The Use of Geostatistics in the Remedial Investigation of the Upper Buffalo River

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Acknowledgements

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  - New York State Department of Environmental Conservation (NYSDEC)
  - Buffalo Niagara Riverkeeper
  - U.S. Army Corps of Engineers
  - EPA Region 2
  - U.S. Fish and Wildlife Service
  - SulTRAC
  - Computer Sciences Corporation (CSC)
  - U.S. EPA Great Lakes National Program Office (GLNPO): Team Chair

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Geostatistics

- Set of statistical techniques used in the analysis of georeferenced data
- Increasingly popular in part due to the availability of geographic information systems (GIS) software
- Powerful tool when used in combination with GIS

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Geostatistics in Sediment Assessment and Remediation

- Describe extent and nature of contamination
- Identify data gaps
- Generate statistical sampling designs
- Calculate sediment volumes
- Develop remedial design
- Evaluate achievement of clean up goals
- Communicate conditions to stakeholders

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What does Geostatistics have to do with Quality?

- Pools data to get the best representation of the site
- Uncertainty can be estimated
- Geostatistical analyses, such as kriging, can support generation of sampling designs (i.e., greatest reduction in uncertainty)
- Large quantities of data can be more easily visualized
- Decisions are defensible, transparent, well-documented, and reproducible

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Kriging

- Evolved in mineral exploration and mining of minerals, ores, and coals
- In 1963, G. Matheron named kriging after Daniel Gerdhaus Krige, a South African mining engineer, who used the technique to more accurately predict the extent of gold deposits in unsampled areas

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Kriging

- Method of interpolation
  - Optimally predicts data values by using data taken at known locations
  - Creates contours or isopleths of data across an area
- Other common methods of interpolation include inverse distance weighting and spline

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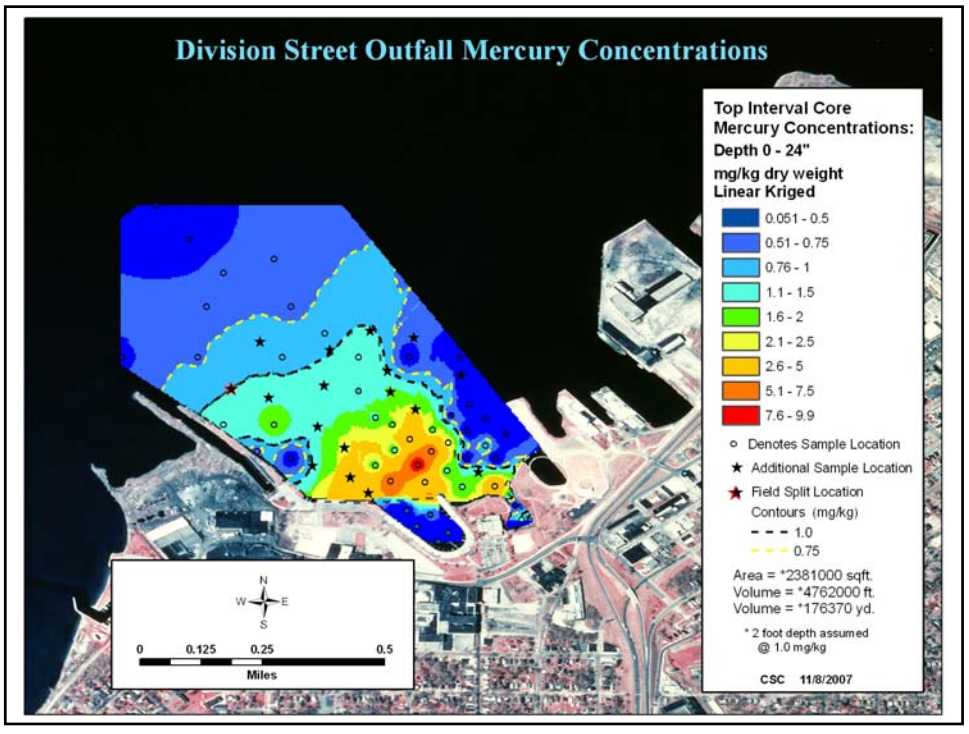
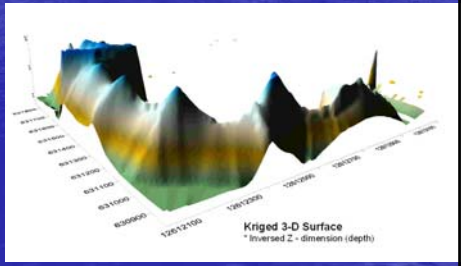
CSC EXPERIENCE. RESULTS.



Sediment Assessment and Remediation Projects using Geostatistics

- Fox River, WI
- Hudson River, NY
- Minnesota Slip, Duluth Harbor, MN
- East Fork Poplar Creek, TN
- Hanford, WA
- Great Lakes Legacy Act
  - Black Lagoon, MI
  - Hog Island, WI
  - Ruddiman Creek, MI
  - Division Street Outfall, MI
  - St. Louis River, WI
  - Ashtabula River, OH
  - Riverview, MI
  - Buffalo River, NY



Buffalo River

- Designated Area of Concern (AoC)
- Located in the City of Buffalo in Western New York State and discharges into Lake Erie
- The impact area is 6.2 miles (10 km) in length
- Characterized by historically heavy industrial development in the midst of a large municipality
- The total drainage area for the watershed is approximately 440 square miles

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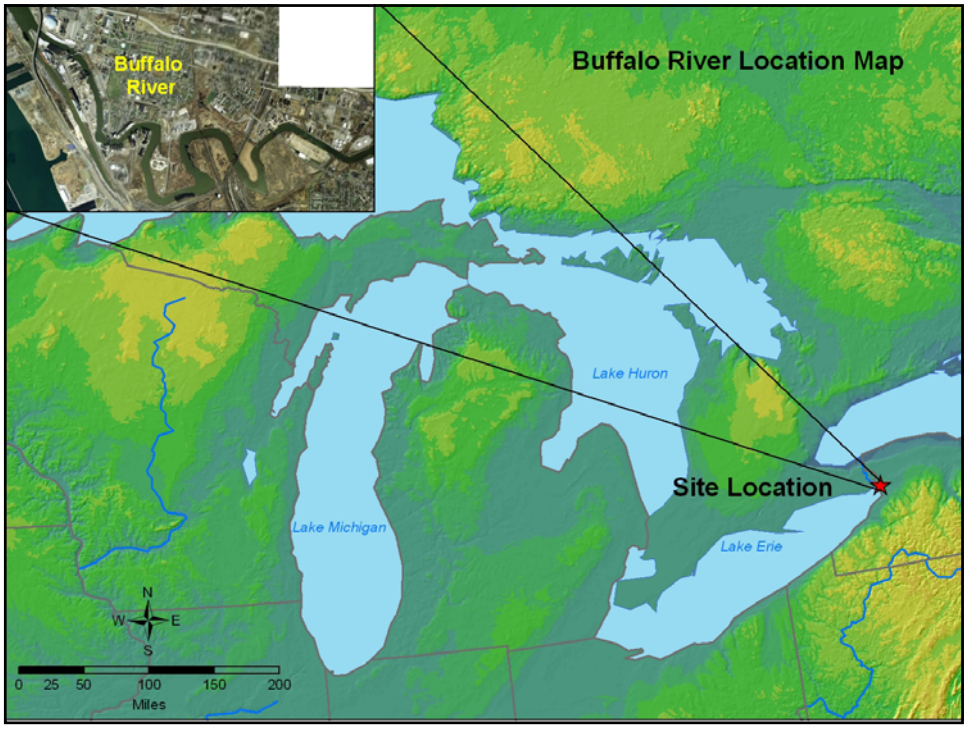

Buffalo River Environmental Concerns

- Sources of contamination include contaminated bottom sediments, combined sewer overflows, inactive hazardous waste sites, and non-point source pollution
- Contaminants of concern (COC) include PCBs, PAHs, metals, and industrial organics
- Fish consumption advisories exist for the AoC

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Buffalo River Feasibility Study

- 2005
  - Sampling conducted within the Upper River
    - describe nature and extent of contamination
    - Conduct human health and ecological risk assessments
- 2007
  - Sampling conducted within the Lower River
    - describe nature and extent of contamination

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Buffalo River Feasibility Study

- Statistical and geostatistical analyses being conducted to:
  - Define the nature and extent of sediment contamination
  - Identify areas exceeding thresholds of concern for several contaminants
  - Calculate sediment volumes targeted for removal
- The results will be incorporated into the Upper Buffalo River Remedial Investigation and Feasibility Study being prepared by GLNPO

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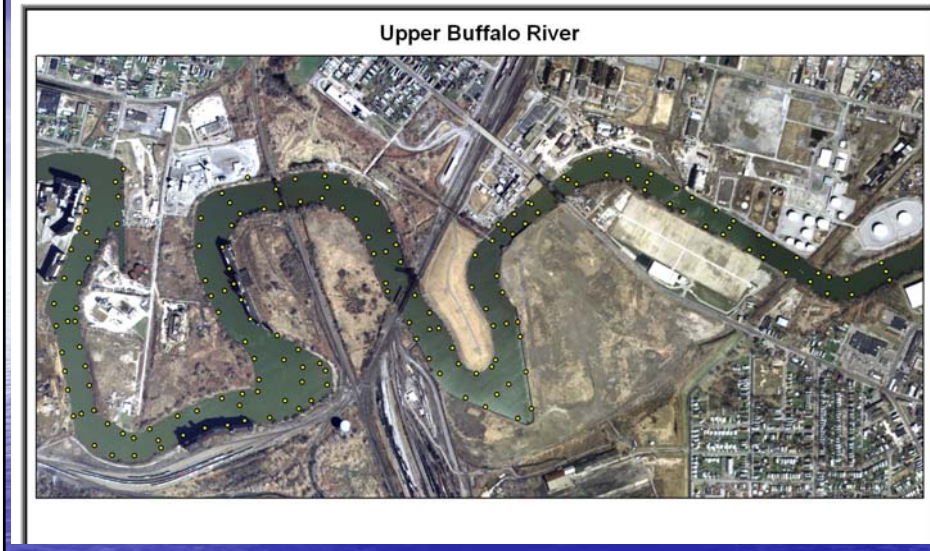

Sample locations for 2005 study of the Upper River

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Geostatistics

The first step is to understand the data!

- Exploratory Data Analysis (EDA)
  - Investigate populations
  - Evaluate the distribution
  - Evaluate correlations

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Exploratory Data Analysis

- Upper River
  - Sediment concentrations for eleven COCs were not normally or log-normally distributed
    - Nonparametric statistics had to be used, where possible, for analysis
  - Concentrations tended to be lower at surface depths compared to subsurface depths
    - These depth categories had to be modeled separately

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Exploratory Data Analysis

- Upper River
  - Strong correlations were observed between some of the analytes
    - One or two metals can be chosen to represent the other metals
    - Total PAHs, benzo(a)anthracene, or benzo(a)pyrene are correlated strongly enough that additional geostatistical analyses can focus on one of these three compounds

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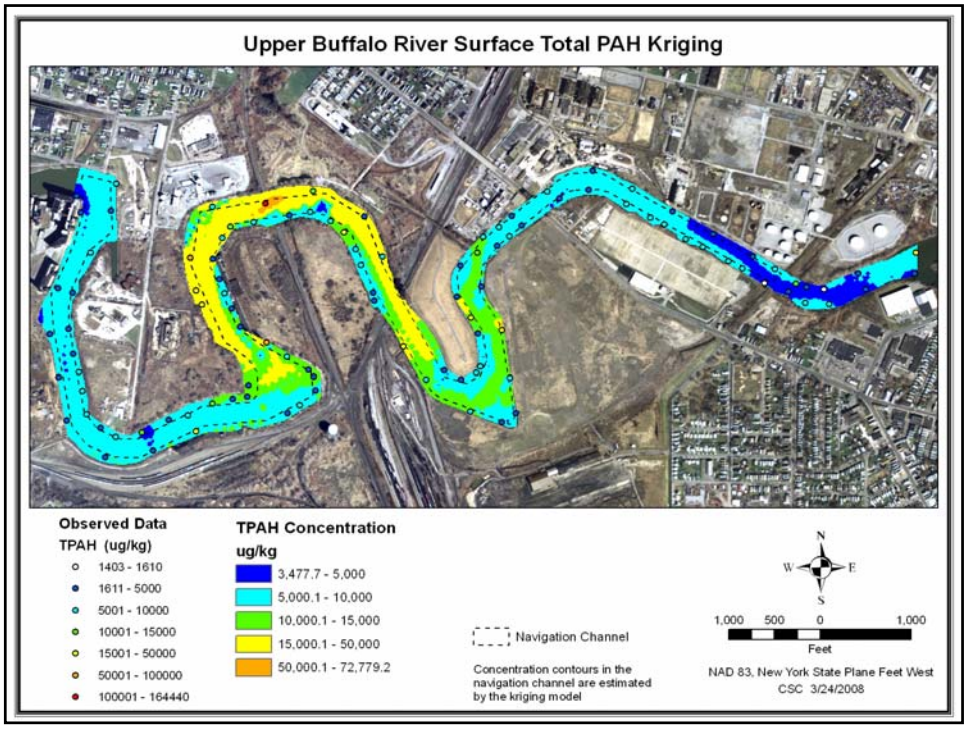
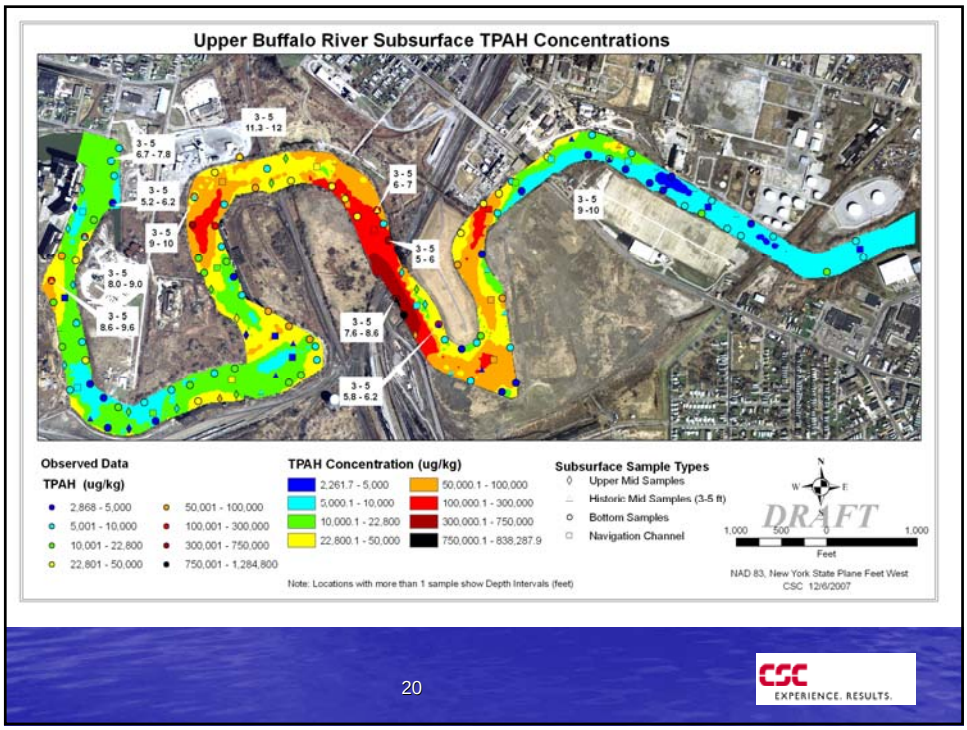
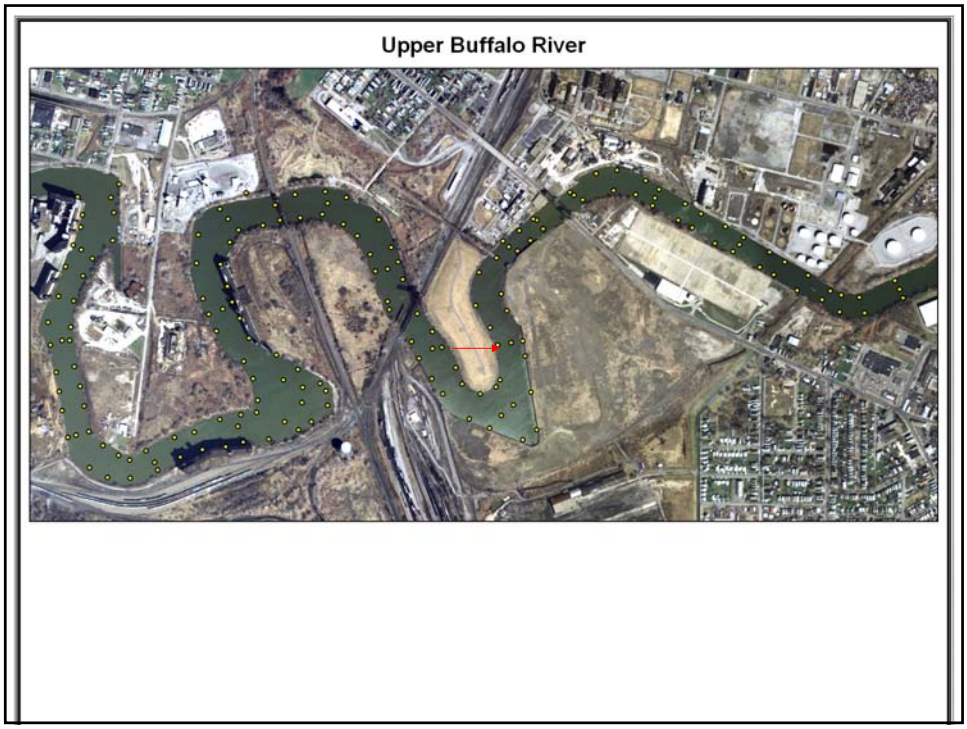
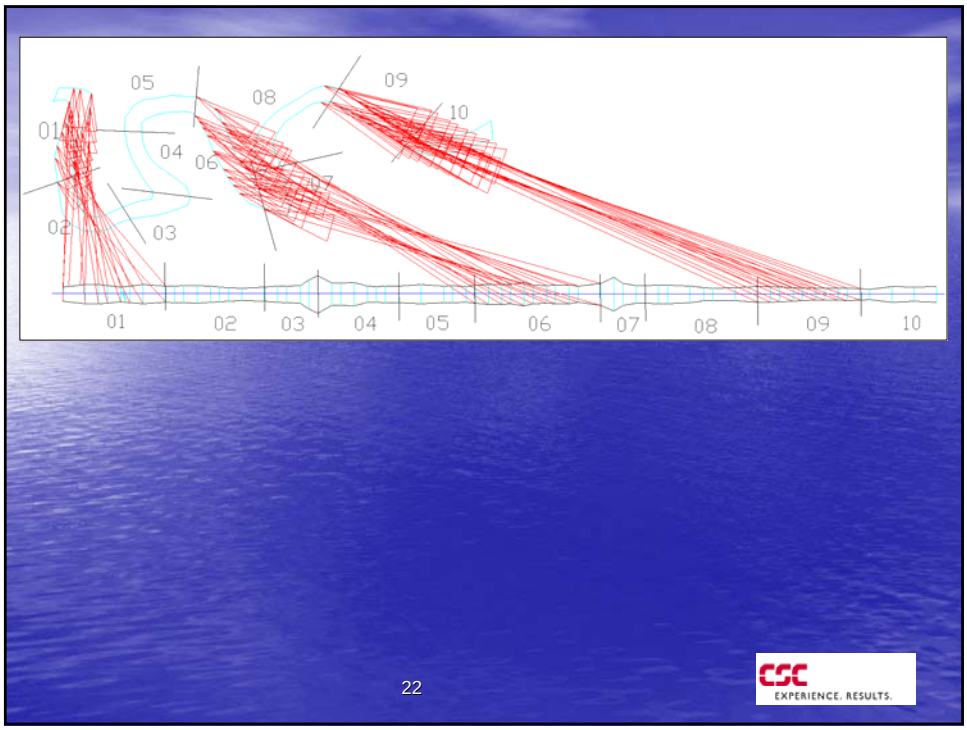
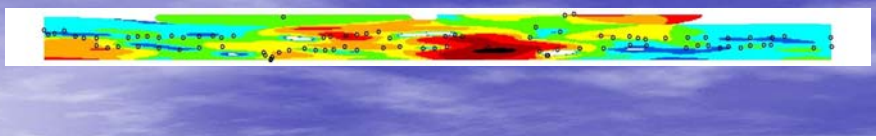

Upper Buffalo River Surface Total PAH Kriging
Observed Data
TPAH (ug/kg)
1403 - 1610
1611 - 5000
5001 - 10000
10001 - 15000
15001 - 50000
50001 - 100000
100001 - 164440
TPAH Concentration
ug/kg
3,477.7 - 5,000
5,000.1 - 10,000
10,000.1 - 15,000
15,000.1 - 50,000
50,000.1 - 72,779.2
Navigation Channel
Concentration contours in the navigation channel are estimated by the kriging model
N
W
E
S
1,000 500 0 1,000
Feet
NAD 83, New York State Plane Feet West
CSC 3/24/2008

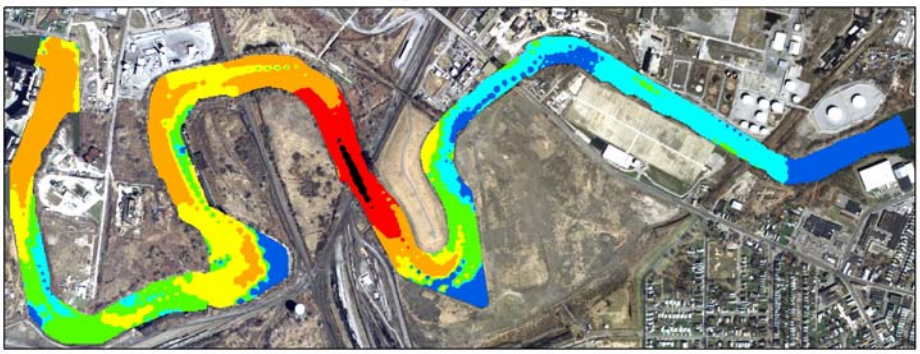

Upper Buffalo River Subsurface TPAH Concentrations
3 - 5 11.3 - 12
3 - 5 6.7 - 7.8
3 - 5 5.2 - 6.2
3 - 5 6 - 7
3 - 5 9 - 10
3 - 5 5 - 6
3 - 5 8.0 - 9.0
3 - 5 8.6 - 9.6
3 - 5 7.6 - 8.6
3 - 5 5.8 - 6.2
Observed Data
TPAH (ug/kg)
2,868 - 5,000
5,001 - 10,000
10,001 - 22,800
22,801 - 50,000
50,001 - 100,000
100,001 - 300,000
300,001 - 750,000
750,001 - 1,284,800
TPAH Concentration (ug/kg)
2,261.7 - 5,000
5,000.1 - 10,000
10,000.1 - 22,800
22,800.1 - 50,000
50,000.1 - 100,000
100,000.1 - 300,000
300,000.1 - 750,000
750,000.1 - 838,287.9
Note: Locations with more than 1 sample show Depth Intervals (feet)
Subsurface Sample Types
Upper Mid Samples
Historic Mid Samples (3-5 ft)
Bottom Samples
Navigation Channel
N
W
E
DRAFT
1,000 500 0 1,000
Feet
NAD 83, New York State Plane Feet West
CSC 12/6/2007
20
csc
EXPERIENCE. RESULTS.


Upper Buffalo River


01
02
03
04
05
06
07
08
09
10
22
EXPERIENCE. RESULTS.



Upper Buffalo River



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EXPERIENCE. RESULTS.

Calculating Sediment Volumes

1. Exploratory Data Analysis
2. Indicator kriging for drivers
3. Identify areas exceeding criteria with specified probability
4. Sediment depth kriging
5. Calculate sediment volumes of area exceeding criteria

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EXPERIENCE. RESULTS.

Contaminants of Concern

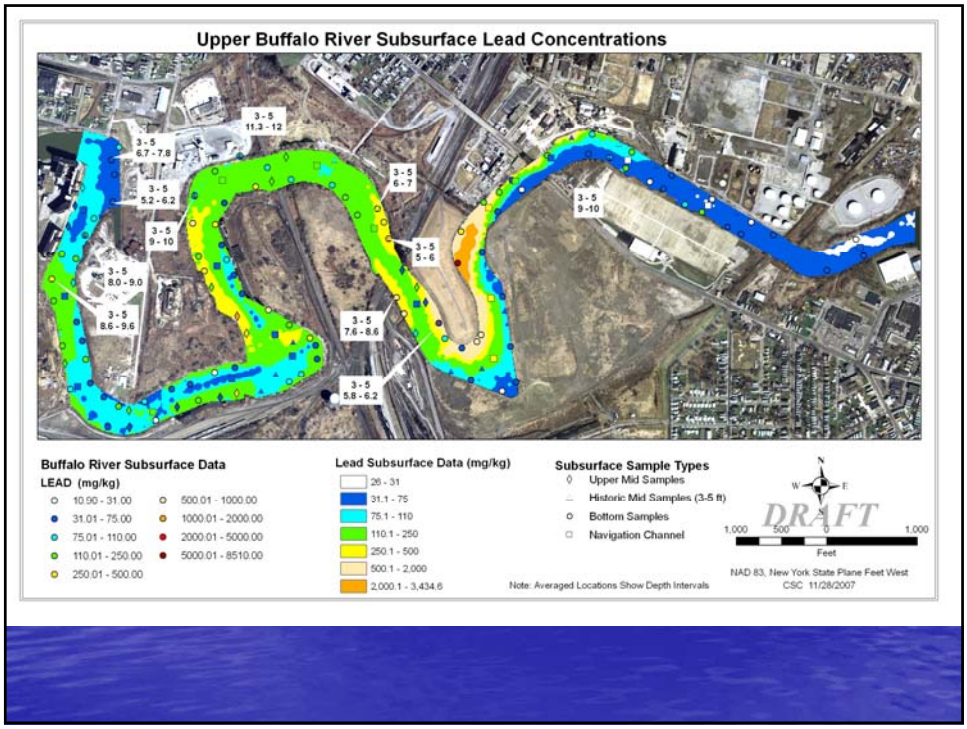
- Arsenic
- Copper
- Lead
- Mercury
- Total PAHs
- Total PCBs
- Gamma-chlordane

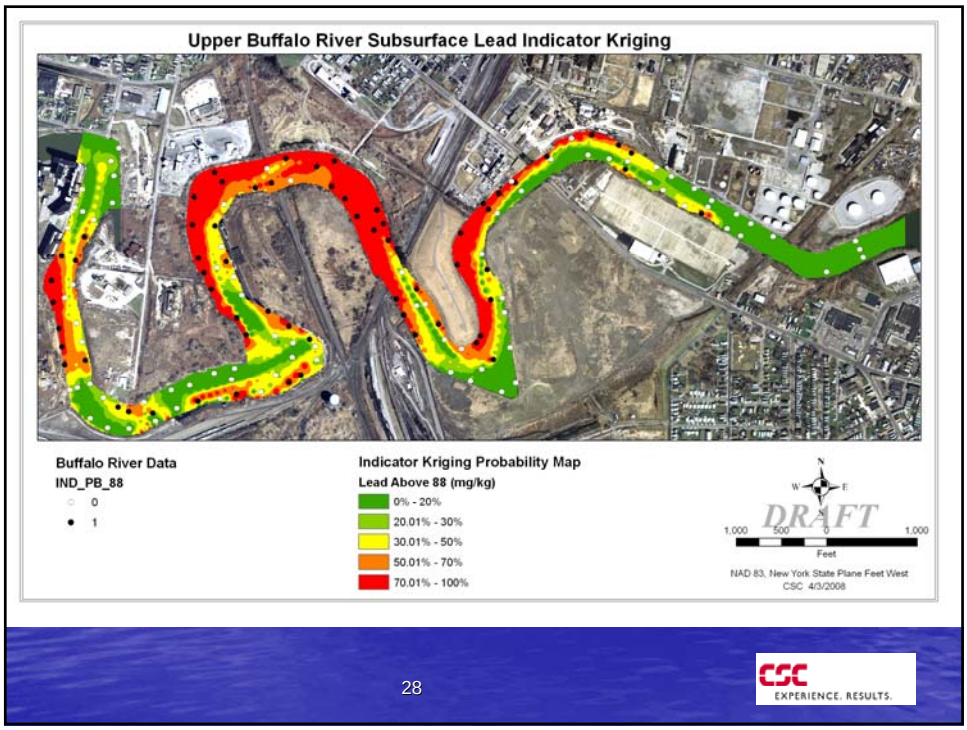
25

Four Drivers

1. Lead
2. Total PAHs
3. Mercury
4. Total PCBs

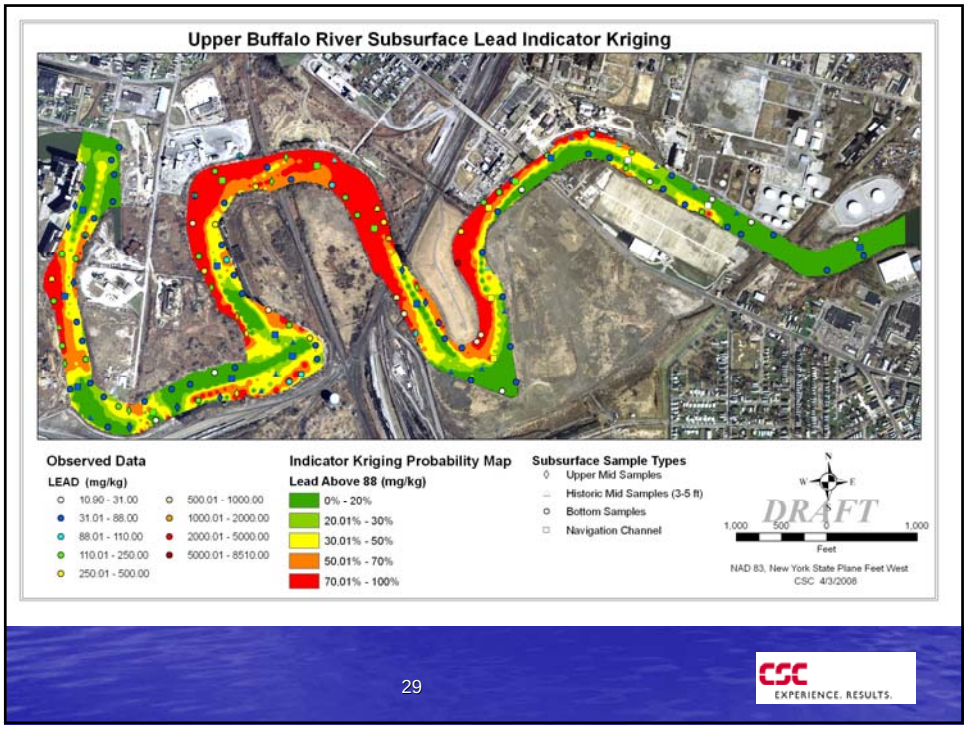
26

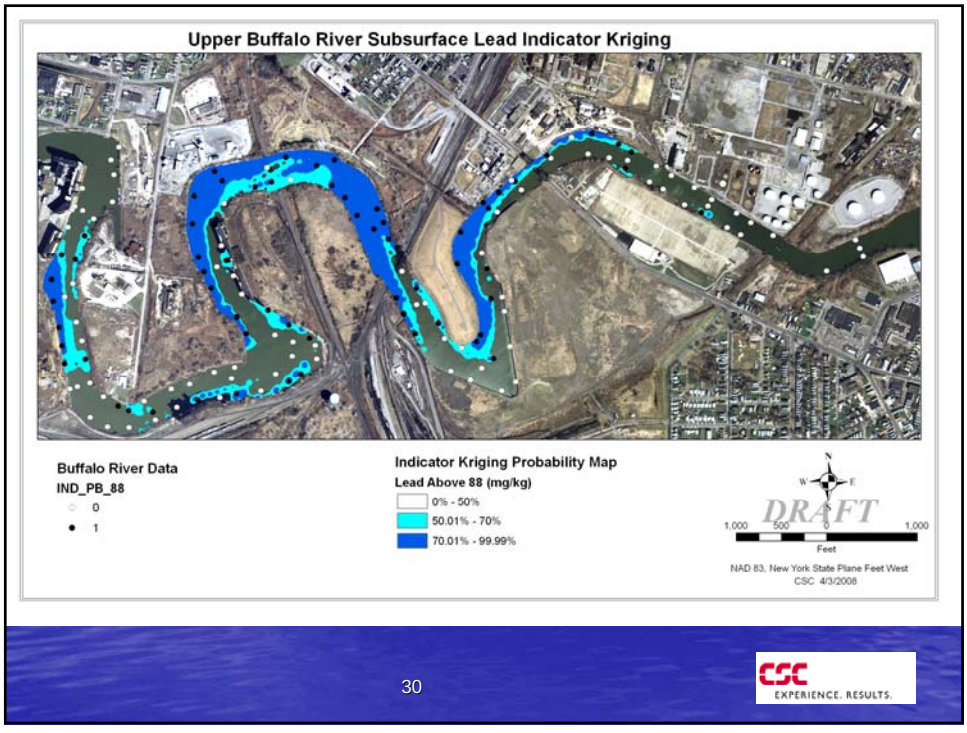


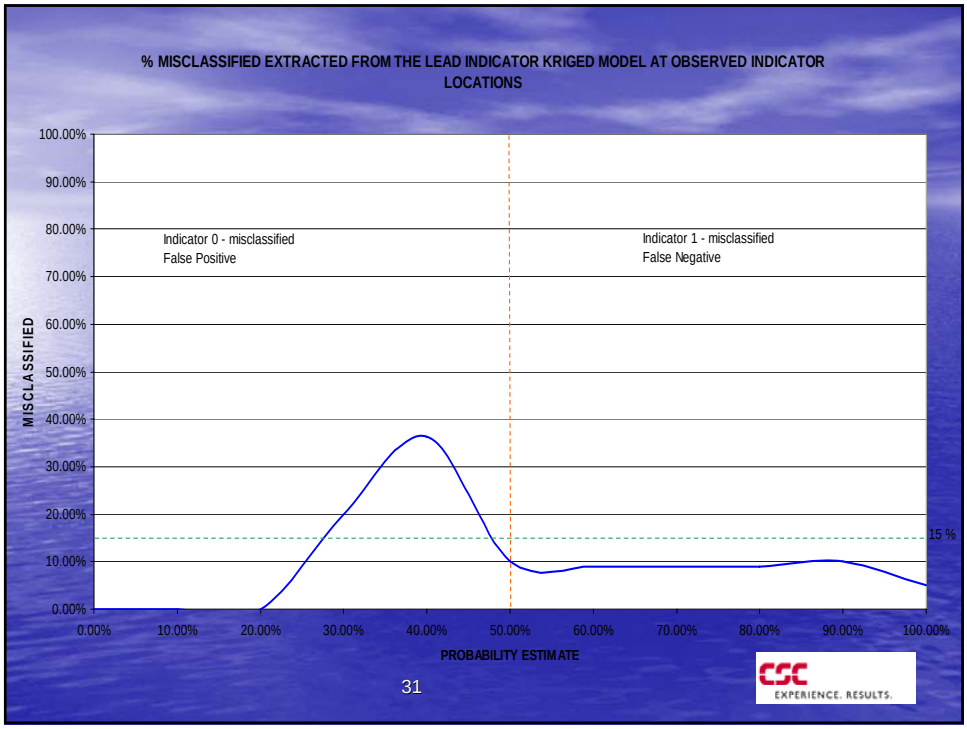


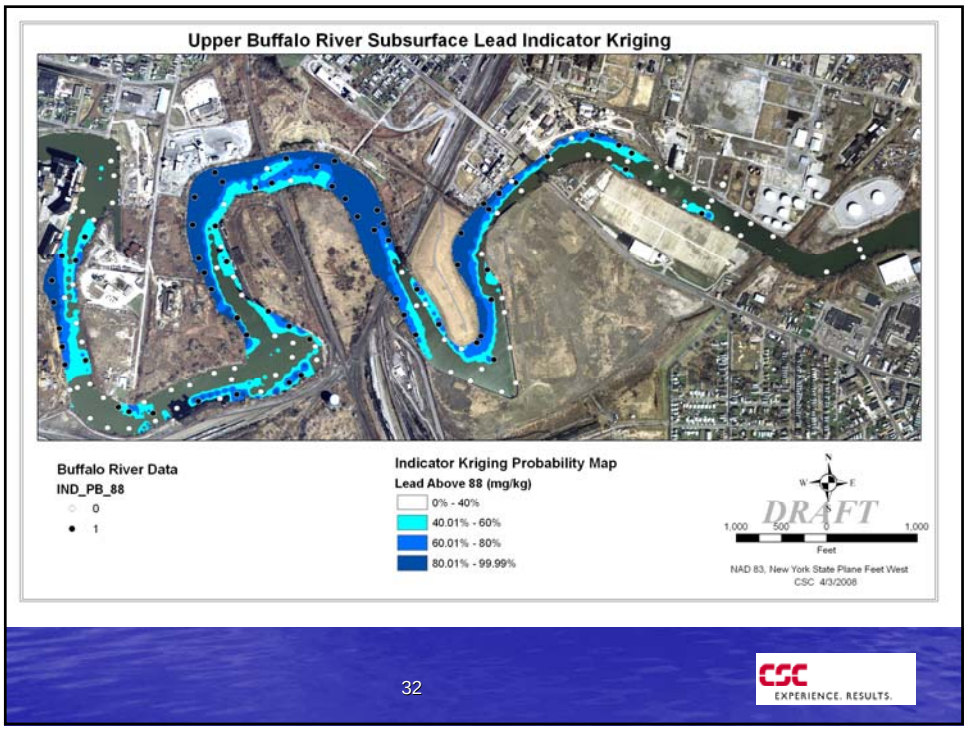
28

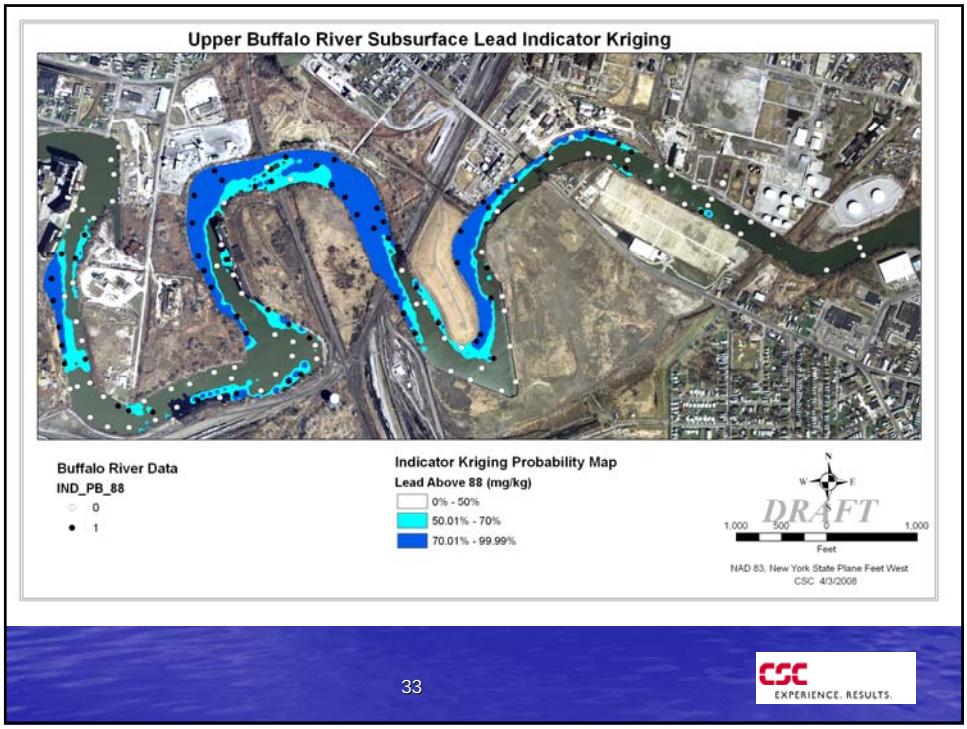
csc EXPERIENCE. RESULTS.

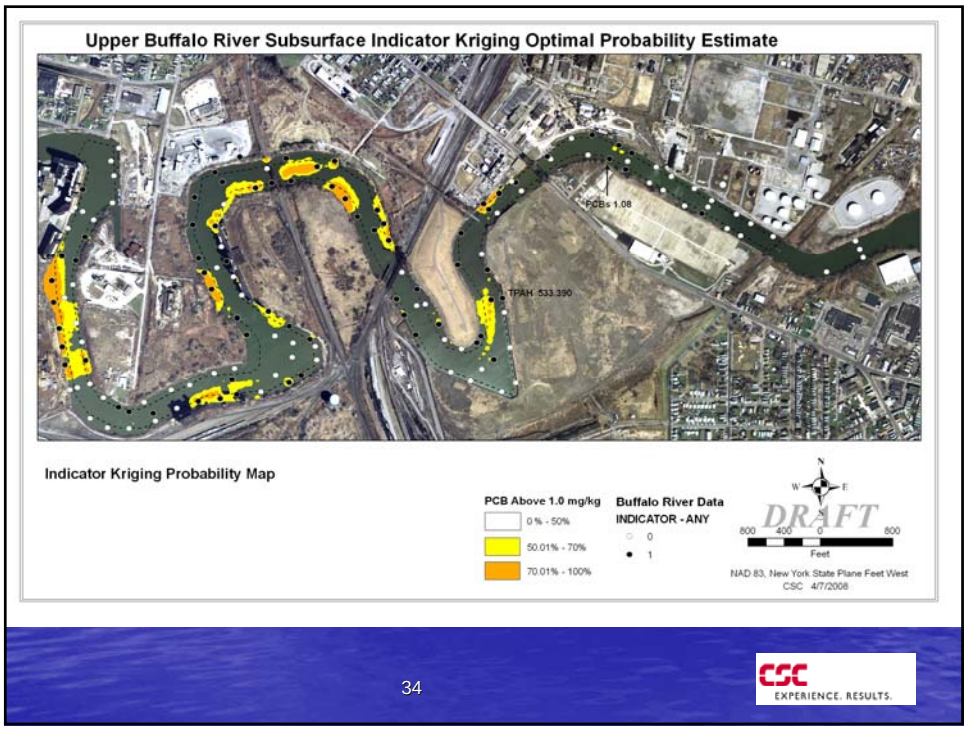

Upper Buffalo River Subsurface Lead Indicator Kriging
Observed Data
LEAD (mg/kg)
10.90 - 31.00
31.01 - 88.00
88.01 - 110.00
110.01 - 250.00
250.01 - 500.00
500.01 - 1000.00
1000.01 - 2000.00
2000.01 - 5000.00
5000.01 - 8510.00
Indicator Kriging Probability Map
Lead Above 88 (mg/kg)
0% - 20%
20.01% - 30%
30.01% - 50%
50.01% - 70%
70.01% - 100%
Subsurface Sample Types
Upper Mid Samples
Historic Mid Samples (3-5 ft)
Bottom Samples
Navigation Channel
N
W
E
S
DRAFT
1,000 500 0 1,000
Feet
NAD 83, New York State Plane Feet West
CSC 4/3/2008
29
CSC
EXPERIENCE. RESULTS.

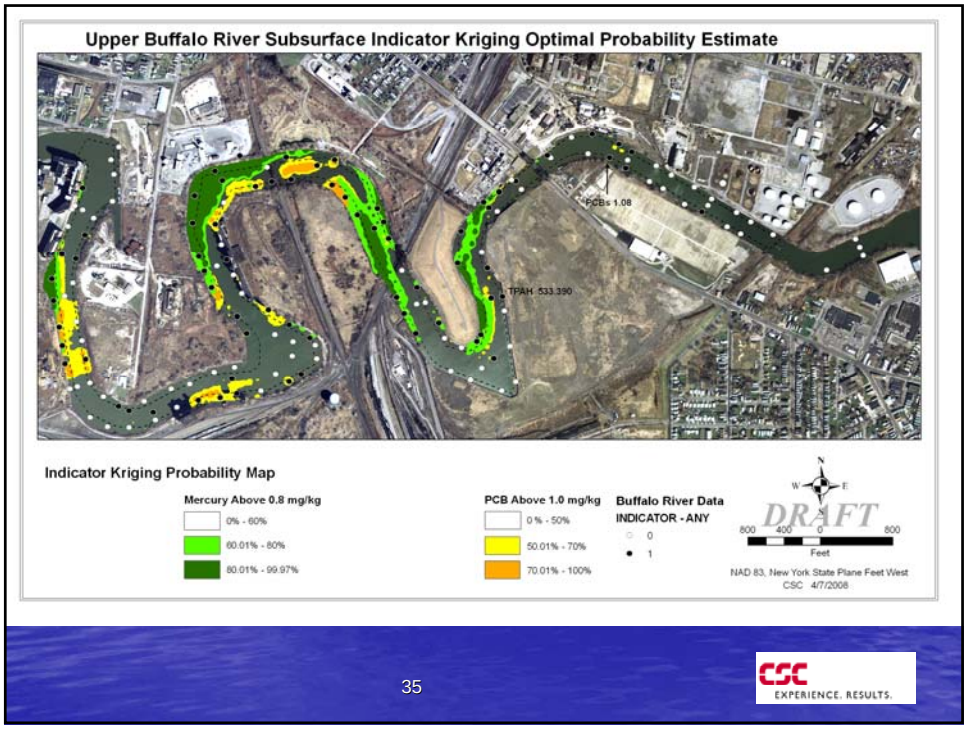

Upper Buffalo River Subsurface Lead Indicator Kriging
Buffalo River Data
IND_PB_88
0
1
Indicator Kriging Probability Map
Lead Above 88 (mg/kg)
0% - 50%
50.01% - 70%
70.01% - 99.99%
N
W
E
S
DRAFT
1,000 500 0 1,000
Feet
NAD 83, New York State Plane Feet West
CSC 4/3/2008
30
CSC
EXPERIENCE. RESULTS.

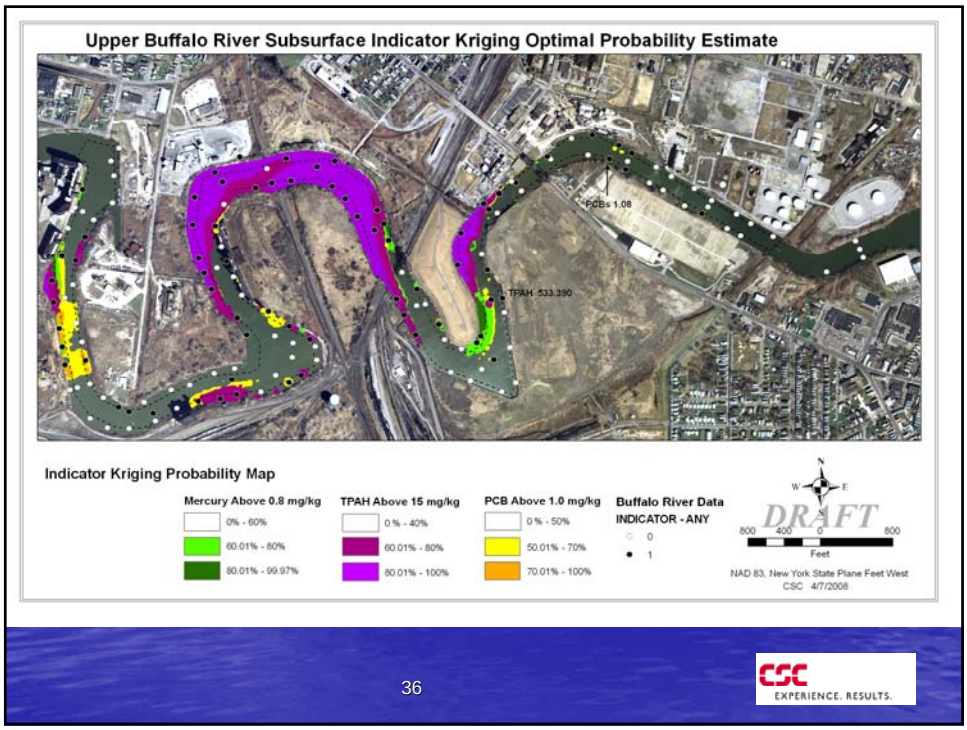

% MISCLASSIFIED EXTRACTED FROM THE LEAD INDICATOR KRIGED MODEL AT OBSERVED INDICATOR LOCATIONS
MISCLASSIFIED
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Indicator 0 - misclassified
False Positive
Indicator 1 - misclassified
False Negative
15 %
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
60.00%
70.00%
80.00%
90.00%
100.00%
PROBABILITY ESTIMATE
31
EXPERIENCE. RESULTS.

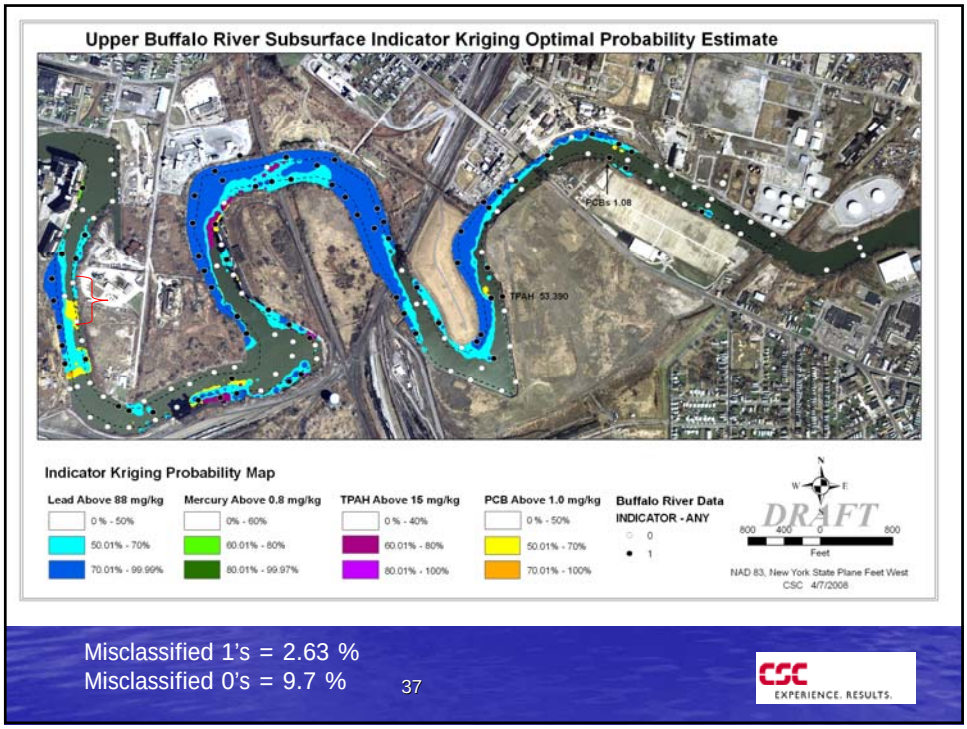

Upper Buffalo River Subsurface Lead Indicator Kriging
Buffalo River Data
IND_PB_88
0
1
Indicator Kriging Probability Map
Lead Above 88 (mg/kg)
0% - 40%
40.01% - 60%
60.01% - 80%
80.01% - 99.99%
DRAFT
1,000
500
0
1,000
Feet
NAD 83, New York State Plane Feet West
CSC 4/3/2008
32
EXPERIENCE. RESULTS.

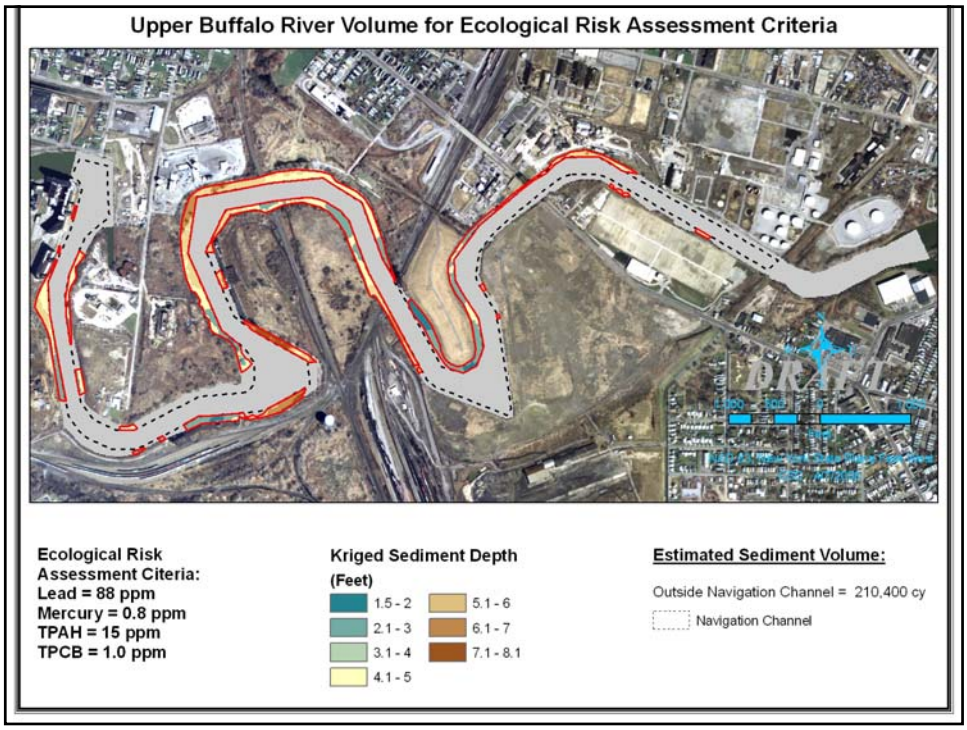

Upper Buffalo River Subsurface Lead Indicator Kriging
Buffalo River Data
IND_PB_88
0
1
Indicator Kriging Probability Map
Lead Above 88 (mg/kg)
0% - 50%
50.01% - 70%
70.01% - 99.99%
DRAFT
1,000 500 0 1,000
Feet
NAD 83, New York State Plane Feet West
CSC 4/3/2008
33
EXPERIENCE. RESULTS.

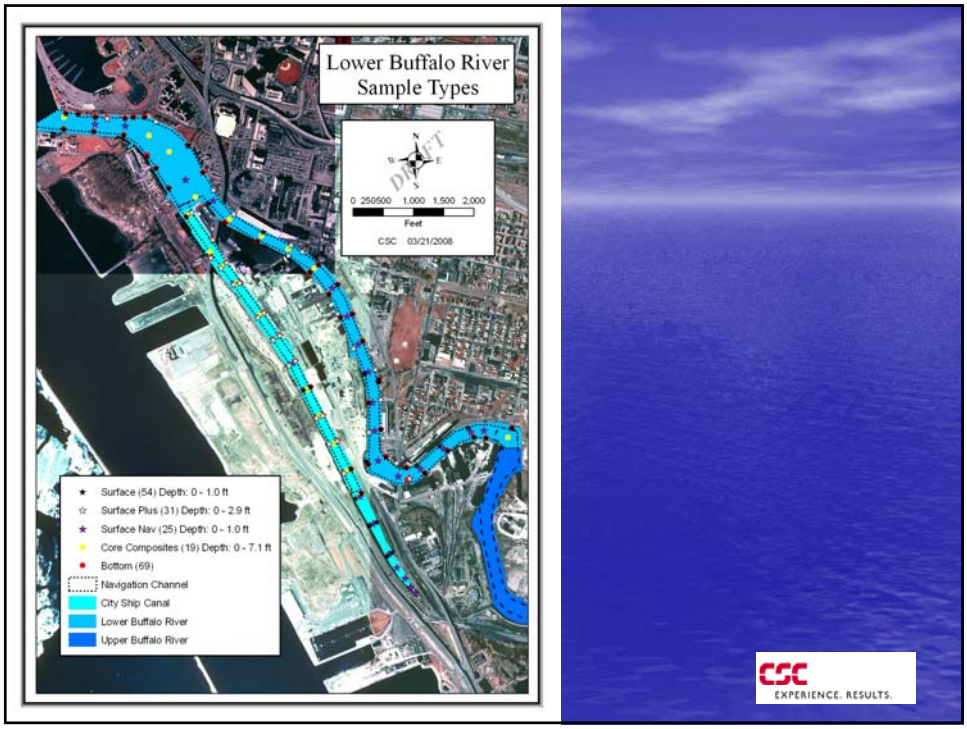

Upper Buffalo River Subsurface Indicator Kriging Optimal Probability Estimate
PCBs 1.08
TPAH 533.390
Indicator Kriging Probability Map
PCB Above 1.0 mg/kg
0 % - 50%
50.01% - 70%
70.01% - 100%
Buffalo River Data
INDICATOR - ANY
0
1
DRAFT
800 400 0 800
Feet
NAD 83, New York State Plane Feet West
CSC 4/7/2008
34
EXPERIENCE. RESULTS.


Upper Buffalo River Subsurface Indicator Kriging Optimal Probability Estimate
PCBs 1.08
TPAH 533.390
Indicator Kriging Probability Map
Mercury Above 0.8 mg/kg
0% - 60%
60.01% - 80%
80.01% - 99.97%
PCB Above 1.0 mg/kg
0 % - 50%
50.01% - 70%
70.01% - 100%
Buffalo River Data
INDICATOR - ANY
0
1
DRAFT
800 400 0 800
Feet
NAD 83, New York State Plane Feet West
CSC 4/7/2008
35
EXPERIENCE. RESULTS.


Upper Buffalo River Subsurface Indicator Kriging Optimal Probability Estimate
PCBs 1.08
TPAH 533.390
Indicator Kriging Probability Map
Mercury Above 0.8 mg/kg
0% - 60%
60.01% - 80%
80.01% - 99.97%
TPAH Above 15 mg/kg
0 % - 40%
60.01% - 80%
80.01% - 100%
PCB Above 1.0 mg/kg
0 % - 50%
50.01% - 70%
70.01% - 100%
Buffalo River Data
INDICATOR - ANY
0
1
DRAFT
800 400 0 800
Feet
NAD 83, New York State Plane Feet West
CSC 4/7/2008
36
EXPERIENCE. RESULTS.


Upper Buffalo River Subsurface Indicator Kriging Optimal Probability Estimate
PCBs 1.08
TPAH 53.390
Indicator Kriging Probability Map
Lead Above 88 mg/kg
0 % - 50%
50.01% - 70%
70.01% - 99.99%
Mercury Above 0.8 mg/kg
0% - 60%
60.01% - 80%
80.01% - 99.97%
TPAH Above 15 mg/kg
0 % - 40%
60.01% - 80%
80.01% - 100%
PCB Above 1.0 mg/kg
0 % - 50%
50.01% - 70%
70.01% - 100%
Buffalo River Data
INDICATOR - ANY
0
1
DRAFT
800 400 0 800
Feet
NAD 83, New York State Plane Feet West
CSC 4/7/2008
Misclassified 1's = 2.63 %
Misclassified 0's = 9.7 %
37
EXPERIENCE. RESULTS.


Upper Buffalo River Volume for Ecological Risk Assessment Criteria
Ecological Risk Assessment Citeria:
Lead = 88 ppm
Mercury = 0.8 ppm
TPAH = 15 ppm
TPCB = 1.0 ppm
Kriged Sediment Depth (Feet)
1.5 - 2
2.1 - 3
3.1 - 4
4.1 - 5
5.1 - 6
6.1 - 7
7.1 - 8.1
Estimated Sediment Volume:
Outside Navigation Channel = 210,400 cy
Navigation Channel
DRAFT


Lower Buffalo River
Sample Types
DRAFT
0 250500 1,000 1,500 2,000
Feet
CSC 03/21/2008
Surface (54) Depth: 0 - 1.0 ft
Surface Plus (31) Depth: 0 - 2.9 ft
Surface Nav (25) Depth: 0 - 1.0 ft
Core Composites (19) Depth: 0 - 7.1 ft
Bottom (69)
Navigation Channel
City Ship Canal
Lower Buffalo River
Upper Buffalo River
csc
EXPERIENCE. RESULTS.