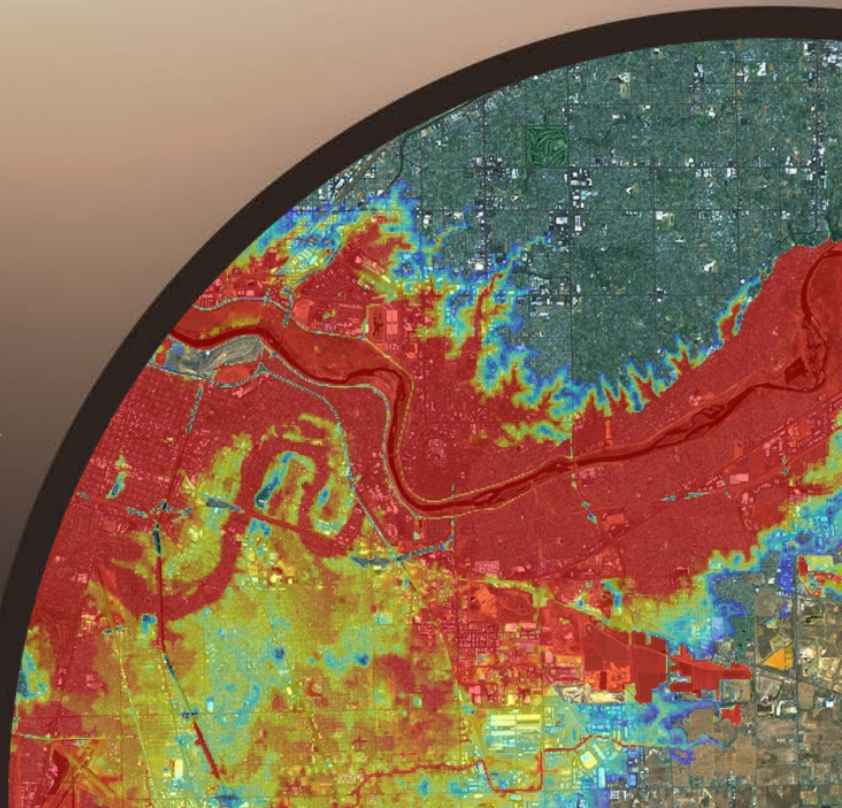
Best Practices in Dam and Levee Safety Risk Analysis

III-1. Consequences (Reclamation)

16 June 2015



RECLAMATION
Managing Water in the West

US Army Corps of Engineers
BUILDING STRONG®

Malpasset Dam – 1959, 400 to 500 Fatalities

Machhu II Dam – 1979, 10,000 Fatalities

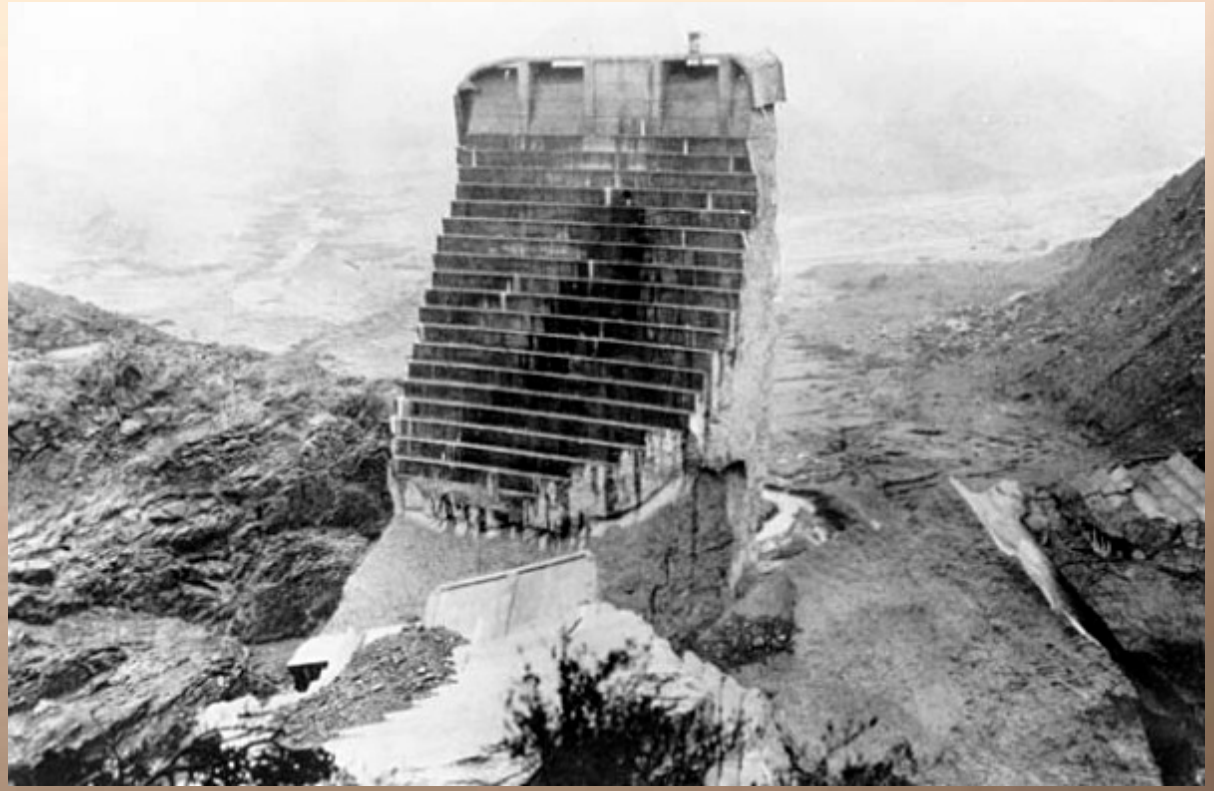
Laurel Run Dam – 1977, 41 Fatalities

Little Deer Creek Dam – 1963, 1 Fatality

Quail Creek Dike – 1989, 0 Fatalities

Selection of Scenarios
Based on Potential Failure Modes

- Static
- Hydrologic
- Seismic



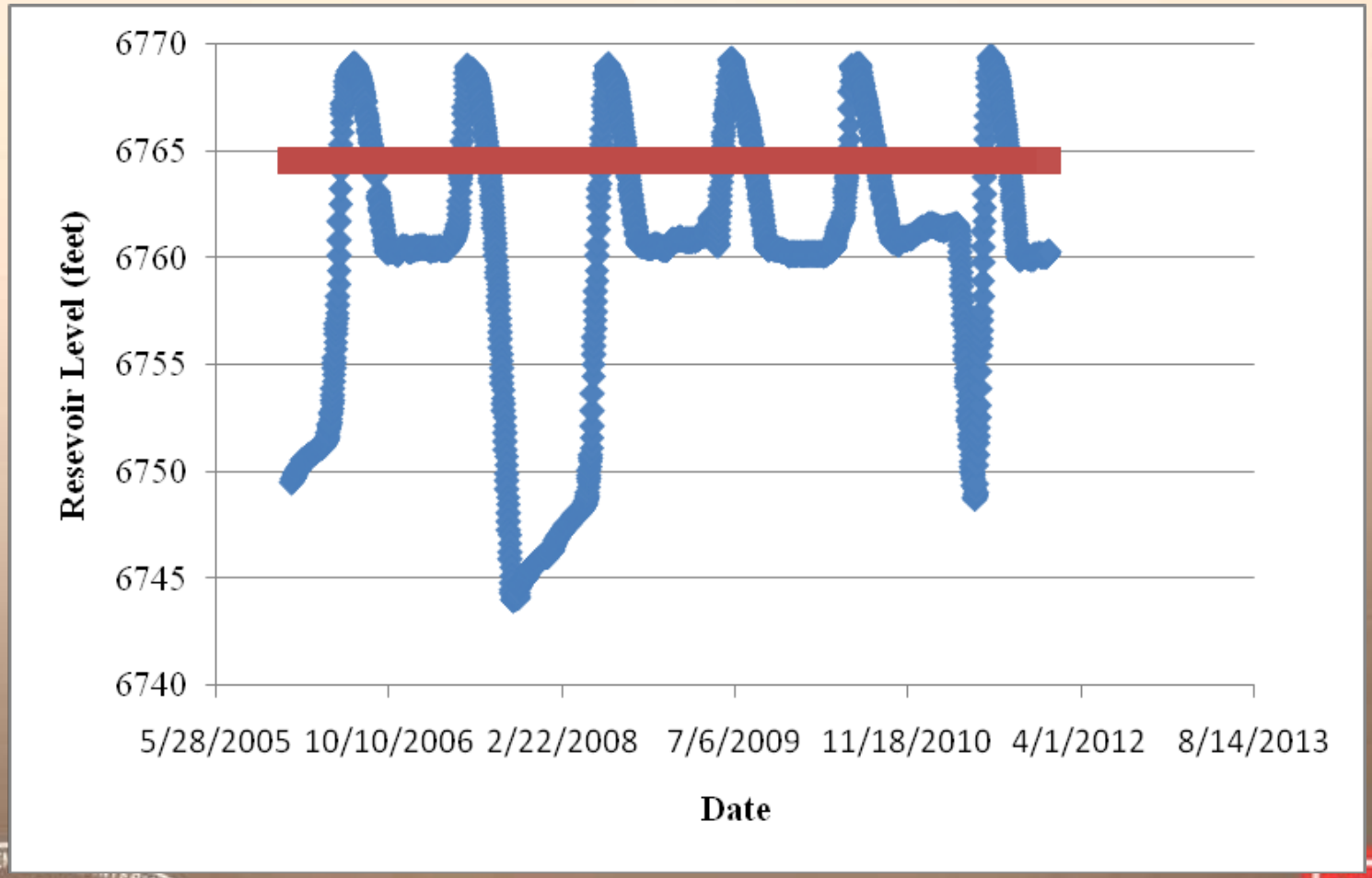
Sub-scenarios

- **Time of day - Typically, more fatalities have occurred during night time flood events, due to people sleeping, darkness, decreased ability to spread warning and a slower evacuation response.**

- **Weekday/Weekend - Recreational areas such as campgrounds, or along rivers where fishing or boating are popular, will see higher PAR number on weekends**

- **Seasonal Variation - Recreational (transient) PAR numbers may widely between summer and winter months.**

Sub-scenarios,
Seasonal Reservoir Variation



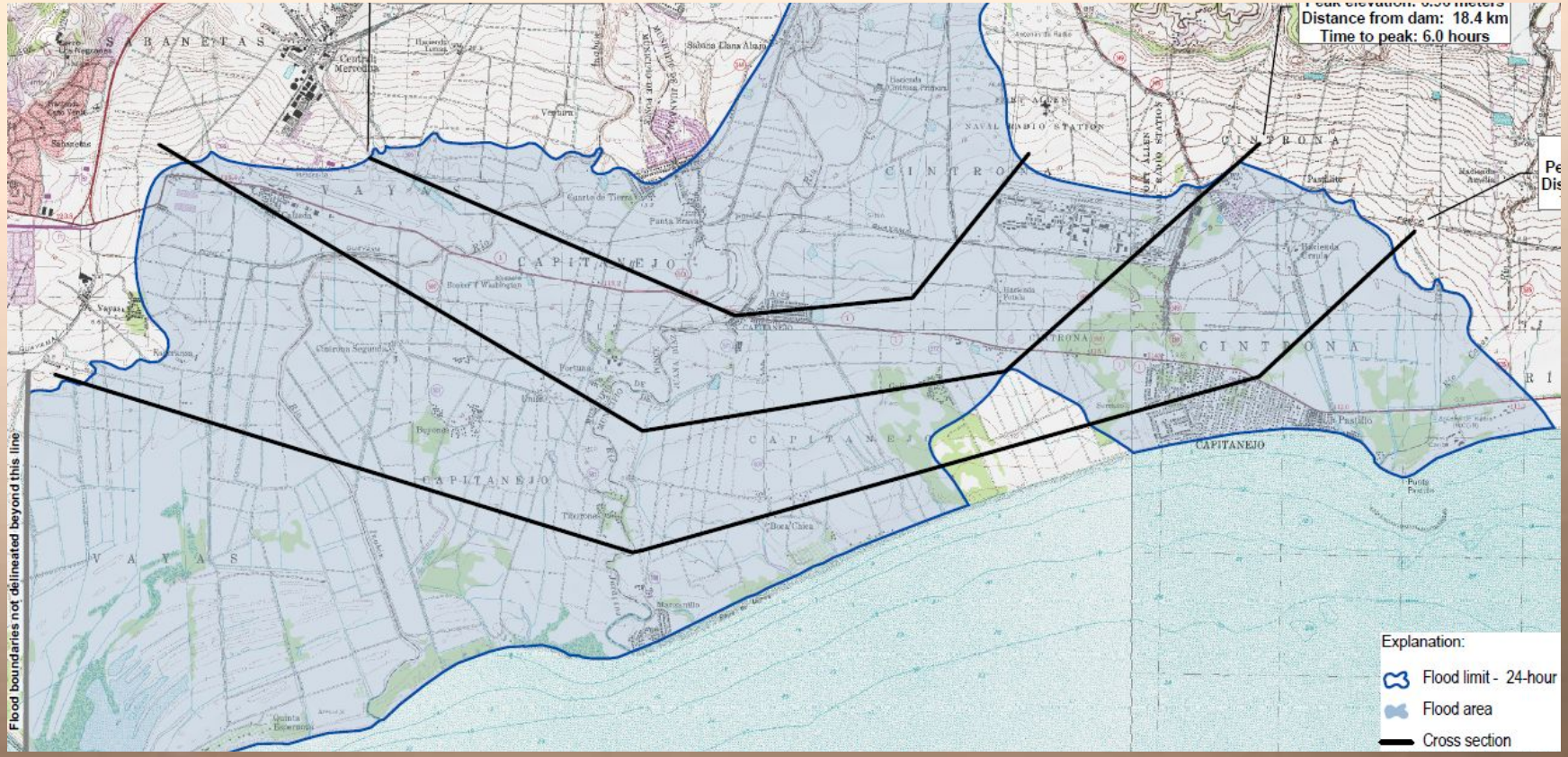
Inundation Modeling

- An important source of information for life loss estimation
- Flooded extent is used to estimate population at risk (PAR)
- Flood wave travel times can be used to estimate warning time
- Hydraulic parameters, depth and DV can be used to assess lethality of flooding

Can I use an existing inundation study for my risk analysis?

- Is the failure scenario similar to the desired scenario in terms of volume, timing and peak discharge?
- Are the breach parameters realistic based on knowledge of the dam?
- Is the modeling that was done appropriate for the downstream conditions? Would 2D modeling change the results significantly?
- In some cases, due to time and budget limitations, you may have no choice but to use the existing inundation study

Example of a 1D inundation study where 2D modeling is more appropriate and would likely change inundation results significantly



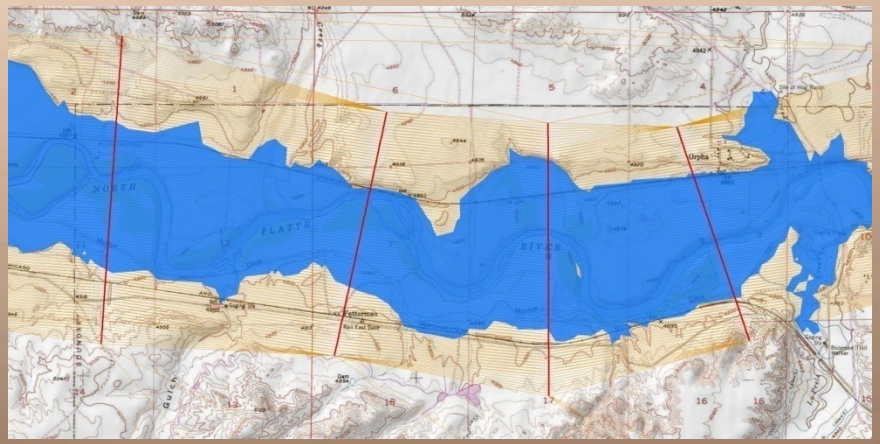
Breach Parameters:

Empirical, Site Specific, Physical-Based

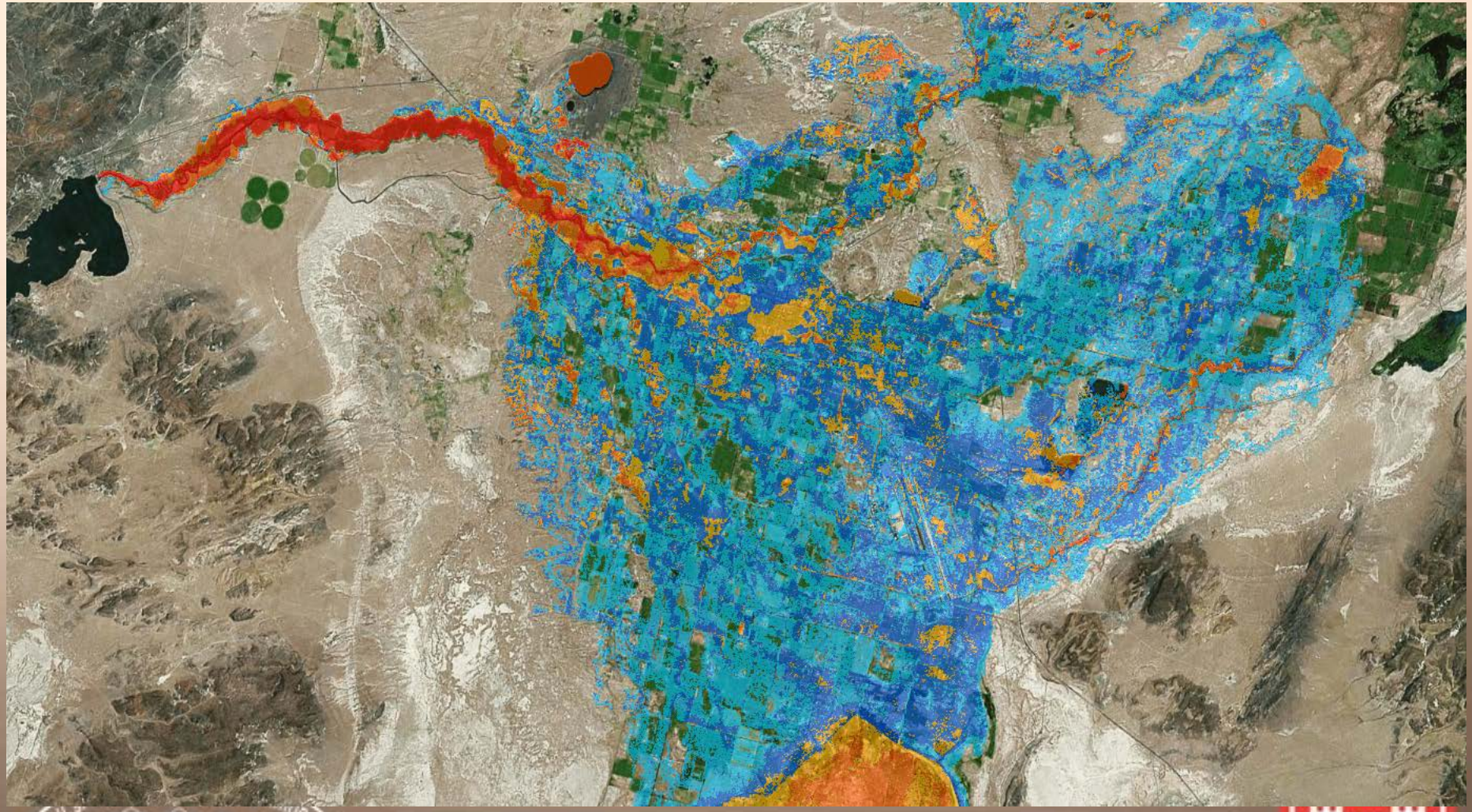
Reference	Number of Case Studies	Relations Proposed (S.I. units, meters, m^3/s, hours)
Johnson and Illes (1976)		$0.5h_d \le B \le 3h_d$ for earthfill dams
Singh and Snorrason (1982, 1984)	20	$2h_d \le B \le 5h_d$ $0.15\ m \le d_{ovtop} \le 0.61\ m$ $0.25\ hr \le t_f \le 1.0\ hr$
MacDonald and Langridge-Monopolis (1984)	42	Earthfill dams: $V_{er} = 0.0261(V_{out}*h_w)^{0.769}$ [best-fit] $t_f = 0.0179(V_{er})^{0.364}$ [upper envelope] Non-earthfill dams: $V_{er} = 0.00348(V_{out}*h_w)^{0.852}$ [best fit]
FERC (1987)		B is normally 2-4 times h_d B can range from 1-5 times h_d Z = 0.25 to 1.0 [engineered, compacted dams] Z = 1 to 2 [non-engineered, slag or refuse dams] t_f = 0.1-1 hours [engineered, compacted earth dam] t_f = 0.1-0.5 hours [non-engineered, poorly compacted]
Froehlich (1987)	43	$\overline{B}^* = 0.47K_o(S^*)^{0.25}$ K_o = 1.4 overtopping; 1.0 otherwise $Z = 0.75K_c(h_w^*)^{1.57}(\overline{W}^*)^{0.73}$ K_c = 0.6 with corewall; 1.0 without a corewall $t_f^* = 79(S^*)^{0.47}$
Reclamation (1988)		$B = (3)h_w$ $t_f = (0.011)B$
Singh and Scarlatos (1988)	52	Breach geometry and time of failure tendencies B_{top}/B_{bottom} averages 1.29
Von Thun and Gillette (1990)	57	B, Z, t_f guidance (see discussion)
Dewey and Gillette (1993)	57	Breach initiation model; B, Z, t_f guidance
Froehlich (1995b)	63	$\overline{B} = 0.1803K_oV_w^{0.32}h_b^{0.19}$ $t_f = 0.00254V_w^{0.53}h_b^{(-0.90)}$ K_o= 1.4 for overtopping; 1.0 otherwise

1D Modeling

- **Works best where the downstream reaches are well defined**
- **Long river reaches are easily accommodated**
- **Downstream hydraulic structures such as dams, culverts, bridges can be easily handled**



2D Inundation Modeling

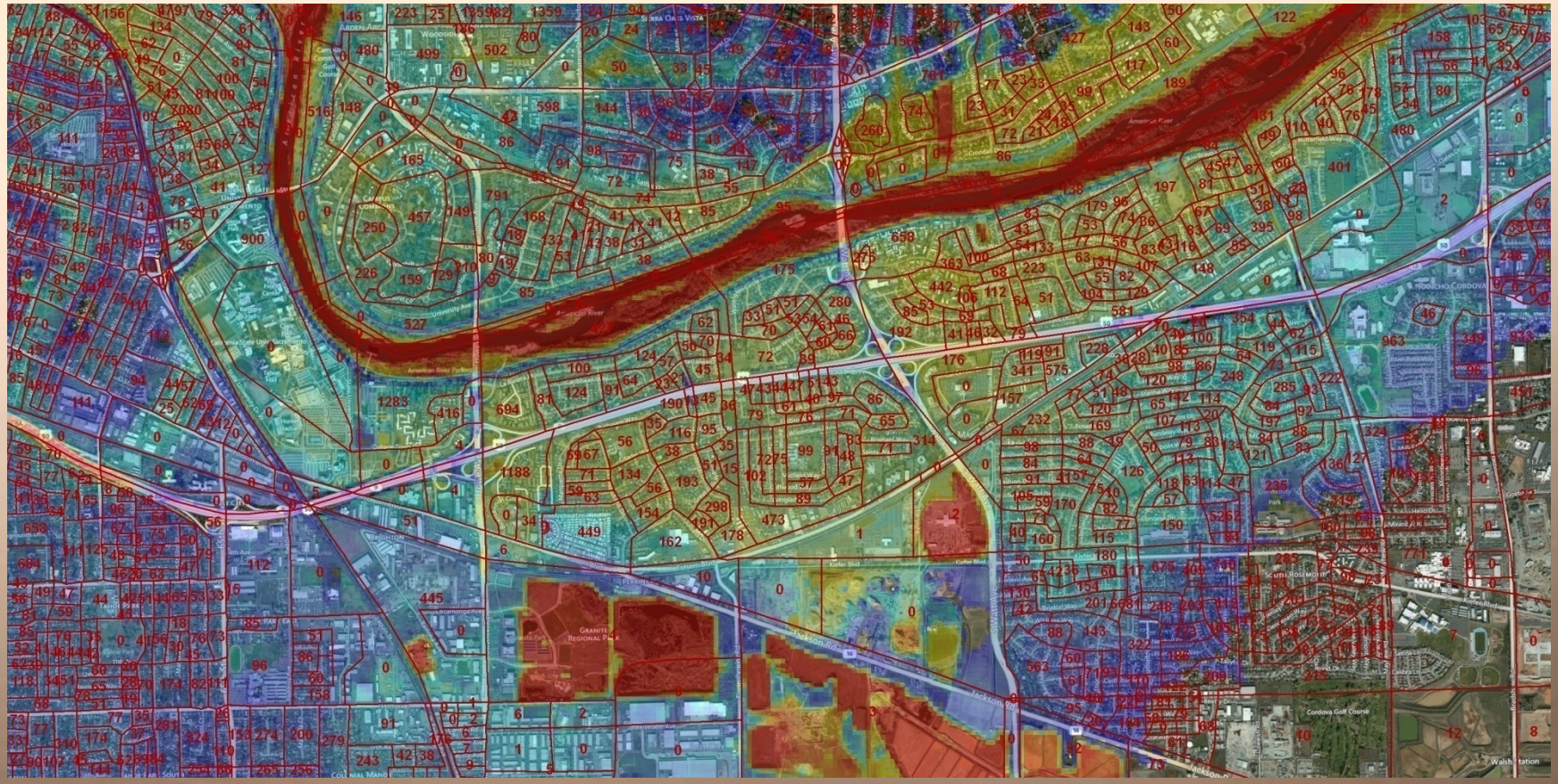


Estimation of Downstream PAR

- PAR is often assumed to be residential PAR

- At a very basic level, PAR can be estimated by counting houses in the inundation zone, either during a site visit, or with online maps (Google, MapQuest), or by overlaying the flood inundation boundary with ortho photos in ArcGIS

A standard method of PAR estimation is to overlay the inundation boundary with census block data



Recreational (Transient) PAR

- Campgrounds, fishing, boating, hiking, etc.
- May have seasonal and weekday/weekend variation
- Estimates can be made by field visits and by obtaining usage data from land managers

Agency-Specific Tools

USACE

- Hazus MH – Census data contained within this model offers estimates of population by census block as well as estimates of structure type and construction

Reclamation

- Tessel – Web based GIS application that contains a database of all inundation polygons for Reclamation dams. A built in census block tool allows “on the fly” reconnaissance level estimation of PAR

Issuance of Warning

Can be broken into stages:

- Detection of the threat - failure or impending failure must be verified
- Decision to issue warning - liability and public trust issues
- Notification of the downstream PAR - different ways that warning can be issued
- Warning dissemination – how will warning spread through downstream areas?

Effectiveness of Warning

- Will the warning be strong and forceful or will it be weak?
- Will people receiving warning take it seriously?
- Will everyone receive the warning?
- Generally warning is more effective during the day than at night

Warning and Evacuation

- Case histories have shown that potential for fatalities generally decrease as distance increases from dam
- Flood wave travel times can be used as a basis for warning time in cases where warning is not issued prior to dam failure

Evacuation

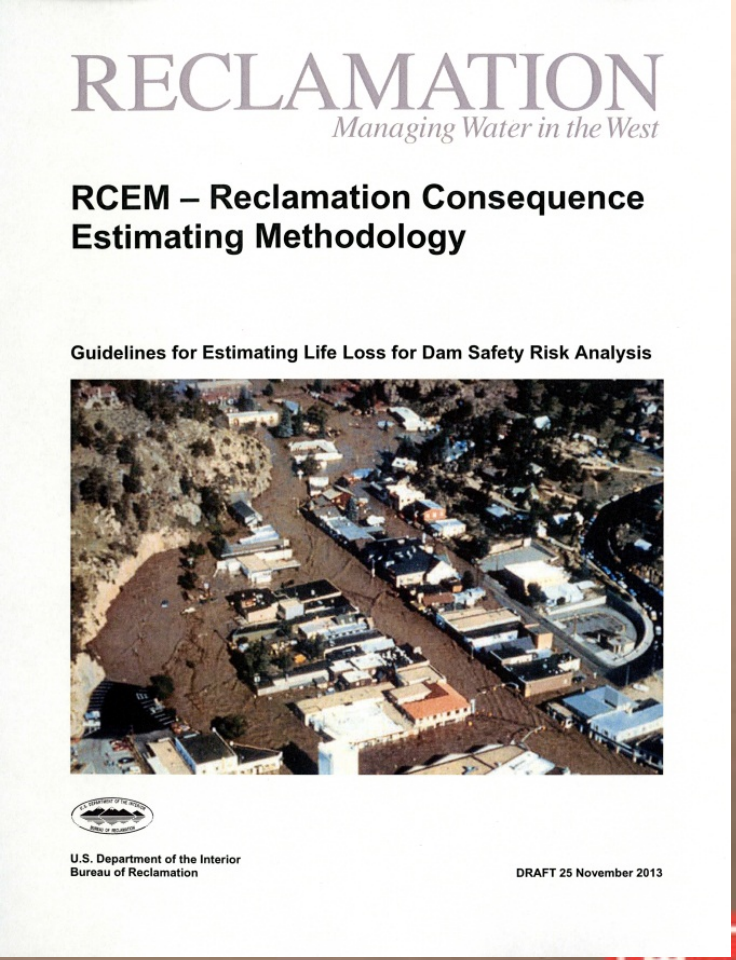
- Will people know where to go?
- Will they have the means to evacuate?
- Would traffic congestion be an issue?
- Some people will delay evacuation
- Some may choose not to evacuate at all

Flooding Intensity and Fatality Rate

- Flood depths and DV have a huge effect on fatality rate
- Deeper depths can make evacuation on foot impossible, submerge roads, float cars and mobile homes, and make structures uninhabitable
- High DV values may destroy all types of structures and can be a measure of lethality

Reclamation Consequence Estimating Methodology (RCEM)

- **An empirical-based methodology**
- **A revision to the DSO-99-06 method previously used by Reclamation**



RECLAMATION
Managing Water in the West

RCEM – Reclamation Consequence Estimating Methodology

Guidelines for Estimating Life Loss for Dam Safety Risk Analysis

U.S. Department of the Interior
Bureau of Reclamation

DRAFT 25 November 2013

Structure of Documents

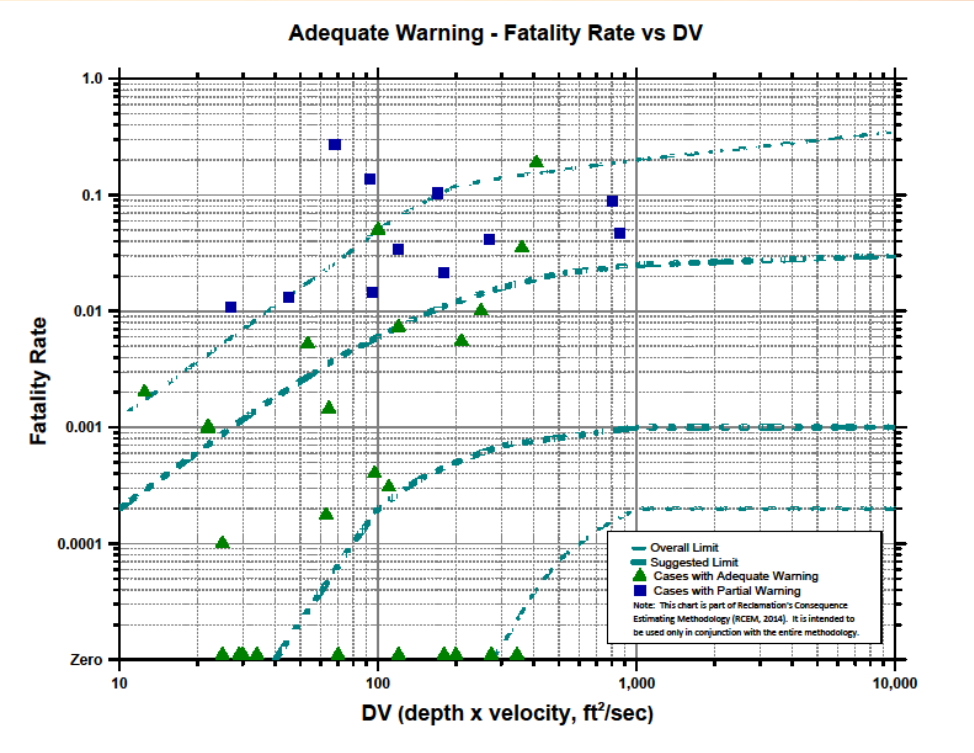
- RCEM – Reclamation Consequence Estimating Methodology, Dam Failure and Flood Event Case History Compilation
- RCEM – Reclamation Consequence Estimating Methodology, Guidelines for Estimating Life Loss for Dam Safety Risk Analysis
- RCEM – Reclamation Consequence Estimating Methodology, Examples of Use
- Fourth Document – Numerical Modeling (Life Safety Model)

Rationale for RCEM

- RCEM is based on about 60 case histories (including the 40 case histories used to develop DSO-99-06); case histories were screened for data quality
- Case histories provided limited to no data on evacuation rates; but evacuation can be considered indirectly in selection of fatality rates
- RCEM encourages the use of case history data to select and support fatality rates

Rationale for RCEM

- **Fatality rates ranges are estimated, based on warning time, intensity of flooding (DV) and other factors**

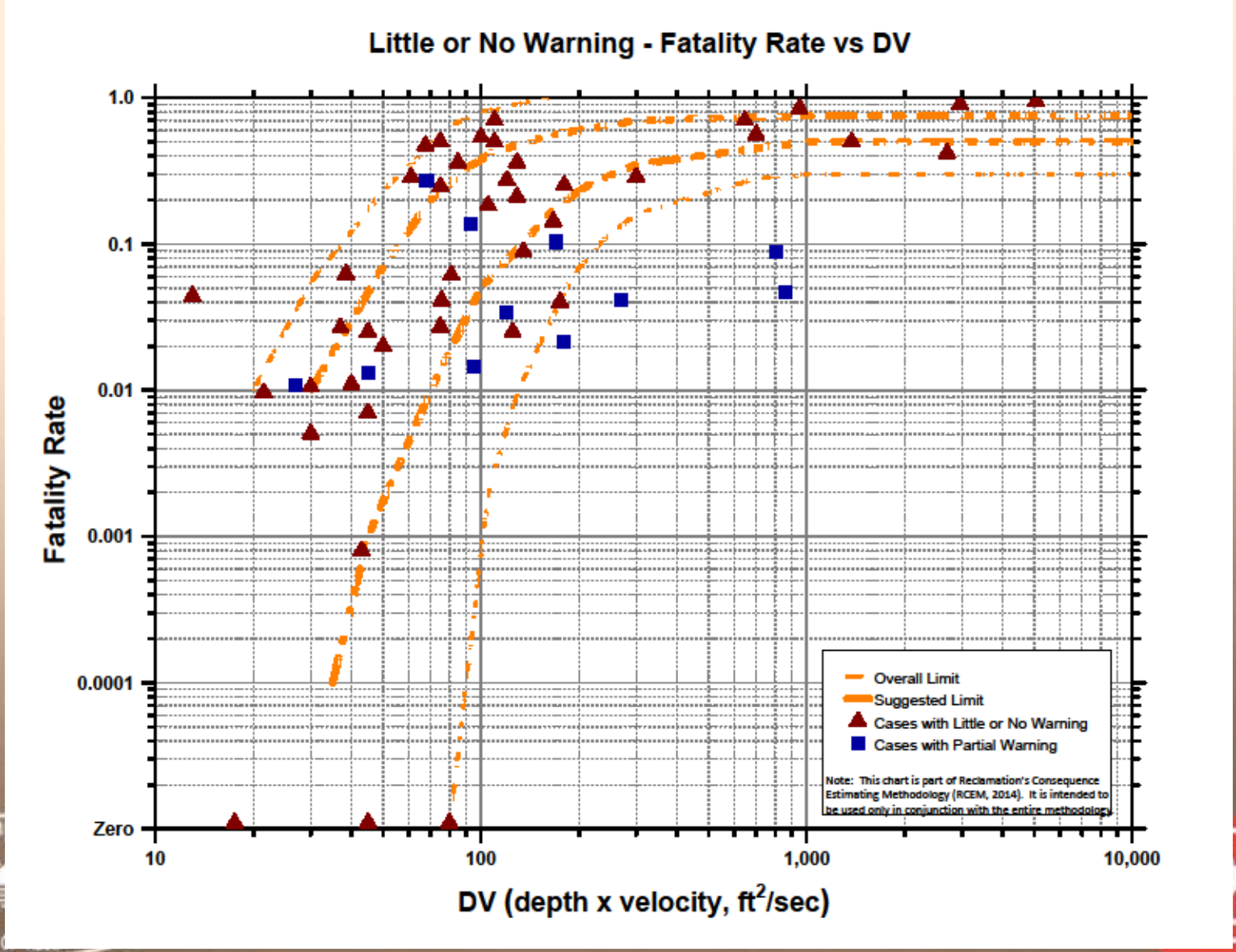


Overview of the Methodology

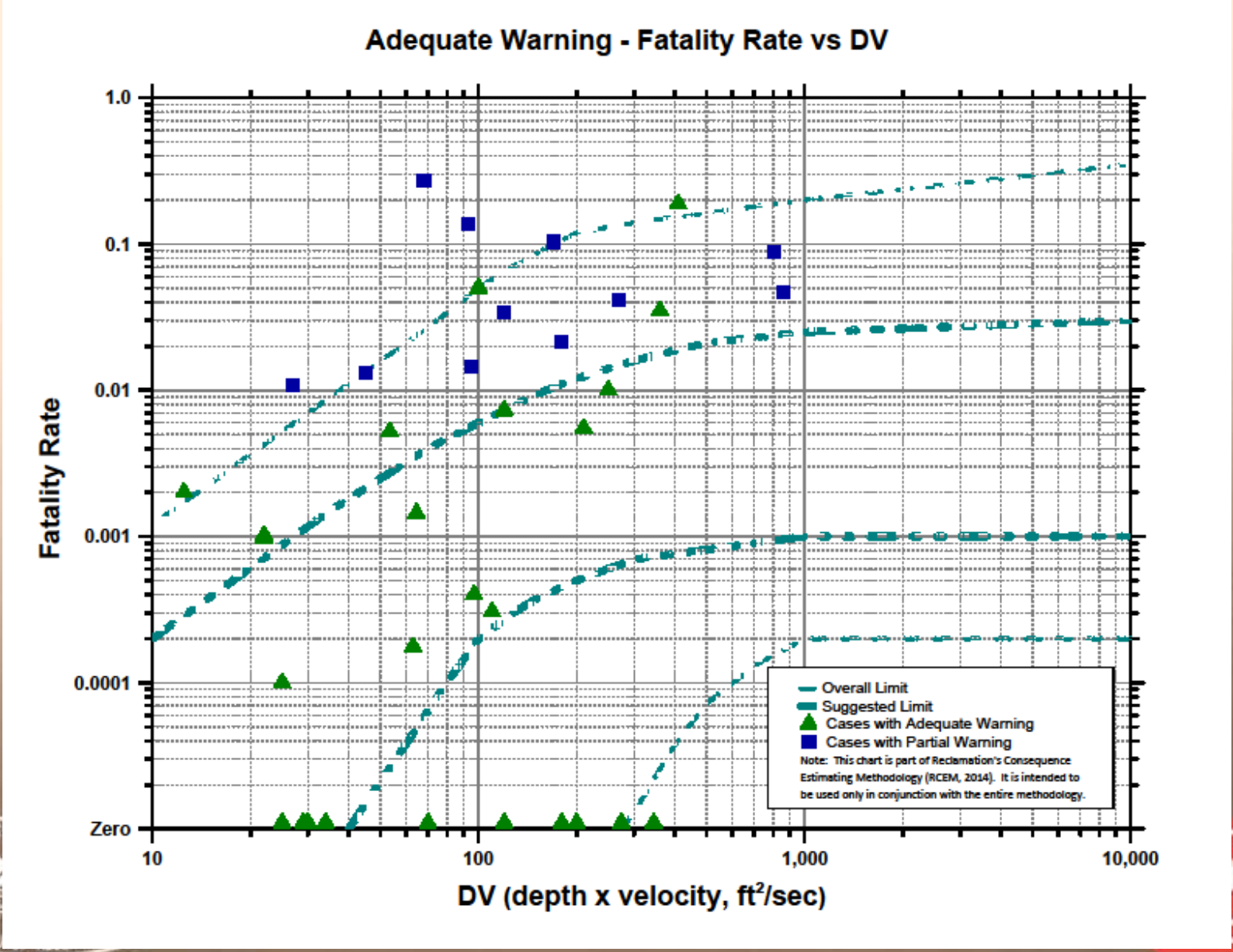
How does RCEM work?

- RCEM is empirical, and relies on data from actual cases of dam breach and natural flood events
- Ranges of fatality rates are estimated based on assumed ranges of warning time and DV
- Fatality rates are applied to the Population at Risk (PAR) within various sub-reaches to develop estimated ranges of life loss

Fatality Rates for Little or No Warning RCEM 2014



Fatality Rates for Adequate Warning RCEM 2014



RCEM Steps for Estimating Life Loss

1. Select dam failure scenarios (e.g. sunny day, flood, etc.) corresponding to dam potential failure modes
2. Select appropriate time categories (e.g. day/night, seasonal, weekend/weekday, etc.)
3. Review/evaluate flood inundation mapping and define appropriate reaches or areas
4. Estimate flood severity range (i.e. DV range) for the flooded areas. Some towns/river reaches may include multiple ranges of DV. Justify the estimates.

RCEM Steps for Estimating Life Loss

5. Estimate the population at risk (PAR) within each reach. Justify the estimates.
6. Estimate when dam failure warnings would be initiated . Estimate the warning time category for flooded areas (e.g. little to no warning, adequate warning, or between the two). Justify the estimates.
7. For each PAR reach, estimate an appropriate fatality rate range based on flood severity, warning time and other considerations. Justify the estimates.

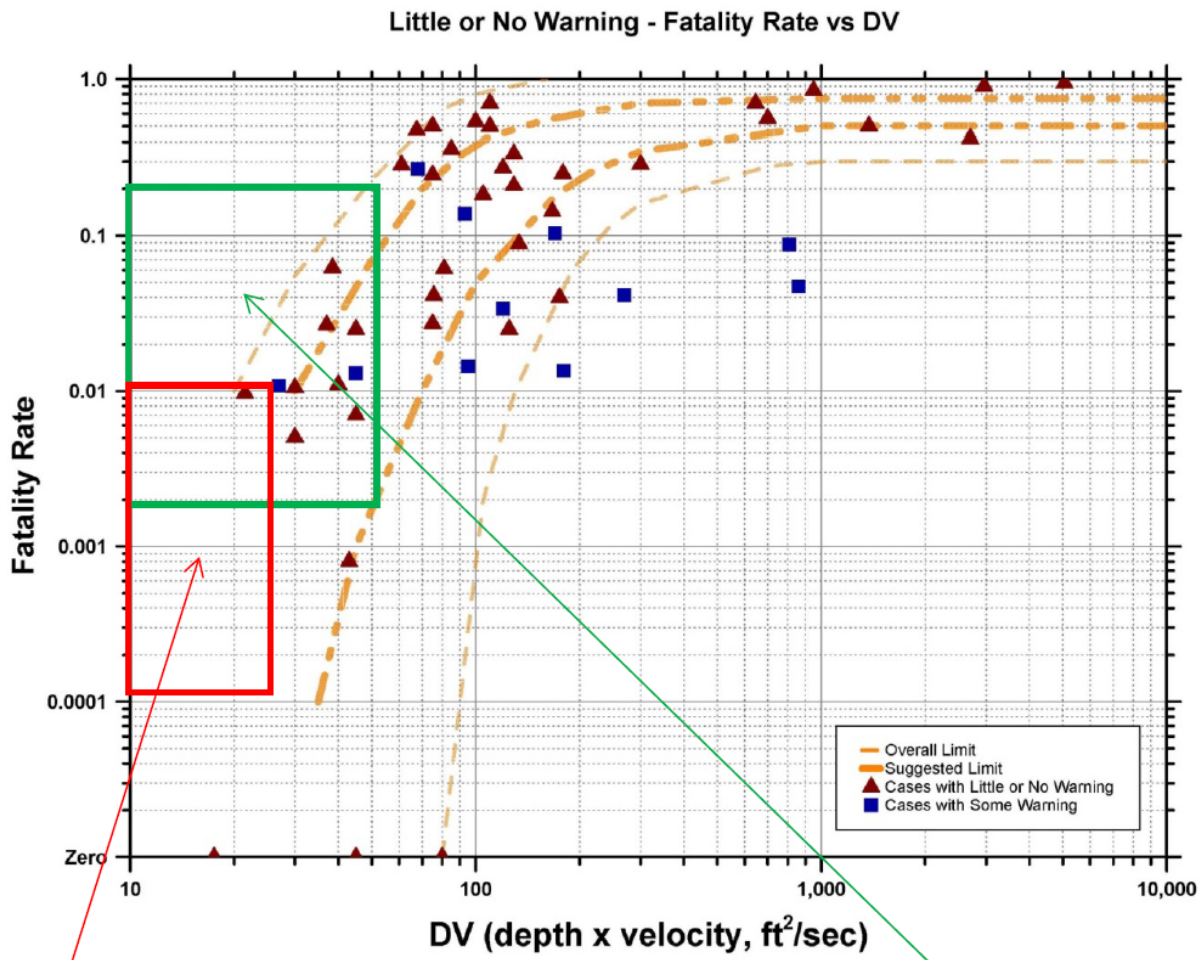
RCEM Steps for Estimating Life Loss

8. Estimate life loss range for each PAR reach. Sum the life loss estimates for each PAR to get the total estimated life loss range. Estimate life loss range for different dam failure scenarios.
9. Evaluate how uncertainties and variability affect overall range of life loss estimates. Perform sensitivity studies if needed.
10. Build the case for the life loss estimates by documenting all assumptions and references used. Discuss confidence in the life loss estimates.

Considerations for Selecting Fatality Rates

- Consider vulnerability of PAR
  - Sheltered in homes versus camping in tents or driving in autos
  - Knowledge of threat (locals versus tourists, warning adequacy)
  - Demographics (elderly, school children, reluctants)
- Amount of warning
  - Many hours or days in some cases versus 60 minutes
  - Adequacy of emergency management capabilities
  - Constraints to evacuation
- Adequacy of inundation model
  - Appropriate for the PFM being considered
  - 1D versus 2D
  - Reasonableness of breach parameters

Example of Fatality Rate Selection



No warning case for permanent residents
DV estimated to range from 5 to 25 ft^2/s
Fatality rate estimated to range from 0.0001 to 0.01
"Suggested Limits" generally assumed for fatality rate

No warning case for automobile PAR
DV estimated to range from 10 to 50 ft^2/s
Fatality rate estimated to range from 0.002 to 0.2
Upper portion of curve assumed for fatality rate
(given vulnerability of automobiles in flood)

Considerations when Using RCEM 2014

- Compare your dam to the case histories
- Use judgment
- Recognize that DV values may vary
- Employ sensitivity studies
- Portray life loss as a range
- Utilize a team approach

RCEM Documents

Available on Reclamation Internet:

- **http://www.usbr.gov/ssle/damsafety/references.html**