The History of Coastal Flood Hazard Assessments in the Great Lakes
The Great Lakes
Some Statistics

- Courtesy of Great Lakes Information Network
- One-fifth of the world’s fresh surface water
- Spread out over the contiguous U.S., would submerge the country under 9.5 feet of water
- More the 94,000 square miles (larger than New York, New Jersey, Connecticut, Rhode Island, Massachusetts, Vermont, and New Hampshire combined)
- 10,900 miles of coastline (U.S. and Canada combined)
- 3,288 miles in Michigan (only Alaska has more)
Just because an inland body of water doesn’t make it immune to risk

- Fast moving squall lines can create localized risks
- Passage of low pressure centers act similar to hurricanes
  - Central pressures recorded similar to those of a tropical or extratropical storm
- Storms can create:
  - Surge
  - Waves
Generalized Coastal Zone Schematic
Wave Runup

Overtopping

Overtopping

Overland Wave Propagation

http://greatlakesresilience.org/stories/wisconsin/nor%e2%80%99easter-coastal-storm-flooding-green-bay
Early attempts to identify flood risks
Waves and Erosion

- **Waves**
  - Leverage USACE Wave Information Study (WIS) 1956-1987
  - Local wave height with recurrence interval of 3 years approximately describes wave action likely to accompany the base flood
  - ½ year was used on Lake Ontario due to a different fit for the wave data on the lake

- **Erosion**
  - Based on FEMA (1989)
  - Erosion (in square feet) = 85.6 * Recurrence Interval (in years)
    - 270 square feet for 3-year recurrence
    - 190 square feet for 2-year recurrence
2009 Update

1. Return period lake level recommended on a USACE (1988) report, but additional 20-years of observations

2. Wave runup is dominant risk and a response based approach is desirable

3. Previous wave guidance included long-term lake processes
# Updated Water Levels

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Combination of Water Levels and Waves

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Great Lakes Coastal Flood Study

- Kicked off in 2009
- Basin-wide assessment of flood risks
- Updated Guidance
## Crosswalk

### Great Lakes Coastal Analysis and Mapping Guidance Updates Comparison

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<th>TOPIC</th>
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<th>SUMMARY OF 2012 UPDATE (MAY 2012)</th>
<th>SUMMARY OF EFFECTIVE GUIDANCE (FEBRUARY 2002)</th>
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</table>
| Water Levels           | D.3.4.4                                     | • Recommends storm surge modeling  
                        |                                | • Considers water level variability over the period of 1960 to 2010  
                        |                                | • Measured data for model calibration  
                        |                                | • Ice cover impacts considered  
                        |                                | • USACE Revised Report on Great Lakes Open-Coast Flood Levels (1988)  
                        |                                | • Water level variability not addressed  
                        |                                | • No consideration of ice cover  
| Incident Wave Conditions | D.3.4.3                                     | • Recommends lake-wide wave modeling  
                        |                                | • Measured data for model calibration  
                        |                                | • Shoreline buffering protection provided by ice cover considered  
                        |                                | • Hindcast data (WIS) recommended source  
                        |                                | • 1½-year (Lake Ontario) and 3-year (Lakes Erie, Huron, Michigan, Superior) identified as appropriate wave conditions for flood insurance study  
                        |                                | • Wave period identified as critical characteristic  
                        |                                | • No consideration of ice cover protecting shoreline from waves  
| Nearshore Wave Transformation | D.3.4.3.1                                 | • 2-D wave modeling recommended for shoaling areas of complex bathymetry  
                        |                                | • 1-D wave modeling (CHORE) for surf zone  
                        |                                | • CSHORE model recommended for assessing surf zone processes  
                        |                                | • Beach morphology change due to lake level cycles  
                        |                                | • Simplified assessments for sheltered waters based on fetch analysis (Automated Coastal Engineering System) recommended  
                        |                                | • Qualitative assessments based on historic response data as available  
                        |                                | • Recommendations for sandy dune and bluffs presented  
| Erosion                | D.3.7                                       | • Sorting specific approach provided  
                        |                                | • CSHORE model recommended for assessing surf zone processes  
                        |                                | • Beach morphology change due to lake level cycles  
                        |                                | • Evaluation based on Criteria for Evaluating Flood Protection Structures for NFIP Purposes (FEMA, 1990)  
                        |                                | • Treatment of failed and removed coastal armoring structures  
                        |                                | • Coastal levees  
| Coastal Structures     | D.3.8                                       | • Evaluation based on Criteria for Evaluating Flood Protection Structures for NFIP Purposes (FEMA, 1990)  
                        |                                | • Treatment of failed and removed coastal armoring structures  
                        |                                | • Coastal levees  
| Wave Setup             | D.3.5.1                                     | • 1-D model (CHORE) recommended  
                        |                                | • 1-D model (CHORE) recommended  
| Wave Runup             | D.3.5.2                                     | • Mase equation for areas where 1-D model not applicable  
                        |                                | • Coastal Engineering Manual (CEM) for vertical structures and stepped wall embankments  
| Wave Overtopping       | D.3.5.3                                     | • Coastal Engineering Manual (CEM) & EuroTop  
                        |                                | • VE Zones not mapped without prior FEMA approval  
| Flood Hazard Mapping   | D.3.9                                       | • Provides references for overtopping analysis  
|                        |                                             | • Definition of SFHA and mapping guidelines  

Draft updated Appendix D.3 is available at [http://www.fema.gov/plan/prevent/fhm/dl_crn.stm](http://www.fema.gov/plan/prevent/fhm/dl_crn.stm). Please submit your comments via email to FEMA-GSA@fema.dhs.gov.
December 1990 Storm
Overall Process

- Offshore Waves
- Still Water Level Levels
- Wave Transformation If Necessary
- Wave Height
- Wave Crest Elevation
- Wave Setup
- Wave Runup
- Wave Overtopping
- Flood Hazard Mapping

- Shoaling Zone
  - Erosion
  - Coastal Structures

- Surf Zone

- Backshore Zone
Study Approach

- **Regional Study Approach**
  - Water level and wave analysis
  - Improvement over community-county
  - Reduces number of boundary conditions
  - Greater consistency in assumptions

- **Local/County Level Activities**
  - Mapping level tasks performed at county level
  - Nearshore wave transformations
  - Wave runup
  - Overland wave propagation
Response Based Analysis

- Attempt to consider all (or most) of the complexity of the contributing processes controlling flooding and derive flood statistics from the results

- Contributing processes to be considered:
  - Water level
  - Wave conditions
  - Topography
Topography & Bathymetry
Updates to Guidance

Overview and Guidance on Selection and Application of Methods (Instructions for Toolbox)

Detailed Guidance on Analyzing Coastal Processes (Toolbox)

Guidance on Use of Results in Hazard Mapping, Documentation, and Reference Information

Guidelines Overview and Important Contributors to Coastal Flooding
D.3.1

Methodology for Storm Sampling and Coastal Flood Frequency Analysis
D.3.2

Methodology for Analyzing Coastal Processes
D.3.3

Waves and Water Levels
D.3.4

Wave Setup, Runup and Overtopping
D.3.5

Overland Wave Propagation
D.3.6

Coastal Erosion
D.3.7

Coastal Structures
D.3.8

Mapping of Hazard Zones and BFEs
D.3.9

Study Documentation
D.3.10

References, Notation, and Acronyms
D.3.11 – D.3.13
Wave Setup

- Description of Wave Setup: localized impacts of water level at the shoreline during severe storms due to transfer of momentum from waves to the water column.
Wave Setup Implications for Flood Hazard Mapping

- Can be a significant contributor to the water level through its contribution to storm surge and should be included in the determination of coastal BFEs.

1-D Surf Zone Model
- Adequately resolve and represent inner surf zone

Parametric representation
- Direct Integration Method

\[
\frac{-\eta}{H_0} = 0.160 \frac{m^{0.2}}{(H_0/L_0)^{0.2}}
\]
Wave Runup

Limit of Wave Runup
Barrier Slope
Breaker Depth

Storm Still
Water Level

Source: FEMA, 2003

Figure D.3.5-5. Wave Runup Sketch
Wave Runup Approach

- Extract water level and wave pairings from the composite storm set
- Apply a method to estimate wave runup for each of the composite storm set pairings
- Conduct a statistical extreme value analysis on the runup elevations to determine 1-percent-annual-chance
Wave Overtopping

- Overtopping Rate Considerations for Establishing Flood Insurance Rate Zones
- Ponding Considerations
Onshore Wave Analysis

Wave Runup

Overland Wave Propagation
Overland Wave Propagation

- How waves interact with landforms
  - Elevation
  - Obstructions
- WHAFIS
  - 1977 NAS report
  - Version 4.0
Transect
Hybrid Analysis

- WHAFIS is designed for event based analysis
  - 1-percent-annual-chance water level
  - 1-percent-annual-chance wave height

- Hybrid
  - Joint probability approach (Nadal-Carabello et al, 2012)
  - Water level
  - Wave height
  - Wave period
Five Scenarios

- Iso-probability curve
  - Maximum water level, associated wave height
  - Maximum wave height, associated water level
  - Intermediate values
- Computed 1-percent-annual-chance water level
- Computed 1-percent-annual-chance wave height
Coastal Erosion

- Episodic, flood-related erosion due to coastal storm events
- Does not consider long-term erosion hazard areas
- Evaluated prior to wave runup and overland wave propagation
Erosion Assessment Methods

- 1-D surf zone dynamics model

Requirements
- Cross-shore profile
- Sediment grain size
Coastal Structures

- Evaluation Criteria
  - Detailed engineering evaluation (FEMA, 1990)
  - Limited data and engineering judgment (USACE, 1989)
Vertical Structures
Sloped Structures

Diagram showing the geometry of a sloping revetment prior to failure and the failure geometry of a sloping revetment.
Updates to Guidance

Overview and Guidance on Selection and Application of Methods (Instructions for Toolbox)

Detailed Guidance on Analyzing Coastal Processes (Toolbox)

Guidance on Use of Results in Hazard Mapping, Documentation, and Reference Information

Guidelines Overview and Important Contributors to Coastal Flooding
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Methodology for Storm Sampling and Coastal Flood Frequency Analysis
D.3.2

Methodology for Analyzing Coastal Processes
D.3.3

Waves and Water Levels
D.3.4

Wave Setup, Runup and Overtopping
D.3.5

Overland Wave Propagation
D.3.6

Coastal Erosion
D.3.7

Coastal Structures
D.3.8

Mapping of Hazard Zones and BFES
D.3.9

Study Documentation
D.3.10

References, Notation, and Acronyms
D.3.11 – D.3.13
Mapping a Coastal Floodplain

- BFE including wave effects
- 100-year stillwater elevation
- Datum (e.g. NGVD, NAVD)

- Properly elevated building
- Unelevated building constructed before community entered the NFIP

- Shoreline
- Sand Beach
- Buildings
- Overland wind fetch
- Vegetated region
- Limit of 100-year flooding and waves
Mapping Example - Ortho
Mapping Example - Terrain
Mapping Example - Mapping Decisions

- **Transect 11**
  - 1% Total Water Level – 586.88 feet
  - Top of coastal feature – 587.77 feet
  - Base Flood Elevation – 587 feet

- **Transect 12**
  - 1% Total Water Level – 591.87 feet
  - Top of coastal feature – 624.47 feet
  - Base Flood Elevation – 592 feet
Mapping Example - Gutters
Brian Caufield, P.E., CFM caufieldba@cdmsmith.com

www.twitter.com/caufieldba