Lake Erie Sediment Budget

Traveling from Toledo to Buffalo

Sit by the Lake, and watch the sediment go by*

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* With apologies to John Fogerty

Outline

1. Background and purpose
2. Phase I. Overview of sediments and transport processes
3. Phase II. Sediment budget
   A. Bluff erosion study
   B. Harbor change study

Problem Statement

- Great Lakes navigation projects in past were managed as isolated entities
- Need data and fundamental background science on what is happening in the entire system
- Need tools to inform decisions on sediment management affecting whole system, not just individual projects
- Potential changes from climate change (less ice? greater frequency/intensity of storms?)
- Limited capacity in existing CDFs and high cost and environmental limitations for new CDFs

LRD and Buffalo District Committed to Regional Sediment Management Principles

- Recognize sediment as a valuable resource
- Manage sediment-related issues in an integrated fashion from upland sources to estuaries and the coast
- Project decisions involving sediment must consider the regional implications and effects over long time scales (decades).
- Take every opportunity to implement RSM principles in all projects

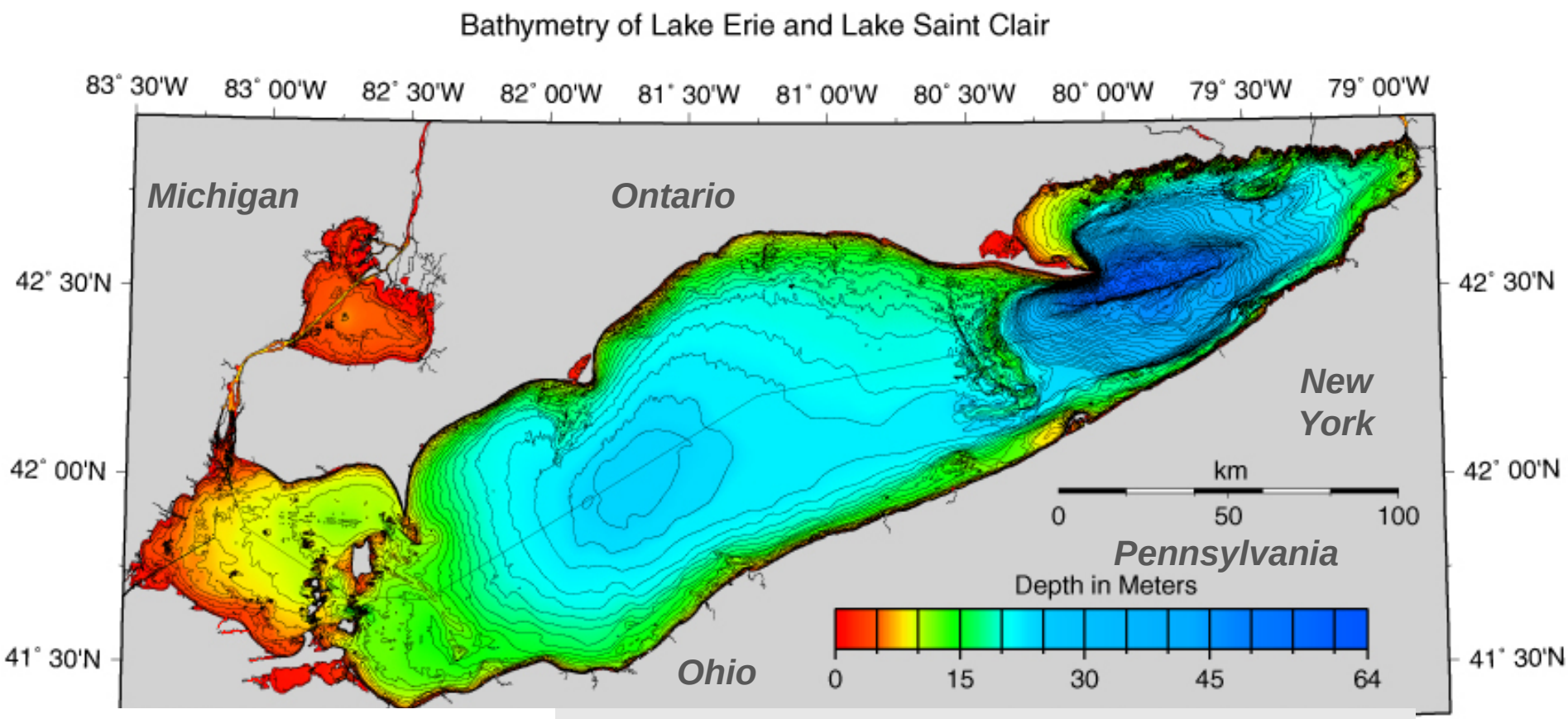
Phase I

- Overview analysis:
  - ►Lake Erie geology
  - ►Physical processes (waves, water levels, ice)
  - ►Sediment sources and sinks
  - ►Jetties, harbors, man-made obstructions
  - ►Transport directions

- Cooperative effort between ERDC, Buffalo District, PA DNR, and Ohio Geological Survey
- Compiled information from widely scattered technical literature, USACE unpub. data, USGS, expertise from Ohio Geol. Survey

Lake Erie

Facts and Figures



Length: 241 miles/388 km
Breadth: 57 miles/92 km
Shoreline: 871 miles/1402 km

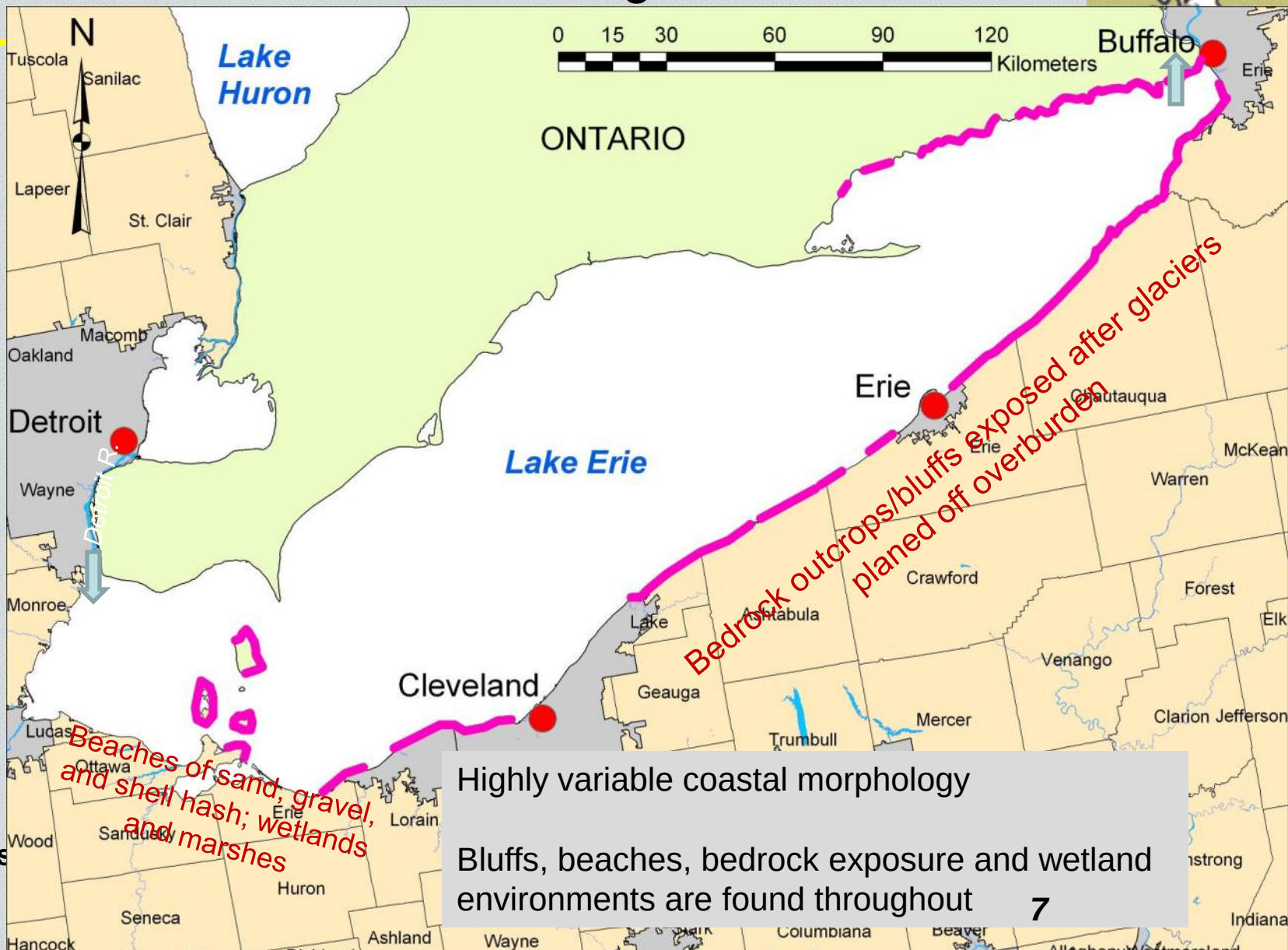
- Shallowest and lowest volume of the Great Lakes
- Shoreline is heavily industrialized and armored
- Large lake seiche setups due to long axis oriented roughly parallel to primary wind direction and shallowness of the lake

Lake Erie

Facts and Figures

Surface: 25,670 km^2, 4th largest Lake

95 % total inflow from upper lakes via Detroit R.



Highly variable coastal morphology

Bluffs, beaches, bedrock exposure and wetland environments are found throughout

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Lake Erie Waves and Water Levels

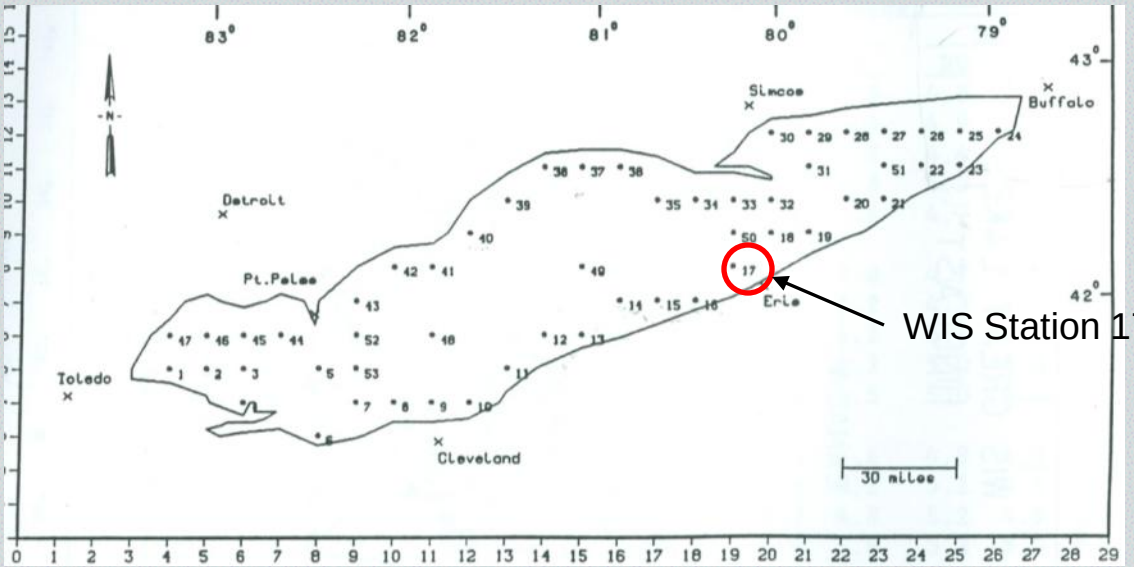
- No long period waves or tides
- Most wave energy comes from gravity waves (T=1-10 sec)
- Net result:
  - Little to no depositional wave energy
  - Net onshore/offshore transport of sediment is almost always lakeward

STATION E17 42.15N 80.35W FOR ALL DIRECTIONS
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD FOR ALL DIRECTIONS

HEIGHT(METRES)	PEAK PERIOD(SECONDS) <3.0	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-LONGER	TOTAL
0.00-0.24	.	242	11	3		.	.	.	.	.	256
0.25-0.49	.	1102	73	32	1	.	.	.	.	.	1208
0.50-0.74	.	1731	497	221	25	.	.	.	.	.	2474
0.75-0.99	.	566	496	274	56	.	.	.	.	.	1392
1.00-1.24	.	77	880	418	170	8	.	.	.	.	1553
1.25-1.49	.	.	210	358	127	14	.	.	.	.	709
1.50-1.74	.	.	36	516	239	42	1	.	.	.	834
1.75-1.99	.	.	.	143	242	44	2	.	.	.	431
2.00-2.24	.	.	.	47	350	68	6	.	.	.	471
2.25-2.49	.	.	.	.	122	86	7	.	.	.	215
2.50-2.74	.	.	.	.	36	145	14	.	.	.	195
2.75-2.99	.	.	.	.	6	63	14	.	.	.	83
3.00-3.24	.	.	.	.	2	37	37	.	.	.	76
3.25-3.49	.	.	.	.	.	5	22	.	.	.	27
3.50+	.	.	.	.	.	2	39	6	.	.	47
TOTAL	0	3718	2203	2012	1376	514	142	6	0	0	

MEAN HS(M)= 1.1 LARGEST HS(M)= 5.6 MEAN TP(SEC)= 4.3 TOTAL CASES= 93504.

Max T: 9.9 sec
Mean T: 4.3 sec



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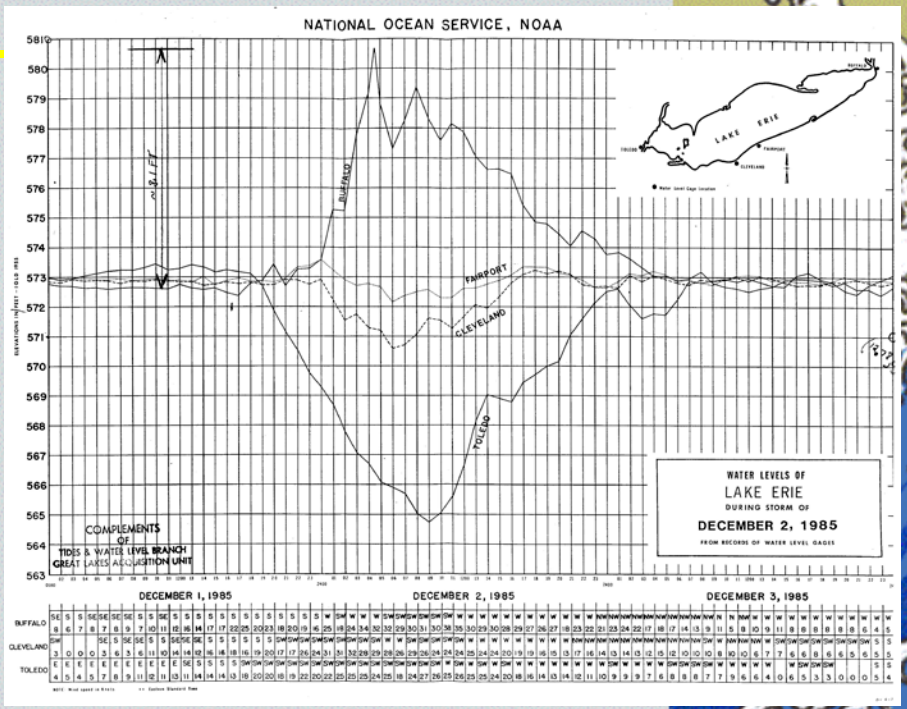
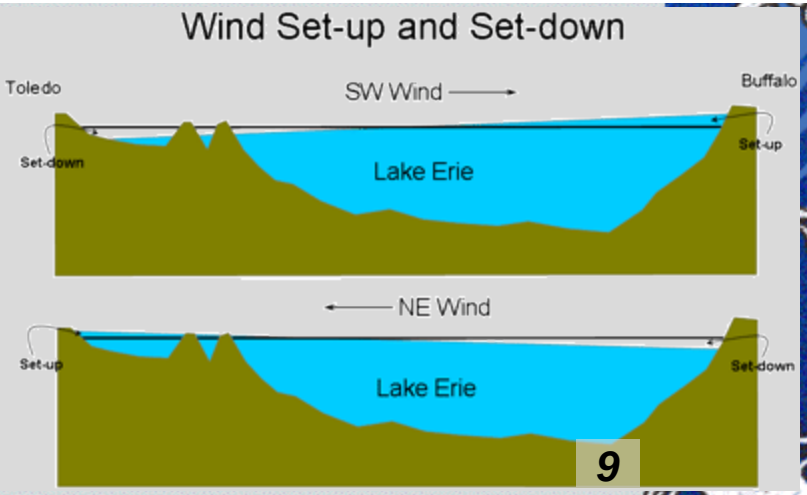
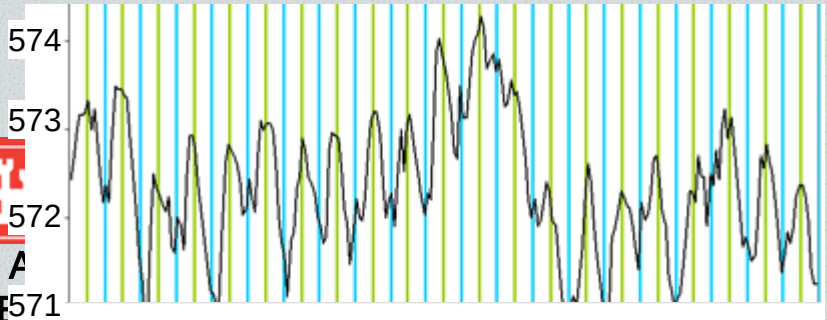
Lake Erie Waves and Water Levels

- Longer period Lake Seiche during extended wind set up
- Ice
  - Lake surface freezes entirely most winters
  - Shore ice protects the beach face
  - Some scour effects at breakup
- Water Levels
  - No man made control structure
  - Water levels dependent entirely on environmental/geological factors
    - Precipitation/evaporation over the entire Great Lakes Basin
    - Isostatic rebound







Lake Erie hydrograph for 1975 – 1995. Water levels vary by year, but the highest levels almost always occur in summer (green lines) and the lowest levels occur in winter (blue lines.)

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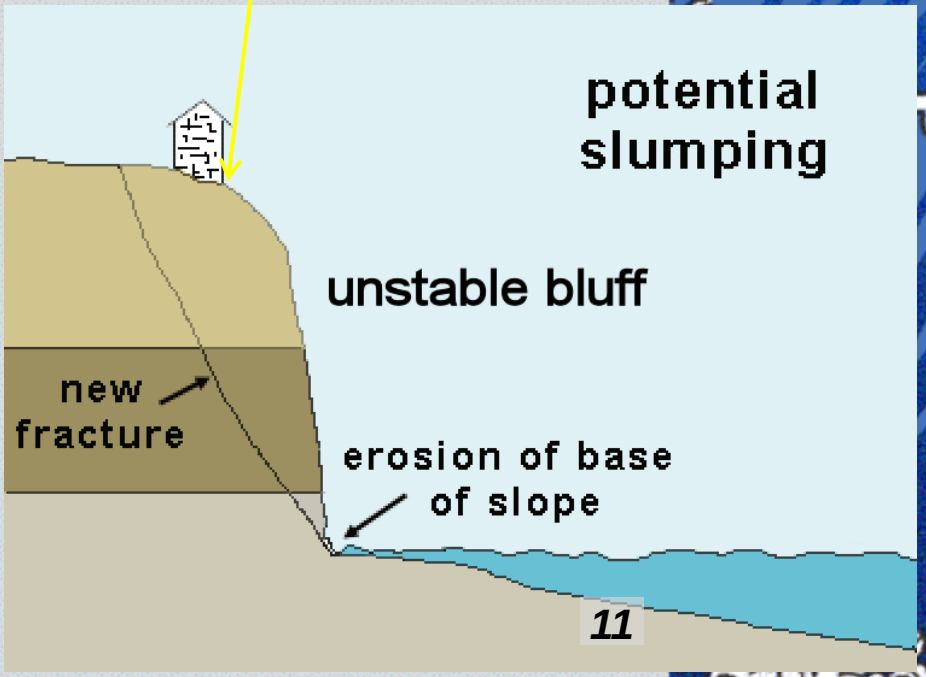
Sediment Sources and Losses

- **Sediment sources:**
  - Material brought down rivers (mostly fine-grained)
  - Industrial dumping and runoff from sewers
  - **Gravel, sand, clay eroded from glacial till bluffs and banks**
  - **Sediment created in situ from bedrock bluff weathering**
  - Limited supply from lake bed lowering and offshore outcrops
- **Sediment losses:**
  - **Wave- and ice-induced transport into deep water**
  - **Material trapped in fillets at harbor jetties**
  - Material dredging from harbor entrance channel and placed in confined disposal facilities or placed in deep water
  - Bluff armoring
  - Beach mining (no longer a factor)

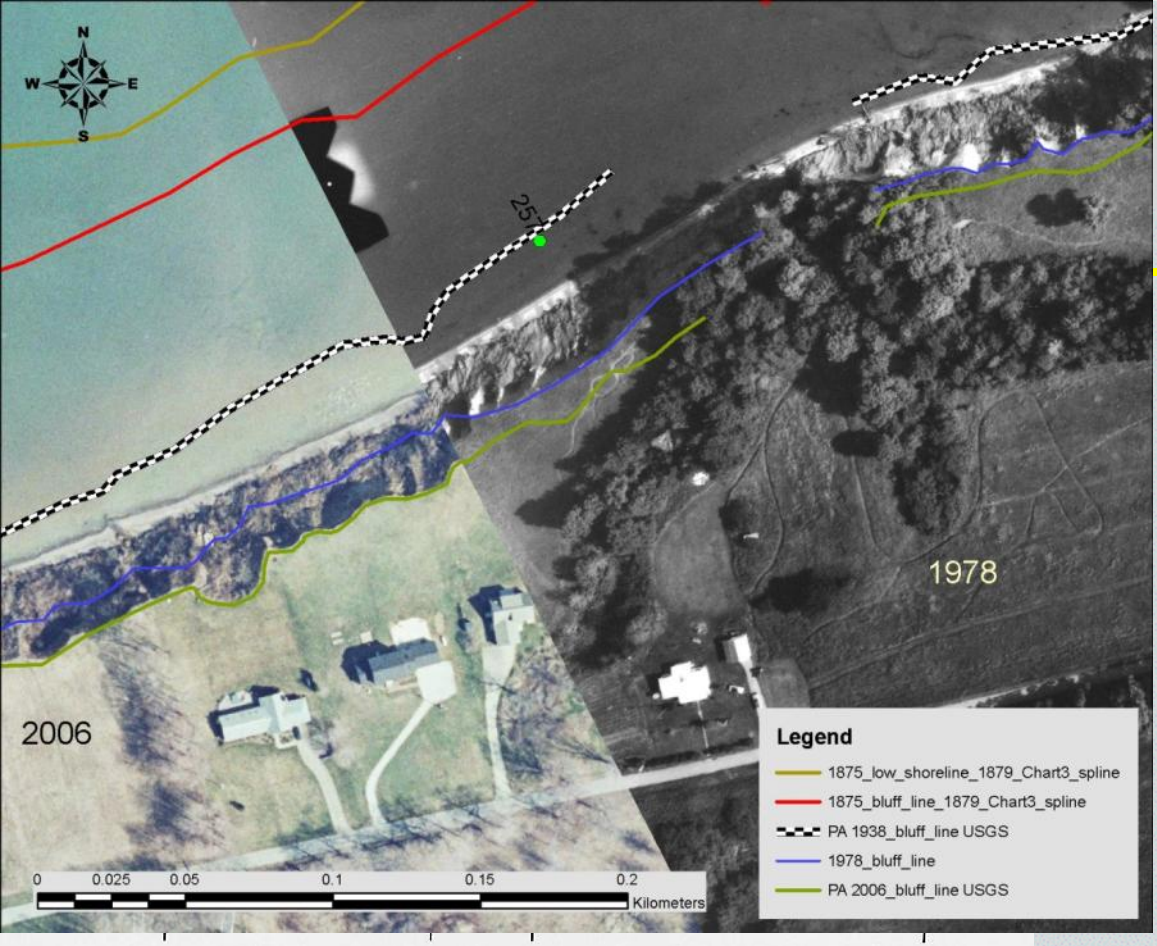
Bluff Recession Eastern Lake Erie

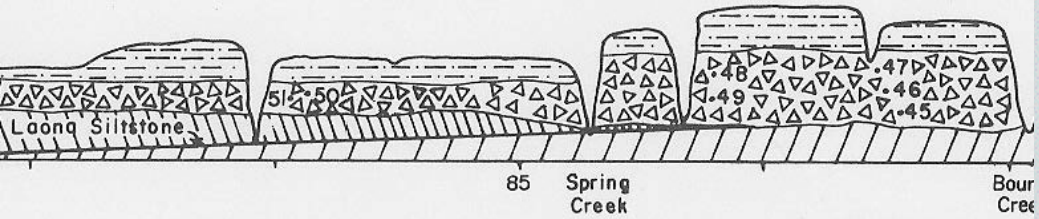
Showse Park, east of Vermilion, OH, August 1999. Low-grade, friable shale weathers from wave impact, groundwater percolation, and freeze-thaw cycles.

Bluff edge



Bluff Recession Eastern Lake Erie





Approach

- Bluff line change measured over time
  - NOAA 1870's Coast Charts
  - Aerial imagery – 1930s, 1970s
- Stratigraphy acquired to determine bluff height and composition
- Coarse fraction estimated from parent material

Bluff Recession Eastern Lake Erie

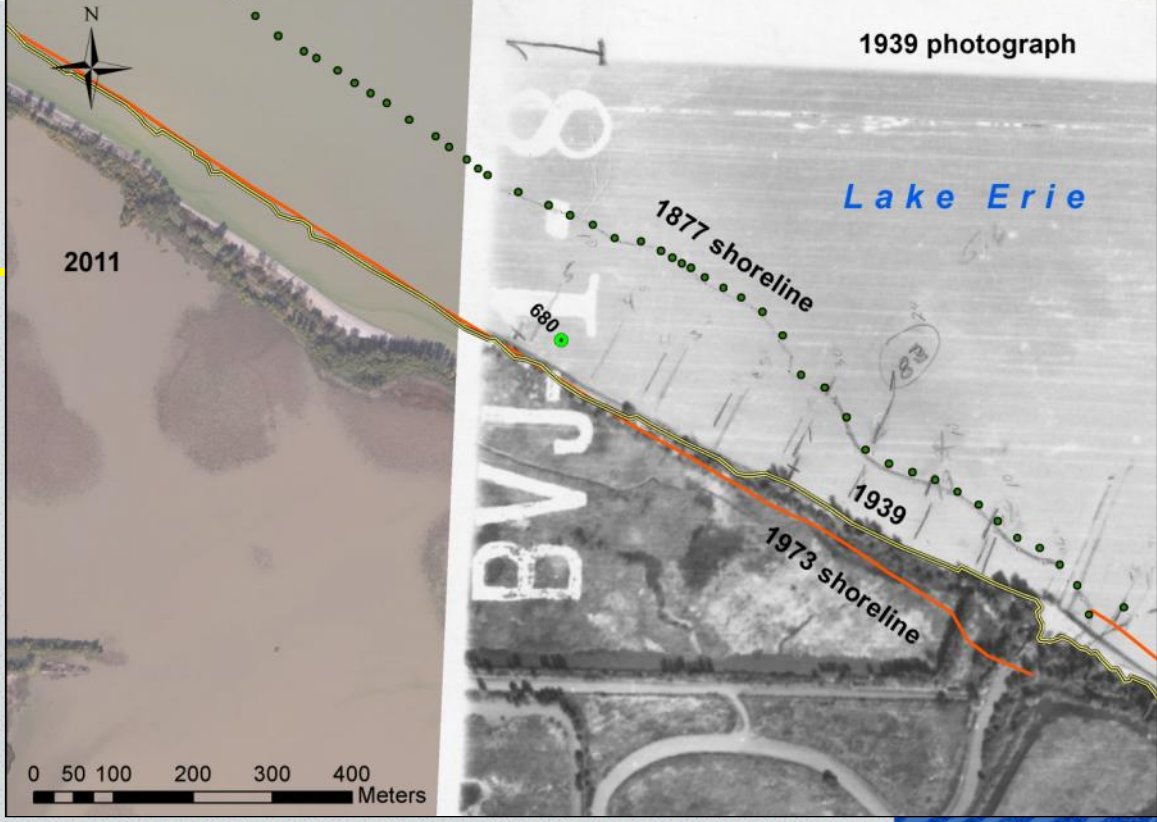
Approach

- The Digital Shoreline Analysis System (DSAS) run to compute transects spaced 50m and determine retreat rates
- Shoreline divided into a series of 1-km reaches (Stewart 1999)
- Bluff erosion rates overlain with 1-km reaches to determine an average retreat rate for the reach

Bluff Recession Western Lake Erie

Approach

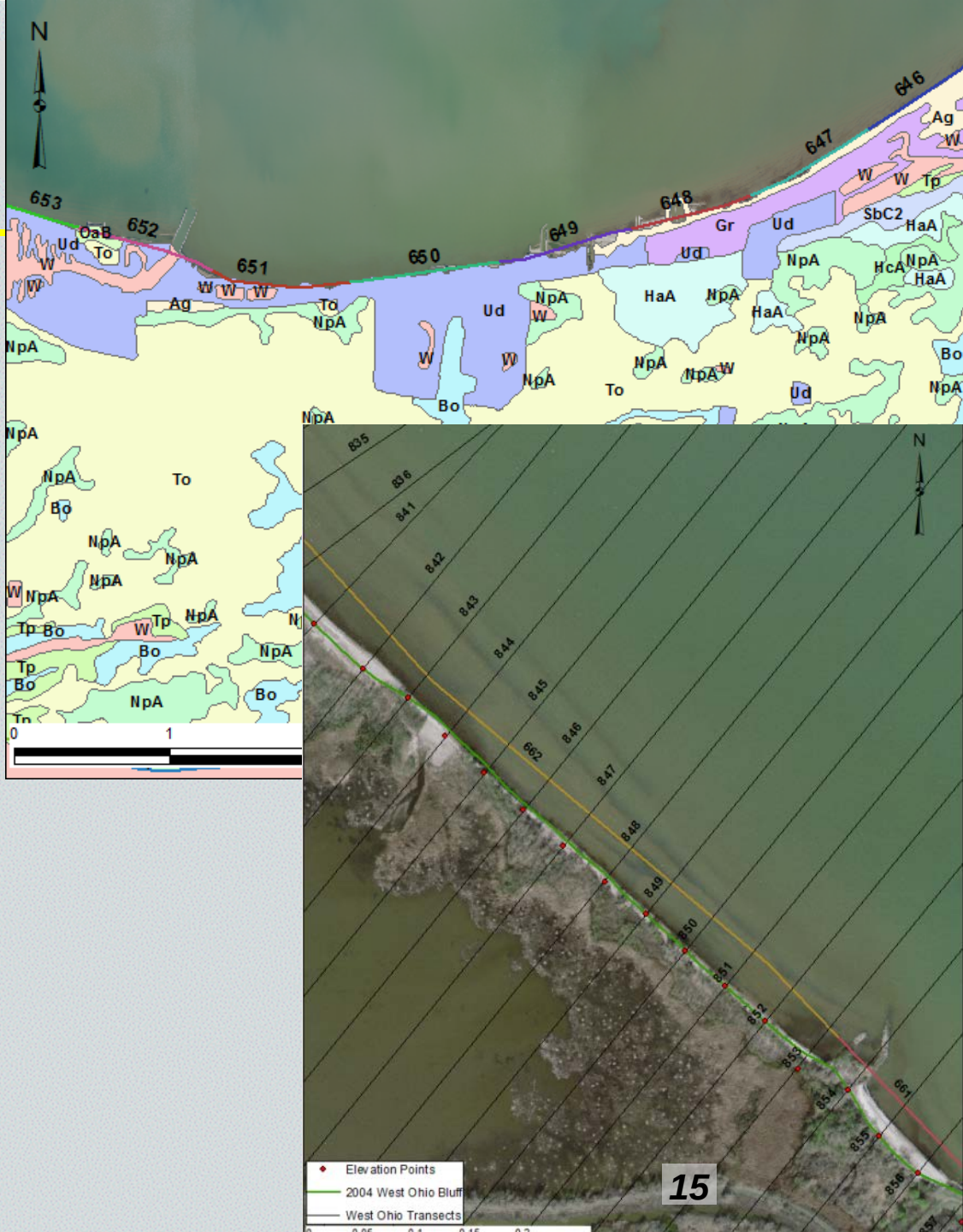
- Presents a challenge due to little to no bedrock exposure
- Sediments consist primarily of highly erodible lacustrine deposits
- A representative "shoreline" used defined by:
  - Sand/mud – vegetation line
  - Tree or vegetation line
  - Prominent scarp
  - Man made feature



Bluff Recession Western Lake Erie

Approach

- Determining stratigraphy of eroded material also presented a challenge
- JALBTCX LiDAR data used to determine representative “bluff” height
- USDA Soil Classifications used to determine coarse fraction
  - A dominant soil unit determined for each 1-km reach
  - Classified as either:
    - Glaciolacustrine (10% coarse)
    - Till/Beach Sand (95% coarse)



Determination of Bluff Volume

Approach

- For each 1-km reach we used:
  - Bluff Height
  - Bluff Composition
  - Recession Rate

Coarse fraction factor:

Shale:	0.3 – 0.5
Till:	0.2 - 0.27
Lacustrine:	0.1
Sand and gravel:	0.95

$$Sed_vol = Strata_ht \times Factor \times \mathrm{Re}cession_rate \times Effective_reach_length$$

- Coarse and fine fractions determined from stratigraphy
  - Fines are lost offshore to deep water
  - 20% of coarse component lost offshore to deep water due to storm waves (Based on USACE Buffalo District 1984)

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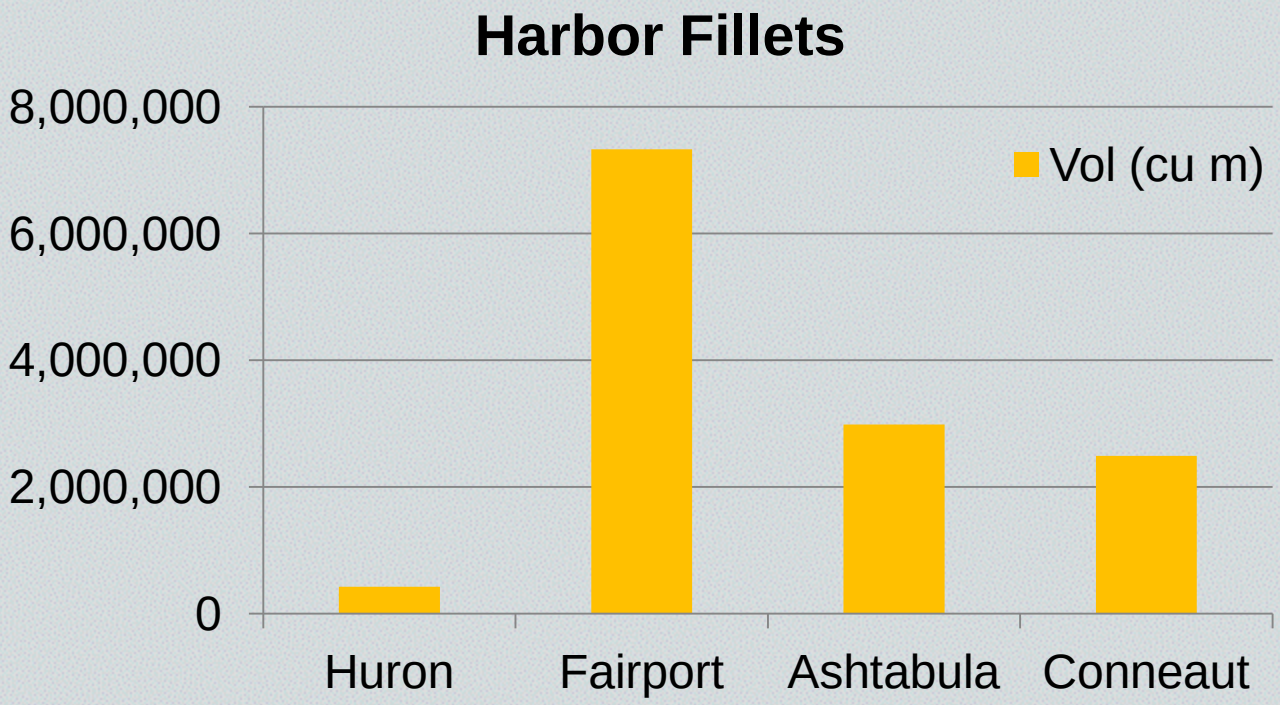
Sediment Sink:
Trapping at Harbor Mouths

Sediment Sink: Trapping at Harbor Mouths

- Greatest loss of sed. from littoral system over 150 years
- 27 harbors, power plants with structures



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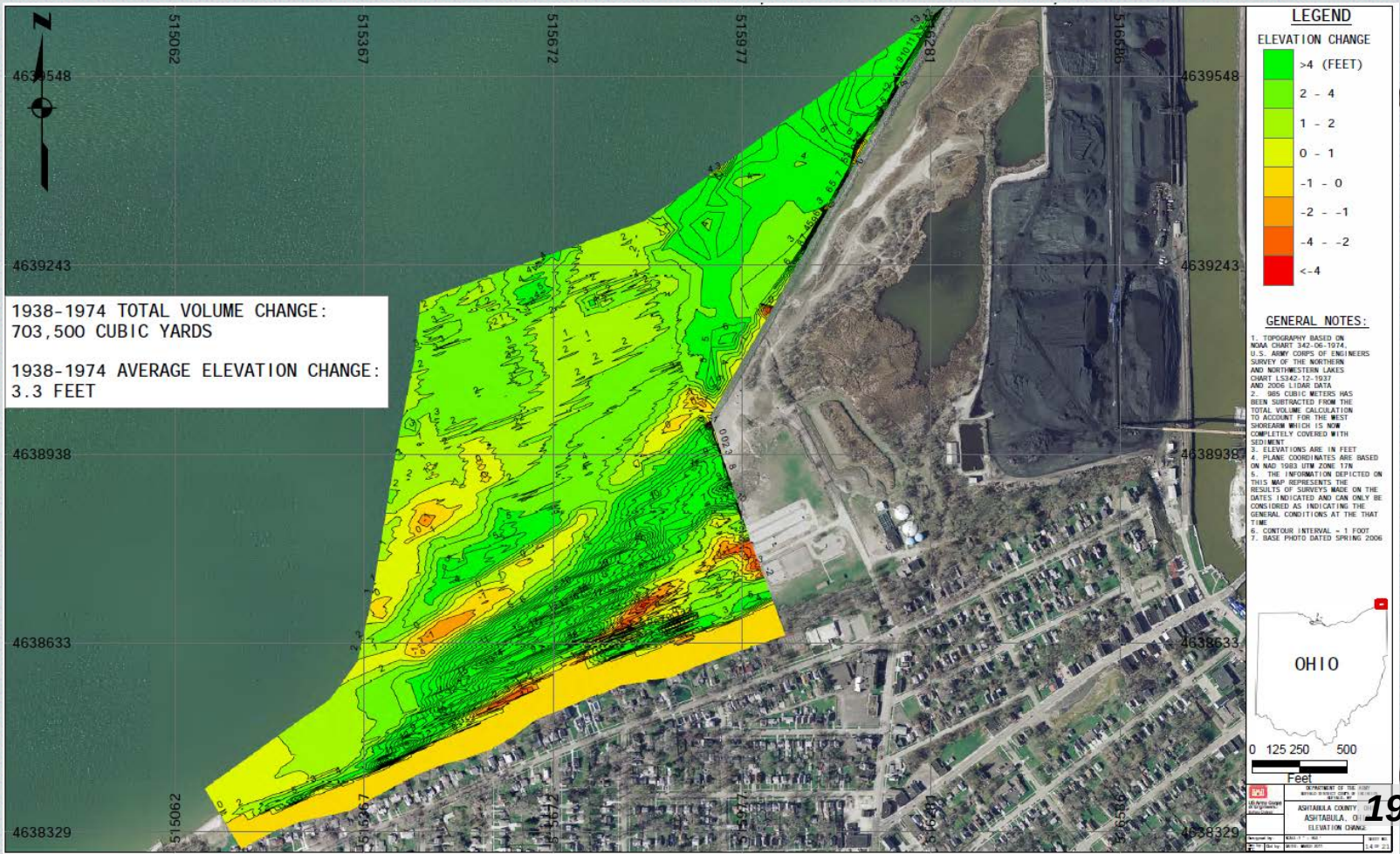
Sediment Sink:
Trapping at Harbor Mouths

Approach

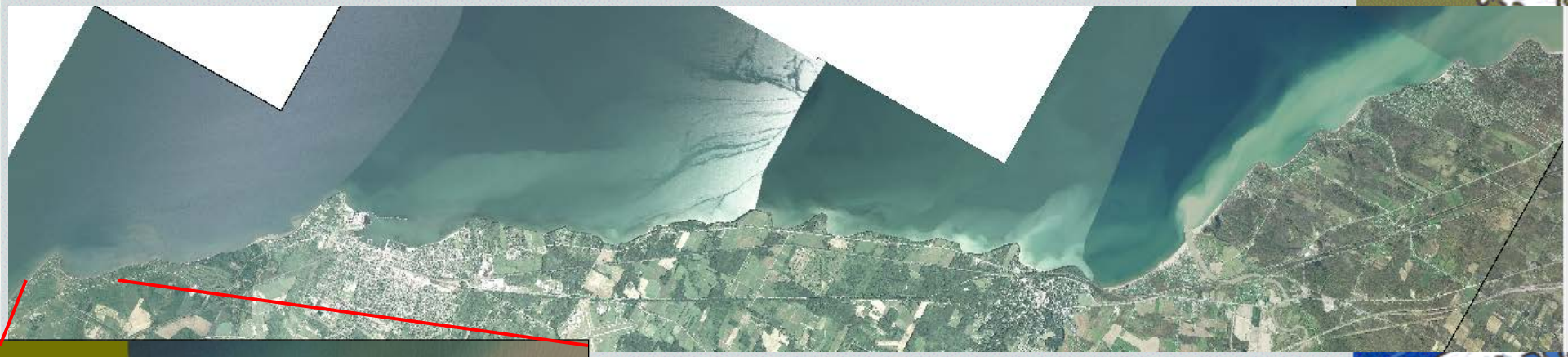
- Major sediment sink: Fillets at Harbor Structures and losses to deep water
  - Fillet volumes computed from historic charts and modern LiDAR data collection



Sediment Sink:
Headlands – NY and PA

Approach

- A series of headlands along the NY and PA coast redirect sediment flux
  - Some sediment lost to offshore



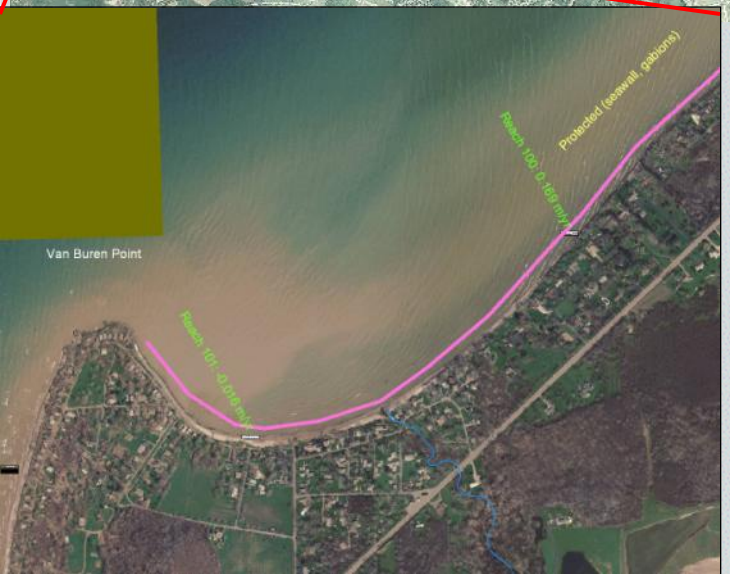
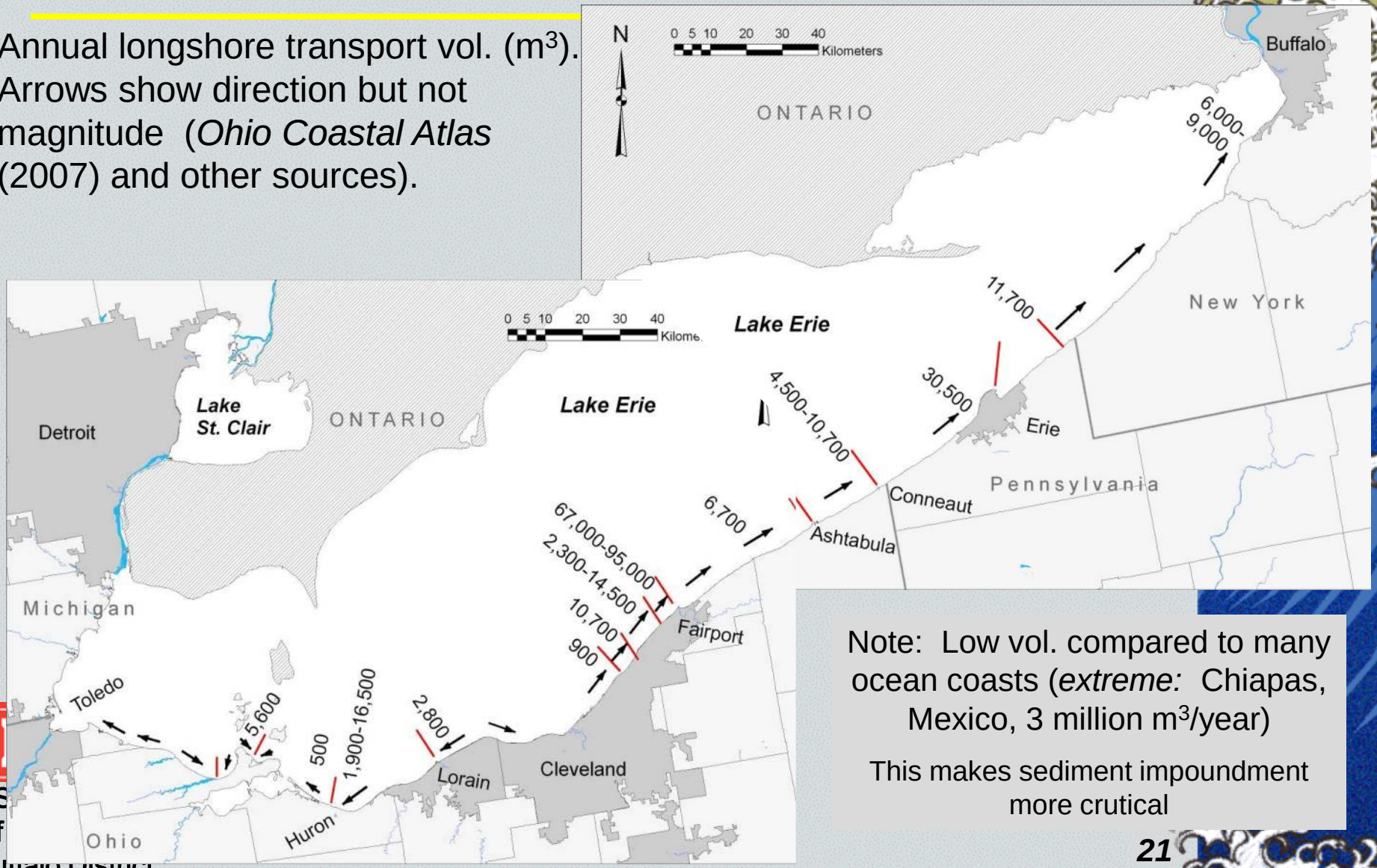


Table 7 - Littoral Cell Losses at Points	
Sturgeon Point	25%
Silver Creek	10%
Fletcher Point	10%
Point Gratiot (Dunkirk)	50%
Van Buren Point	50%
Barcelona	50%
Twenty-mile Creek	25%
Crittendon Point	50%

Longshore Sediment Transport

Annual longshore transport vol. (m^3). Arrows show direction but not magnitude (*Ohio Coastal Atlas* (2007) and other sources).



Note: Low vol. compared to many ocean coasts (*extreme:* Chiapas, Mexico, 3 million m^3/year)

This makes sediment impoundment more crutical

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Phase II: Sediment Budget

- Define littoral cells based on geologic or morphologic characteristics
- Evaluate bluff recession (ERDC)
- Calculate volumes at harborfillets (LRB)
- Sediment Budget Analysis System (SBAS) extension within ArcMap™ GIS software

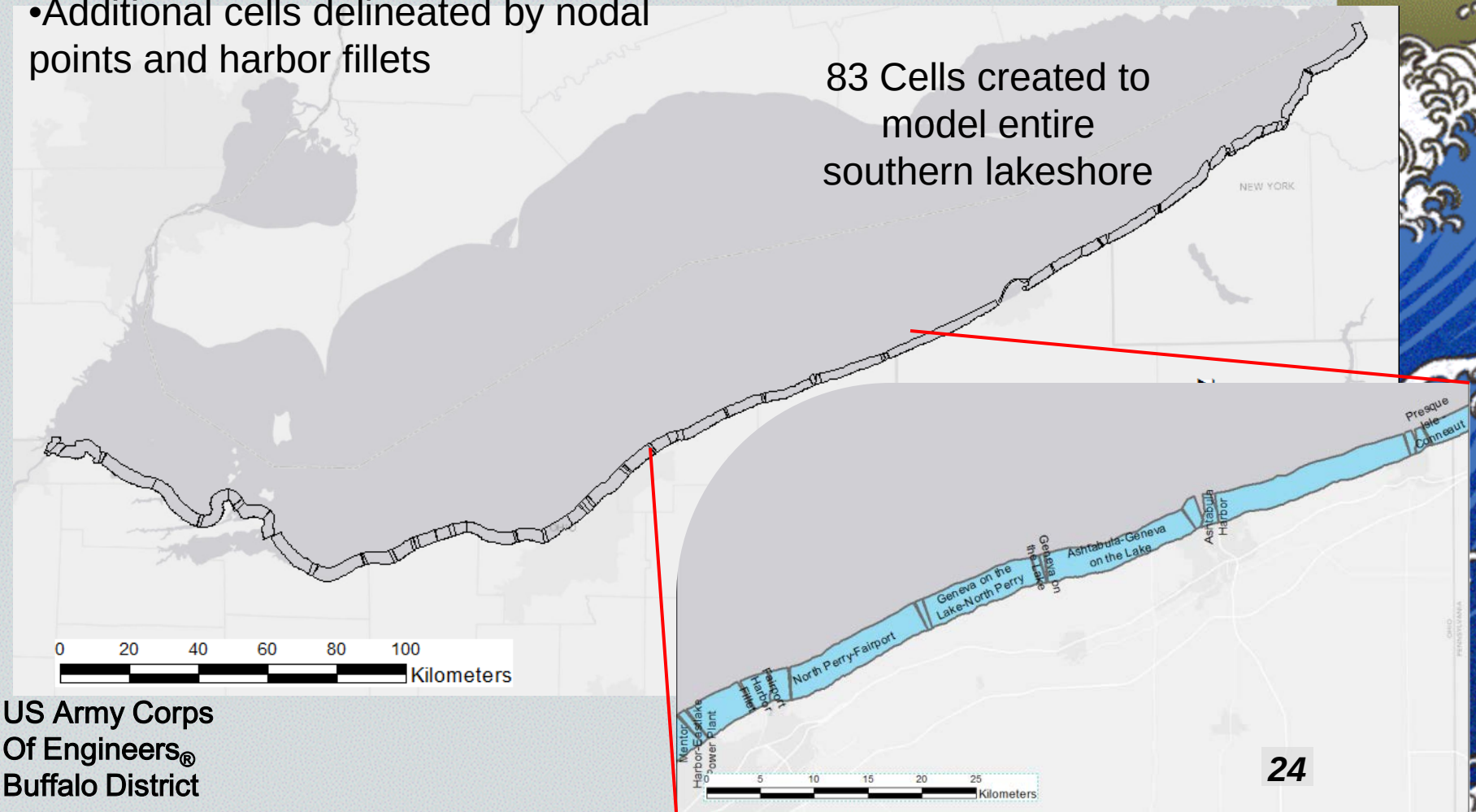
Sediment Budget Timeframes

- Sediment Budgets established for four timeframes:
  - Undeveloped (1860s-1930s)
  - Mid Century (1930s-1970s)
  - Recent (1970s-2000s)
  - Future (2000s -)
    - Future sediment budget based on shore hardening in place in 2006
    - Recent time frame sediment inputs reduced where the shoreline is hardened
- All data entered into SBAS for ArcMap 10

Sediment Budget Cells

- For most of the shoreline, Cells bounded by harbor structures
- Additional cells delineated by nodal points and harbor fillets

83 Cells created to model entire southern lakeshore



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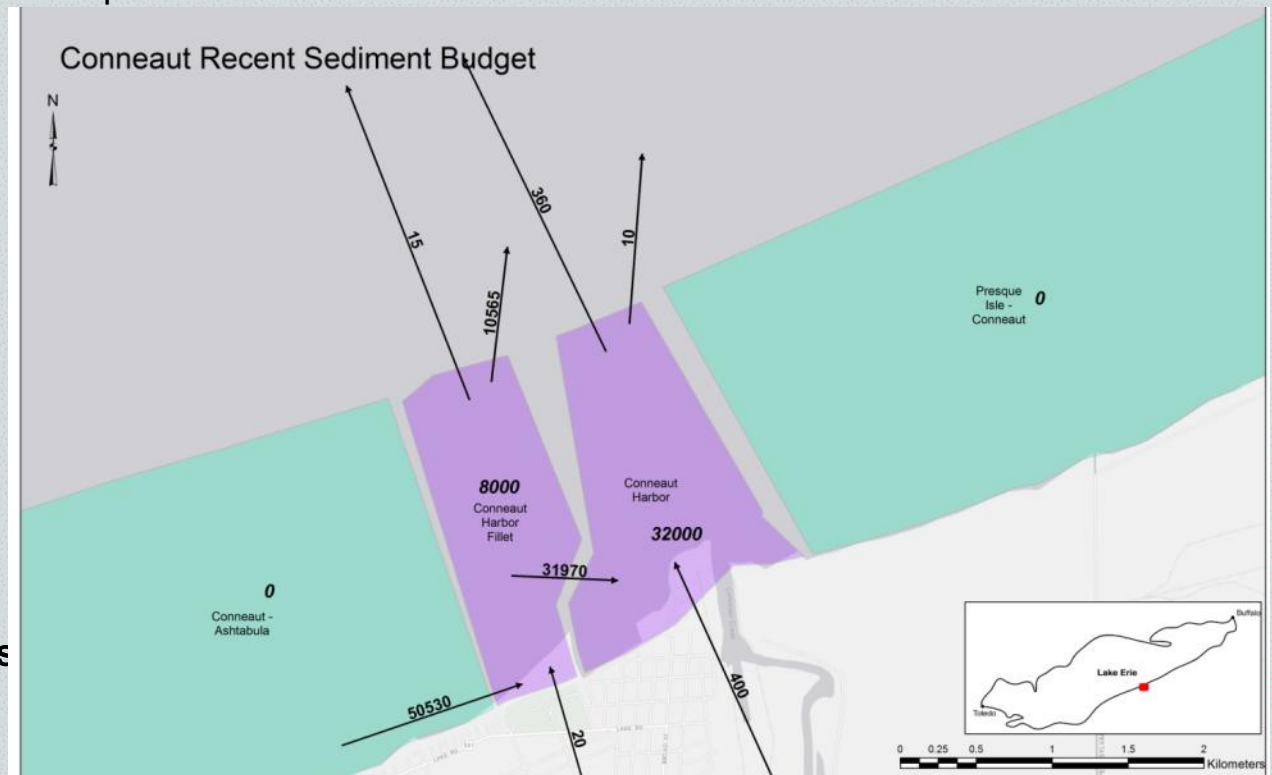
Sediment Budget Fluxes

Fluxes are vector based representations of sediment movement within SBAS

- Generally – 4 fluxes per cell:
  - Bluff input
  - Loss of fines to deep water
  - Coarse loss to deep water
  - Transport downdrift
- Also modeled where necessary:
  - Coarse loss at end of cell (well developed fillets, headlands)
  - Bedload input (Cattaraugus Creek)



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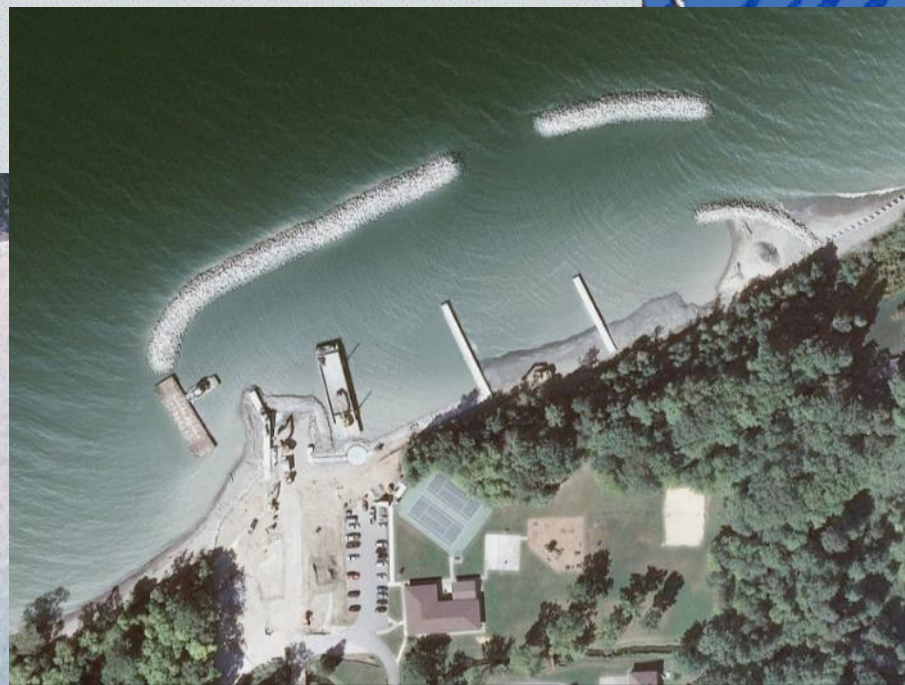
Harbor/Bluff Erosion Comparison

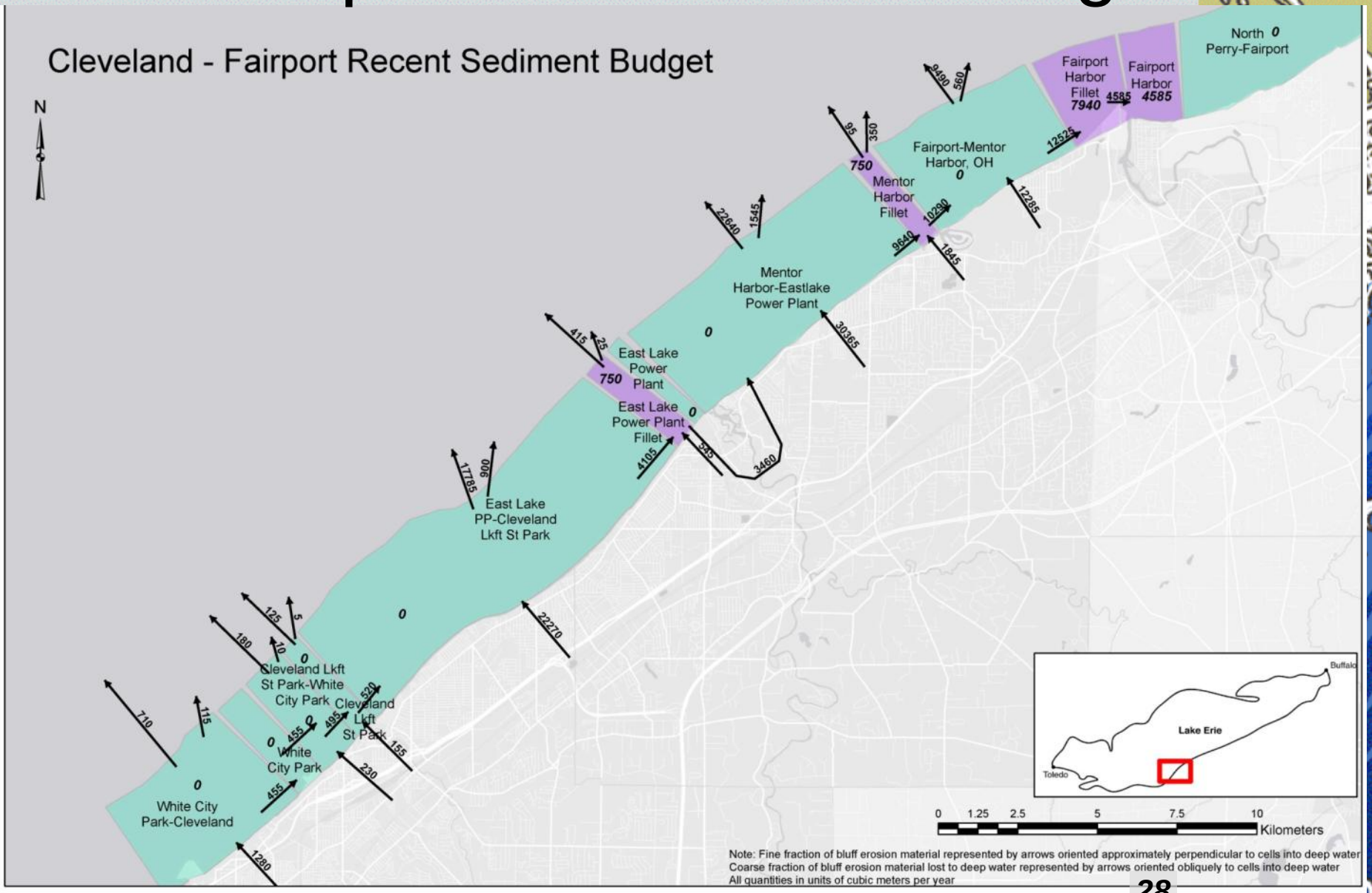
- Where harbor computations were completed, accretion was compared to bluff erosion volumes
  - 9 Harbors completed as of May 2013
  - Additional 5 planned
- Presque Isle Phase II GDM (1984) presented an additional point of comparison
- Harbor bypassing quantities compared
  - 7 marinas/harbors
- In general – results match up

Harbor/Bluff Erosion Comparison

- Townline Park Marina, North Perry, OH
  - Constructed 2009, immediate sedimentation/bypassing issues
  - Bypassing an average of 21,500 cu. m per year 2010-2012, including 24,000 in 2011 and 31,300 in 2012
  - Predicted littoral volume moving through the system:
    - Recent: 34,800 cu. m per year
    - Future: 26,600 cu. m per year



Completed Sediment Budget



Conclusions/Future Data Needs

- For much of Lake Erie, the bluff erosion and harbor accretion values match well
- Some areas under-predict, others over-predict
  - Additional study into the process under which shale degrades
  - Additional study into detailed composition of till bluffs along the coast
  - Additional study into bedload contribution from other streams besides Cattaraugus Creek
  - Analysis of historical (1800s) vs. recent riverine sediment load
- Future Products
  - ERDC Technical Reports
  - Journal Papers
  - SBAS outputs to central server

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Questions?