Going Beyond LAMP: A Probabilistic Approach for Mapping Flooding Risk near Lake Okeechobee, Florida

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Lake Okeechobee—Where is it?
Lake Okeechobee

- Largest lake in SE US
- “Big water”
- ~ 730 mi² / ~143 mi
- Avg depth 9 ft
- Greater Everglades
- Water supply
- Flood control
Lake Okeechobee

Kissimmee River

Caloosahatchee River

Everglades National Park

St. Lucie Canal

Everglades Agricultural Areas

Photo: Google Earth
History of Herbert Hoover Dike

Areas damaged by 1926 and 1928 hurricanes

Source: USACE
History of Herbert Hoover Dike

Over time, the HHD’s uses evolved to provide water supply, increased protection from flooding, and navigation.

What began as a levee built to protect from floods became a dam...
FEMA Flood Insurance Study

• Mapping issues

  ➢ Outdated maps (over 30 years old in many cases)
  ➢ Maps lack consistency across county lines
  ➢ Many areas with “undefined” flood elevations
  ➢ Inaccurate flood risk identification
FEMA Flood Insurance Study

ZONE B
FEMA Flood Insurance Study
How much protection from flooding does HHD provide here?
Levees must comply with design, operation, maintenance, and freeboard requirements

Levee accreditation: Reduced flood risk
Issues

- HHD’s geotechnical condition → Serious breach threat
  - Levee made from silts, clays, sand, limestone…and whatever was available at the edge of the lake
  - No compaction
  - No seepage control
- Failure mechanisms
  - Piping
  - Erosion from wave action
- Lack of emergency spillway capacity
Main issue: *internal erosion or piping*
Wave erosion

Source: USACE
Issue

- Lack of emergency spillway capacity
  - Spillways may lower the lake’s elevation at about 1 in/week
  - Water may come in 6 times faster than the USACE can release it
Issue

- LORS 2008 – Lake Okeechobee Regulation Schedule
  - Agreed upon by the state and federal governments
  - Goal: to maintain water level between 12.5 and 15.5 feet (NGVD)
FEMA Flood Insurance Study

Challenges

- Define and measure failure risk
- Determine mapping method
- Model for the nation?
In the past, the levee was simply “removed”
FEMA Levee Analysis and Mapping Approach (LAMP)

Goal

To provide guidance for assessing flood risk for non-accredited levee systems.
FEMA team:

Taylor Engineering
AECOM
University of North Florida

(Effort began in 2011)
Measure the risk

- 2-D dam-break modeling analysis
- Joint probability method analysis
- Flood risk mapping
You have seen this before.

The analysis resembles FEMA’s modern approach to calculating coastal flood risk.
Dam-break analysis

- Use of MIKE software
- USACE-defined reaches
- LiDAR
Lake Okeechobee’s storage volume

How does the lake’s storage volume compare with other dams?
Largest reservoir in the U.S.

Gross storage volume:

29 Million ac-ft
Lake Okeechobee’s storage volume

Upstream boundary condition

(~7\textsuperscript{th} largest reservoir by storage in the country)
MIKE21 model mesh

- “Sunny day” break
- Exceeds 400,000 nodes
- Mesh is subdivided by model reach
- Roughness based on 60-ft Manning’s n grid
- Mesh adds major hydraulic features (roads, canals)
- Starting water surface elevations
  - For FEMA study: 14, 15, 16, 17, 18, 19, 20, 21 ft NAVD
MIKE21 Model Mesh
MIKE21 Model Mesh

Model mesh nodes and elevations (Reaches 2, 3)
Dam-break model results – Reach 2

Note: Inundation limited to canals near breach

Maximum WSE, Lake Elev. 14 ft NAVD
Dam-break model results – Reach 2

Reach 2
HHD Breach

Maximum Water Level

Maximum WSE,
Lake Elev.
17 ft NAVD
Dam-break model results – Reach 2

Maximum WSE,
Lake Elev.
20 ft NAVD
Dam-break model results – Reach 2

Maximum WSE, Lake Elev. 25 ft NAVD
Simulation time

- Simulations must reach peak elevations

Figure: USACE
The statistical analysis helps produce the 1% annual chance flood elevation or flood depth. Three components:

1. Stage-frequency analysis for Lake Okeechobee
2. Dike fragility curves for every reach
3. Joint probability analysis
Stage-frequency

**Figure: USACE MRR**

### Table

<table>
<thead>
<tr>
<th>Lake Level (NAVD)</th>
<th>Lake Level (NGVD)</th>
<th>Combined* Percent Chance Exceedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 ft</td>
<td>15 ft</td>
<td>78.5</td>
</tr>
<tr>
<td>15 ft</td>
<td>16 ft</td>
<td>53</td>
</tr>
<tr>
<td>16 ft</td>
<td>17 ft</td>
<td>15.72</td>
</tr>
<tr>
<td>17 ft</td>
<td>18 ft</td>
<td>4.38</td>
</tr>
<tr>
<td>18 ft</td>
<td>19 ft</td>
<td>3.16</td>
</tr>
<tr>
<td>19 ft</td>
<td>20 ft</td>
<td>2.22</td>
</tr>
<tr>
<td>20 ft</td>
<td>21 ft</td>
<td>1.23</td>
</tr>
<tr>
<td>21 ft</td>
<td>22 ft</td>
<td>0.68</td>
</tr>
</tbody>
</table>

*Based on multiple simulations with varying initial lake level.*
Figure: USACE MRR
Joint probability method analysis

Goal: calculate the 1% annual chance flood elevation

Event A → Dike failure at given elevation
Event B → Lake reaching a given elevation

- Failure frequency curve
  - Combined probability of failure for entire HHD → $P(A|B)$
- **Failure rate** (events per year)
  - Failure rate [events/year] → $P(A\cap B)$
    - $P(A\cap B) = P(A|B)P(B)$
- Allocation of total dike failure rate
  - $Rate_{i,j} = \frac{P_{i,j}}{\sum_{i=1}^{8} P_{i,j}} \times TotalRate_j$  where $TotalRate_j = P(A\cap B)$
Joint probability analysis

HHD failure frequency curve

\[ P(A|B) \]

Lake’s stage-frequency curve

\[ P(B) \]

Failure rate curve

\[ P(A \cap B) \]
Joint probability analysis

Reach failure probability \((p_{i,j})\)

Allocated failure rate
\((p_{i,j} \times \text{Total rate})\)

<table>
<thead>
<tr>
<th>Reach</th>
<th>Lake Water Surface Elevation (ft, NAVD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14</td>
</tr>
<tr>
<td>Reach 1A</td>
<td>1.50E-04</td>
</tr>
<tr>
<td>Reach 1B</td>
<td>1.50E-04</td>
</tr>
<tr>
<td>Reach 1C</td>
<td>4.45E-03</td>
</tr>
<tr>
<td>Reach 2</td>
<td>5.00E-03</td>
</tr>
<tr>
<td>Reach 3</td>
<td>3.85E-03</td>
</tr>
<tr>
<td>Reach 4</td>
<td>5.00E-05</td>
</tr>
<tr>
<td>Reach 5</td>
<td>5.00E-05</td>
</tr>
<tr>
<td>Reach 6A</td>
<td>2.00E-05</td>
</tr>
<tr>
<td>Reach 6B</td>
<td>3.00E-05</td>
</tr>
<tr>
<td>Reach 7</td>
<td>2.50E-04</td>
</tr>
<tr>
<td>Reach 8</td>
<td>5.00E-05</td>
</tr>
</tbody>
</table>

\[
Rate_{i,j} = \frac{P_{i,j}}{\sum_{i=1A}^8 P_{i,j}} \times \text{TotalRate}_j
\]
Statistical analysis

Histogram of Element 128456

Gaussian redistribution

Histograms of flooded depths

Gaussian Redistribution of Accumulated Rate
Statistical analysis

Cumulative density curve

Rate 0.01 times per year (1% annual chance event)

Flood depth = 1.9 ft
Statistical analysis
Floodplain mapping
Floodplain mapping

[Image of floodplain map]
Final Comments and Conclusions

• Cooperation between FEMA/USACE to identify risk
• The HHD cannot be certified
  ➢ Risk is better understood
• This method has been widely used in coastal studies
• First time that a probabilistic method with 2D flood modeling has been applied to levee/dam failure for a FEMA FIS (maybe)

• Improvements:
  ➢ Probabilistic breach evolution
  ➢ Seiche and wind setup in the lake
  ➢ Update fragility curves
  ➢ Increase number of dam-break simulations
By the way...

- The Herbert Hoover Dike is undergoing repairs
  - Cutoff wall and seepage berm
  - Estimated completion in 2030

Figure: USACE
Acknowledgment

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• Co-authors and modelers
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THANK YOU