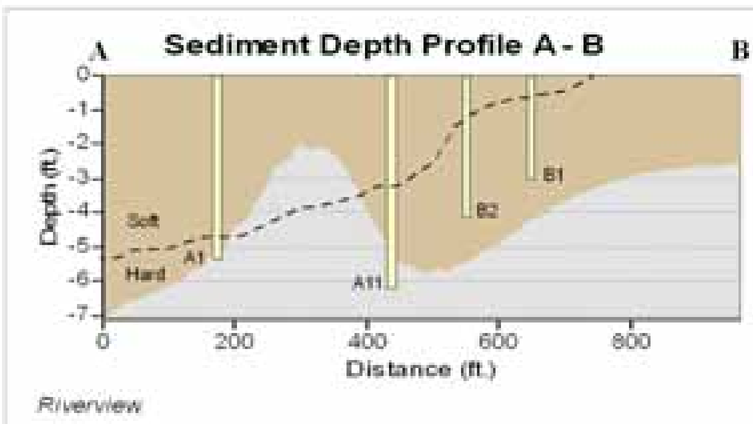
1. Confirmed that the reduced boundary would remove 40k cy of sediment (contract)
2. Optimized removal of most of the mass of the contamination (Cr > 2500 mg/kg and Hg > 1.0 mg/kg)

Advanced kriging:

- Variography – examines the 3 dimensional variation and distribution of the data
- Linear kriging assumes the data are distributed and vary along a line (sediment depth – typical)
- Log kriging data that are log normally distributed (most contamination)
- Anisotropy – an example in a river system


Sediment Depth
N
W
E
S
0 100 200 400 600 800
Feet
Van Alstyne Blvd
Biddle Ave
A1
A11
B2
B1
C1
C11
C3
C12
D2
D3
Core Locations
Sediment Depth (ft.)
Kriged Sediment Depth
Feet
0 - 3
4 - 5
6 - 7
8 - 9
10 - 12
13 - 15
16 - 18
CSC 5/1/07
MAP 1


Core Locations
Sediment Depth
Feet
0 - 3
4 - 5
6 - 7
8 - 9
10 - 12
13 - 15
16 - 18
A
A1
A11
B2
B1
C1
B
C11
N
W
E
S
0 100 200 400 Feet


Sediment Depth Profile A - B
A
B
Depth (ft.)
0
-1
-2
-3
-4
-5
-6
-7
Soft
Hard
A1
A11
B2
B1
0
200
400
600
800
Distance (ft.)
Riverview

Conclusions:

- Kriging provides a powerful tool for sediment remediation projects
- Calculates volume of sediment from point data
- Optimizes mass removal of contamination
- Spatial and 3-D Analyst provide a powerful visualization for these projects
- Questions?

Reina Downing
Geologist/GIS Analyst
Computer Sciences Corporation
6101 Stevenson Avenue
Alexandria, VA 22304
(703) 461-2427
rdowning2@csc.com