

# ***How to Read an INUNDATION MAP***

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[grichards@gfnet.com](mailto:grichards@gfnet.com)



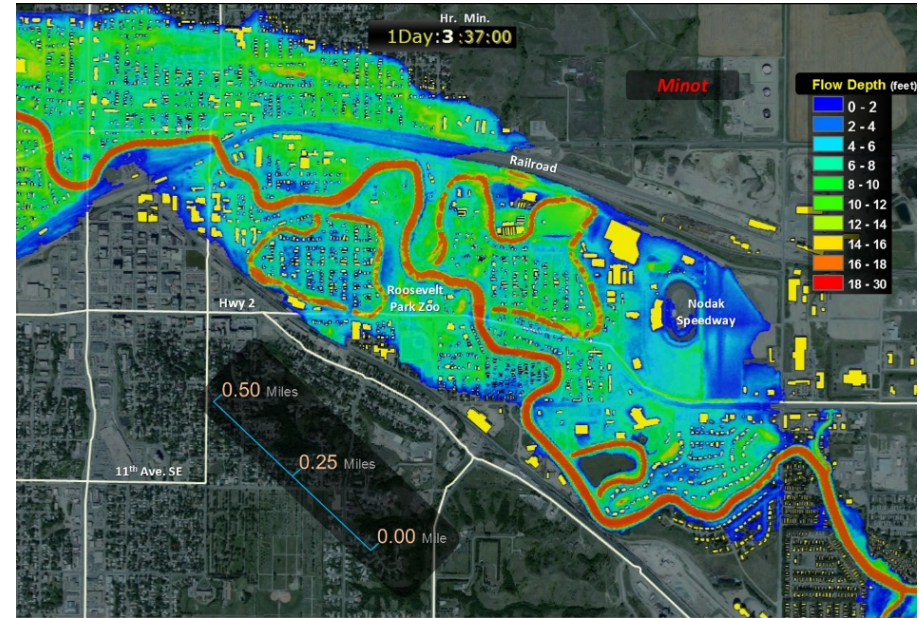
**Gannett Fleming**

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# Purpose of EAP Dam Breach Inundation Maps

*To assist the dam owner and emergency management authorities with identifying critical infrastructure and population-at-risk sites that may require protective measures and warning and evacuation planning.*

*(FEMA P-946, 2013)*



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# What Are We Mapping? The Mechanics of a Dam Failure Flood Wave

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**South Fork Dam Failure  
Johnstown, Pennsylvania  
May 31, 1889  
2,209 fatalities**

## What Are We Mapping? The Mechanics of a Dam Failure Flood Wave

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*The wall of water swept through in such a way that it left almost nothing to suggest that there had ever been such a place as Mineral Point. The town was simply shaved off, right down to the bare rock...*

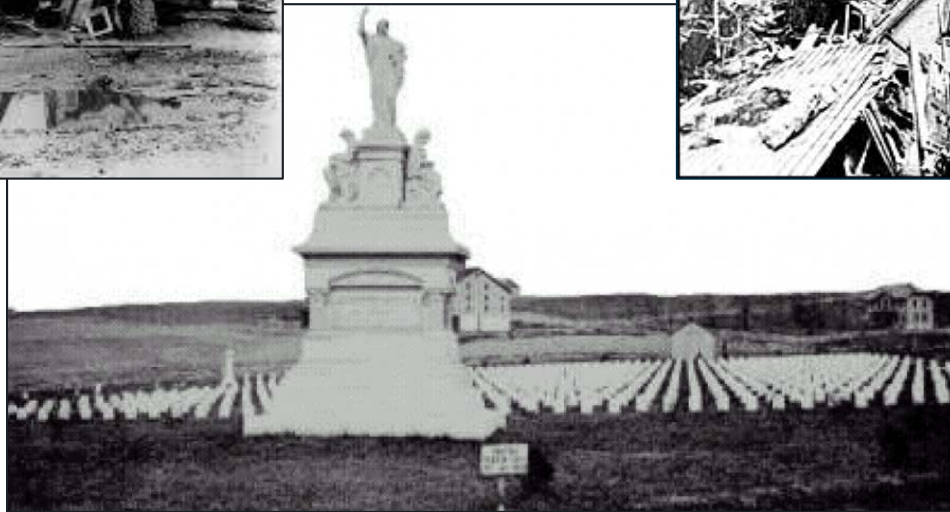
*“The Johnstown Flood”  
by David McCullough*





# What Are We Mapping? The Mechanics of a Dam Failure Flood Wave

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## **What Are We Mapping? The Mechanics of a Dam Failure Flood Wave**

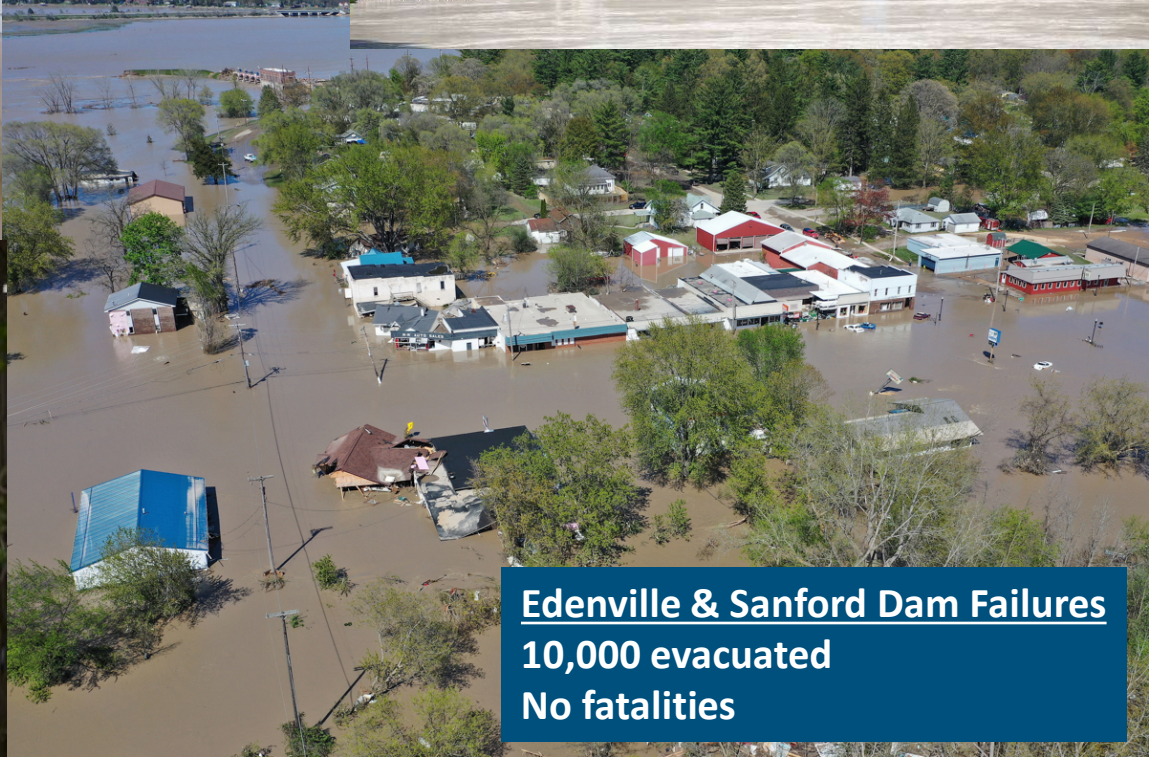
Edenville Dam, Michigan  
May 2020

Source: YouTube/Lynn Coleman  
[https://youtu.be/Hc3u\\_CHVHJf](https://youtu.be/Hc3u_CHVHJf)









**Edenville & Sanford Dam Failures**  
**10,000 evacuated**  
**No fatalities**



# What Are We Mapping? Insights from Past Failures

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1. Not an exact science –uncertainty due to bridges, debris, modeling assumptions, etc.



# What Are We Mapping? Insights from Past Failures

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1. Not an exact science –uncertainty due to bridges, debris, modeling assumptions, etc.
2. **We can't foresee the future.**  
**Maps provide approximate areas of inundation for a variety of potential failure scenarios.**
  - Sunny Day vs. PMF
  - Operational Scenario
  - Location of Breach







**Sunny Day or  
Fair Weather Failure**

Piping failure or  
geologic,  
structural, seismic  
and human-  
influence failure

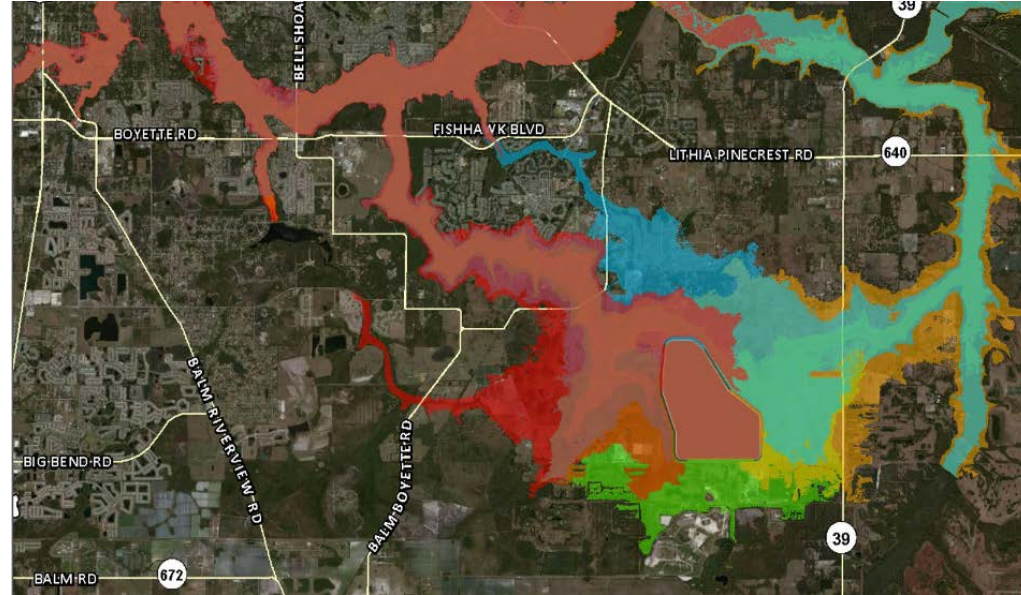


**Probable Maximum  
Flood (PMF) or Wet  
Weather Failure**

Overtopping  
failure

# What Are We Mapping? Insights from Past Failures

1. Not an exact science –uncertainty due to bridges, debris, modeling assumptions, etc.
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**Maps provide approximate areas of inundation for a variety of potential failure scenarios.**
  - Sunny Day vs. PMF
  - Operational Scenario
  - Location of Breach



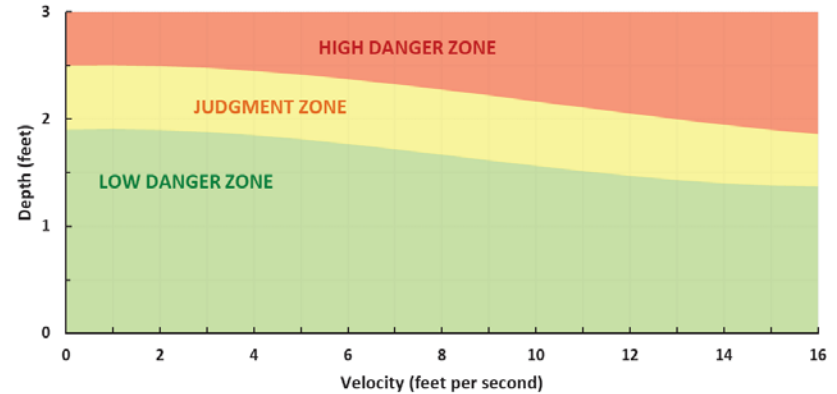


# What Are We Mapping?

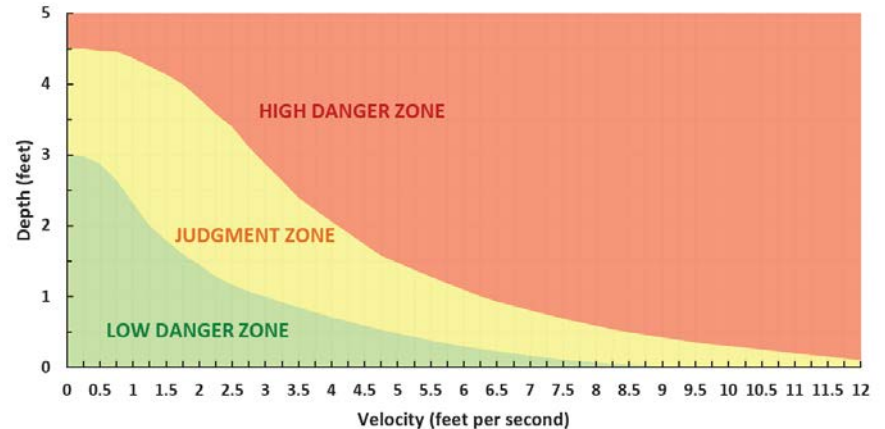
## Insights from Past Failures

1. Not an exact science – lots of uncertainty due to bridges, debris, modeling assumptions, etc.
2. We can't foresee the future. Inundation maps are intended to provide approximate areas of inundation for a variety of potential failure scenarios.
3. **Depth, velocity, and timing information can be very helpful in evacuation planning efforts**

**Figure 3.** Depth-Velocity-Flood Danger Level Relationship for Mobile Homes (Bureau of Reclamation, 1988).



**Figure 5.** Depth-Velocity-Flood Danger Level Relationship for Adults (Bureau of Reclamation, 1988).



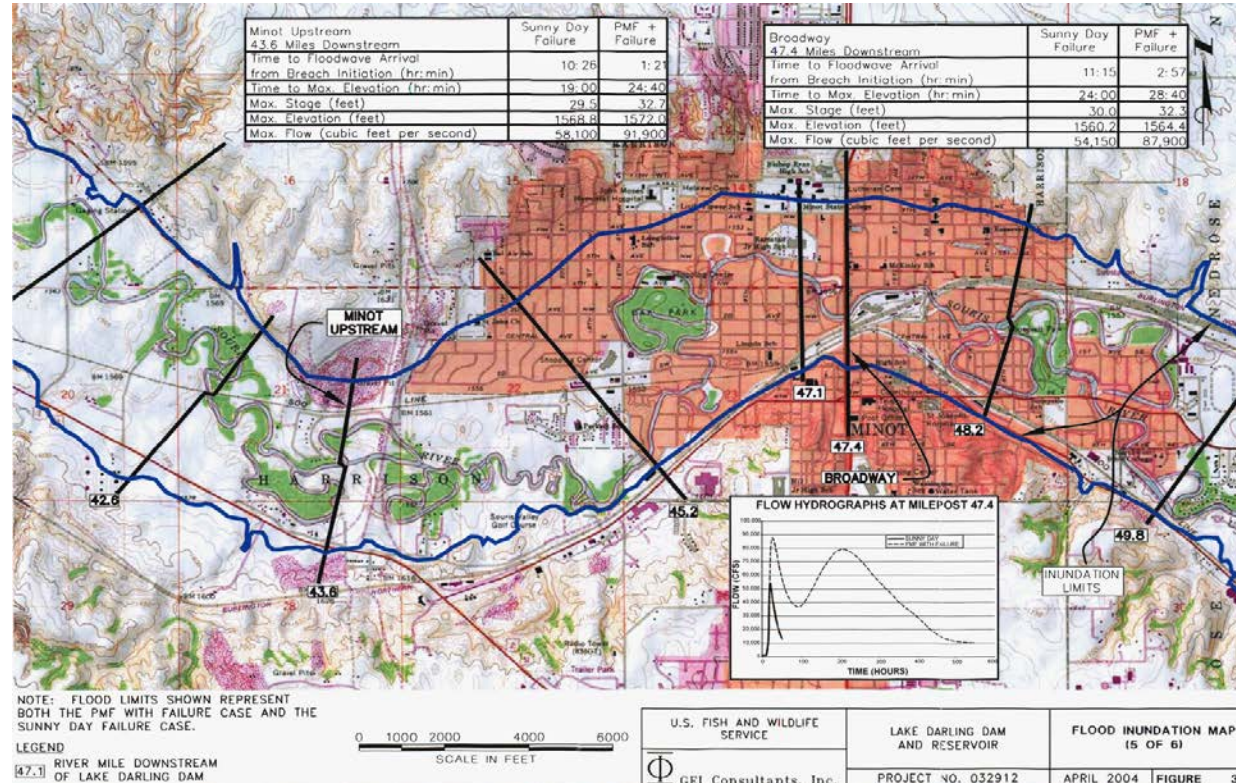
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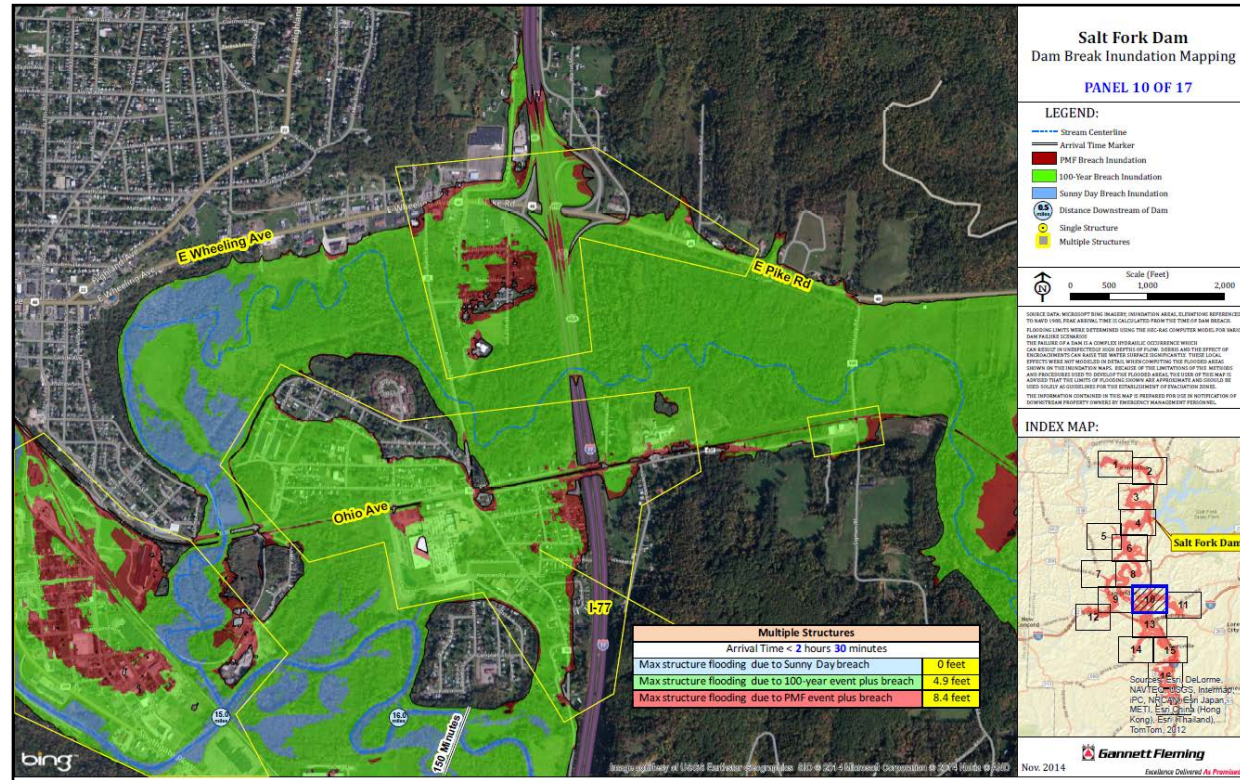
# What Are We Mapping? Floodplain Estimation Techniques

- By Hand (Judgment)
- Hydrologic Routing:
  - DAMBRK (1977)
- One-dimensional models:
  - NWS DAMBRK (1988)
  - HEC-RAS (1995)
  - FLDWAV (1998)

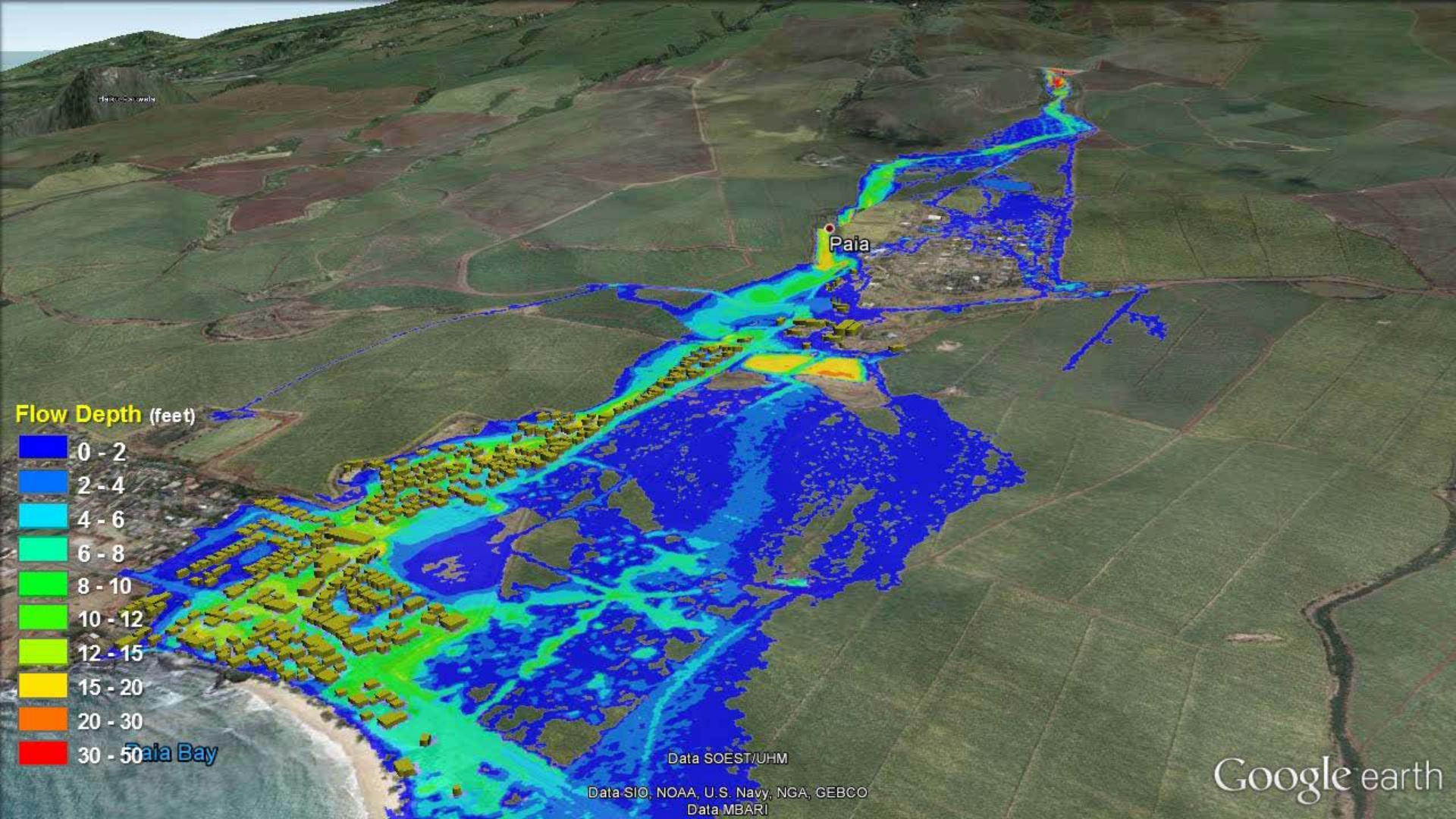


# What Are We Mapping? Floodplain Estimation Techniques

- By Hand (Judgment)
- Hydrologic Routing:
  - DAMBRK (1977)
- One-dimensional models:
  - NWS DAMBRK (1988)
  - HEC-RAS (1995)
  - FLDWAV (1998)
- Two-dimensional models:
  - DSS-WISE
  - MIKE 21
  - XP-SWMM
  - FLO-2D
  - HEC-RAS









15:01:00

Hr. Min.



Minot

4th Ave. NW

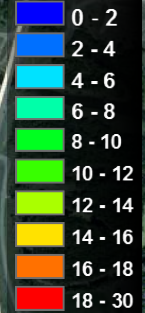
Arrowhead Shopping Center

Oak Park

Railroad

Minot High School

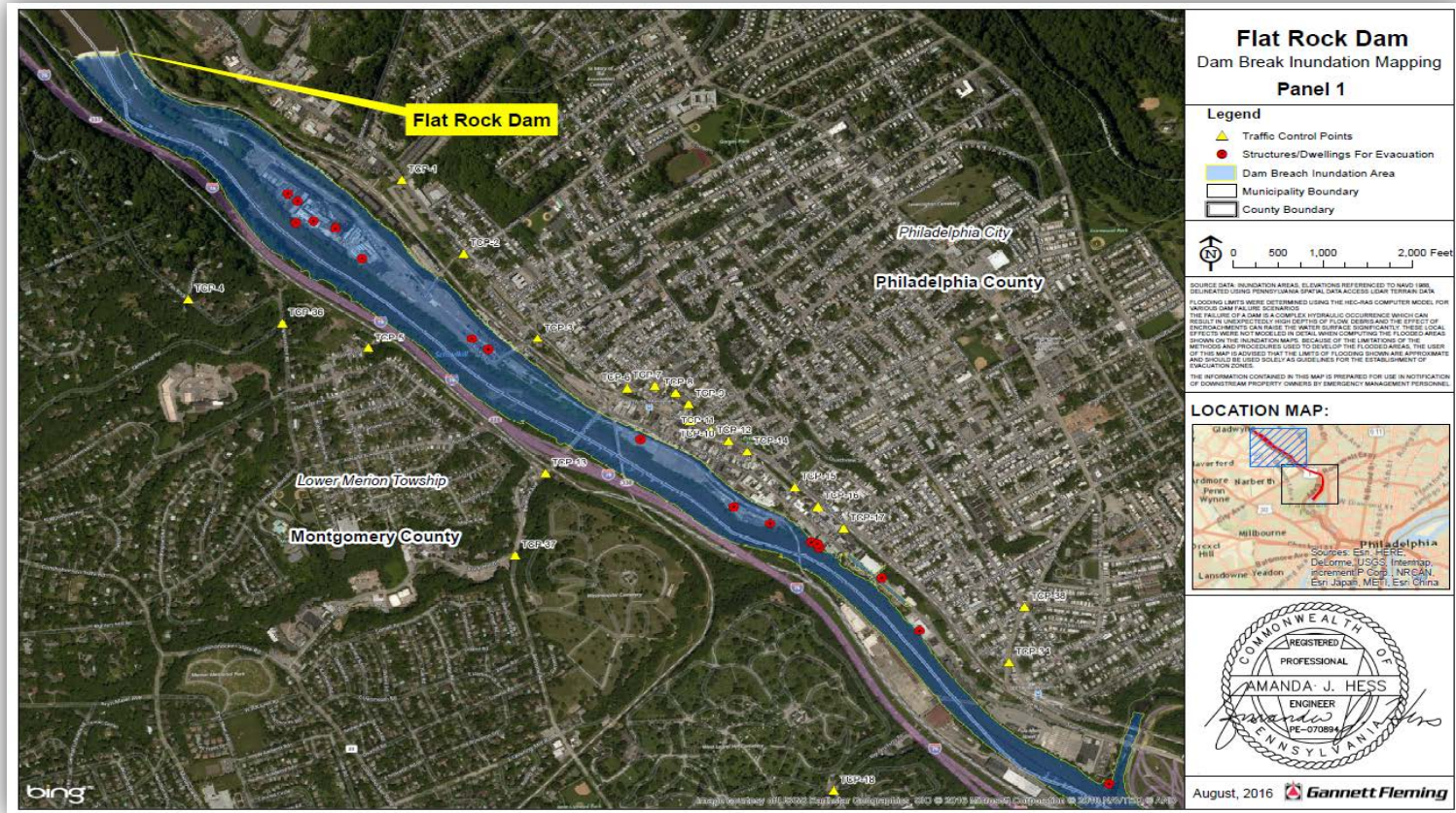
Flow Depth (feet)



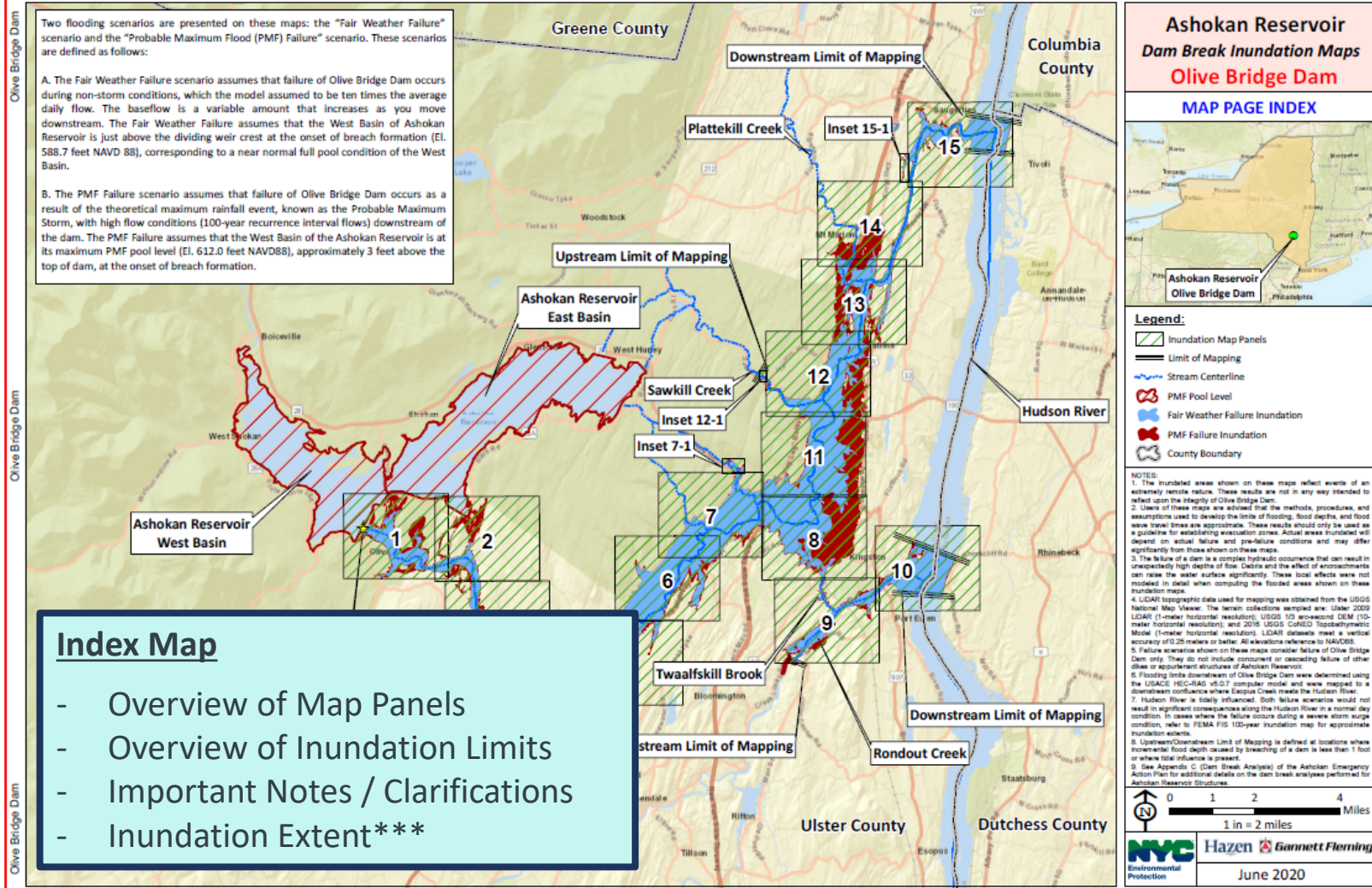
Gannett Fleming



# How to Read an Inundation Map?







Two flooding scenarios are presented on these maps: the "Fair Weather Failure" scenario and the "Probable Maximum Flood (PMF) Failure" scenario. These scenarios are defined as follows:

A. The Fair Weather Failure scenario assumes that failure of Olive Bridge Dam occurs during non-storm conditions, which the model assumed to be ten times the average daily flow. The baseflow is a variable amount that increases as you move downstream. The Fair Weather Failure assumes that the West Basin of Ashokan Reservoir is just above the dividing weir crest at the onset of breach formation (EL. 588.7 feet NAVD 88), corresponding to a near normal full pool condition of the West Basin.

B. The PMF Failure scenario assumes that failure of Olive Bridge Dam occurs as a result of the theoretical maximum rainfall event, known as the Probable Maximum Storm, with high flow conditions (100-year recurrence interval flows) downstream of the dam. The PMF Failure assumes that the West Basin of the Ashokan Reservoir is at its maximum PMF pool level (EL. 612.0 feet NAVD88), approximately 3 feet above the top of dam, at the onset of breach formation.

- ### Index Map
- Overview of Map Panels
  - Overview of Inundation Limits
  - Important Notes / Clarifications
  - Inundation Extent\*\*\*

## Ashokan Reservoir Dam Break Inundation Maps Olive Bridge Dam

### MAP PAGE INDEX

**Legend:**

- Inundation Map Panels
- Limit of Mapping
- Stream Centerline
- PMF Pool Level
- Fair Weather Failure Inundation
- PMF Failure Inundation
- County Boundary

**NOTES:**

1. The inundated areas shown on these maps reflect events of an extremely remote nature. These results are not in any way intended to reflect upon the integrity of Olive Bridge Dam.
2. Users of these maps are advised that the methods, procedures, and assumptions used to develop the limits of flooding, flood depths, and flood wave travel times are approximate. These results should only be used as a guideline for establishing evacuation zones. Actual areas inundated will depend on actual future and pre-failure conditions and may differ significantly from those shown on these maps.
3. The failure of a dam is a complex hydraulic occurrence that can result in unexpectedly high depths of flow. Debris and the effect of encroachments can raise the water surface significantly. These local effects were not modeled in detail when computing the flooded areas shown on these inundation maps.
4. LIDAR topographic data used for mapping was obtained from the USGS National Map Viewer. The terrain collection acquired are: Under 2009 LIDAR (1-meter horizontal resolution); USGS 100 m-resolution DEM (10-meter horizontal resolution); and 2018 USGS CoReD Topobathymetric Model (1-meter horizontal resolution). LIDAR datasets meet a vertical accuracy of 0.25 meters or better. All elevations reference to NAVD88.
5. Failure scenarios shown on these maps consider failure of Olive Bridge Dam only. They do not include containment or cascading failure of other dams or equipment structures of Ashokan Reservoir.
6. Flooding limits downstream of Olive Bridge Dam were determined using the USACE HEC-RAS v5.0.7 computer model and were mapped to a downstream confluence where Esopus Creek meets the Hudson River.
7. Hudson River is likely influenced. Both failure scenarios would not result in significant consequences along the Hudson River in a normal day condition. In cases where the failure occurs during a severe storm surge condition, refer to FEMA FIS 100-year inundation map for appropriate inundation extents.
8. Upstream/Downstream Limit of Mapping is defined at locations where theoretical flood depth caused by breaching of a dam is less than 1 foot or where local influence is present.
9. See Appendix C: Dam Break Analysis of the Ashokan Emergency Action Plan for additional details on the dam break analysis performed for Ashokan Reservoir Structures.

0 1 2 4 Miles  
1 in = 2 miles

**NYC** Environmental Protection **Hazen** **Gannett Fleming**  
June 2020



## Dam Breach Inundation Map

### Mineral Ridge Dam



### Legend

- Sunny Day Breach
- 25% PMF Breach
- PMF Breach
- Cross Section Location
- Stream Centerline



| Mahoning River - S Main Street<br>3.5 miles upstream of dam |                       |                    |                      |
|---|-----------------------|--------------------|----------------------|
| Failure Scenario  | Time of Arrival (hrs) | Time of Peak (hrs) | Max WSEL (ft NAVD88) |
| Sunny Day   | 0.3                   | 2.3                | 875.27               |
| 25% PMF   | 0.2                   | 2.2                | 883.06               |
| PMF   | 0.1                   | 1.8                | 887.90               |

| Mosquito Creek - Federal Street<br>4.1 miles upstream of dam |                       |                    |                      |
|--|-----------------------|--------------------|----------------------|
| Failure Scenario   | Time of Arrival (hrs) | Time of Peak (hrs) | Max WSEL (ft NAVD88) |
| Sunny Day  | 0.4                   | 2.8                | 871.47               |
| 25% PMF  | 0.2                   | 11.9               | 875.96               |
| PMF  | 0.2                   | 16.2               | 880.63               |

| Mosquito Creek - Park Avenue<br>3.5 miles upstream of dam |                       |                    |                      |
|---|-----------------------|--------------------|----------------------|
| Failure Scenario  | Time of Arrival (hrs) | Time of Peak (hrs) | Max WSEL (ft NAVD88) |
| Sunny Day   | 0.3                   | 2.3                | 875.22               |
| 25% PMF   | 0.2                   | 2.2                | 883.04               |
| PMF   | 0.1                   | 1.8                | 887.85               |

| Mahoning River - Belmont Avenue<br>3.2 miles downstream of dam |                       |                    |                      |
|--|-----------------------|--------------------|----------------------|
| Failure Scenario   | Time of Arrival (hrs) | Time of Peak (hrs) | Max WSEL (ft NAVD88) |
| Sunny Day  | 0.3                   | 2.3                | 875.32               |
| 25% PMF  | 0.2                   | 2.2                | 883.08               |
| PMF  | 0.2                   | 1.8                | 887.89               |

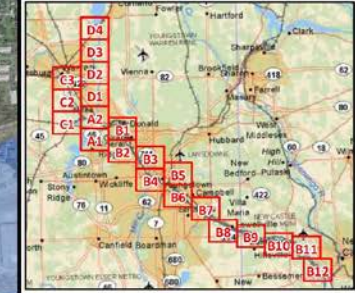
NOTES: BASE MAP DERIVED FROM GIS DATA AND PENNSYLVANIA STATEWIDE IMAGERY PROGRAMS. ROAD NAMES OBTAINED FROM COLE FENCHOT AND MARKING AND TURN RELL SURVEY COORDINATES.

MAP IS COMPILED AND PRINTED IN GRID DATE PLANE COORDINATE SYSTEM WITH UNITS OF FEET AND HORIZONTAL DATUM OF NAD83. THE FLOOD ELEVATIONS ARE REFERENCED TO THIS DATUM. CRITICAL DATING, TIME OF ARRIVAL AND TIME TO PEAK ARE CALCULATED FROM THE BEGINNING OF DAM BREACH FORMATION.

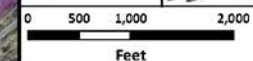
FLOODING LIMITS WERE DETERMINED USING THE IEC CAS COMPUTER MODEL FOR THE PROBABLE MAXIMUM FLOOD (PMF) DAM. BASELINE HYDROGRAPH, 25% OF THE PROBABLE MAXIMUM FLOOD (PMF) DAM. BASELINE HYDROGRAPH AND A "SUNNY DAY" DAM. BASELINE HYDROGRAPH. THE FAILURE OF A DAM IS A COMPLEX HYDRAULIC OCCURRENCE WHICH CAN RESULT IN UNEXPECTEDLY HIGH DEPTHS OF FLOOD DEPOSITS AND THE EFFECT OF ENVIRONMENTAL CAN CAUSE THE WATERS SURFACE SIGNIFICANTLY. THESE LOCAL EFFECTS WERE NOT MODELED IN DETAIL WHEN COMPUTING THE FLOODING LIMITS SHOWN ON THE INUNDATION MAPS. BECAUSE OF THE LIMITATIONS OF THE METHOD AND PACKAGES USED TO DEVELOP THE FLOODING LIMITS, THE USER OF THIS MAP IS ADVISED THAT THE LIMITS OF FLOODING SHOWN ARE APPROXIMATE AND SHOULD BE USED ONLY AS GUIDELINES FOR THE ESTABLISHMENT OF EVACUATION ZONES.

THE INFORMATION CONTAINED IN THIS MAP IS PREPARED FOR USE IN NOTIFICATION OF DOWNSTREAM PROPERTY OWNERS BY EMERGENCY MANAGEMENT PERSONNEL.

### Overview Map:



September 2010



A2

## Typical Information on an Inundation Map

- Topographic and/or aerial imagery basemap
- Inundation limits for multiple failure scenarios
- Legend / Notes



| Wynkoop Road<br>15.2 miles downstream from Olive Bridge Dam |                      |               |
|---|----------------------|---------------|
| HEC-RAS XS 95487  | Fair Weather Failure | PMF Failure   |
| Flood Wave Arrival Time                                     | 1 hr 20 min          | 0 hr 50 min   |
| Time to Peak Flood Elevation                                | 3 hr 25 min          | 2 hr 05 min   |
| Peak Flood Elevation (NAVD88)                               | 185.5 ft             | 200.3 ft      |
| Max. Depth to Channel Bottom                                | 47.3 ft              | 62.1 ft       |
| Incremental Rise (failure vs. non-failure)                  | 40.6 ft              | 25.9 ft       |
| Peak Discharge  | 715,100 cfs          | 1,456,900 cfs |

| Arrival Time = 70 Min<br>13.2 miles downstream from Olive Bridge Dam |                      |               |
|--|----------------------|---------------|
| HEC-RAS XS 106167  | Fair Weather Failure | PMF Failure   |
| Flood Wave Arrival Time  | 1 hr 10 min          | 0 hr 40 min   |
| Time to Peak Flood Elevation   | 2 hr 00 min          | 2 hr 00 min   |
| Peak Flood Elevation (NAVD88)  | 192.8 ft             | 208.1 ft      |
| Max. Depth to Channel Bottom   | 38.8 ft              | 54.2 ft       |
| Incremental Rise (failure vs. non-failure)                           | 32.9 ft              | 27.7 ft       |
| Peak Discharge   | 747,700 cfs          | 1,607,900 cfs |

Page 7 Match Line

Hurley

15  
Flow Direction

## Typical Information on an Inundation Map

- Structures / communities at risk
- Identification of critical facilities and shelters
- Traffic control measures and traffic routes

## Legend:

- Fair Weather Failure Inundation
- PMF Failure Inundation
- Distance Downstream from Olive Bridge Dam (miles)
- Fair Weather Failure Arrival Time
- Stream Centerline
- PMF Pool Level
- City/Town Boundary
- County Boundary
- Table Callout Locator
- USGS Stream Gage
- 20-foot Contour Interval
- Page Match Line

## Critical

- Potable Water Facility
- Law Enforcement Facility
- Assisted Living/ Nursing Home
- Correctional
- Hospital
- Heliport
- Fire Station/EMS
- Emergency Medical Service
- School
- College/University
- Wastewater Treatment Plant
- Dam
- Campground
- Petroleum Bulk Station/Terminal

| 6.0 Miles Downstream of Goodwin Dam |             |         |
|-------------------------------------|-------------|---------|
| Scenario                            | Sunny Day   | PMF     |
| Arrival Time                        | 2 hr        | ----    |
| Time to Max Elev.                   | 2 hr 30 min | ----    |
| Max Elevation (ft)                  | 161.1       | 190.2   |
| Max Flood Depth (ft)                | 8.9         | 35.0    |
| Incremental Flood Depth (ft)        | 8.9         | ----    |
| Max Flow (cfs)                      | 2,500       | 150,600 |

| Sunny Day | PMF     |
|-----------|---------|
| 6 hr      | ---     |
| 8 hr      | ---     |
| 136.8     | 190.2   |
| 4.6       | 35.3    |
| 4.6       | ---     |
| 500       | 150,500 |

- ### Typical Information on an Inundation Map
- Maximum water surface elevations
  - Peak discharge (cubic feet per second, cfs)
  - Maximum depths
  - Maximum velocities
  - Time of arrival / Time to peak / Duration





# Dam Breach Inundation Mapping

PANEL 10 OF 20

- AREA POTENTIALLY SUBJECTED TO FLOODING DURING SUNNY DAY FAILURE
- AREA POTENTIALLY SUBJECTED TO FLOODING DURING PROBABLE MAXIMUM FLOOD FAILURE
- STRUCTURE POTENTIALLY SUBJECTED TO FLOODING DURING SUNNY DAY FAILURE



SOURCE DATA: BING MAP ORTHO IMAGERY MADE AVAILABLE FROM ARGIS ONLINE FREE USGS WEB MAPPING SERVICE. INUNDATION AREAS AND ELEVATIONS REFERENCED TO NAVD 1988, DELINEATED USING A SURFACE CREATED FROM LIDAR DIGITAL TERRAIN MODEL.

MADE (DISCLAIMER): GANNETT FLEMING MAKES NO WARRANTIES OR GUARANTEES REGARDING THE ACCURACY, SUFFICIENCY, OR COMPLETENESS OF INFORMATION PRESENTED ON THIS MAP. MAPPED LIMITS OF FLOODED AREAS AND FLOOD WAVE TIMES OF ARRIVAL AND TIMES TO PEAK ARE APPROXIMATE AND ARE SUBJECT TO CERTAIN ASSUMPTIONS AND GENERALIZATIONS THAT ARE NECESSARY FOR AND INTRINSIC TO THE DAM FAILURE FLOOD WAVE MODELING AND MAPPING PROCESS. MODIFICATIONS TO FLOODPLAIN FEATURES CAN SIGNIFICANTLY ALTER THE INUNDATION LIMITS AND TIMES PRESENTED ON THIS MAP. TIME INTERVALS AND EXTENT OF INUNDATION RESULTING FROM AN ACTUAL DAM FAILURE EVENT MAY DIFFER SUBSTANTIALLY FROM THE INFORMATION PRESENTED ON THIS MAP. IT IS PRUDENT TO ASSUME THAT PERIPHERAL AREAS LOCATED OUTSIDE OF THE DEMARCATED INUNDATION LIMITS COULD ALSO BE SUBJECT TO FLOOD INUNDATION.

NOTES TO MAINTENANCE: THIS INFORMATION CONTAINED IN THIS MAP IS INTENDED FOR USE IN NOTIFICATION OF THE DOWNSTREAM POPULATION AT RISK BY EMERGENCY MANAGEMENT PERSONNEL. FLOOD WAVE TIME OF ARRIVAL AND TIME TO PEAK ARE CALCULATED FROM AND RELATIVE TO THE BEGINNING OF DAM BREACH FORMATION.   
 \*WELL - WATER SURFACE ELEVATION

## INDEX MAP:

Upper Souris National Wildlife Refuge, Ward County, ND



Copyright © 2015, Decimite

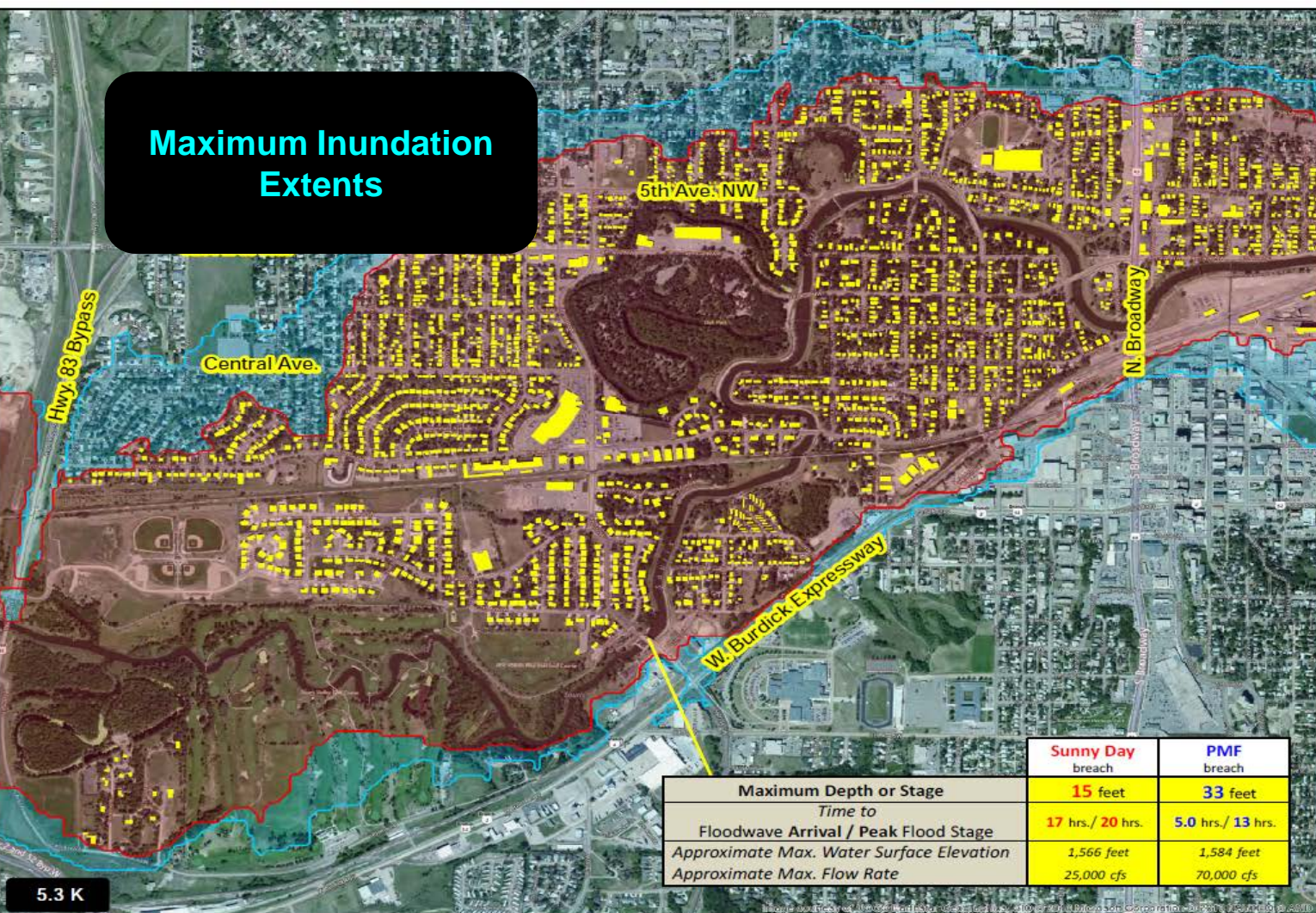
Nov. 2016

**Gannett Fleming**

25

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## Maximum Inundation Extents



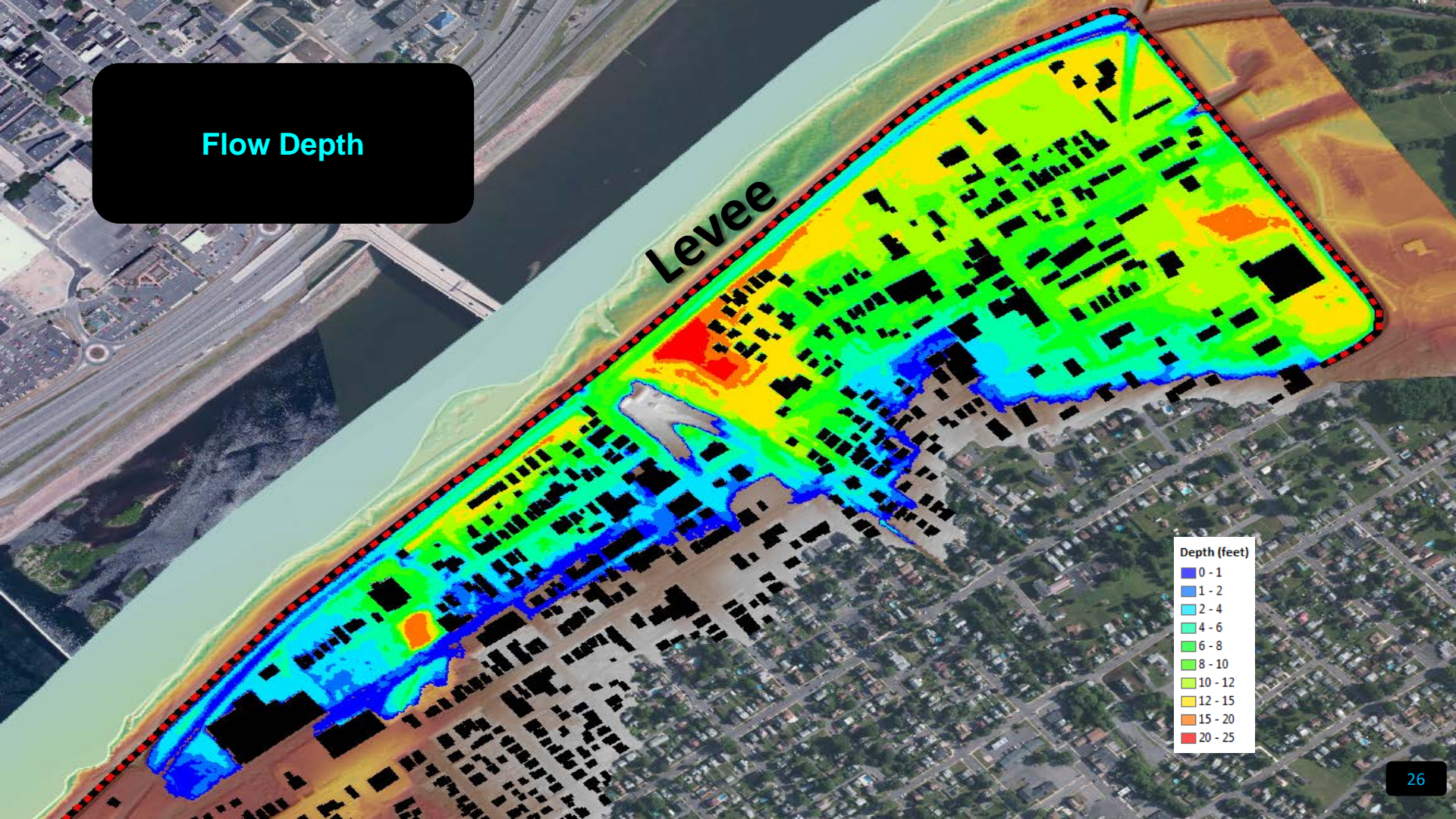
5.3 K

|  | Sunny Day breach  | PMF breach         |
|--|-------------------|--------------------|
| Maximum Depth or Stage                       | 15 feet           | 33 feet            |
| Time to Floodwave Arrival / Peak Flood Stage | 17 hrs. / 20 hrs. | 5.0 hrs. / 13 hrs. |
| Approximate Max. Water Surface Elevation     | 1,566 feet        | 1,584 feet         |
| Approximate Max. Flow Rate                   | 25,000 cfs        | 70,000 cfs         |

Image courtesy of Lake Darling Dam project, Nov. 2016. Decimite Corporation. BSR-10-000000-000000-000000



## Flow Depth



## Flow Depth





## Flow Depth





## Flow Depth







Flow Velocity

Flow Velocity





Section 1

Depth \* Velocity

Section 2

Section 3

bing

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Section 1

Section 2

Section 3



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Rocky Mountain Arsenal

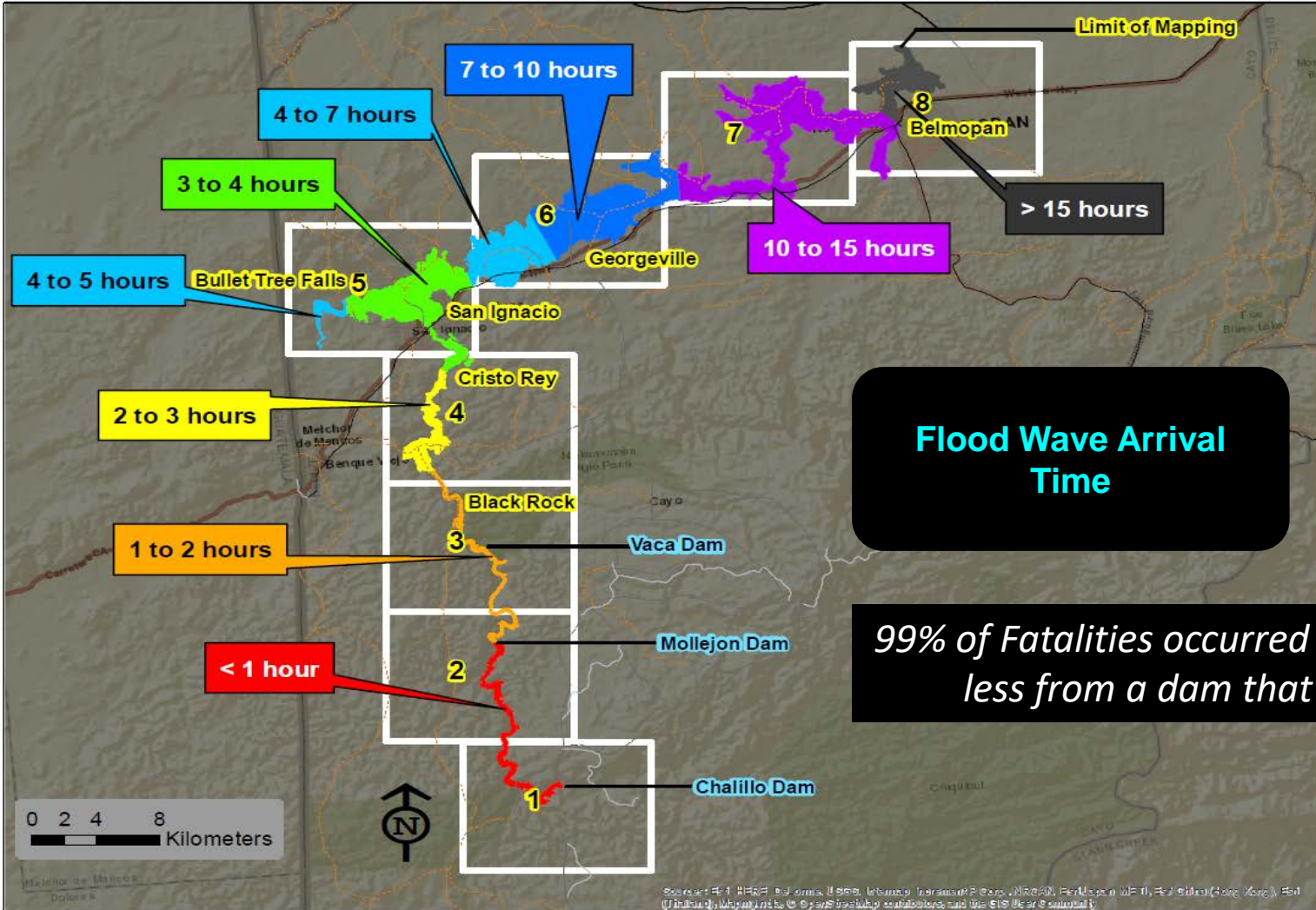


### Legend

● Point Locations (Detailed)

**Lake Ladora Sunny Day D\*V**





## Flood Wave Arrival Time

FLOOD INITIAL  
ARRIVAL TIMES MAP

*99% of Fatalities occurred 15 miles or less from a dam that failed*



### Main Street n of dam

| Time of<br>Peak (hrs) | Max WSEL<br>(ft NAVD88) |
|-----------------------|-------------------------|
| 2.3                   | 875.27                  |
| 2.2                   | 883.06                  |
| 1.8                   | 887.90                  |

### Mosquito Creek - Federal Street 4.1 miles upstream of dam

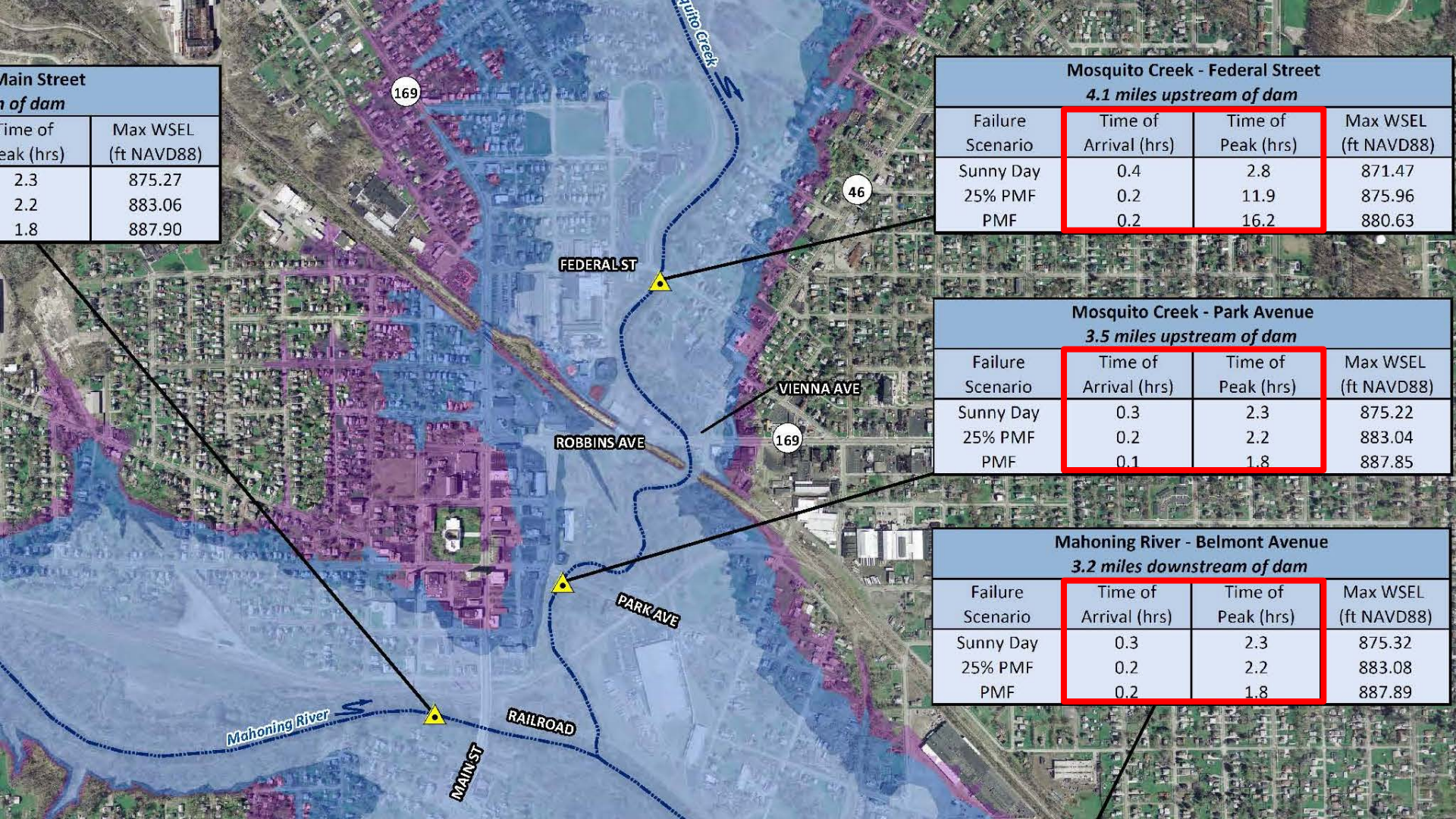
| Failure<br>Scenario | Time of<br>Arrival (hrs) | Time of<br>Peak (hrs) | Max WSEL<br>(ft NAVD88) |
|---------------------|--------------------------|-----------------------|-------------------------|
| Sunny Day           | 0.4                      | 2.8                   | 871.47                  |
| 25% PMF             | 0.2                      | 11.9                  | 875.96                  |
| PMF                 | 0.2                      | 16.2                  | 880.63                  |

### Mosquito Creek - Park Avenue 3.5 miles upstream of dam

| Failure<br>Scenario | Time of<br>Arrival (hrs) | Time of<br>Peak (hrs) | Max WSEL<br>(ft NAVD88) |
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| Sunny Day           | 0.3                      | 2.3                   | 875.22                  |
| 25% PMF             | 0.2                      | 2.2                   | 883.04                  |
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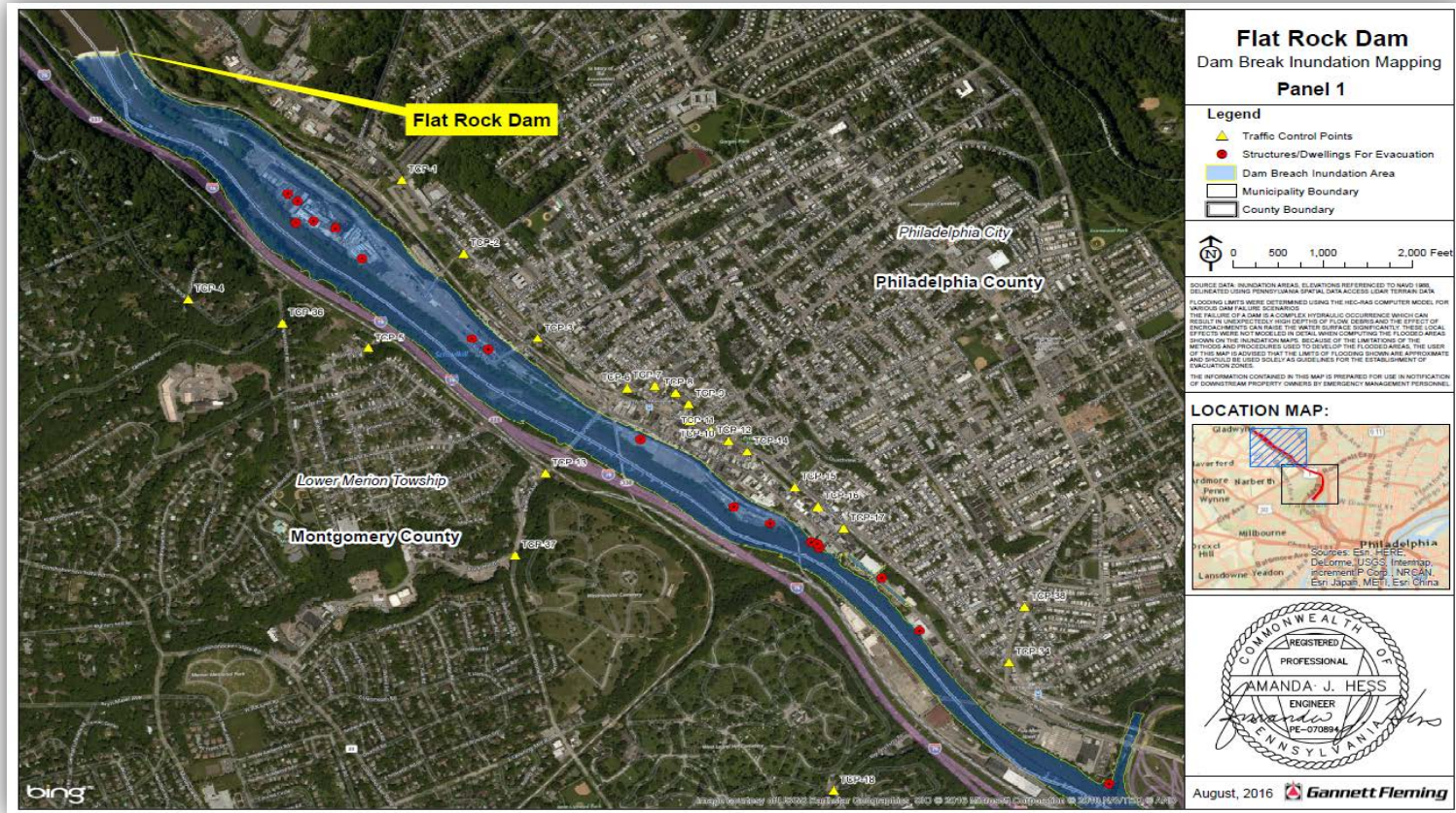
### Mahoning River - Belmont Avenue 3.2 miles downstream of dam

| Failure<br>Scenario | Time of<br>Arrival (hrs) | Time of<br>Peak (hrs) | Max WSEL<br>(ft NAVD88) |
|---------------------|--------------------------|-----------------------|-------------------------|
| Sunny Day           | 0.3                      | 2.3                   | 875.32                  |
| 25% PMF             | 0.2                      | 2.2                   | 883.08                  |
| PMF                 | 0.2                      | 1.8                   | 887.89                  |





# How to Read an Inundation Map?





## Some Parting Advice

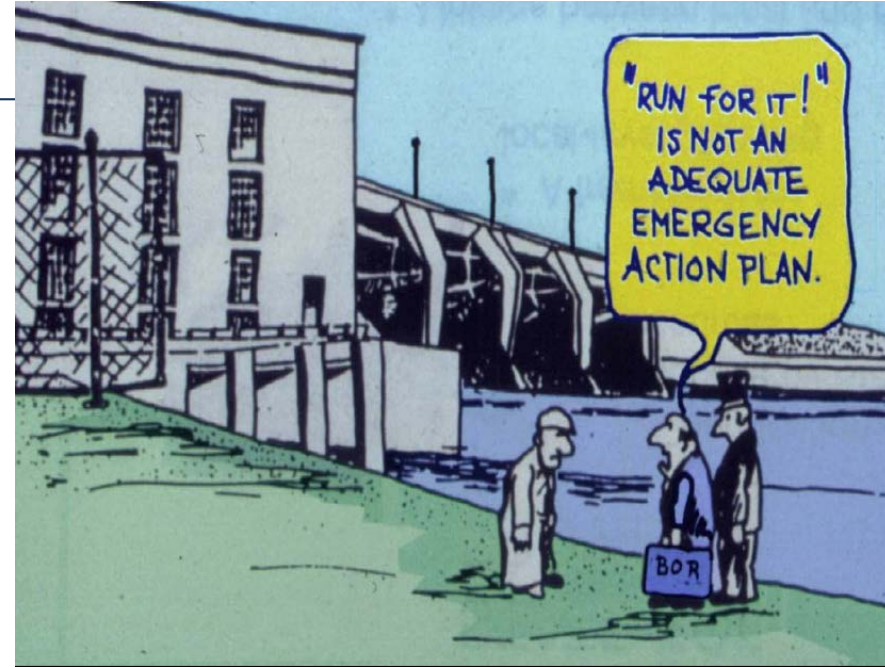
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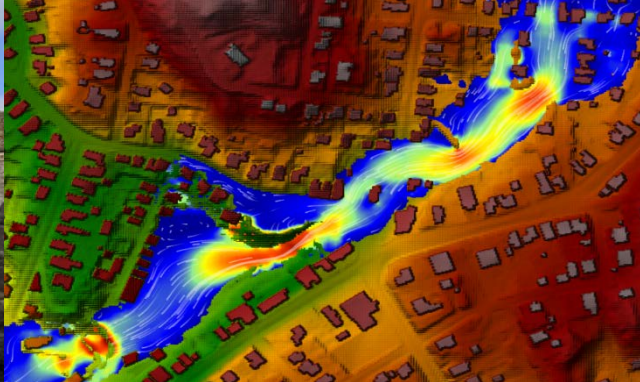
### Don't wait until a crisis to study your inundation maps:

- Understand the potential flood severity and danger zones
- Use the maps to inform evacuation plans
- Exercise the EAP

### Be aware of development in or near the inundation zone:

- New developments not shown on the maps may be at risk
- Other changes that could impact flooding extents (e.g. highway embankments, bridge replacements, warehouses, etc.)





# ***How to Read an INUNDATION MAP***

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