Decline of Lake Michigan-Huron Levels Caused by Erosion of the St. Clair River

W.F. Baird & Associates Coastal Engineers

(in association with Frank Quinn)

April 13, 2005

Outline

- Problem Definition
- Understanding of Water Balance In Great Lakes
- Possible Causes of Head Decline
- Four Independent Analysis
- Conclusions and Future Studies

Relevant Water Level Gauges in the Study Area

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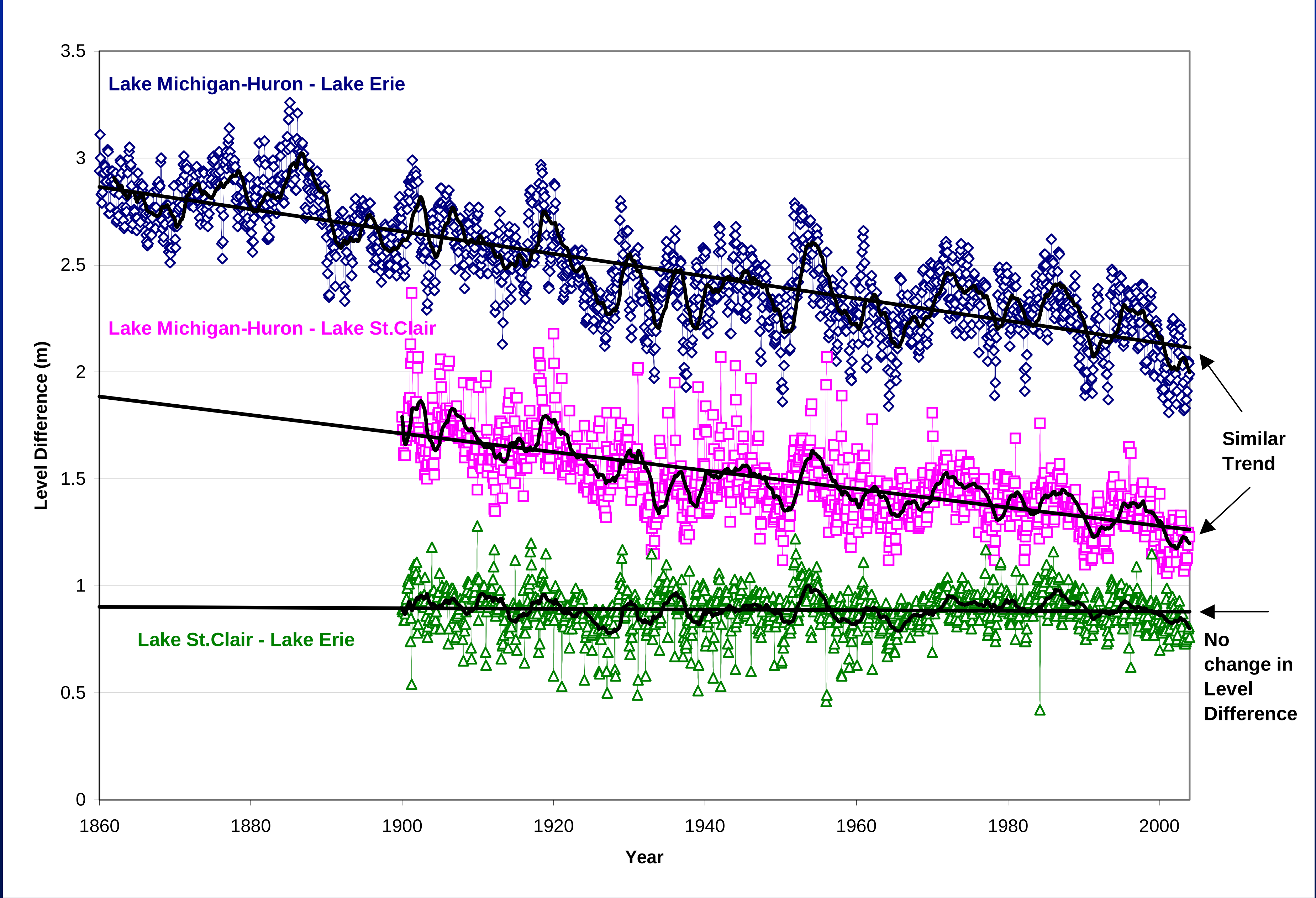
Head Decline Between Lakes Michigan-Huron and Erie



Historic Regime Change (IJC, 1987)

Regime Change	Date	Estimated Effect on Lake Huron Water Level (m)
6.1 m Navigation Channel Dredging	1855 to 1906	-0.11 to -0.21
Removal of Shoal from St. Clair Flats	1906	-0.01
Sinking of Steamers Fontana and Martin	1900	+0.03
Sand and Gravel Mining	1908 to 1925	-0.09
Dredging 7.6 m Navigation Channel	1930 to 1937	-0.05
Dredging 8.2 m Navigation Channel	1960 to 1962	-0.13
NET EFFECT	1855 to 1962	-0.36 to –0.46

In the Recent 30+ Years (1971 – present)

- No significant known human actions influencing Lake Michigan-Huron and the St. Clair River
- Direct impact of 1960 - 1962 navigation channel deepening project would have ceased to be a factor after 10 years

What Caused this Head Decline?

- Post-glacial rebound impacts
- Net basin supply change and shift
- Erosion of the St. Clair River
- ???

Outline

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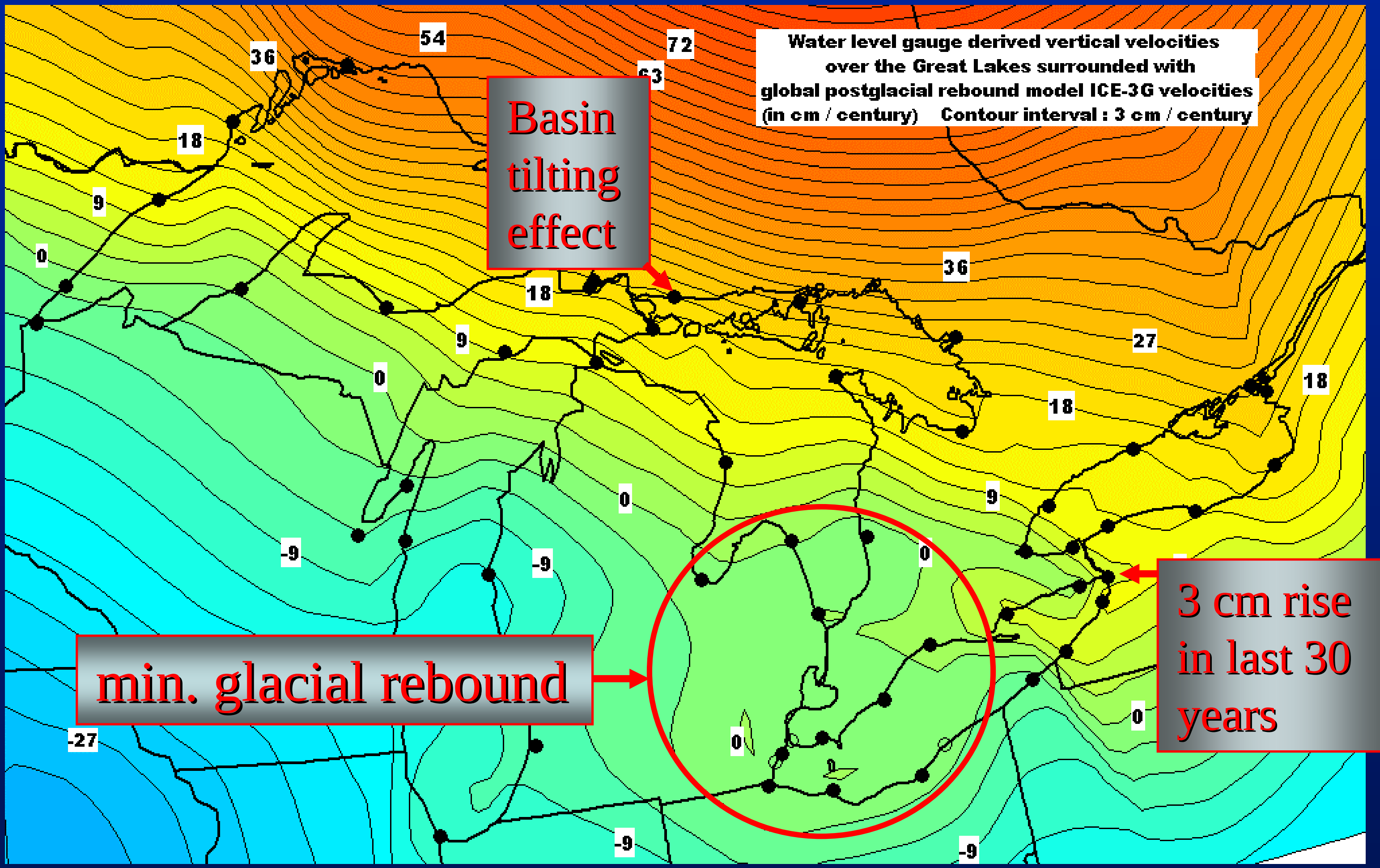
Possible Causes of Head Decline

- Post-glacial rebound impacts
- Net basin supply change and shift
- Erosion/dredging in the St. Clair River

Differential Rebound



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Impact in Last 30 Years

- 3 cm lake level rise on Lake Erie
- 1.5 cm lake level rise on Lake MH

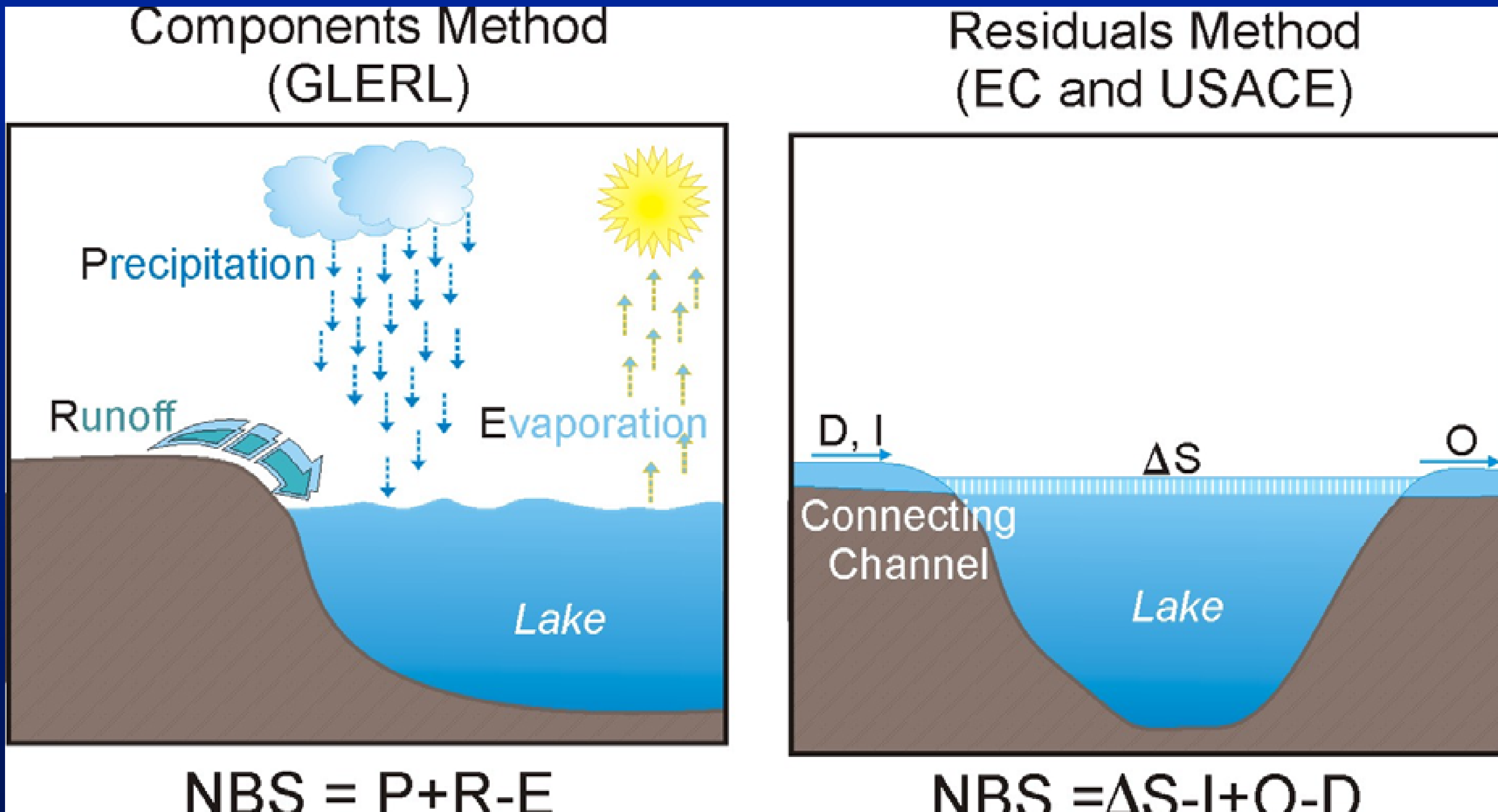
- Conclude: no significant contribution (1.5 cm) on head drop between Lake MH and Erie

Possible Causes of Head Decline

- Post-glacial rebound impacts
- Net basin supply change and shift
- Erosion/dredging in the St. Clair River

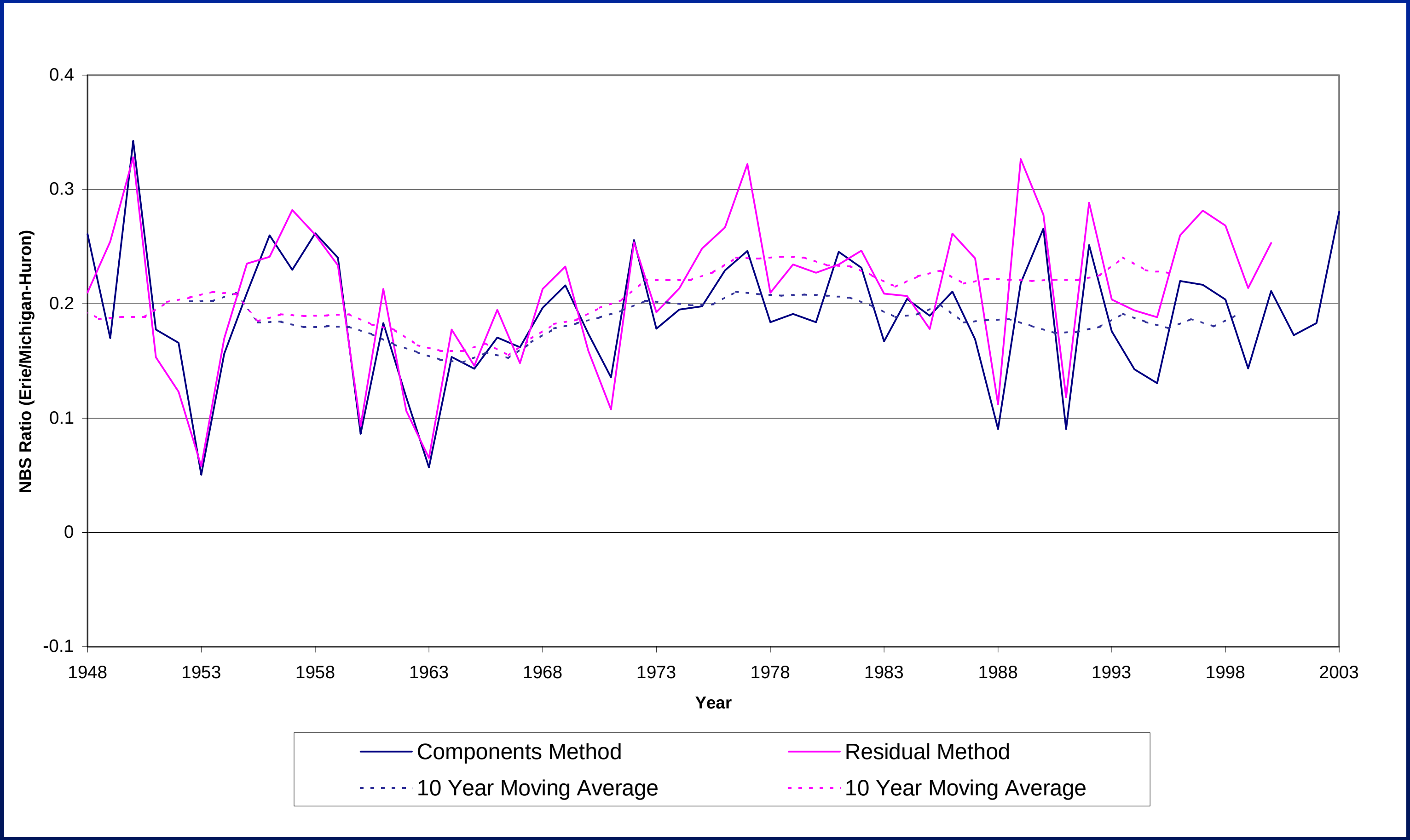
Net Basin Supply (NBS)

- NBS is the total net water supply to a lake
- Two methods of calculating NBS
  - *Components Method (GLERL)*
  - *Residuals Method (EC and USACE)*



Components Method
(GLERL)
Precipitation
Runoff
Evaporation
Lake
NBS = P+R-E
Residuals Method
(EC and USACE)
D, I
ΔS
O
Connecting
Channel
Lake
NBS =ΔS-I+O-D

Relative NBS (Lake Erie/Lake Huron)



Data using Components and Residual methods diverge.

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Key Points on an NBS Shift

- Residual NBS shift is probably produced by the incorrect flow data
- If it is occurring (and this seems unlikely or at least unproven) NBS shift would not have a significant contribution to the observed head drop (almost certainly less than 4 cm)

Possible Causes of Head Decline

- Post-glacial rebound impacts
- Net basin supply change and shift
- Erosion/dredging in the St. Clair River

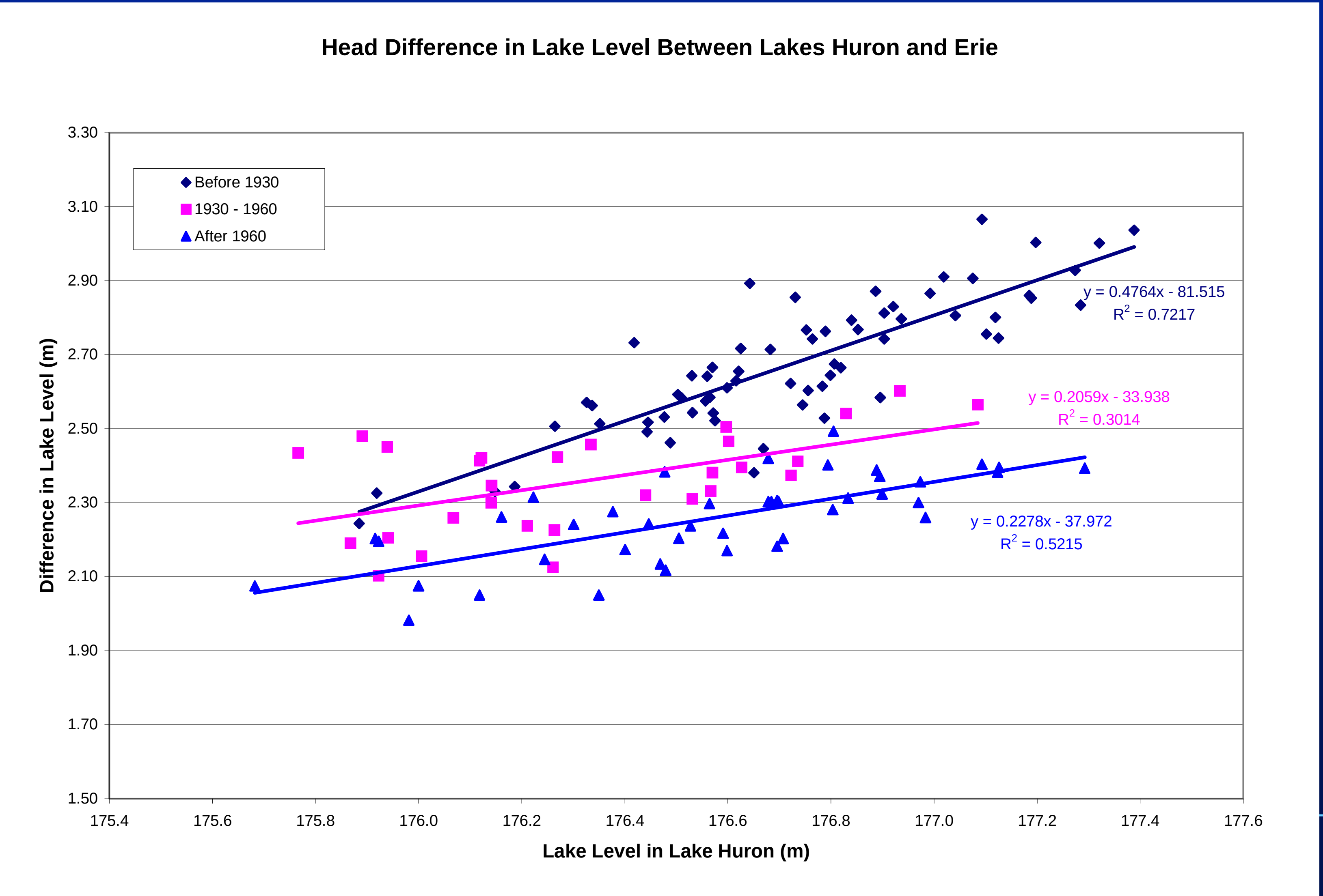
Outline

- Problem definition
- Understanding of water balance in the Great Lakes
- Possible causes of head decline
- Four independent analysis for erosion
- Conclusions and Future Studies

Four Independent Analyses

- Hydraulic analysis using gage relationships
- Normalization analysis using water balance equation on Lake Erie
- GIS analysis on historical bathymetry change
- Numerical modeling

Historical Change of Relationship between Heads (MH –E) and Lake Level (Cleveland)



Four Independent Analyses

- Hydraulic analysis using gage relationships
- Normalization analysis using water balance equation on Lake Erie
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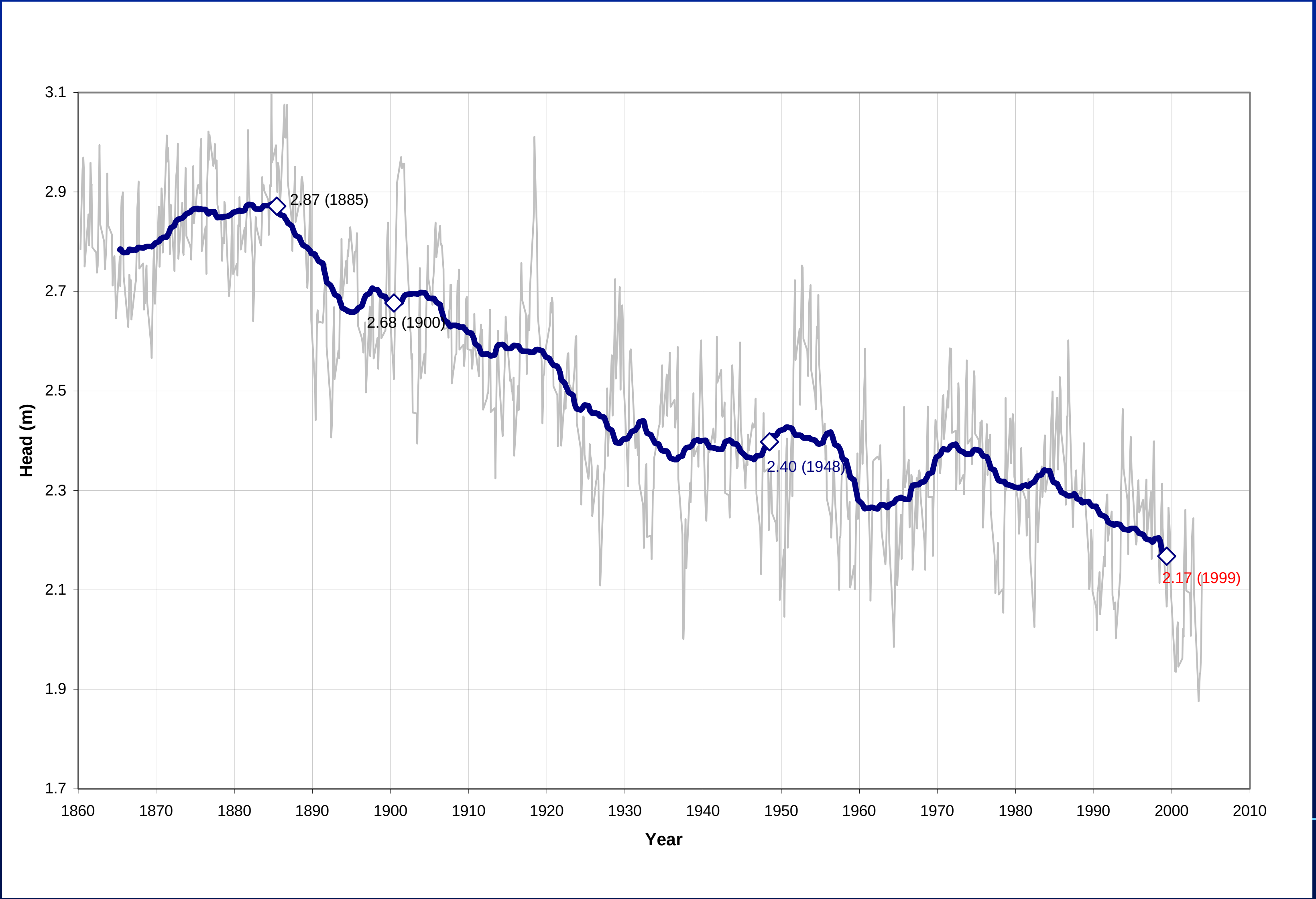
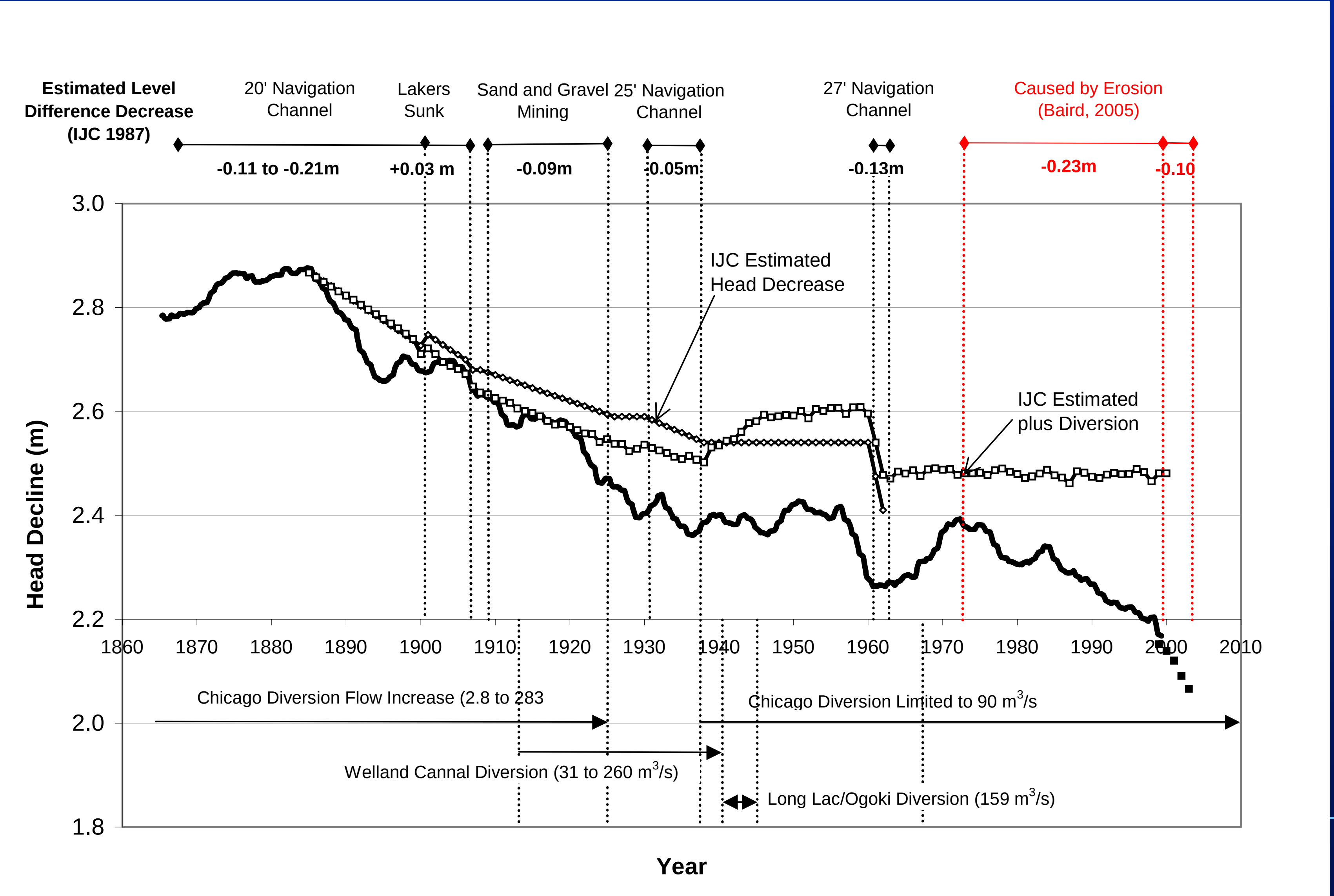
- Numerical modeling

Residual Head (Recorded Head – Normalized Head + 2.5)



Compare to IJC Estimates (1985, 1987)



Key Points from Normalization Analysis

- Reproduces well the historic regime change events and diversions
- Clearly indicates continuous head decline since 1971, in which the head variation caused by natural climatic change is filtered out
- The head decline must be caused mostly by regime change of the St. Clair River

Four Independent Analyses

- Hydraulic analysis using gage relationships
- Normalization analysis using water balance equation on Lake Erie
- GIS analysis of historical bathymetry change
- Numerical modeling

Historic Dredging and Events

Regime Change	Date	Estimated Effect on Lake Huron Water Level (m)
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Erosion of St. Clair River Channel

- 1867 Bathymetry
- 1929 Bathymetry
- 1971 Bathymetry (1948 in Figures)
- 2000 Bathymetry

1867 Bathymetry Upper St. Clair River

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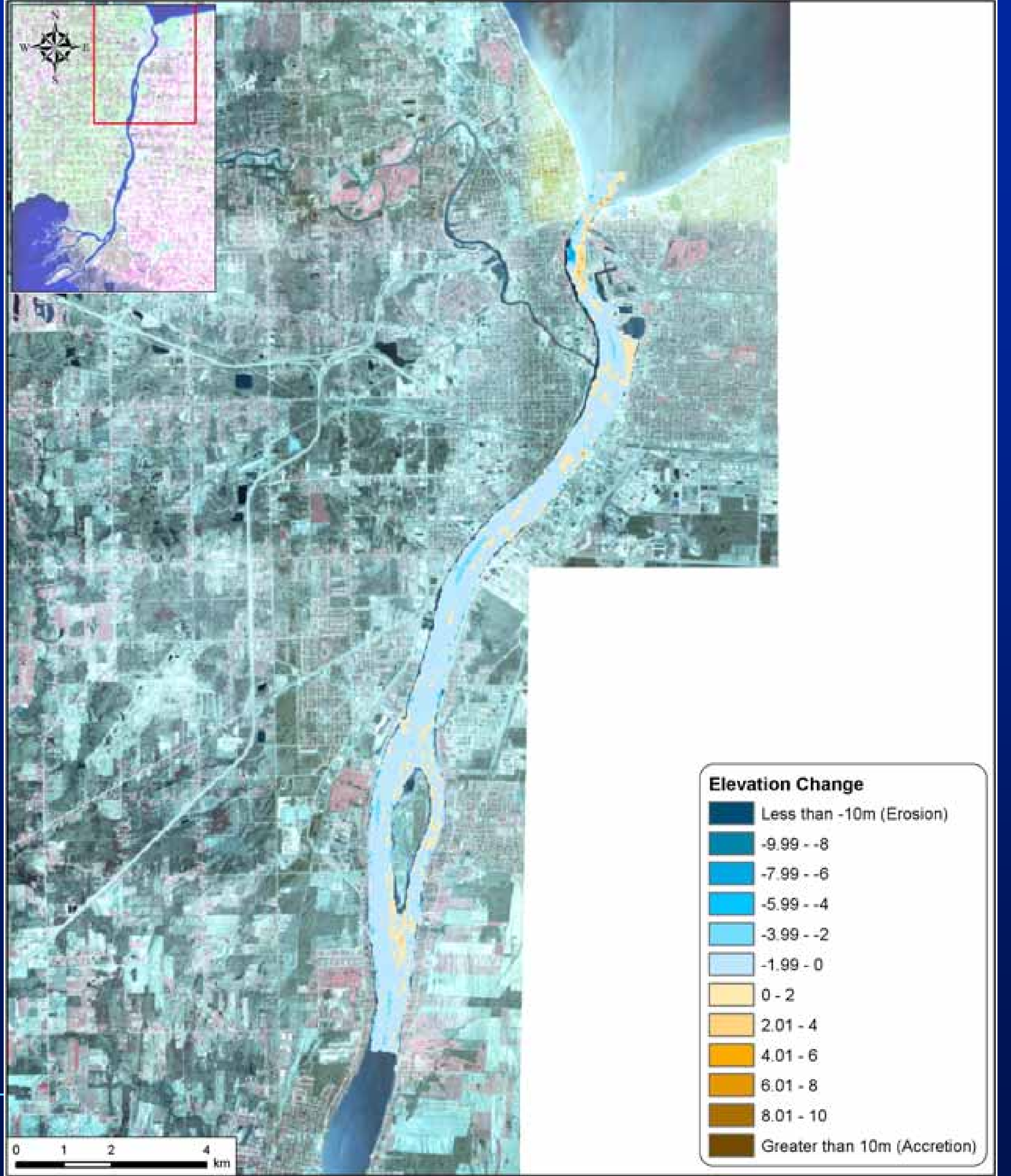
Comparison 1971-2000 Bathymetry

Net Erosion



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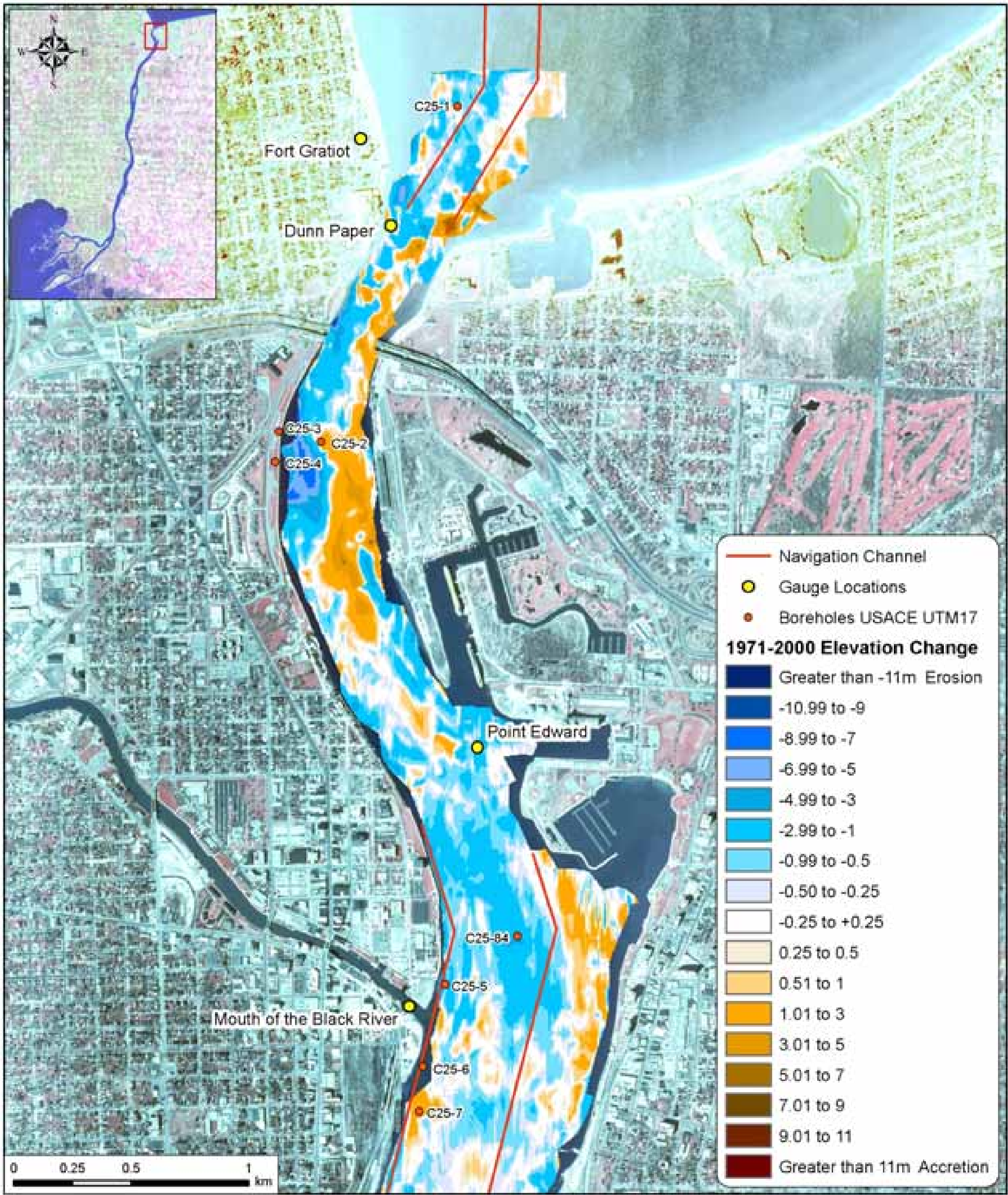
Upper River Erosion and Accretion Patterns



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Comparison 1971-2000 Bathymetry

Net Erosion

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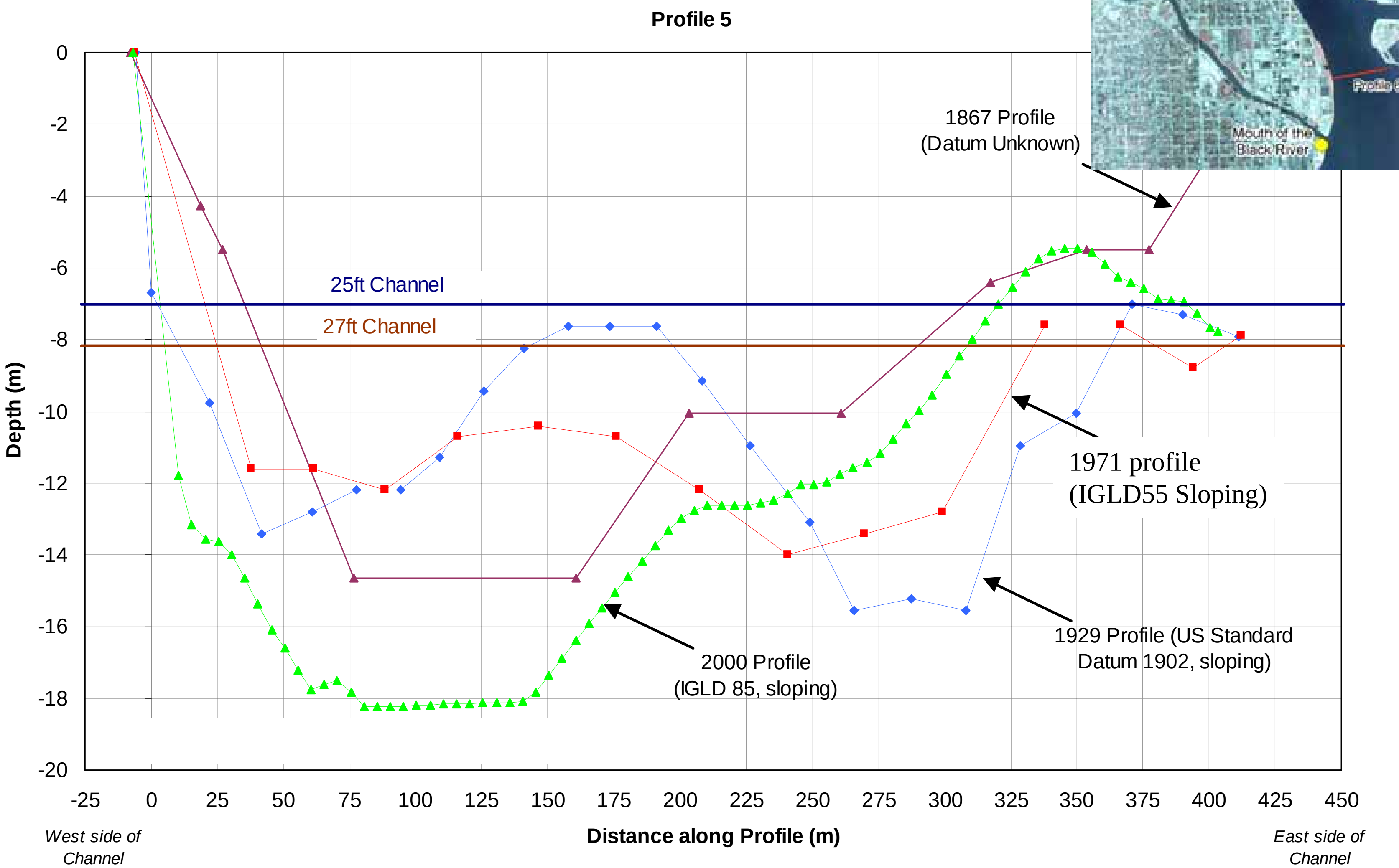

Profile 5
Depth (m)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-25
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
Distance along Profile (m)
West side of Channel
East side of Channel
25ft Channel
27ft Channel
1867 Profile (Datum Unknown)
1971 profile (IGLD55 Sloping)
1929 Profile (US Standard Datum 1902, sloping)
2000 Profile (IGLD 85, sloping)

Fort Gratiot
Profile 1
Dunn Paper
Profile 2
Profile 3
Profile 5
Profile 4
Point Edward
Profile 6
Mouth of the Black River

Key Points From GIS Analysis of Bathymetry Change

- The St. Clair River has eroded significantly between 1971 and 2000
- The erosion mostly explains the decline of Lake Michigan-Huron levels
- Continuous erosion results primarily in an upstream lake drop

Four Independent Analyses

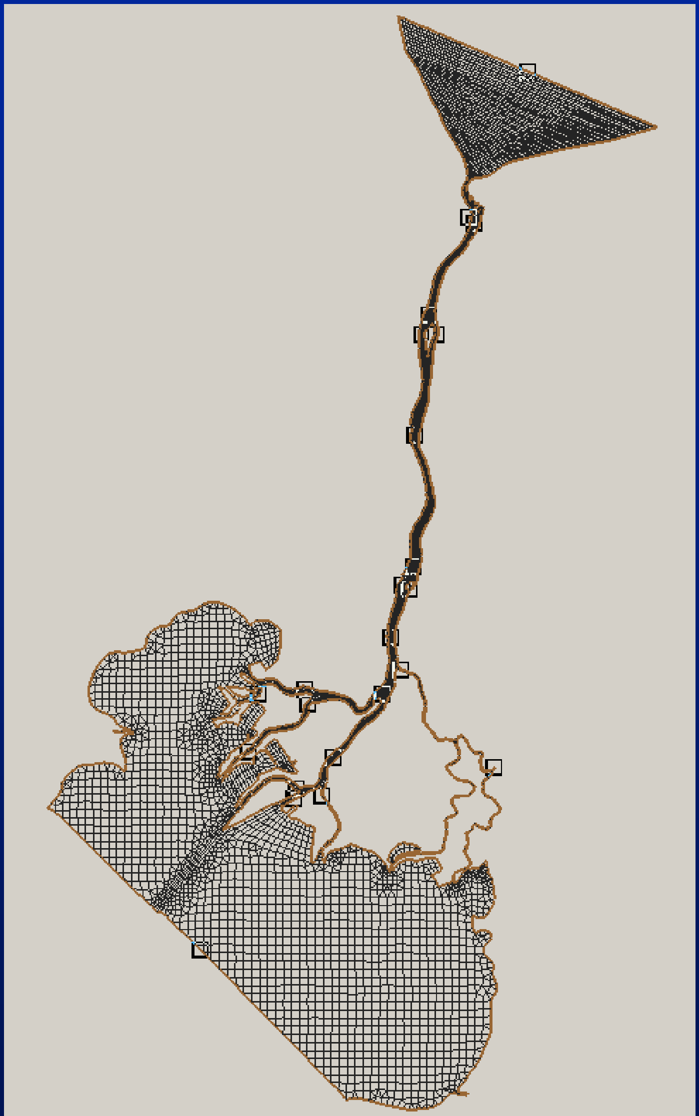
- Hydraulic analysis using gage relationships
- Normalization analysis using water balance equation on Lake Erie
- GIS analysis on historical bathymetry change
- Numerical modeling

Numerical Modeling

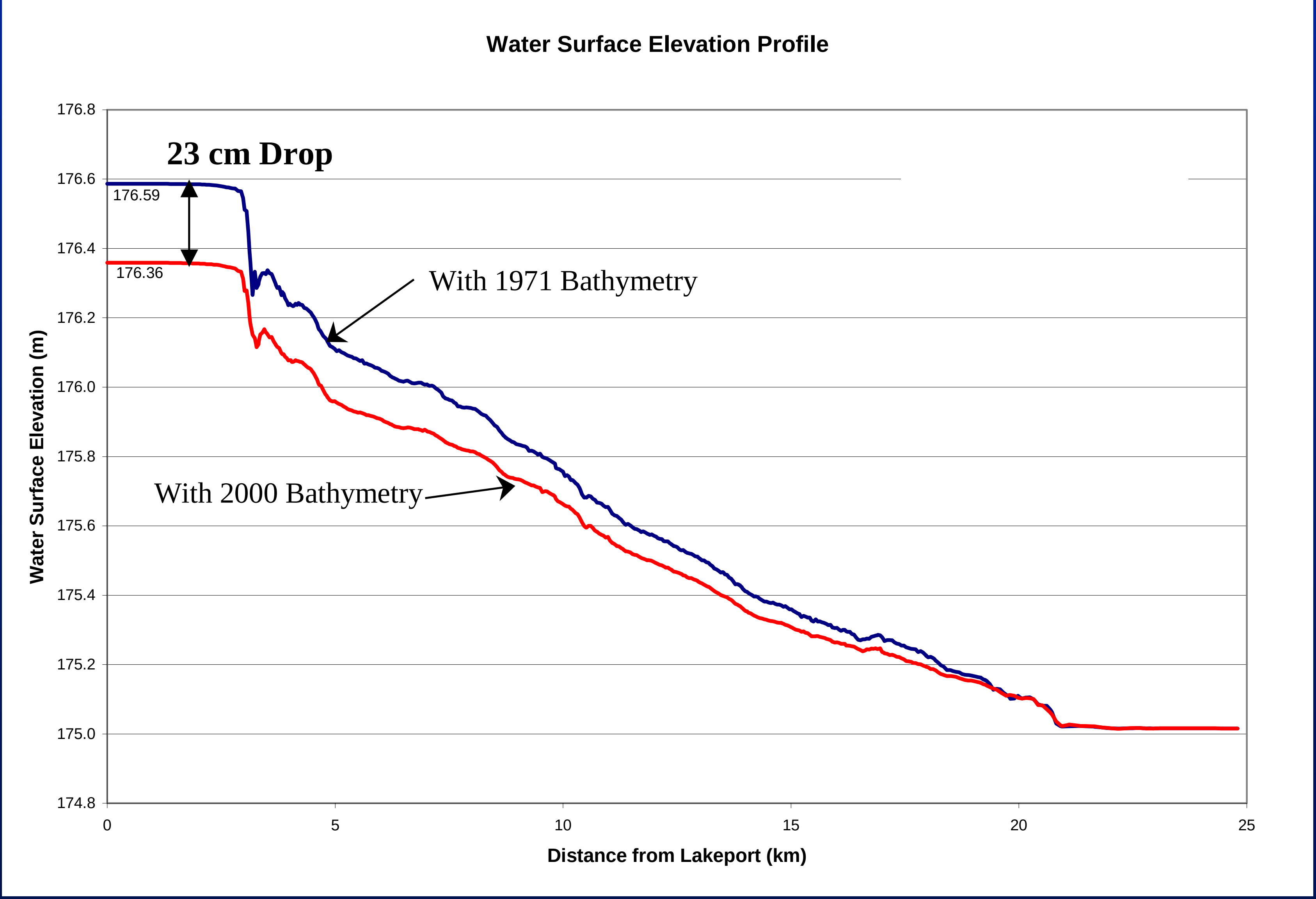
- Two numerical models applied in the St. Clair River and parts of Lakes Huron and St. Clair
  - *RMA2 – a 2D hydrodynamic model*
  - *MISED – a 3D hydrodynamic and sediment transport model*

RMA2 Model

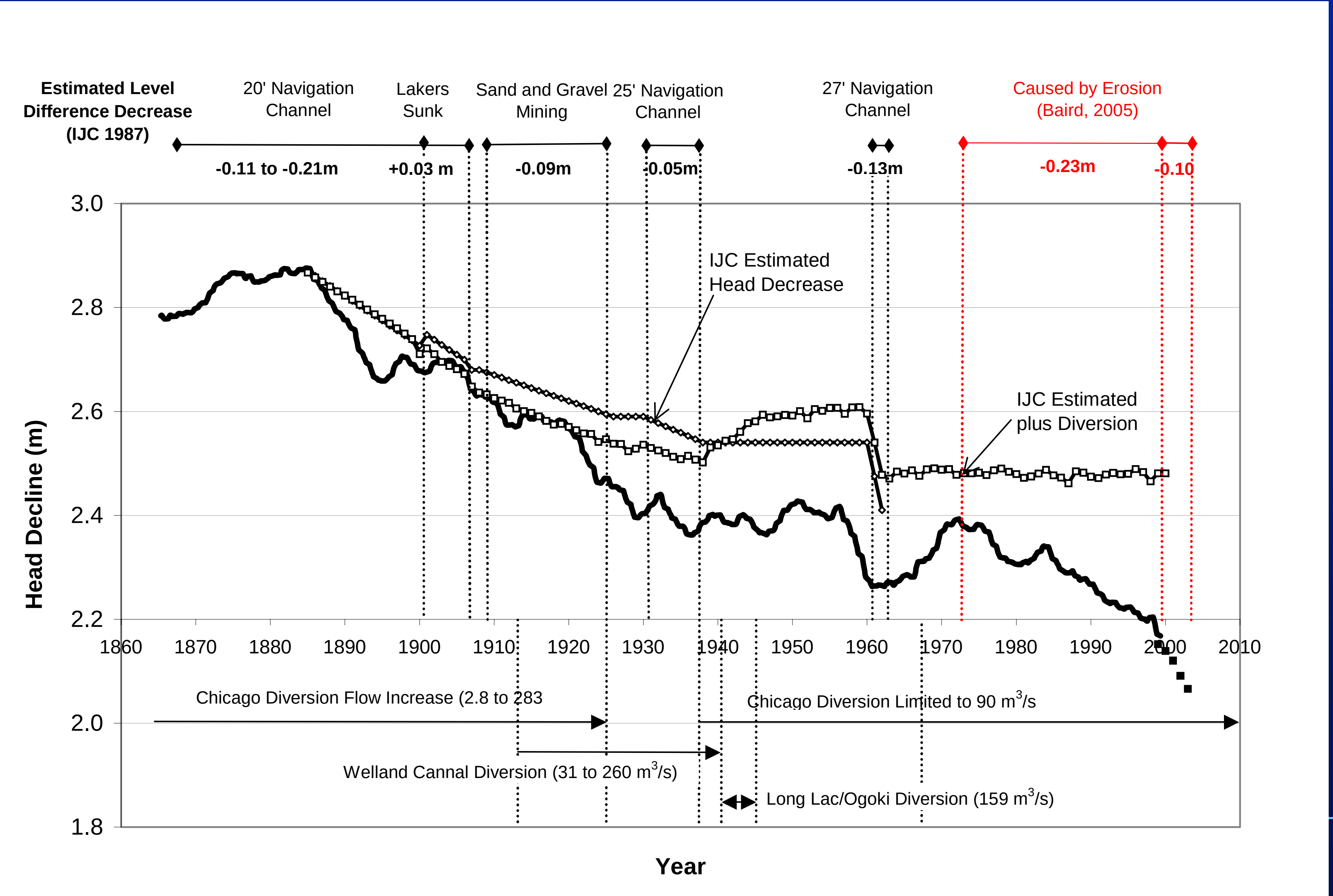
- Originally from USACE, Detroit District
- Model was developed and calibrated by USACE/USGS using 1999-2000 ADCP data
- Model domain adjusted and included
  - *The St. Clair River*
  - *Part of Lake Huron*
  - *Part of Lake St. Clair River*



Lake Huron Level Drops with 2000 Bathymetry (using the same flow – mean flow)

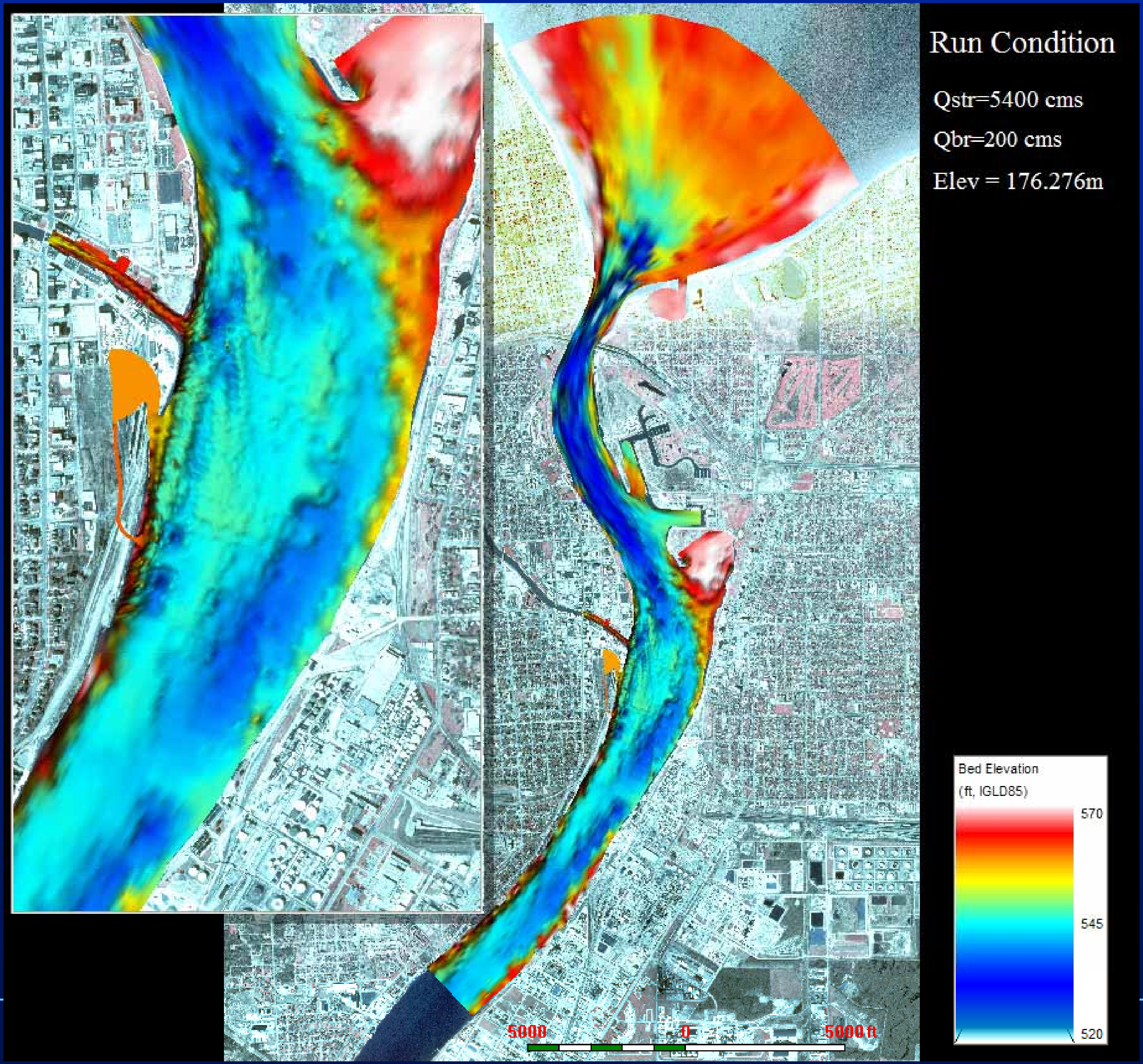


Compare to IJC Estimates (1985, 1987)

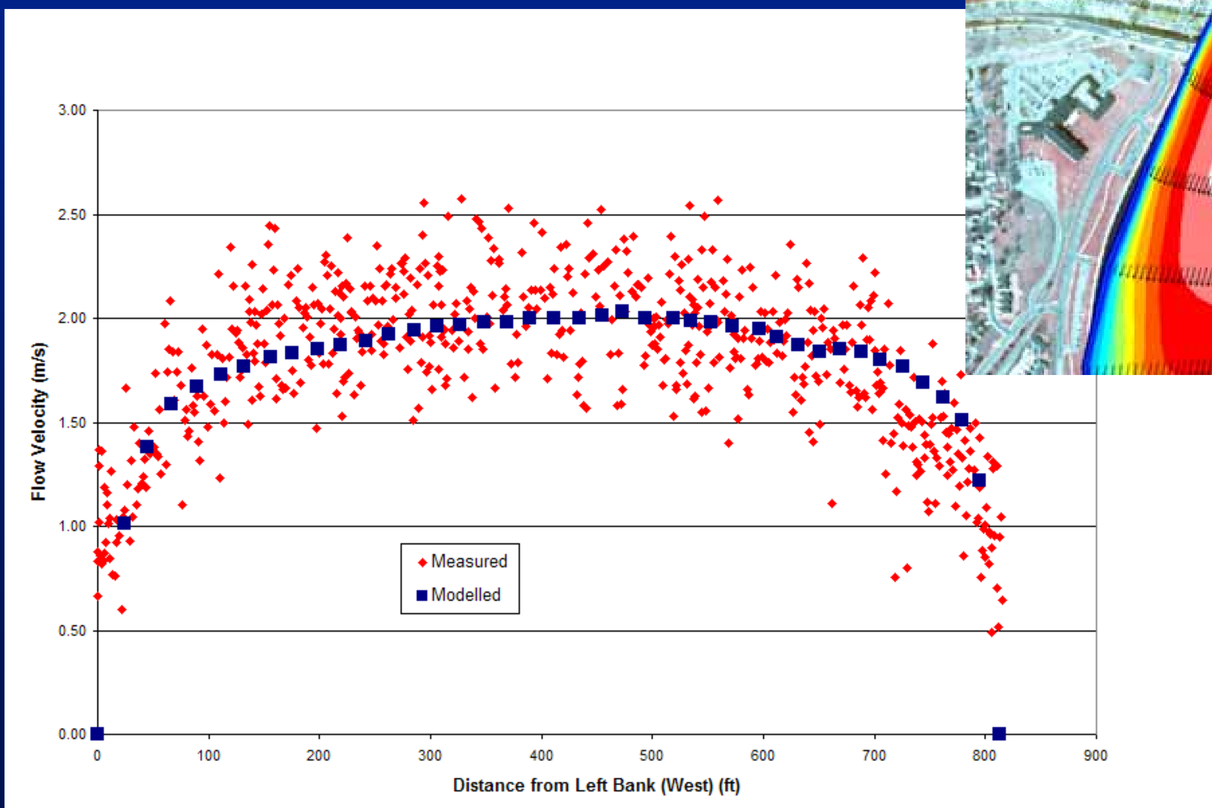


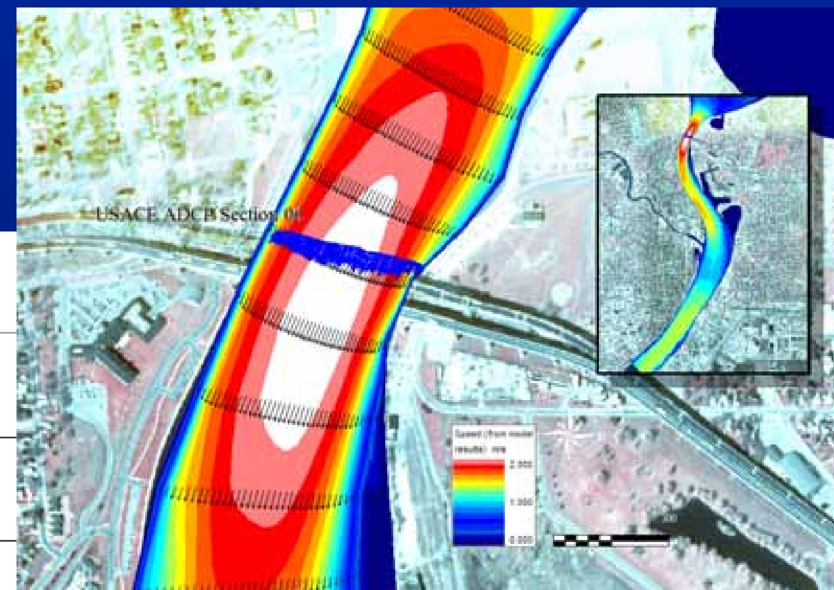
MISED Modeling

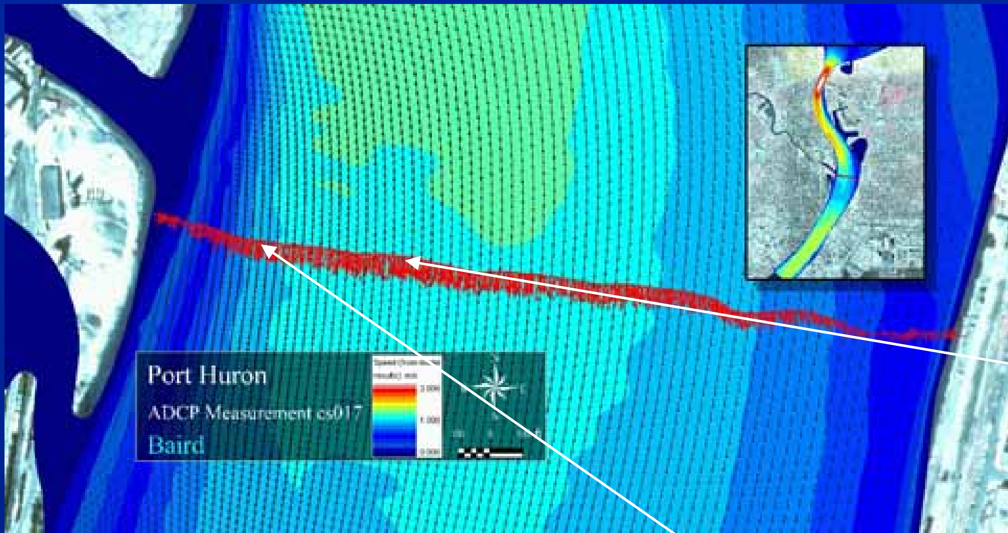
- Baird in-house model - a 3D hydrodynamic and sediment transport model
- Very detailed modeling application (2 to 4 meter grid resolution near the month of Black River)
- Model Domain
  - *Part of Lake Huron*
  - *Upper part of the St. Clair River*

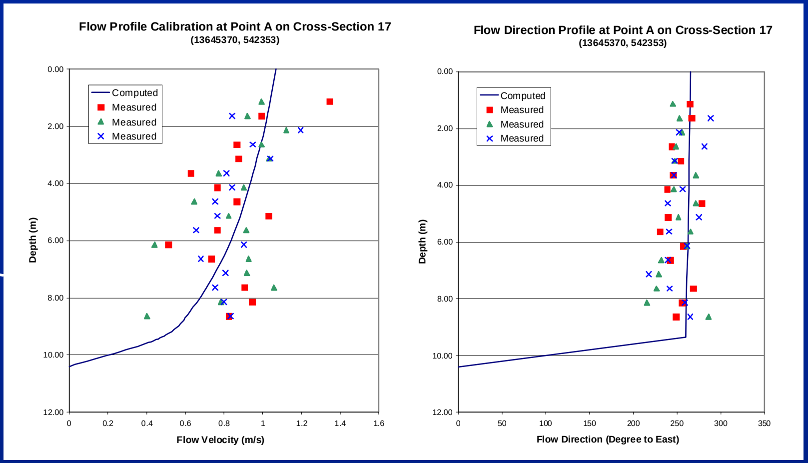

Run Condition
Qstr=5400 cms
Qbr=200 cms
Elev = 176.276m
Bed Elevation
(ft, IGLD85)
570
545
520
5000
0
5000 ft

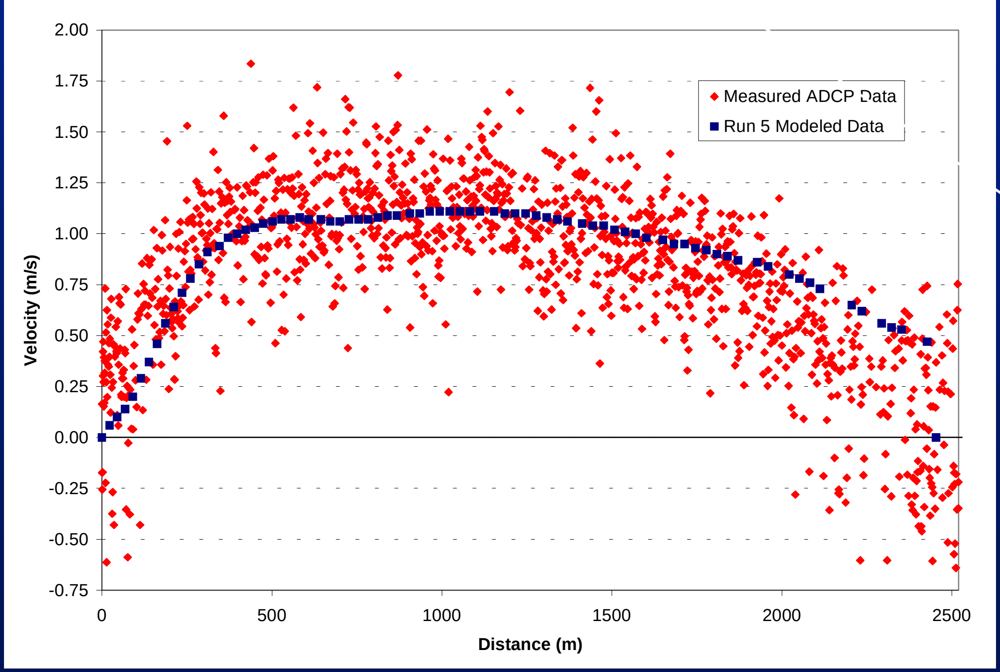
Calibrated with USACE ADCP Data (X-Section 06)

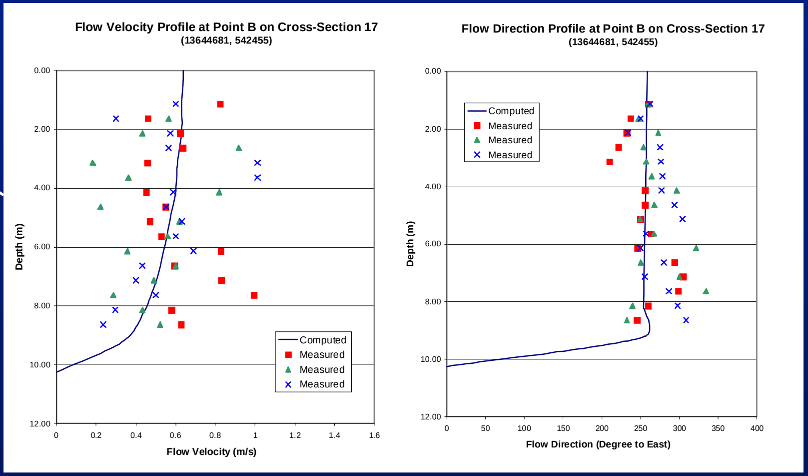












X-Section 17

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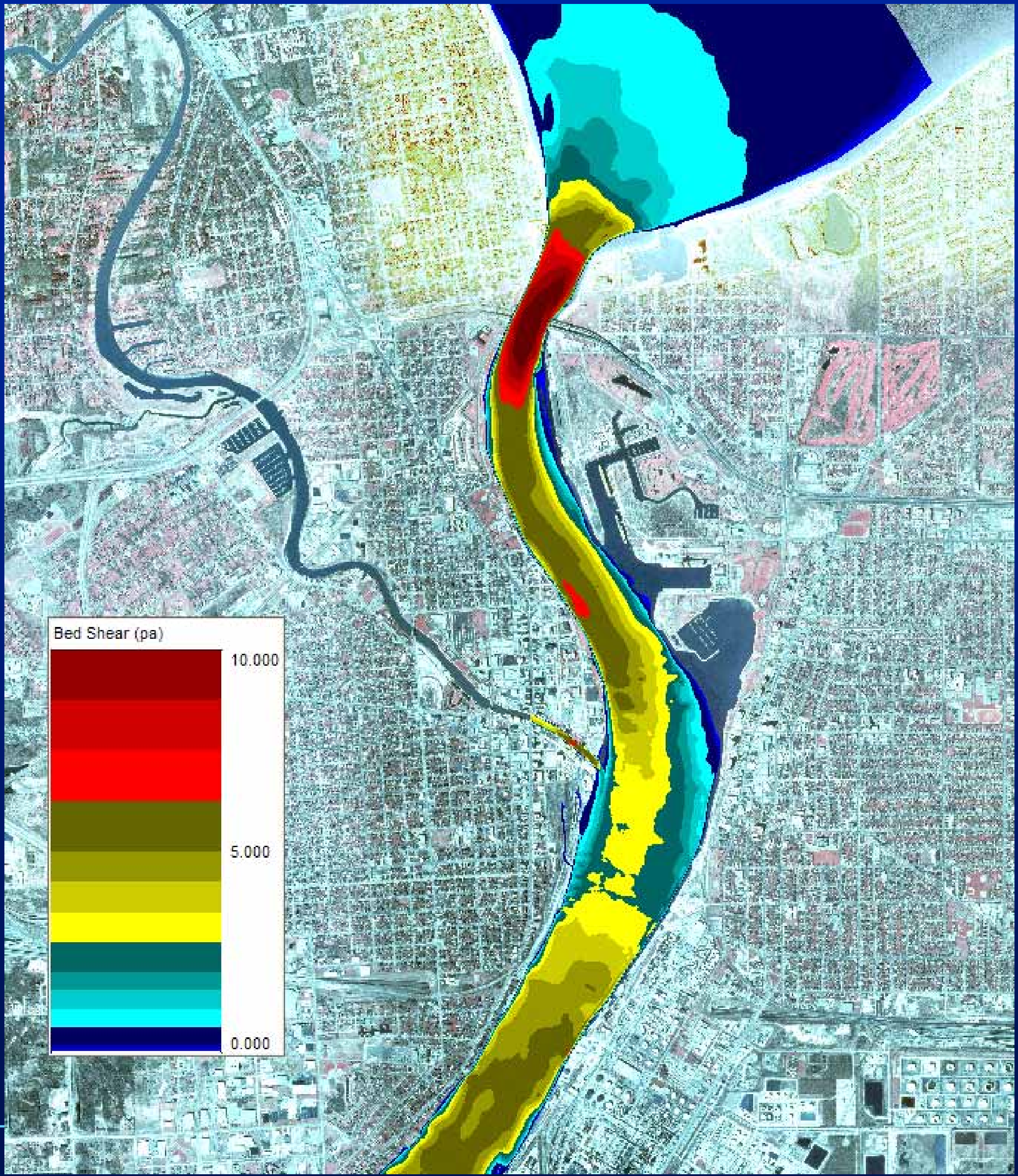
Erosion Potential

- Red – Fine Gravel
- Yellow – Very Fine Gravel
- Green – Medium Sand
- Blue – Finer than Medium Sand




Port Huron
Mised Modeling Baird
100 0 100 ft
Qser=5300 cms
Qbr=10 cms
Water level=175.95 m, IGLD85

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Riverbed Erosion

- Erosion generally caused by:
  - *More sediment moving out of an area than into that area*
  - *Exposure of an irreversibly erodible sediment (removal of lag)*
- The possible causes for recent erosion include:
  - *aggregate mining*
  - *coastal shore protection*
  - *riverbank protection, and*
  - *indirectly, dredging*
  - *Ship-enhanced erosion and transport*

Outline

- Problem Definition
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Conclusions – What has happened…

- Water level data shows a previously undetected/unexplained 25 to 35 cm drop in head difference between M-H and E over the past 30 to 35 years
- High lake levels between 1970 and 1998 had previously masked the full extent of the head drop

Conclusions – What has caused it…

- In the last 30 to 35 years, of the 25 to 35 cm drop:
  - *Glacial rebound accounts for less than 2 cm (Erie rise)*
  - *NBS shift accounts for less than 4 cm (even this unlikely)*
  - *Continuous erosion may have raised Lake Erie by 2 cm*
  - *No significant contribution from change due to diversions*
  - *Numerical model of 1971 and 2000 bathymetry (representing significant erosion) can account for 23 cm of change – all resulting from a fall of Lake Michigan-Huron due to increased flow capacity on the St. Clair River*

Conclusions – What about the future…

- Both the hydraulic analysis and the normalization analysis suggest the decline in head difference (due mostly to a fall of Lake Michigan) is ongoing
- Lake level change due to erosion is irreversible
- Long-term cycles suggest falling lake levels over the next 80 years
- Latest climate change also predicts reduction in lake levels

Conclusions – What triggered and sustains the erosion…

- Lakes Michigan-Huron have been relatively stable for 2000 to 3000 years due to a stable outlet
- Recent changes that may have contributed to triggering and sustaining erosion:
  - *Sand mining*
  - *Dredging (indirectly)*
  - *Coastal protection and structures*
  - *River bank protection*
  - *Ship-enhanced erosion and transport*

Future Studies

- Bathymetry survey of the upper river and lake (and review any 1980s, 1990s bathymetry)
- Boreholes of the eroding area, ROV, geophysical surveys
- 3D modeling of waves, currents, sand transport, cohesive sediment erosion and morphodynamics
- Geomorphic assessment, detailed sediment budget
- Explanation of the erosion
- Development/testing of solutions

Outline

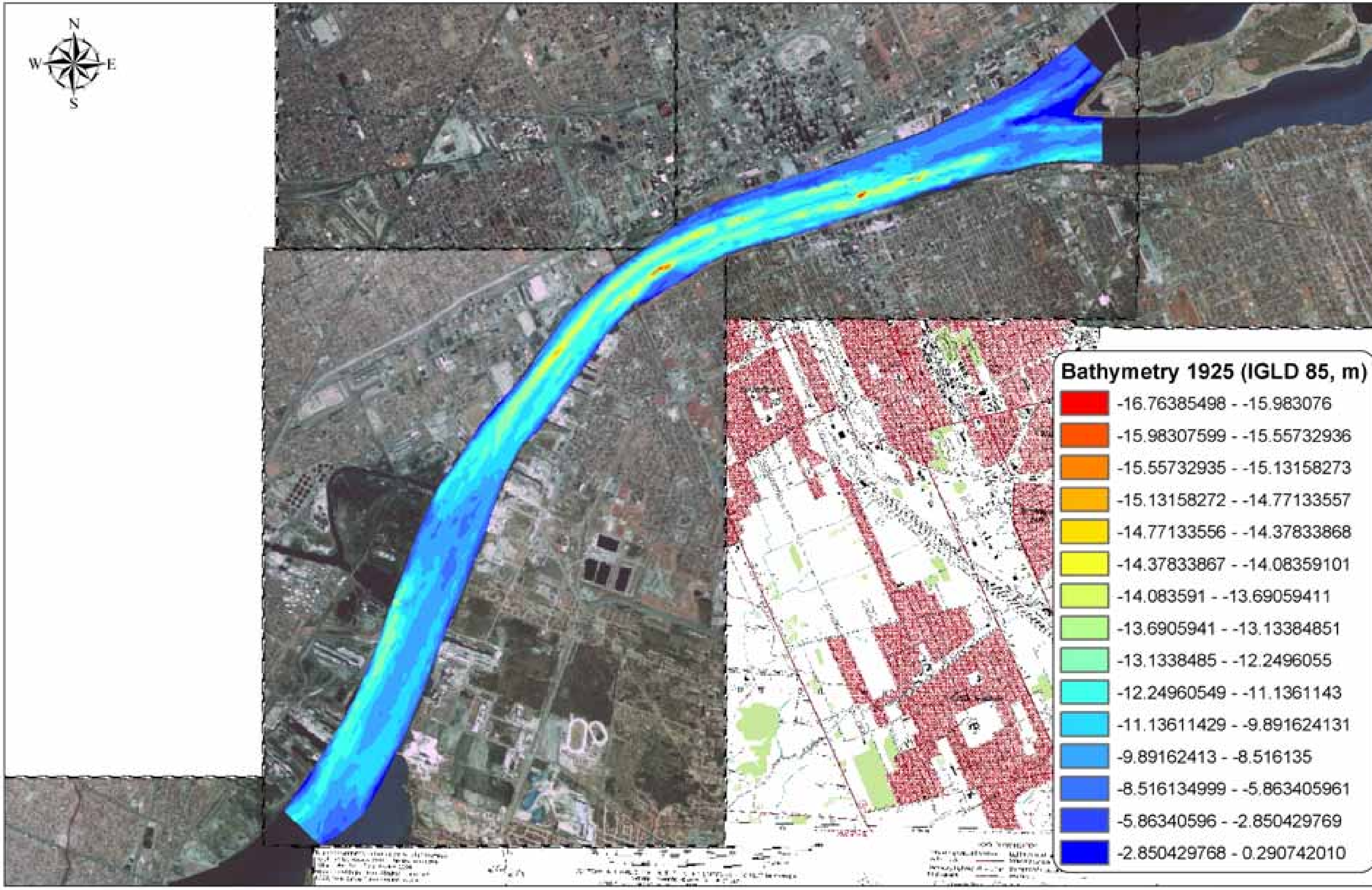
- Pdf's of erosion
- Physical model of St. Clair and Black River
- Detroit River

Acknowledgements

- Baird & Associates completed this work through funding by the GBA Foundation
- Cooperation and assistance of the USACE, Environment Canada and the Great Lakes Environmental Research Laboratory is gratefully acknowledged
- Many thanks to Frank Quinn for his valuable input and review of our work.

Detroit River, Fighting Island to Belle Isle - Analysis of River Bed Erosion

W.F. Baird & Associates Coastal Engineers



0 500 1,000 2,000 m

0 2,500 5,000 10,000 ft

Scale 1:72,000

1925 BATHYMETRY

Bathymetry Grid Created from 1925 Survey Data (IGLD 85, metres)

Photo Date: 1998

Projection: UTM Zone 17N
Datum: NAD 83

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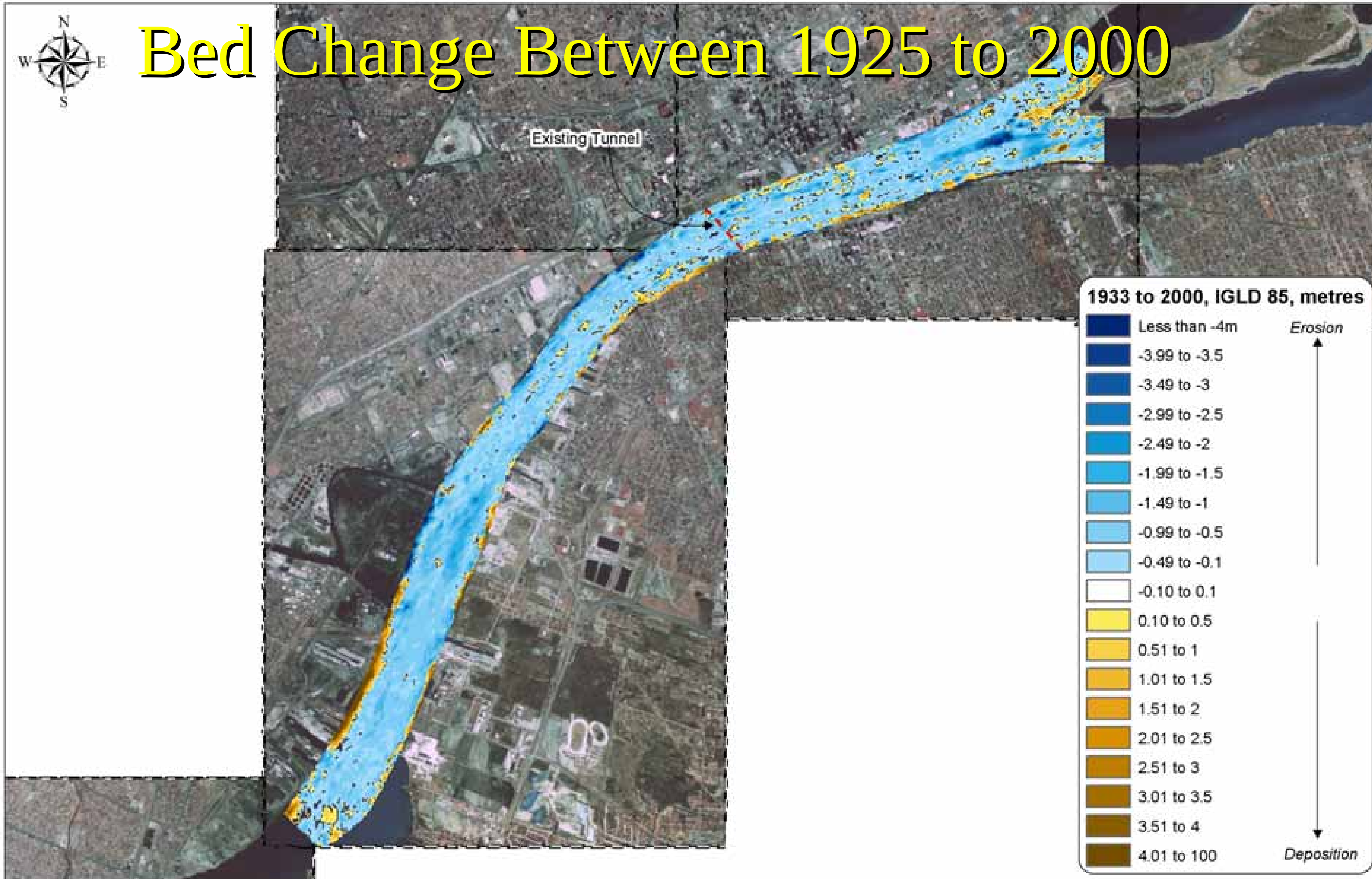
Bed Change Between 1925 to 2000



0 500 1,000 2,000 m

0 2,000 4,000 8,000 ft

Scale 1:72,000

ELEVATION COMPARISON

Change in Elevation from 1933 to 2000 (in metres, IGLD 85)

Detroit River Tunnel Scour

Photo Date: 1998

Projection: UTM Zone 17N
Datum: NAD 83

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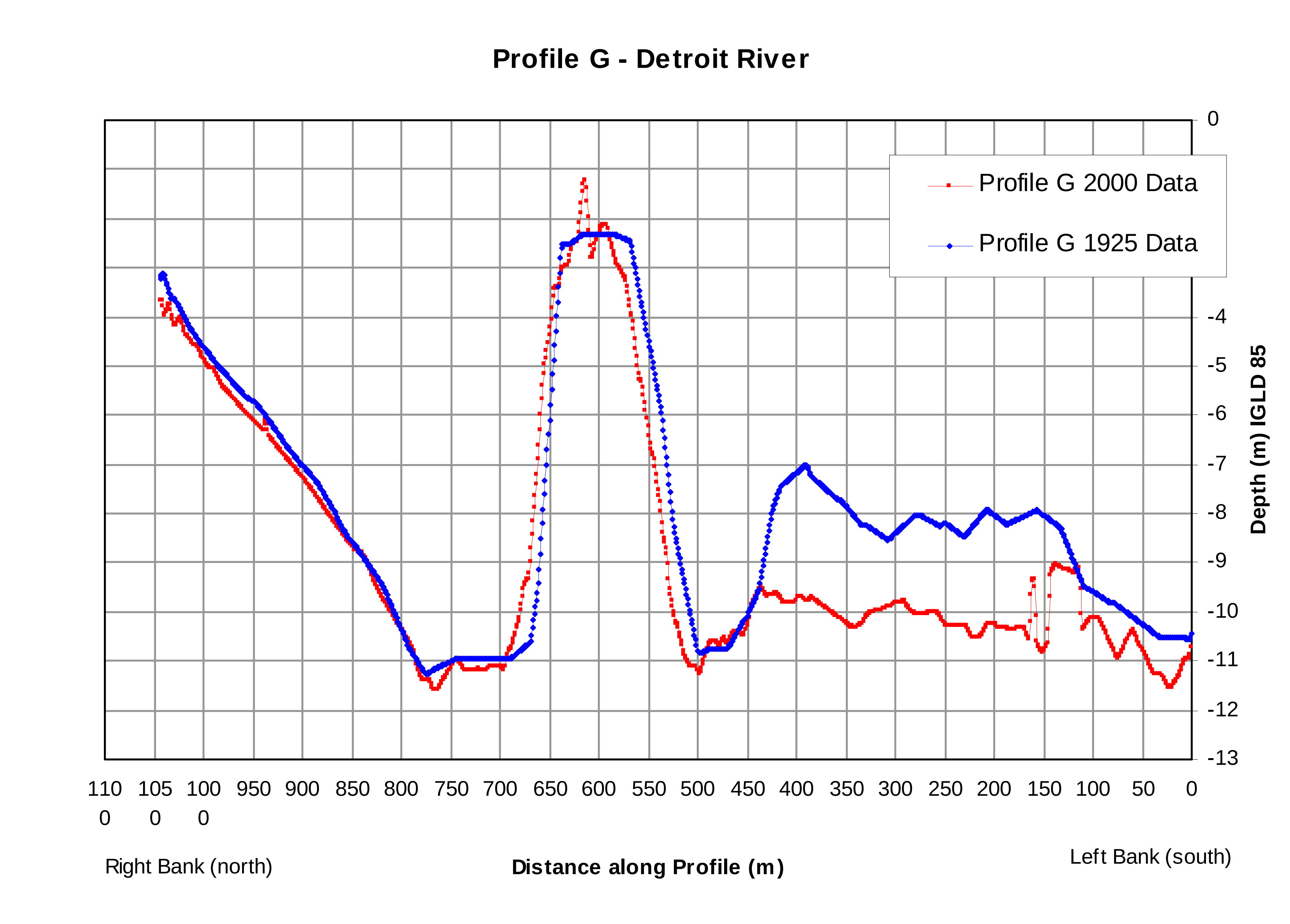
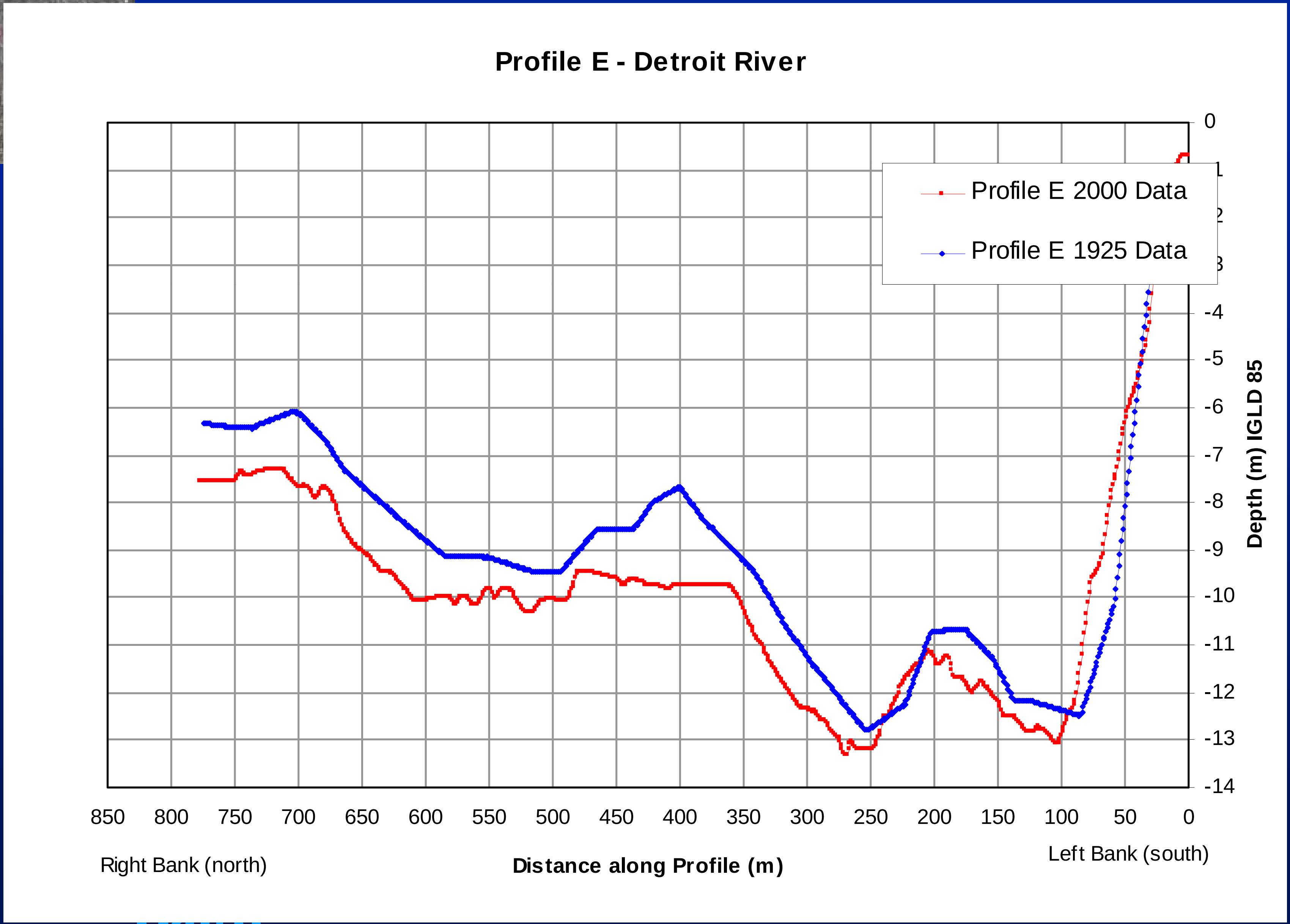
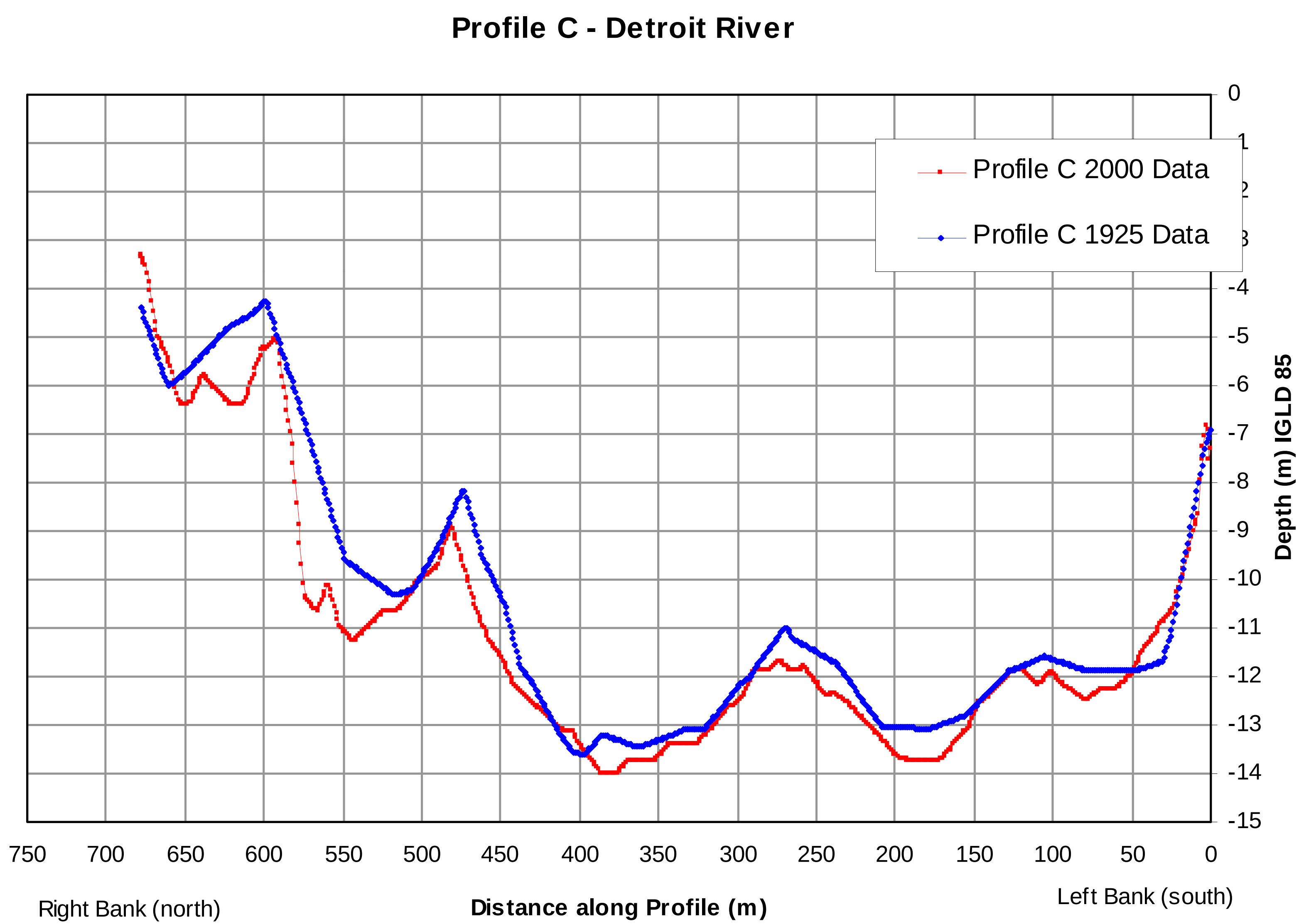


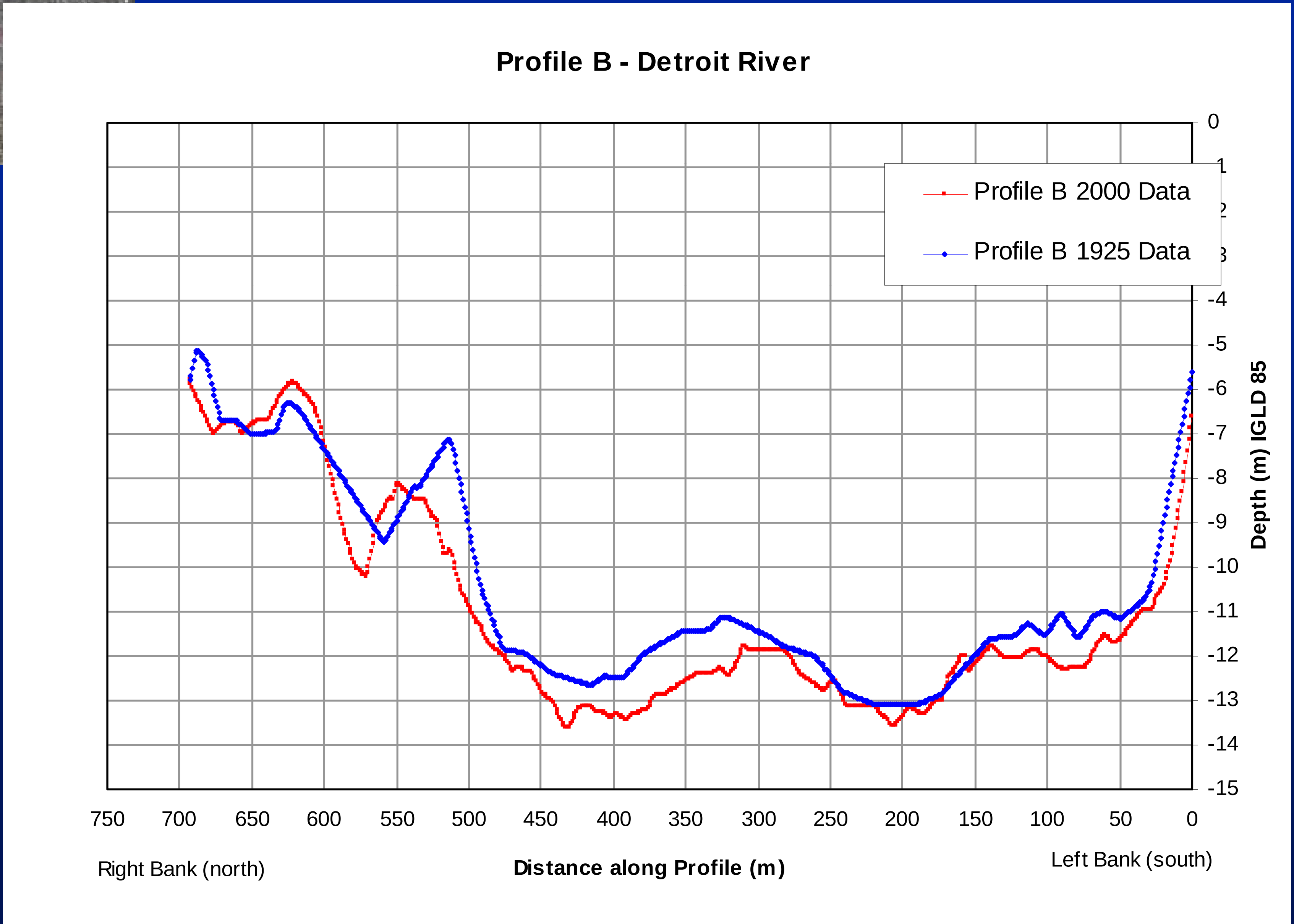
Profile G - Detroit River
Profile G 2000 Data
Profile G 1925 Data
0
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
Depth (m) IGLD 85
110
0
105
0
100
0
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Right Bank (north)
Distance along Profile (m)
Left Bank (south)

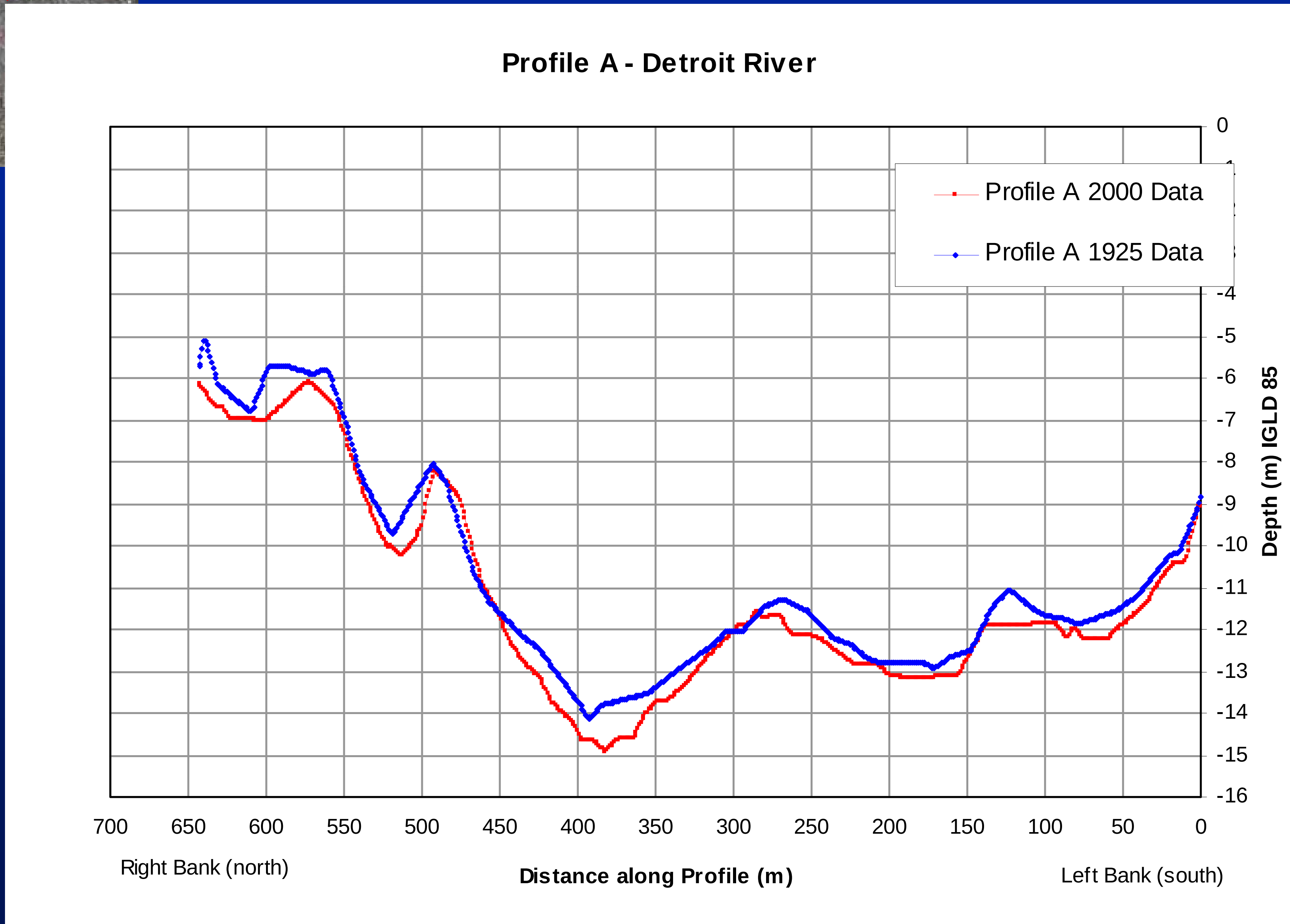


Profile E - Detroit River
Profile E 2000 Data
Profile E 1925 Data
0
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
Depth (m) IGLD 85
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Right Bank (north)
Distance along Profile (m)
Left Bank (south)

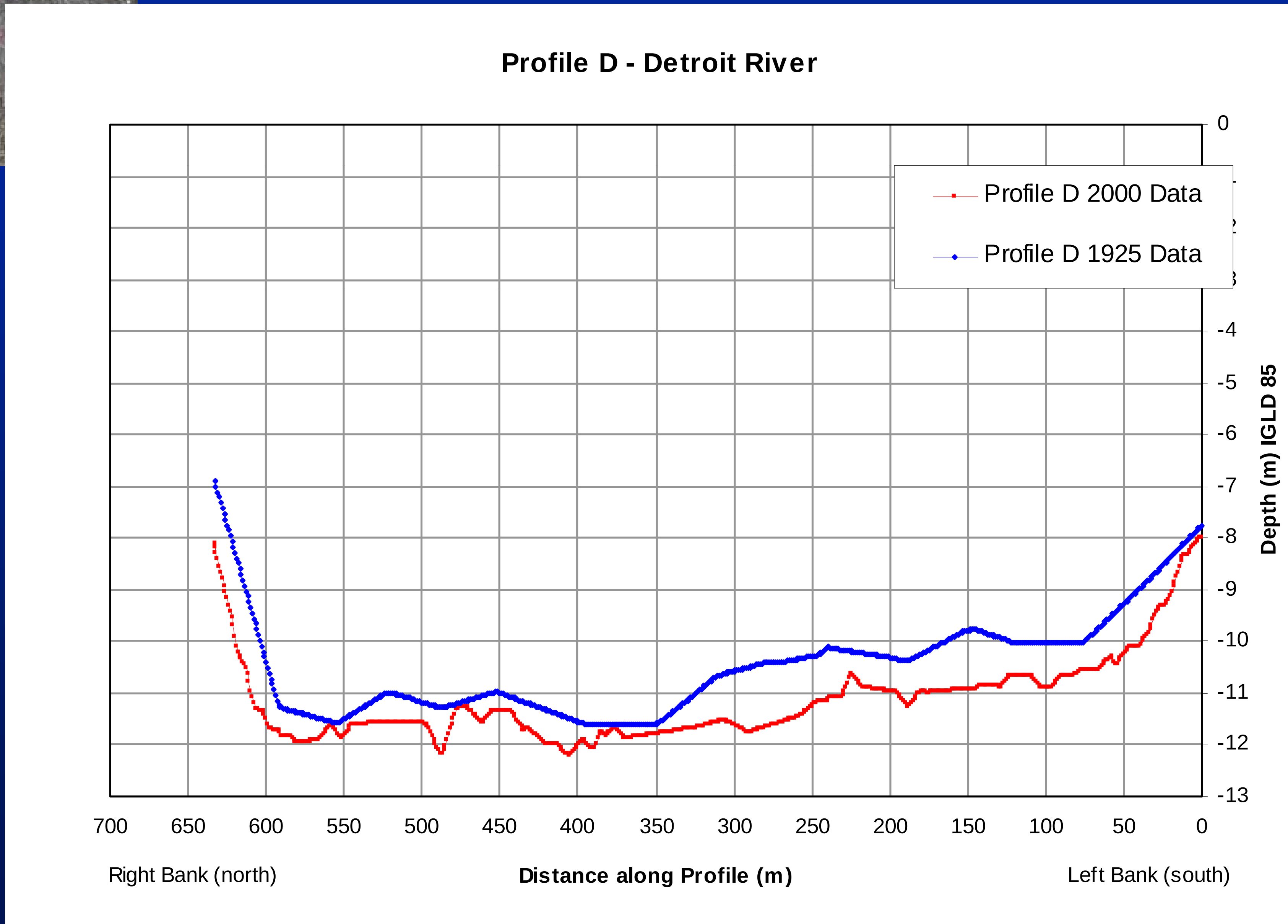


Profile C - Detroit River
Profile C 2000 Data
Profile C 1925 Data
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
Depth (m) IGLD 85
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Right Bank (north)
Distance along Profile (m)
Left Bank (south)

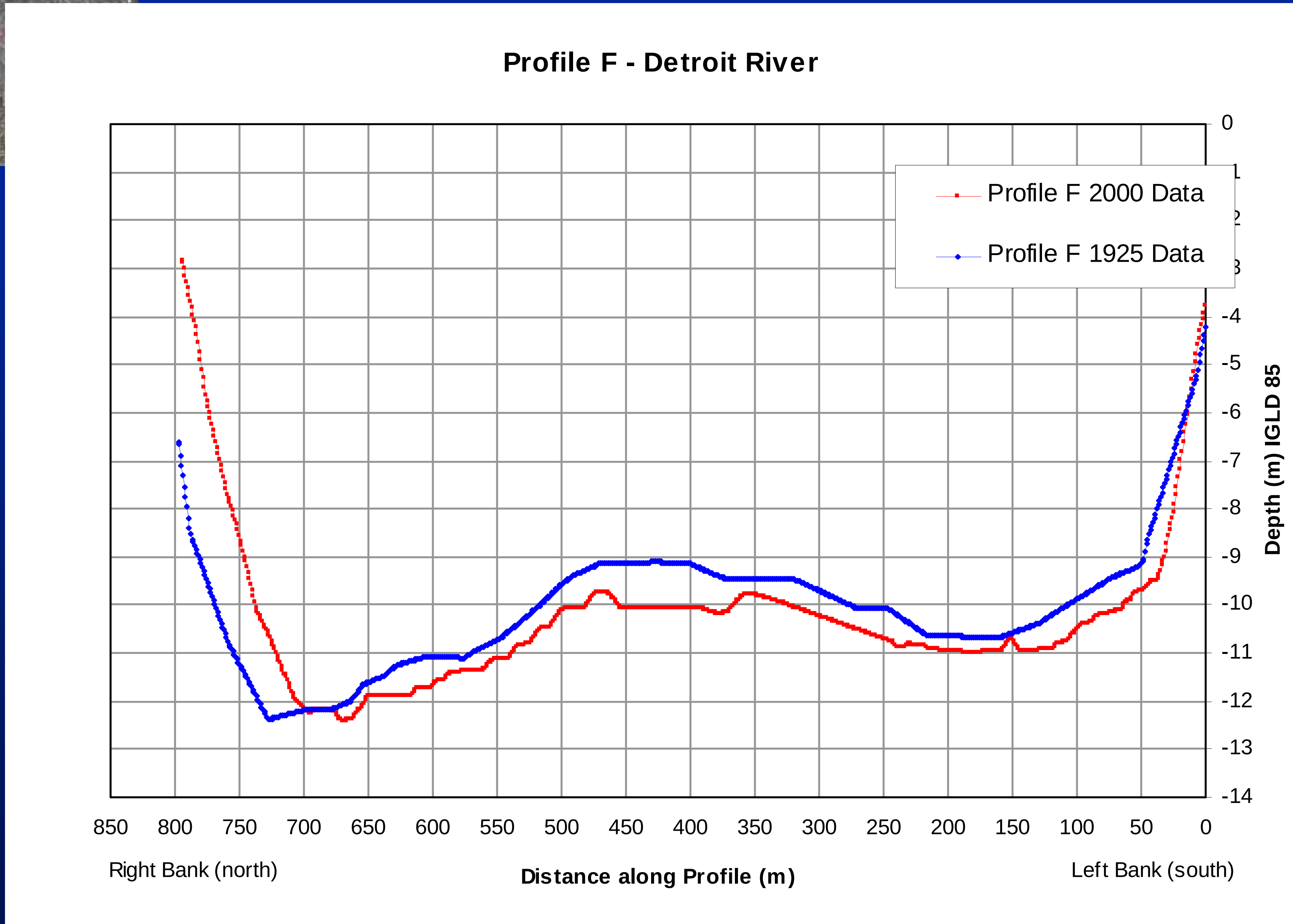

Profile B - Detroit River
Profile B 2000 Data
Profile B 1925 Data
Depth (m) IGLD 85
0
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Right Bank (north)
Distance along Profile (m)
Left Bank (south)



Profile A - Detroit River
Profile A 2000 Data
Profile A 1925 Data
0
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
Depth (m) IGLD 85
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Right Bank (north)
Distance along Profile (m)
Left Bank (south)



Profile D - Detroit River
Profile D 2000 Data
Profile D 1925 Data
0
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
Depth (m) IGLD 85
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Right Bank (north)
Distance along Profile (m)
Left Bank (south)



Profile F - Detroit River
Profile F 2000 Data
Profile F 1925 Data
0
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
Depth (m) IGLD 85
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Right Bank (north)
Distance along Profile (m)
Left Bank (south)

Bed Changes Between 1925 and 2000

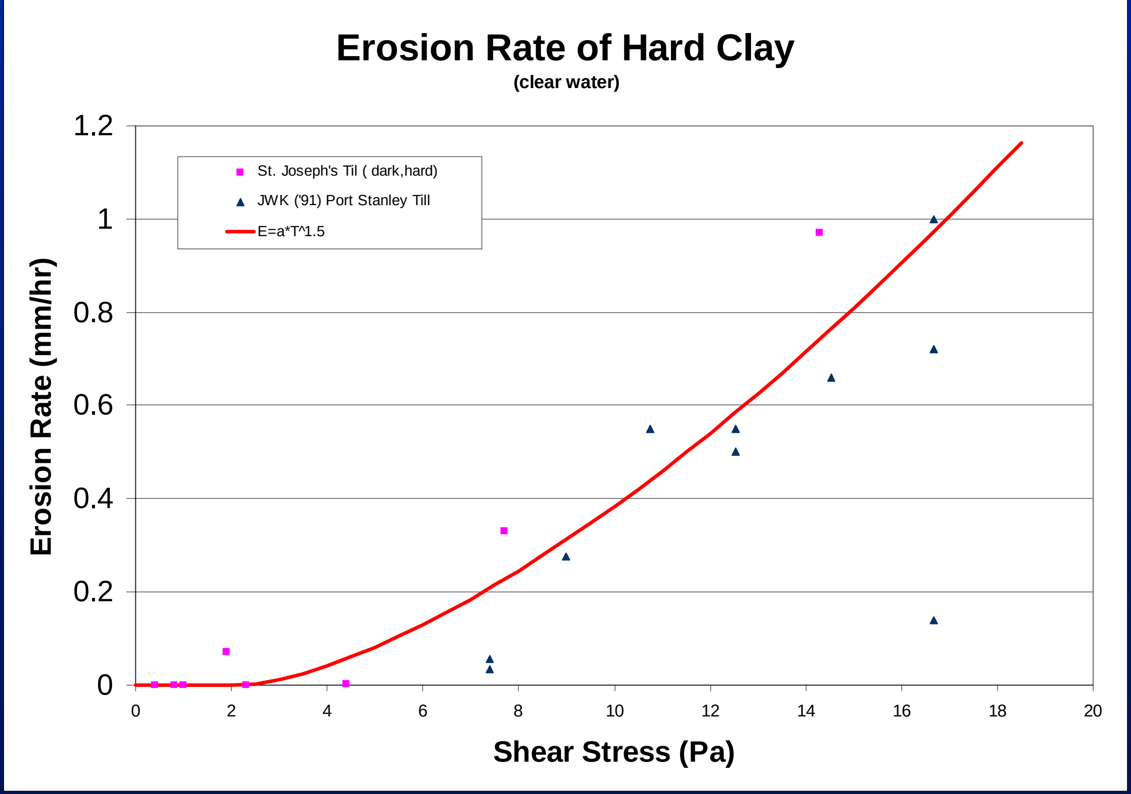
- Generally, the river bed is in an erosional state
- About 1 metre of downcutting on average for this section of the river bed in 75 years

River Scour Assessment

- Water level data collection and analysis
- Bed sediment erodibility
- 100 year scour depth assessment
  - *River scour under natural river flows*
  - *Storm surge impact*
  - *Ship traffic, ice jam, and global warming impacts*

Bed Sediment Erodibility for Hard Clay

- $$E = aT^{1.5}$$
- E – erosion rate in mm/hr
- a – constant (=0.06)
- $T = (\tau_b - \tau_{cr}) / \tau_{cr}$
- τ_b – bed shear stress
- τ_{cr} – critical shear stress for erosion (=2.25 pa)



100 Years of Erosion Under Natural Flow

- Estimated flow velocity is in range of 0.6 to 0.8 m/s
- Consistent with the flow velocity measured in the river
- In total 0.4 m erosion is predicted for pure natural river flow (monthly data) over 100 years according to the erodibility equation

Storm Surge Impact

- Strong winds are most likely during fall and early spring
- The setup and setdown of lake levels increases flow velocity in the river
- Flow velocity depends on surge strength and duration
- Use daily data to estimate surge impact from 1970 to 2003

Storm Surge Impact

- Estimated flow velocity: –0.2 to 1.0 m/s
- In total about 1.4 m erosion is predicted for storm surge plus natural flow (daily data) over 100 years (using 30 years data)

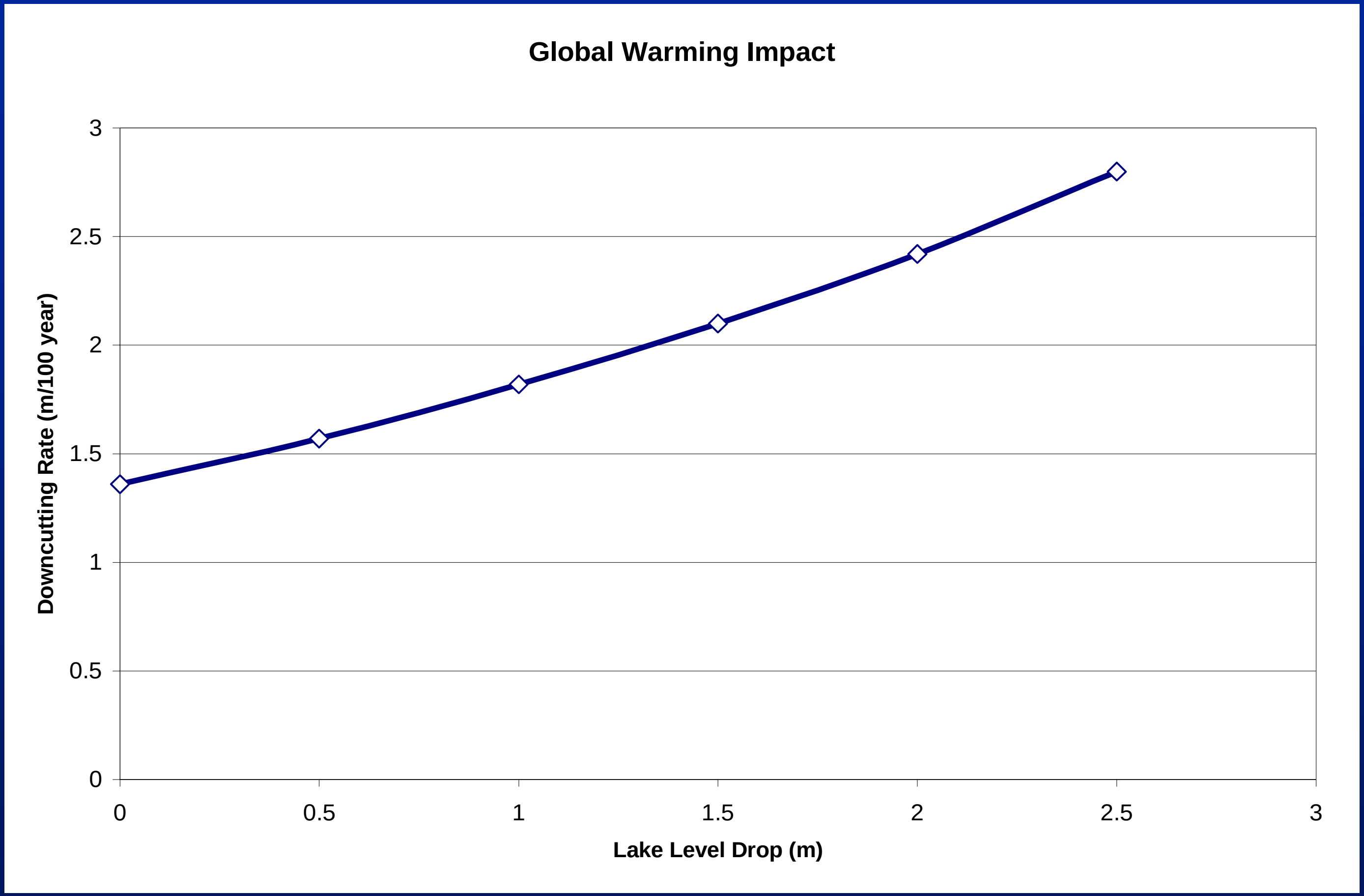
Ship Traffic Impact

- Ship propeller erosion
  - *Function of ship size/draft, propeller type, and traffic*
  - *Largest vessel with full power can generate about 4 m/s flow velocity near bed (depth 13 m) at the project site*
  - *However, vessel speed is limited to 10.2 knots (5 m/s)*
- Ship traffic data required
- Additional local erosion (about 0.5 m) may be caused by ship traffic at some locations
- Ships have less impact in other areas

Global Warming

- The temperature in the Great Lakes region could rise 2 to 4 °C by the end of the 21st century
- Precipitation could increase by 25%
- More intense rainstorms
- Great Lakes levels are expected to fall by 1.5 to 8 feet (0.5 m to 2.4 m);

Global Warming Impact on River Scour



- The downcutting rate may be more than that predicted because of more storm surges caused by global warming

Verification

	Measured and from bathymetry comparison	Predicted
Downcutting	1.25 m (max. 2.0 m)	1.36 m
Flow velocity	0.6 – 0.75 m/s	0.6 – 0.8 m/s

Predictions for the next 100 years

- Assume the flow condition to be unchanged
  - *Natural flows – the same as past*
  - *Storm Surge – the same as past*
  - *Global warming – lake level drop of 0.5 m*
  - *Ship traffic – not considered*
- 1.32 m of additional downcutting by 2103

Preliminary Findings
– Bathymetry Comparison

- River bed changes since 1925 year
  - *Most of the river was in downcutting state*
  - *The average erosion in the reach from Fighting Island to Belle Isle Island is about 1 m*

Preliminary Findings
– Dynamic Analysis

- The analysis predicted the observed erosion in the past 100 years
- Bed changes estimated over past 100 years
  - *About 0.4 m scour caused by natural flow*
  - *Additional 1 m scour contributed by storm surges*

Preliminary Findings
– Dynamic Analysis

- Surges are the main driving force for scour
- Ship traffic contributes to river scour, particularly at the project site
- More erosion will be expected due to global warming
- Ice jams likely do not have a significant influence on river scour