Estimating Dam Failure Life-Loss Consequences to Transient Populations for Hazard Potential Classification of Dams

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U.S. DEPARTMENT OF HOMELAND SECURITY

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Outline

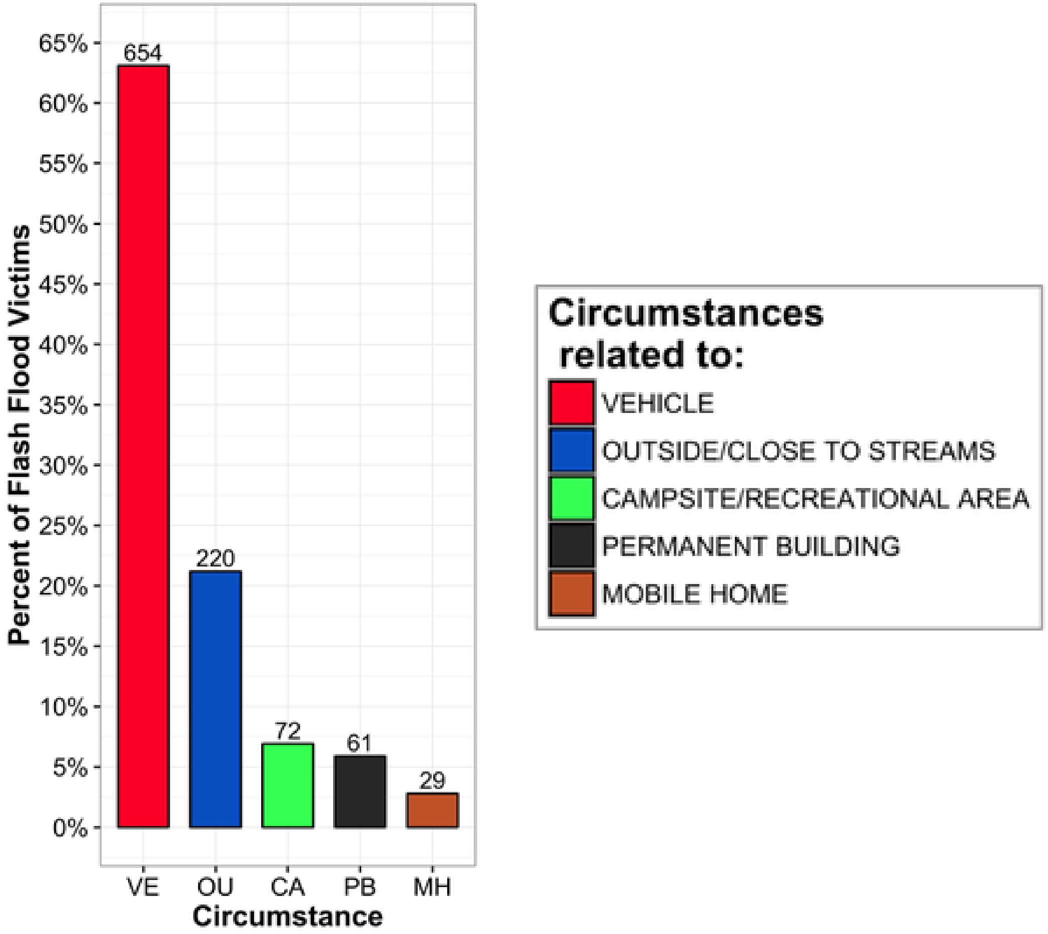
- Why estimate consequences to transient populations-at-risk (PAR)?
- How are consequences to transient PAR typically estimated?
- What is the method developed by the BIA Safety of Dams (SOD) Program?
- Provide an example application of the BIA SOD method.
- Discuss data gaps and next steps.

Why? – Most Flood Related Fatalities Involve Vehicles

Over 90%* of flood fatalities in the U.S. between 1996 and 2014 involved transient PAR.

- 63% involved vehicles
- 21% occurred outdoors/close to streams
- 7% occurred at campsites/recreational areas
- <10% occurred at permanent buildings/mobile homes

*Anquetin, S., Gourley, J., Ruin, I., and Tertin, G. 2016. A Situation-Based Analysis of Flash Flood Fatalities in the United States. In *Bulletin of the American Meteorological Society*.



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Why? – Vehicles Float Relatively Easily

Waverly, TN flooding (2021)

Why? – Dam Safety Planning

Hazard Potential Classification

Hazard Potential Classification	Loss of Human Life	Economic, Environmental, Lifeline Losses
Low	None expected	Low and generally limited to [dam] owner
Significant	None expected	Yes
High	Probable. One or more expected.	Yes (but not necessary for this classification)

Federal Emergency Management Agency (FEMA). 2004. Hazard Potential Classification System for Dams (FEMA 333). Federal Guidelines for Dam Safety, April.

Why? – Dam Safety Planning (2)

Dam Safety Prioritization with Limited Resources

Underestimation = Under-investment
= Increased risk at the subject dam

Overestimation = Over-investment
= Increased risk at other dams

How?

Existing Methodologies

1. What constitutes a hazardous flooding condition?

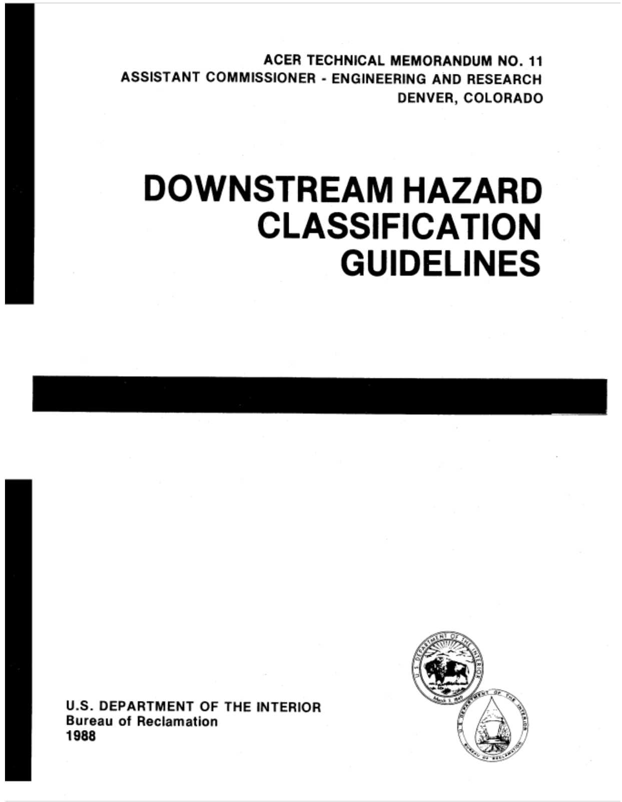
2. What is the PAR that may be exposed to hazardous flooding conditions?

3. How many fatalities can be expected given the expected PAR and flood severity?

- Federal Guidelines for Dam Safety—Hazard Potential Classification System for Dams (FEMA 333)
- Downstream Hazard Classification Guidelines, Assistant Commissioner—Engineering and Research Technical Memorandum No. 11 (ACER 11)
- Reclamation Consequence Estimating Methodology (RCEM)
- LifeSim Life-Loss Estimation Model

How? (2)

ACER 11 (Reclamation, 1988)


ACER TECHNICAL MEMORANDUM NO. 11
ASSISTANT COMMISSIONER - ENGINEERING AND RESEARCH
DENVER, COLORADO

DOWNSTREAM HAZARD CLASSIFICATION GUIDELINES

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
1988

Key Concepts:

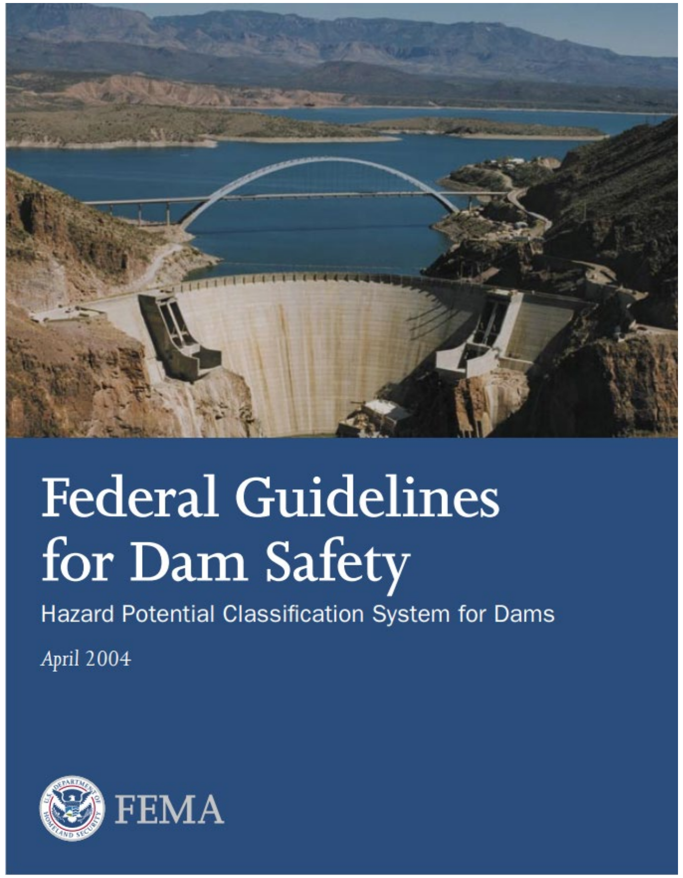
- Advances category of "lives in jeopardy" to include all individuals within the potential dam failure inundation boundaries who would be subject to danger if they took no action to evacuate.
- Limits assessment of consequences to direct downstream impacts resulting from the dam failure flood. Does not consider situations such as a vehicle crash resulting from road damage after the flood wave has passed.
- Defines flood danger levels for motorists and pedestrians within several plots of depth versus velocity.

Limitations:

- Offers no specific methods for estimating transient PAR and associated fatalities.
- Arbitrarily dismisses unpaved roads which are common below BIA dams and may have significant use.

How? (3)

FEMA 333 (FEMA, 2004)



Key Concepts:

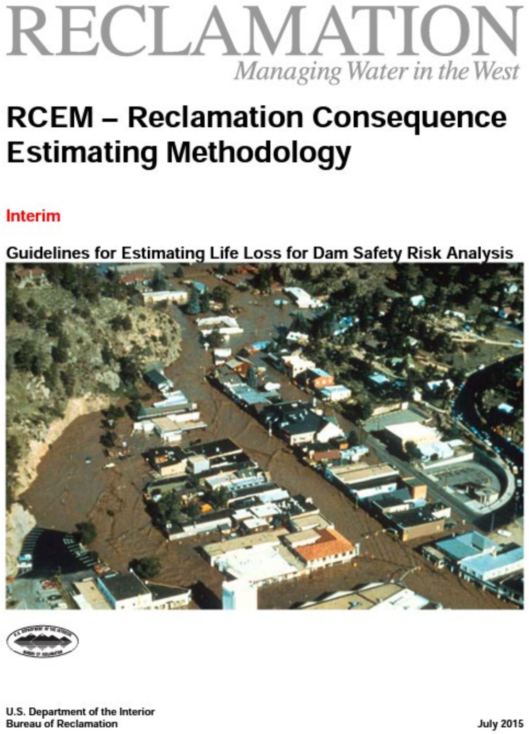
- Assigns a high-hazard potential classification if loss of at least one life is determined to be probable (likely to occur; reasonably expected; realistic).
- Makes no allowances for evacuation or other emergency actions by the population because emergency procedures should not be a substitute for appropriate design, construction, and maintenance of dam structures.
- Asserts that judgment and common sense must ultimately be a part of any decision on classification.

Limitations:

- Provides no specific methods for estimating flood severity, transient PAR, or fatalities.

How? (4)

Reclamation Consequence Estimating Methodology (Reclamation, 2015)


RECLAMATION
Managing Water in the West

RCEM – Reclamation Consequence Estimating Methodology

Interim

Guidelines for Estimating Life Loss for Dam Safety Risk Analysis

U.S. Department of the Interior
Bureau of Reclamation

July 2015

Key Concepts:

- Estimates life loss by empirical method based on case histories, which included evacuation.
- Defines PAR as the number of people occupying the dam failure floodplain prior to the issuance of any warning or evacuation.
- Provides some guidance on estimating PAR located within structures and at recreational areas. Recommends application of incremental PAR.
- Assigns fatality rates based on flood severity and assumption of either little-to-no warning or partial-to-adequate warning.
- Recognizes that rate of rise plays a role in life loss during a flood.
- Of the 91 case studies, 13 reported motorist fatalities or near-misses with a minimum vehicular life loss of 0, median life loss of 3, average life loss of 6, and maximum life loss of 17.
- When vehicular life loss was reported in the RCEM case studies, it represented between 60% and 100% of the total reported life loss during the event, and it typically occurred within a few miles of the flooding source.

Limitations:

- Provides no specific methods for estimating transient PAR at roadways.

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How? (5)

Key Concepts:

- Helps estimate spatially distributed life loss below a failed dam using a computational method.
- Computes fatalities during a flood event as a function of flood severity, population at risk, structural resilience, warning system effectiveness, mobilization effectiveness, road capacity and proximity to safety, and vehicle/human resilience to flood forces.
- Technical manual summarizes state-of-the-practice research relevant to fatality estimation, including flood severity for various types of populations and associated fatality rates given high and low flood severity.

Limitations:

- Model is not set up to include non-evacuating traffic on roadways.
- Offers no specific methods for estimating transient PAR.

LifeSim (USACE, 2020)

US Army Corps
of Engineers
Hydrologic Engineering Center

HEC-LifeSim
Life Loss Estimation

Technical Reference Manual

Version 2.0
July 2020

Approved for Public Release. Distribution Unlimited.

CPD-97a
Standard Form 298 (Rev. 8/98)

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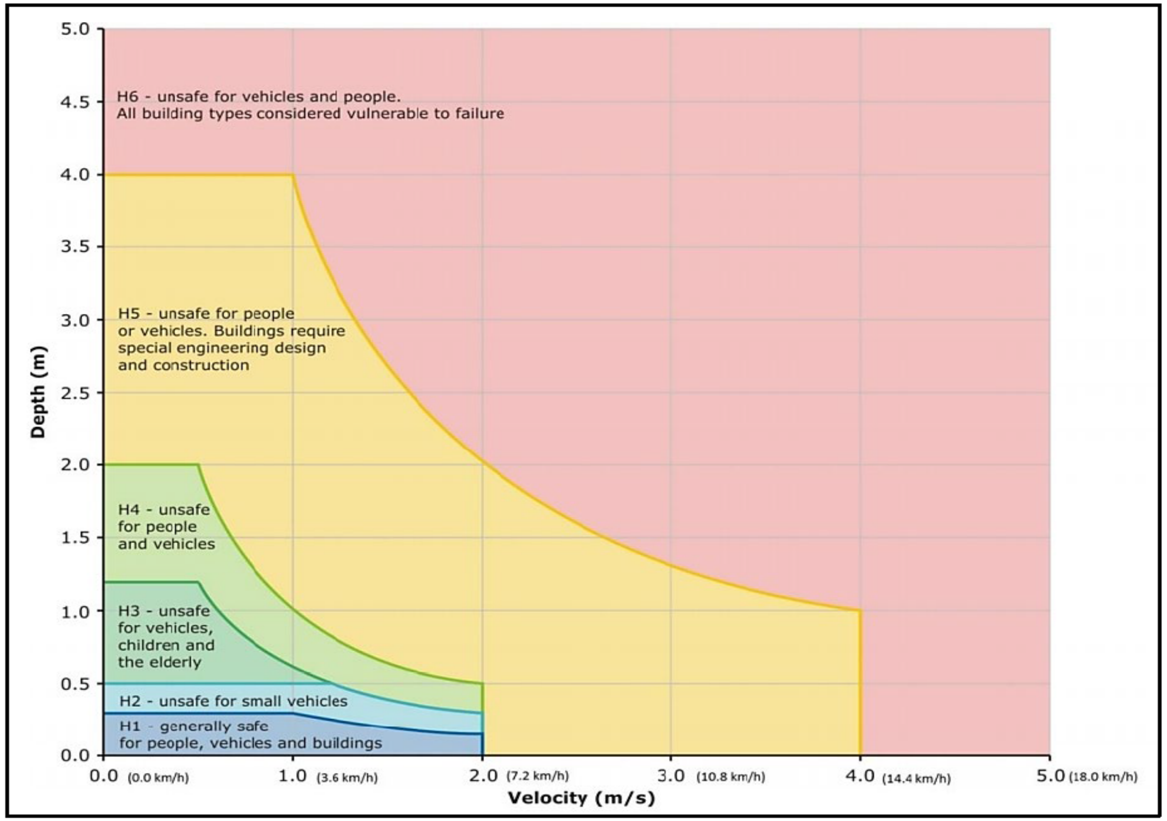
How? (6)

LifeSim (USACE, 2020)

The LifeSim technical documentation summarizes state-of-the-practice research into structure, vehicle, and human stability under flood loads and provides hazard curves defining unsafe depth vs. velocity for structures, people, and vehicles.

LifeSim Flood Hazard Vulnerability Curve



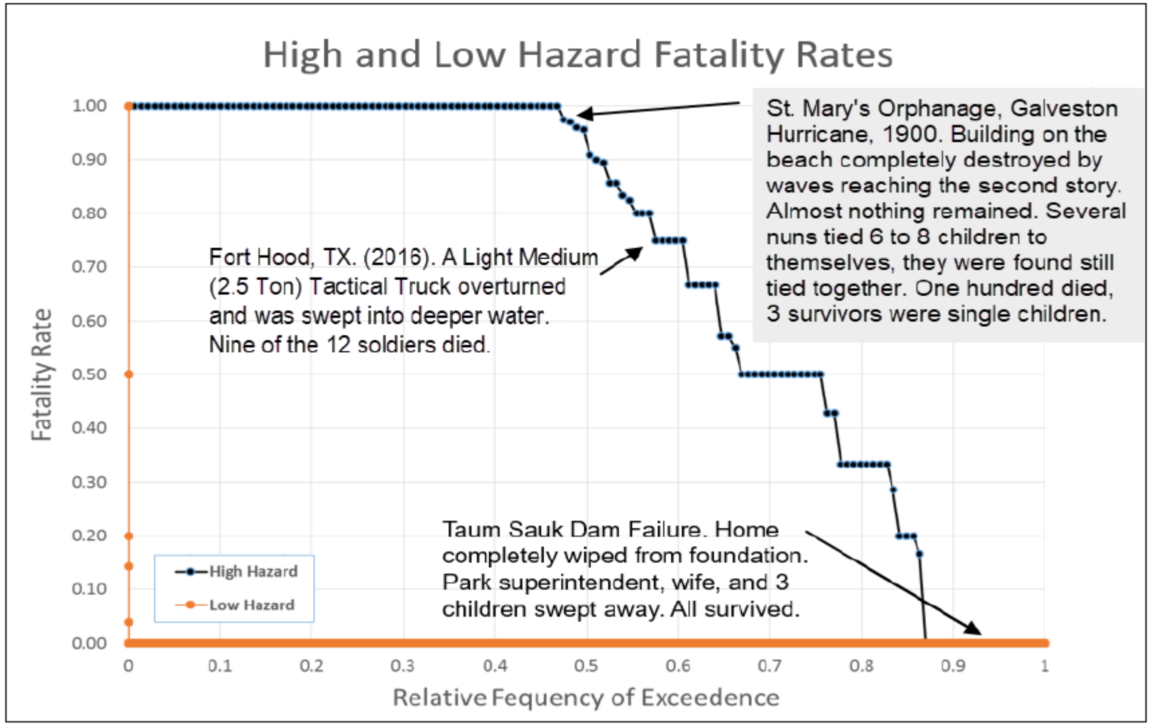
U.S. Army Corps of Engineers (USACE). 2020. LifeSim (HEGLifeSim) Life-Loss Estimation Technical Reference Manual, Version 2.0

How? (7)

LifeSim (USACE, 2020)

The LifeSim model incorporates research of observed fatality rates from actual flood events to compute life loss for each simulated flood event.

LifeSim Fatality Function



U.S. Army Corps of Engineers (USACE). 2020. LifeSim (HEC-LifeSim) Life-Loss Estimation Technical Reference Manual, Version 2.0

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How? (8)

Key Takeaways from Existing Methods

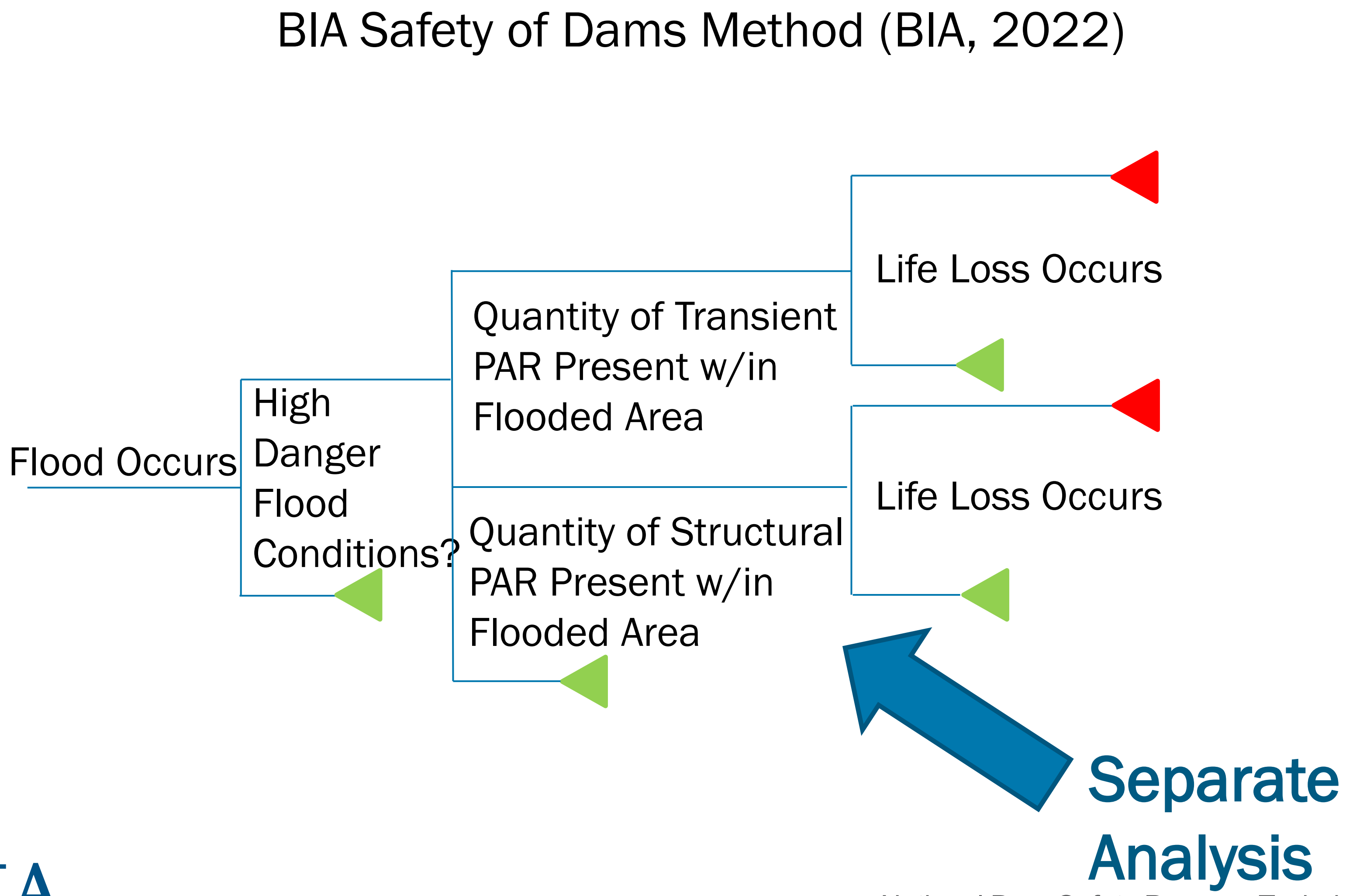
- A classification of high-hazard potential requires an incremental probable life loss of at least one (FEMA 333). Determine *incremental probable* life loss due to *direct* dam failure impacts to downstream *PAR*, where:
  - *Incremental* life loss is the life loss expected due to the dam failure/mis-operation portion of the flood (FEMA 333);
  - *Probable* life loss is life loss that is likely to occur; reasonably expected; realistic (FEMA 333). It is a function of the probability that life loss occurs given that a quantity of PAR and potentially lethal flood conditions are both present at the same time;
  - *Direct* impacts are directly attributed to the uncontrolled release of water impounded by the dam (ACER 11);
  - *Indirect* impacts result from secondary effects of the flood (ACER 11); and
  - *Transient PAR* are those people who are already on or attempting to enter a roadway, sidewalk, bicycle path, walking/hiking trail, or campground/recreational facility when it is inundated (ACER 11) (i.e., located within the potential inundation area at the onset of the flood).

How? (9)

Key Takeaways from Existing Methods (continued)

- A consistent method for estimating downstream transient PAR, which historically account for over 90% of life loss during flood events, is needed. Most BIA dams are very rural and transient PAR may account for a significant percentage of the overall PAR. The method for estimating probable transient PAR should consider the following:
  - When determining probable life loss for hazard potential classification studies, do not consider the condition of the dam and do not consider allowances for early warning, evacuation, or other emergency actions by the population (FEMA 333). However, it may be reasonable to consider warning time from natural means (flood rate of rise) (RCEM).
  - Good judgement is critical when estimating probable life loss (FEMA 333). Key considerations for estimating probable life loss include the expected time of day, season, and weather during the event; analysis uncertainties and the reasonableness of analysis assumptions.

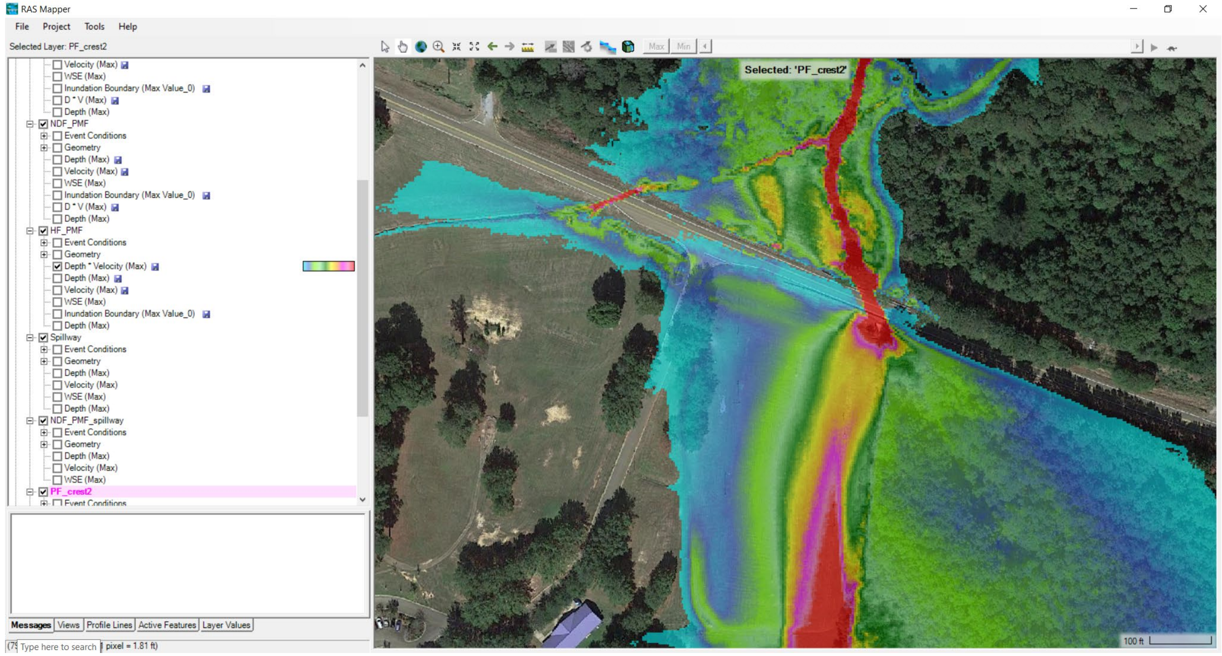
What is the BIA Method?



What is the BIA Method? (2)

BIA Safety of Dams Method (2022)

1. Estimate the extent of potentially lethal flood conditions.
   - Use hydraulic model results and LifeSim stability criteria to determine the spatial and temporal extents of high-hazard flooding.
   - If visibility of the flood is impaired and moving PAR may be unable to stop prior to entering the flooded facility, adjust the length of potentially lethal flood conditions by adding the stopping distance required based on speed of travel.



What is the BIA Method? (3)

2. Estimate the population at risk at each location of transient PAR impacted by high-hazard flood conditions.
   - For example, at a roadway estimate the total number of vehicles potentially occupying the hazardous inundation area at the onset of the flood. To avoid double counting, do not consider PAR evacuating from structures. Structural PAR should be considered under a separate analysis.

V(Onset) = (AADT/24)/FFS*L

Where V(Onset) = Vehicles w/in Inundated Area at Flood Onset (vehicles)

AADT = Average Annual Daily Traffic (vehicles/day)

FFS = Free Flow Speed (miles/hour)

L = Length of High Hazard Inundated Roadway (miles)

- Determine the floodwave rate of rise and PAR travel speed to determine if the PAR can leave the inundation area prior to arrival of the high danger portion of the floodwave.

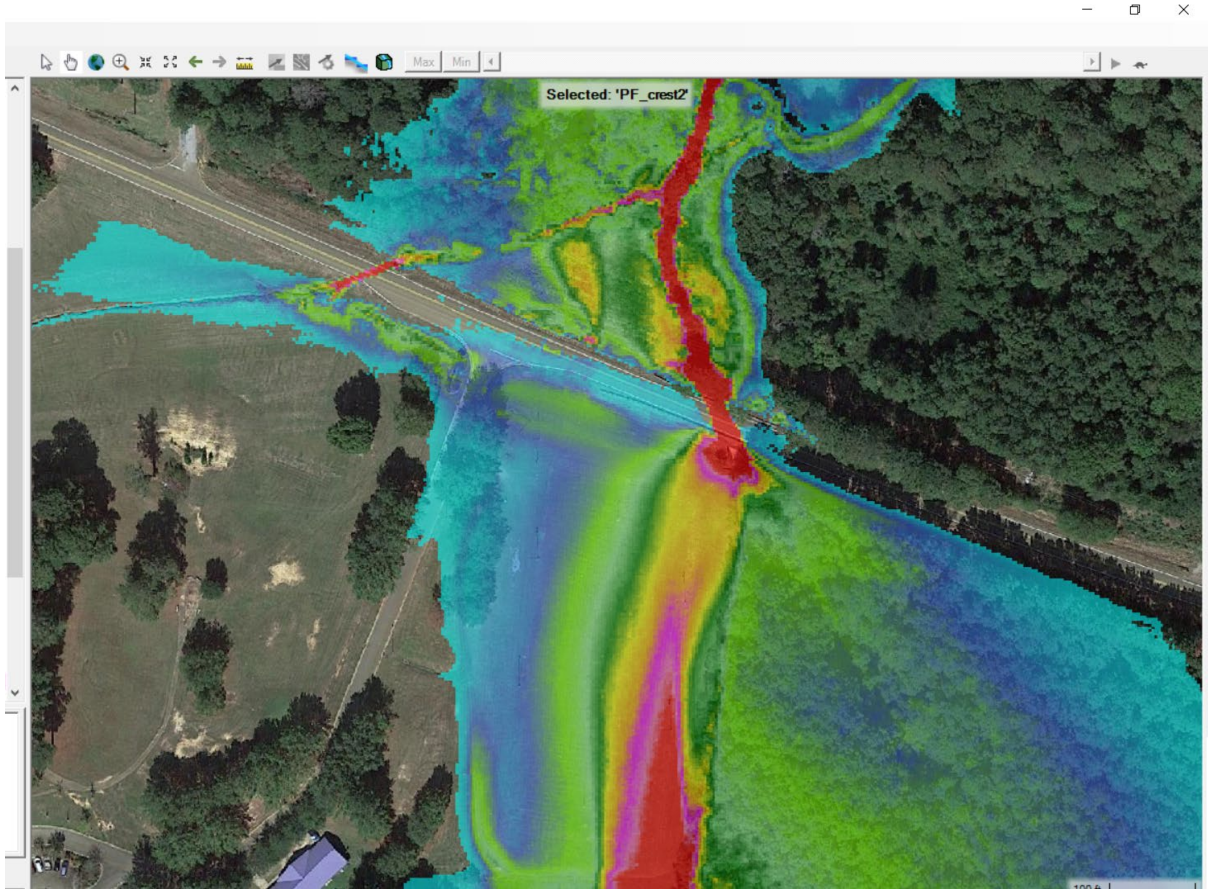
What is the BIA Method? (4)

3. Estimate incremental life loss.
   - Assume two people per impacted vehicle unless more site-specific information is available.
   - Apply the LifeSim high-hazard curve and/or RCEM fatality estimation method for each impacted vehicle.
   - A life-loss result greater than or equal to 0.5 is considered *probable.*
4. Perform a sensitivity analysis of key model assumptions and variables.
   - Consider the weather, daytime/nighttime, season, and other conditions that may be present during the dam failure event and adjust traffic density, travel speeds, sight/stopping distance, and occupancy assumptions accordingly.
5. Use good judgment. Are results reasonable?

Example

- This is a 19-ft-tall dam with 66 ac-ft storage capacity.
- A two-lane 30 mph rural residential road traverses the floodplain 0.1 mile below the dam.
- There is an Early Childhood Learning Center adjacent to the dam accessed by the road.
- Sight distance is approximately 1,000 ft and stopping distance is 200 ft.
- The state DOT reports an AADT of 110 vehicles per day for a similar nearby road.
- Two 36-in diameter culverts pass outflows from under the road.

Example: Estimate the Extent of Potentially Lethal Flood Conditions



- Analyze results of HEC-RAS hydraulic model for a sunny-day internal erosion breach of the dam in addition to a PMF non-dam-failure and PMF overtopping dam-failure event.
- Extract the length and duration of high-hazard conditions using LifeSim criteria.

Event	Max Depth (ft)	Max Velocity (fps)	High Hazard Inundated Length (mi)	High Hazard Inundated Duration (hr)	Floodwave Travel Time (hr)	Floodwave Rate of Rise (ft/hr)
Sunny-Day	1.6	12.7	0.07	0.1	0.1	53
PMF NDF	1.5	11.0	0.06	1.0	0.1	>53
PMF Hydrologic Failure	2.7	22	0.10	1.3	0.1	>53

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Example: Estimate Vehicular PAR and Life Loss

- A PMF at this location would result from an extremely large hurricane/tropical storm event that would be forecast well in advance. Driving on roads designed for drainage of much smaller events likely not possible.
- Research reported by the Federal Highways Administration indicates that heavy rain may reduce roadway traffic volume and travel speeds.
- Rate of Rise is high but sight distance/visibility is good.
- Assume traffic is spread evenly throughout day and night and is composed of 50% high-/low-clearance vehicles with 2 passengers each.
- Apply Life-Sim and/or RCEM fatality estimation method.
- Upper Bound Sensitivity Analysis for Sunny Day Event
  - Assume that 75% of daily traffic is spread evenly throughout 12 daytime hours and is composed of all school buses with 72 occupants each serving the Early Childhood Center
  - Expected life loss is still <0.5.

Event	ADT*	Free Flow Speed (mph)	Vehicles/mi	Vehicles/hr	Vehicles Capacity w/in Inundated Area at Onset of Flood	Total Low Clearance Vehicles	Total High Clearance Vehicles
Sunny-Day	110	30	0.2	4.6	0.011	0.005	0.005
PMF NDF	0	0	0.0	0.0	0.000	0.0	0.0
PMF Hydrologic	0	0	0.0	0.0	0.000	0.0	0.0

Event	PAR	Estimated Direct Fatalities
Sunny-Day	0.02	0.0
PMF NDF	0.0	0.0
PMF Hydrologic	0.0	0.0

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Data Gaps and Next Steps

- Facility and vehicle occupancy statistics (AADT, etc.) are not available everywhere. Site-specific studies may be necessary at some locations.
- Results are sensitive to assumptions such as weather, season, and time of day.
- Case studies that provide detailed analysis of consequences to transient PAR (categorized, quantified, and separated clearly from structural PAR) during actual flood events could be used to assess whether results are reasonable.

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References

1. American Association of State Highway and Transportation Officials (AASHTO). 2011. *A Policy on Geometric Design of Highways and Streets.* 6th ed. Washington D.C.

2. Federal Emergency Management Agency (FEMA). 2004. *Hazard Potential Classification System for Dams (FEMA 333)*. Federal Guidelines for Dam Safety, April.

3. U.S. Army Corps of Engineers (USACE). 2020. *Hydrologic Engineering Center – LifeSim (HEC-LifeSim) Life Loss Estimation Technical Reference Manual, Version 2.0*.

4. U.S. Bureau of Indian Affairs (BIA). 2018. *DRAFT Safety of Dams Program Handbook: Division of Power – Branch of Dam Safety, Security, and Emergency Management, Publication 55 IAM-1H*.

5. U.S. Bureau of Reclamation (Reclamation). 1988. *Downstream Hazard Classification Guidelines*, Assistant Commissioner – Engineering and Research (ACER) Technical Memorandum No. 11, Assistant Commissioner – Engineering and Research, Denver, Colorado.

6. Reclamation. 2015. *RCEM – Reclamation Consequence Estimating Methodology*. Denver, CO. July.

7. Reclamation. 2020. *Assessing Lethality at Road Crossings*. Presentation given in Denver, CO.

8. U.S. Federal Highway Administration (FHWA). 2006. *Empirical Studies on Traffic Flow in Inclement Weather*. Publication No. FHWA-HOP-07-073

9. U.S. Fish and Wildlife Service (USFWS). 2020. Guidance on Estimating Life Loss from a Dam Failure on Highways.

Thank You

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