Use of Geostatistical Mapping Techniques to Develop Wave Runup Depth Grid Products

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Methodology to Determine Process-Based Total Water Level Profiles in Areas Dominated by Wave Runup

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Study Team – FEMA and Contractor Partners

- **Ed Curtis**: FEMA Region IX
- **Vince Geronimo**: Project Manager
- **Darryl Hatheway**: Technical Lead
- **Kristen MacDougall**: GIS Lead
- **Jeremy Mull**: Coastal Engineer
- **Sarah Kassem**: Coastal Engineer
- **Elena Drei-Horgan**: Coastal Engineer
The FIRM shows which areas are expected to flood during the 1-percent-annual-chance event.

- Highlights the inland extent of flooding (flood zone boundaries)
Pilot Study Area

- Aptos, CA
- Detailed CCAMP OPC Study data
- Presence of homes/structures within the mapped 1% annual chance flood hazard
- Community could benefit from the flood risk mapping layers
Coastal Depth and Velocity Mapping Layers

**ISSUES**
- Localized Vulnerability
- Hydrodynamic forces can damage structures
- Sediment scour, compromised foundations

**BENEFITS**
- Provide detailed flood characteristics
- Identify areas subject to greatest forces
- Identify safe areas during a coastal storm event
1D to 2D: Geostatistical Analyst
Coastal Depth and Velocity Mapping Layers – Concepts

- This approach has been generally applied along the east and Gulf coasts, where TWL are dominated by storm surge and are more constant.

- This approach is problematic on west coast where TWL are dominated by wave setup and runup.

Source: FEMA Guidance for Flood Risk Analysis and Mapping, Flood Depth and Analysis Grids
Coastal Depth and Velocity Mapping Layers - Concepts

Use of Geostatistical Mapping Techniques to Develop Wave Runup Depth Grid Products
GIS Tools & Input

- **DEM**
  - Bathy
  - Topo

- **Post-Processed Transect Profiles**
  - Ground profile
  - WSE
  - Depth

- **AOI**
  - FIRM Data (Runup Reaches)
  - Transect Locations

- Geostatistical Analyst
- Spatial Analyst
- 3D Analyst
Import profile data

** known Interpolation issue:
http://help.arcgis.com/EN/arcgisdesktop/10.0/help/index.html#/00vt00000004000400040

Tobler’s First Law of Geography:
Everything is related to everything else, but near things are more related than distant things
Prepare the Areas of Interest

Santa Cruz
OPC Coast

Aptos Area

AOIs and DEMs
Geostatistical Wizard: CoKriging
Use of Geostatistical Mapping Techniques to Develop Wave Runup Depth Grid Products

Geostatistical Wizard: Error Analysis
WSE (Constant)
Data QC

- Cross-Validation (ESRI tool)
- Error visualization (G/A Wizard)
- Manual cross-validation
  - Visual inspection in ArcMap
  - Cross-validation with Post-processed transect points (T_76; T_78)
    - Create a run for 1 reach with two transects. Run reach with only 1 transect as the WSE interpolation source. Compare to real transect points. Run reach with only the other transect as the WSE interpolation source. Compare to real transect points. Evaluate interpolation accuracy.
- 3D Analyst profiles: TWL/Depth vs. Ground
- Buffer the last inland point by 3m; it should intersect the 1% boundary (work within the resolution of the 3m DEM)
Data QC – 3D Analyst

Use of Geostatistical Mapping Techniques to Develop Wave Runup Depth Grid Products
Depth (Varying)
## ASCE, USACE, FEMA Flood Severity Calculations

<table>
<thead>
<tr>
<th>ASCE/USACE/FEMA Flood Severity Metric</th>
<th>Characteristic</th>
<th>ArcGIS Raster Math</th>
<th>Depth (ft)</th>
<th>Velocity (ft/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth $d$</td>
<td>Coastal Flood Depth (ft)</td>
<td>$d^{-1}$</td>
<td>1</td>
<td>5.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>8.02</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>9.83</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>11.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>12.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>13.90</td>
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<td></td>
<td></td>
<td></td>
<td>7</td>
<td>15.01</td>
</tr>
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<td></td>
<td></td>
<td>8</td>
<td>16.05</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>9</td>
<td>17.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>17.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11</td>
<td>18.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12</td>
<td>19.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>13</td>
<td>20.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14</td>
<td>21.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15</td>
<td>21.98</td>
</tr>
<tr>
<td>Velocity $V = \sqrt{gd}$</td>
<td>Coastal Flood Velocity (ft/s)</td>
<td>Power($(d \times 32.2), 0.5$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth x Velocity $dV$</td>
<td>Hydrodynamic Force (ft$^2$/s)</td>
<td>$d \times V$</td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth x Velocity Squared $dV^2$</td>
<td>Hydrodynamic Force (ft$^3$/s$^2$)</td>
<td>$d(V \times V)$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^{1}$ $D_{max}$ is 15ft in the Coastal Construction Manual
Velocity (Varying)
### Visualizing Flood Severity

<table>
<thead>
<tr>
<th>Flood Severity Category</th>
<th>Depth Range (ft)</th>
<th>Depth x Velocity Range (ft²/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>&lt; 0.5</td>
<td>&lt; 2.2</td>
</tr>
<tr>
<td>Medium</td>
<td>0.5 – 1.0</td>
<td>2.2 – 5.4</td>
</tr>
<tr>
<td>High</td>
<td>1.0 – 2.0</td>
<td>5.4 – 16.1</td>
</tr>
<tr>
<td>Very High</td>
<td>2.0 – 2.8</td>
<td>16.1 – 26.9</td>
</tr>
<tr>
<td>Extreme</td>
<td>&gt; 2.8</td>
<td>&gt; 26.9</td>
</tr>
</tbody>
</table>
Coastal Depth x Velocity Mapping Layers – Detailed Comparison

- Note the difference between Constant method Hydrodynamic force and Varying method Hydrodynamic Force at subset of structures.
Assumptions

• Normalizing Data Trends
• Boundaries based on depth or independent characteristics
  – Overtopping
  – PFD
  – V/A Gutter
• Post-processing profile 0-depth points versus Limit of Coastal Inundation
• Homogeneity Test
  – Each Runup Reach is unique
• Data Clipping
  – Processing Time
  – Interpolation across Runup Reach boundaries
• Data Units
  – Meters versus Feet: horizontal and vertical datum
• Densification of Data
## TWL With Multiple Return Periods

<table>
<thead>
<tr>
<th>Analysis Transect</th>
<th>Backshore</th>
<th>50% (2-yr)</th>
<th>20% (5-yr)</th>
<th>10% (10-yr)</th>
<th>4% (25-yr)</th>
<th>2% (50-yr)</th>
<th>1% (100-yr)</th>
<th>0.2% (500-yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>58</td>
<td>Beach + Bluff</td>
<td>18.1</td>
<td>19.3</td>
<td>20.2</td>
<td>21.3</td>
<td>22.0</td>
<td>22.7</td>
<td>24.2</td>
</tr>
<tr>
<td>66</td>
<td>Beach + Bluff</td>
<td>16.1</td>
<td>17.3</td>
<td>18.2</td>
<td>19.4</td>
<td>20.3</td>
<td>21.2</td>
<td>23.2</td>
</tr>
<tr>
<td>68</td>
<td>Beach + Seawall</td>
<td>14.6</td>
<td>15.8</td>
<td>16.7</td>
<td>17.8</td>
<td>18.7</td>
<td>19.6</td>
<td>21.7</td>
</tr>
<tr>
<td>73</td>
<td>Beach + Bluff</td>
<td>16.0</td>
<td>17.3</td>
<td>18.4</td>
<td>19.7</td>
<td>20.8</td>
<td>21.9</td>
<td>24.6</td>
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<tr>
<td>76</td>
<td>Beach</td>
<td>15.7</td>
<td>16.9</td>
<td>17.9</td>
<td>19.1</td>
<td>20.0</td>
<td>21.0</td>
<td>23.1</td>
</tr>
<tr>
<td>78</td>
<td>Revetment + Beach</td>
<td>15.8</td>
<td>17.1</td>
<td>18.1</td>
<td>19.4</td>
<td>20.4</td>
<td>21.4</td>
<td>23.7</td>
</tr>
</tbody>
</table>

Image sources: FEMA.gov
Considerations

• Apply methodology selectively – consider availability of data and analysis type, geomorphology, populated areas, presence of structures
• Use of specialized GIS utilities
• Complete a Cost-Benefit Analysis
• Expand study area
• Present Velocity information to communities effectively
• Consider other metrics of measuring risk to structures, flood severity
• Consider TMAC Recommendations, structure-level analysis