RECLAMATION

Managing Water in the West

RCEM – Reclamation Consequence Estimating Methodology

Interim

Examples of Use

U.S. Department of the Interior
Bureau of Reclamation

June 2014

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Introduction

This document is intended to be used in conjunction with two other companion documents dealing with the estimation of life loss resulting from dam failure. A number of case histories involving natural floods and dam failure floods are summarized in the *Dam Failure and Flood Event Case History Compilation* [1]. Reclamation's 2014 methodology for estimating life loss, primarily rooted in empirical interpretation of dam failure and flood case histories, is outlined in *Guidelines for Estimating Life Loss for Dam Safety Risk Analysis* [2].

General Usage

There is large uncertainty inherent in the estimation of life loss resulting from dam failure. There are large possible variations in the development and progression of breach flows, as well as numerous potential ways that the downstream public receives warning (if any) and the manner in which they respond to warning. The *Case History Compilation* [1] is an excellent reference that illustrates the wide range of possible outcomes from dam failure, ranging from no fatalities to thousands of lives lost. Both the *Case History Compilation* and this document are intended to reflect the variability associated with life loss, as well as encourage the use of judgment in considering the many variables associated with estimating life loss. Lessons learned from the case histories show that a wide range of fatality rates are possible, and thus a range of life loss should be portrayed rather than single point values. The examples contained herein reflect this approach.

Description of Examples

A variety of examples were chosen to show many of the different situations that may arise when estimating life loss at a given facility. This document contains a number of different situations frequently encountered in Reclamation dam safety evaluations. In fact, the examples are based on Reclamation facilities that have been modified or adjusted as needed to demonstrate key aspects of the methodology. The examples illustrate consequence estimation based on different types of inundation data, which can range from highly detailed two-dimensional (2D) hydraulic studies to one-dimensional (1D) studies produced during the early 1980s that may contain minimal information.

A brief description of each example in this document is included below. The examples illustrate how Reclamation's 2014 methodology can be used under a variety of situations. Three of the examples provided here are generally basic and not overly complex, and represent the type of documentation that would be provided as a chapter in a Comprehensive Review (CR) report. A fourth example (Example Dam 2) is more complex and represents a greater level of study; it is intended to serve as an example of an Issue Evaluation (IE) document. Ideally, when estimating life loss for a facility, one (or more) of these examples may have aspects similar to the dam being evaluated, and thus may provide some insight on the issues to consider and a possible approach to be utilized.

Example Dam 1 – CR-level
This first example represents a relatively average size embankment dam and reservoir that has all three basic failure scenarios: static, hydrologic, and seismic. Available data consist of an older, 1980s-vintage inundation study and maps with somewhat limited information on inundation depths and velocities. The downstream population at risk (PAR) consists almost solely of permanent residents, including a town of roughly 5,000 inhabitants located only 6.5 miles downstream from the dam. The inundation area extends for more than 70 miles, and features varying levels of flood severity (as measured by DV values). Estimated life loss for the different scenarios ranges from less than ten to many hundreds.

Example Dam 2 – IE-level
This example features a large embankment dam (250 feet high) with a reservoir of 125,000 ac-ft. The credible failure modes include a static internal erosion potential failure mode and a hydrologic overtopping potential failure mode. A modern inundation study was performed that included one-dimensional modeling in the canyon immediately downstream of the dam and two-dimensional modeling at the mouth of the canyon, where the river widens and passes through a well-developed city starting about 10 miles downstream of the dam. The downstream PAR is concentrated, with up to about 1,000 people (residential and recreational) in the canyon and about 12,000 residential PAR in the city. DV values are high in the canyon and variable in the city. Estimated life loss is variable because of the significant difference in warning time between the two potential failure mode (PFM) scenarios. The life loss estimate ranges from 3 to 25 for the flood overtopping PFM and about 200 to 1200 for the static internal erosion PFM.

Example Dam 3 – CR-level
This example features a concrete gravity dam that would likely fail rapidly with a peak breach outflow of up to 500,000 ft^3/s. The inundation study was conducted in 1987 and the 1D study considered failure and non-failure of the dam during the PMF. The PAR in the first 8 miles downstream of the dam consists of scattered rural residences, dude ranches and numerous campgrounds. A community with an estimated PAR of 1700 people is located about 36 miles downstream and includes about 70 percent of the total PAR. Sunny day failure modes (which could include during either static or seismic conditions) and a hydrologic potential failure mode were estimated. DV values are indicative of medium to high flood severity. Seventy five to eighty percent of the life loss is estimated to occur in the first 8 miles downstream of the dam even though this reach only contains about 10 percent of the total PAR, due to limited warning time. Estimated mean loss of life ranges from about 40 to 160 people.

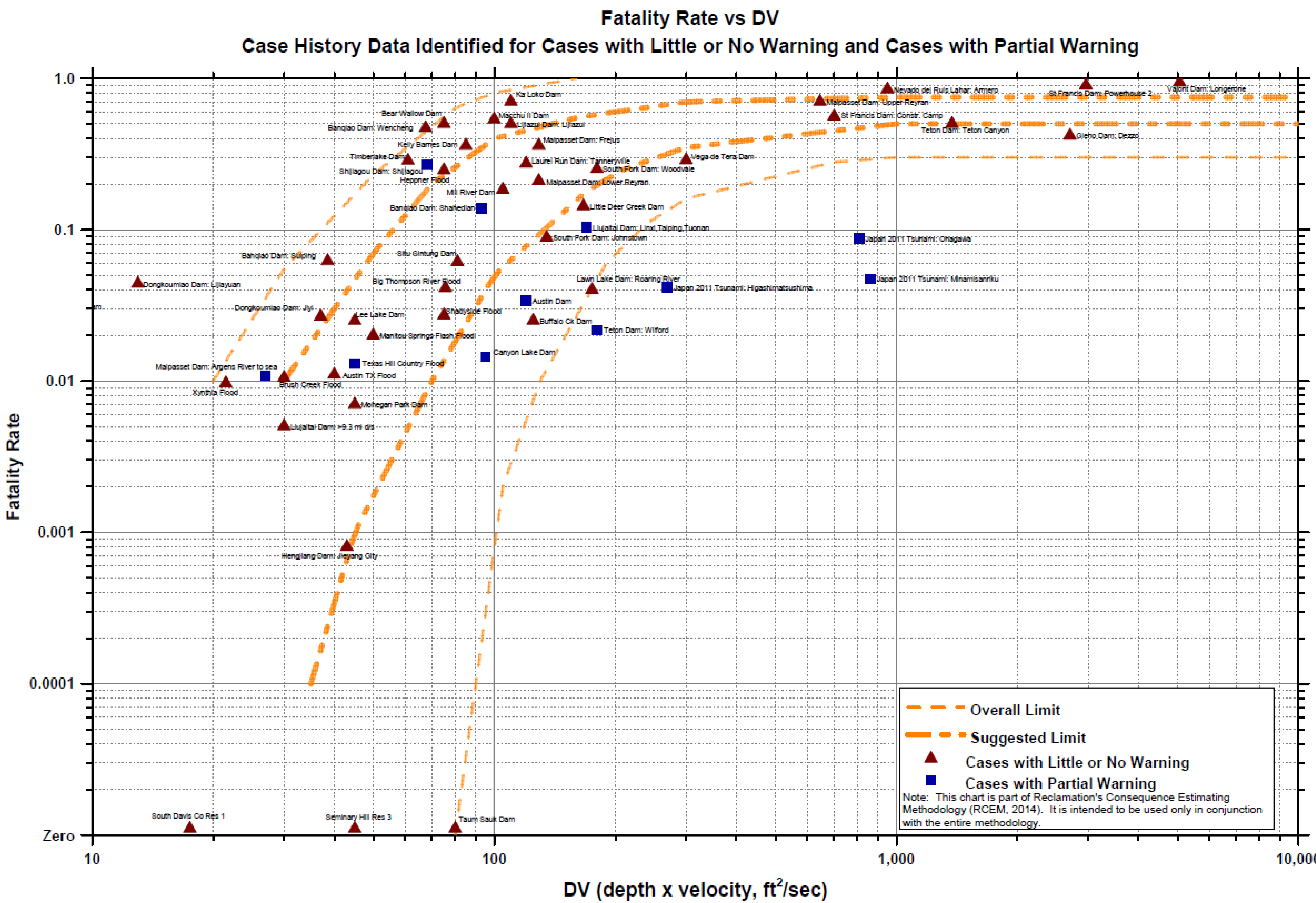
Example Dam 4 – CR-level
This example features a large embankment dam (225 feet high) with a reservoir of 125,000 ac-ft. The credible failure modes are sunny day internal erosion potential failure mode and a hydrologic internal erosion potential failure mode. A 1982 inundation study was available, and was based on the dam failure occurring with the reservoir at the top of the flood storage. Failure of Example Dam 4 would cause the failure of a downstream dam. The downstream PAR was residential and ranges from about 4000 to 5000 people. DV values were greater than 170 for all downstream reaches considered. Estimated life loss averages for the different PFMs ranged from 3 to about 100 people.

Format of Examples

Three examples included in this document each follow a similar template, which is based on a typical write-up for a Consequence section in a Comprehensive Review report. Ideally, sufficient information is portrayed in each example section or paragraph to clearly indicate the assumptions or rationale for each step, and show how the life loss estimate was derived. For higher level evaluations, additional detail and discussion is typically necessary. The Issue Evaluation example represents such an expanded write-up.

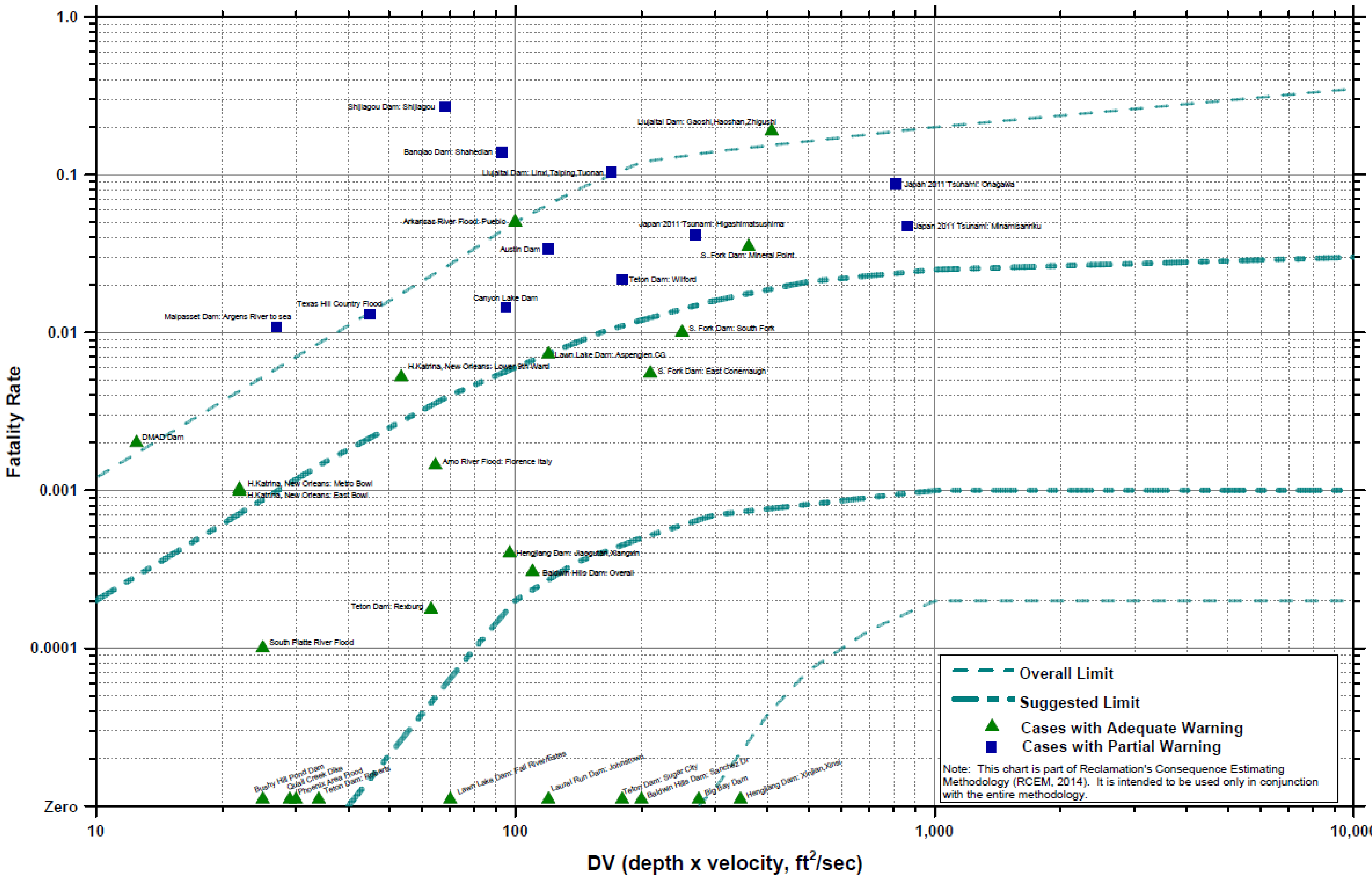
Graphical Approach

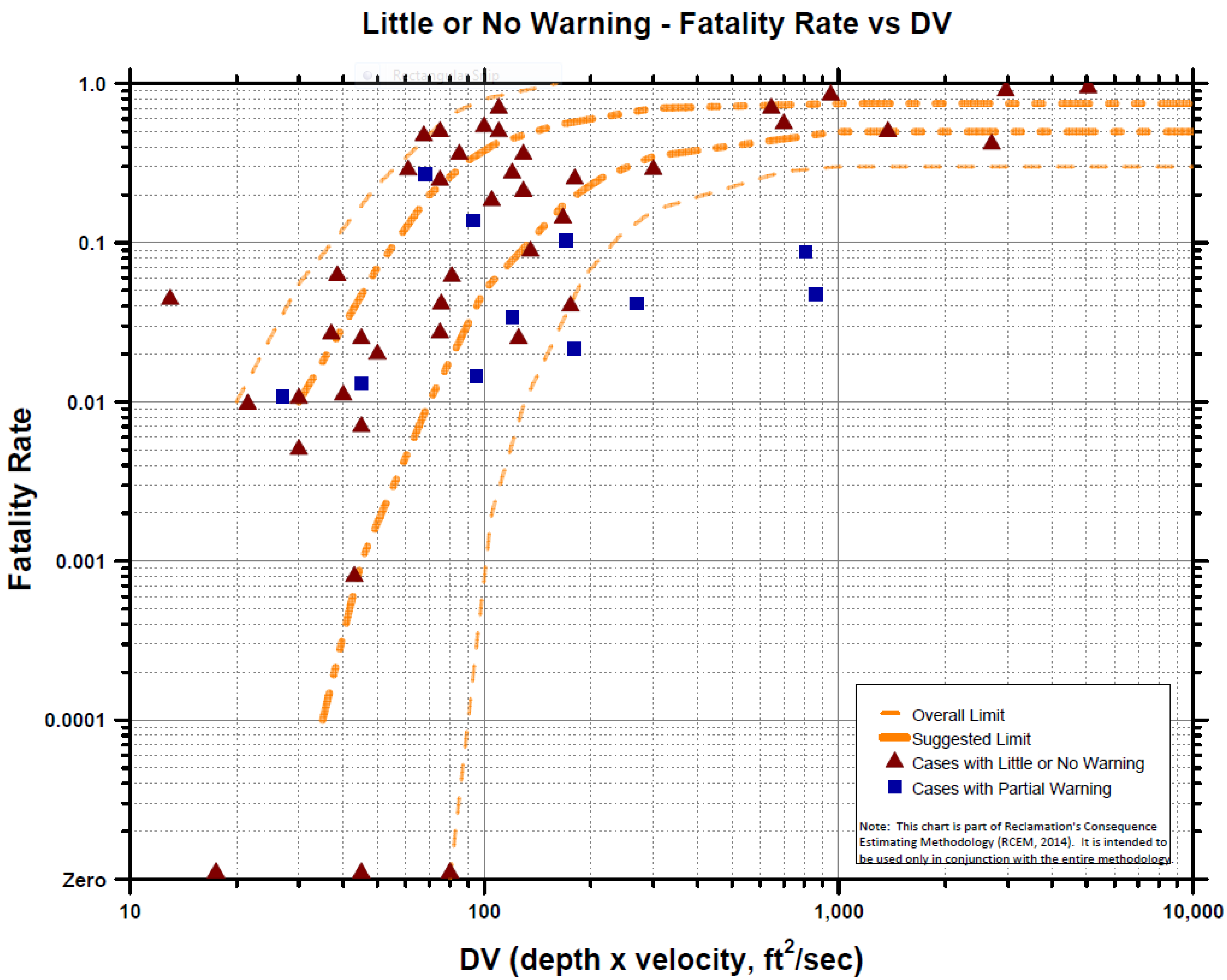
For reference in the following examples, the graphs for fatality rates versus DV as portrayed in Reclamation's 2014 methodology document [2] are repeated below. The two 11x17 figures on the following pages show both the suggested and overall fatality rates in addition to showing the labeled case history points used to develop the curves. The additional 8.5x11 figures are the same curves but without the case history points labeled (which can be copied and used for plotting values at any facility being evaluated).

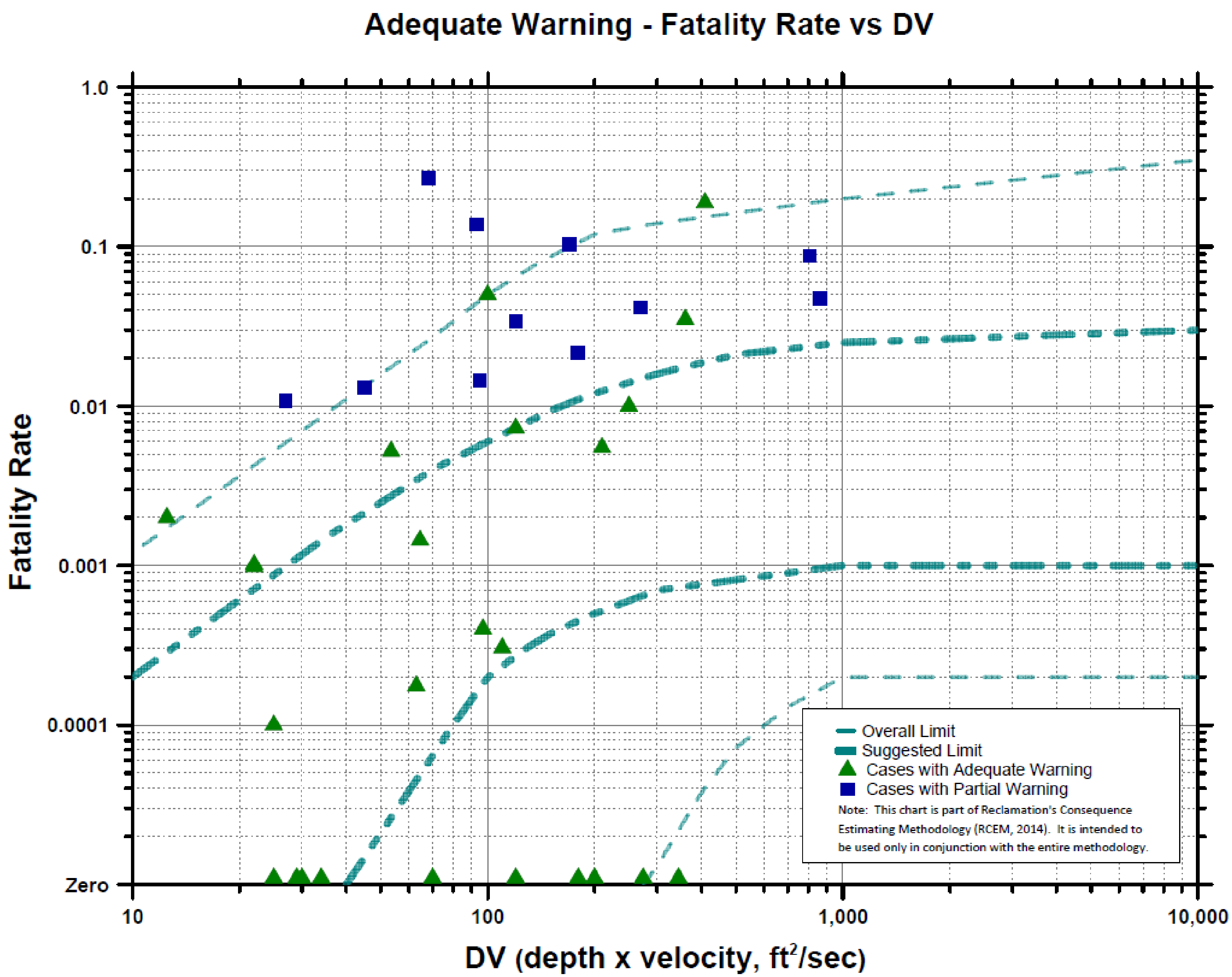

Fatality Rate vs DV
Case History Data Identified for Cases with Little or No Warning and Cases with Partial Warning
Fatality Rate
DV (depth x velocity, ft²/sec)
1.0
0.1
0.01
0.001
0.0001
Zero
10
100
1,000
10,000
Overall Limit
Suggested Limit
Cases with Little or No Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.
Nevado del Ruiz Lahar: Armero
St Francis Dam: Powerhouse 2
Vajont Dam: Longerone
Ka Loko Dam
Malpasset Dam: Upper Reyran
St Francis Dam: Constr. Camp
Teton Dam: Teton Canyon
Gleno Dam: Dezzo
Bear Wallow Dam
Machu II Dam
Banqiao Dam: Wencheng
Lijiazui Dam: Lijiazui
Malpasset Dam: Frejus
Kelly Barnes Dam
Timberlake Dam
Laurel Run Dam: Tanneryville
Vega de Tera Dam
Shijiagou Dam: Shijiagou
South Fork Dam: Woodvale
Heppner Flood
Malpasset Dam: Lower Reyran
Mill River Dam
Banqiao Dam: Shahedian
Little Deer Creek Dam
Liujiatai Dam: Linxi,Taiping,Tuonan
South Fork Dam: Johnstown
Japan 2011 Tsunami: Onagawa
Banqiao Dam: Suiping
Situ Gintung Dam
Dongkoumiao Dam: Lijiayuan
Big Thompson River Flood
Lawn Lake Dam: Roaring River
Japan 2011 Tsunami: Minamisanriku
Japan 2011 Tsunami: Higashimatsushima
Austin Dam
Dongkoumiao Dam: Jiyi
Lee Lake Dam
Shadyside Flood
Buffalo Ck Dam
Manitou Springs Flash Flood
Teton Dam: Wilford
Canyon Lake Dam
Malpasset Dam: Argens River to sea
Texas Hill Country Flood
Austin TX Flood
Xinthia Flood
Brush Creek Flood
Mohegan Park Dam
Liujiatai Dam: >9.3 mi d/s
Hengliang Dam: Jieyang City
South Davis Co Res 1
Seminary Hill Res 3
Taum Sauk Dam

Fatality Rate vs DV

Case History Data Identified for Cases with Adequate Warning and Cases with Partial Warning




Little or No Warning - Fatality Rate vs DV
Fatality Rate
1.0
0.1
0.01
0.001
0.0001
Zero
10
100
1,000
10,000
DV (depth x velocity, ft2/sec)
Overall Limit
Suggested Limit
Cases with Little or No Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.


Adequate Warning - Fatality Rate vs DV
1.0
0.1
0.01
0.001
0.0001
Zero
Fatality Rate
10
100
1,000
10,000
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.

Uncertainty and Variability

Estimates of loss of life entail both uncertainty and variability. Uncertainty in the life loss estimate occurs because of the rather large uncertainty in fatality rates for a given failure scenario, and to a lesser extent uncertainty in the hydraulic modeling of the breach outflow. Variability occurs because fatality rates are very sensitive to warning times (particularly in the first few miles below the dam), time of day and year, infrastructure damage that could result from an earthquake severe enough to cause failure of the dam, etc. It is not appropriate to represent the loss of life from a given PFM as a single "point" estimate. Rather, life loss estimates should consider several different warning scenarios and their relative likelihood. Something as apparently minor as the weather or the day of the week could have a major effect, because they could govern whether recreationists are present along the river, or whether the dam tender is scheduled to visit the site on the day of or the day before failure, or not until the following week. Several of the examples in this report include more than one possible warning scenario, and calculation of a weighted average. Example probability distribution functions to represent the overall uncertainty in the life loss range are included in Example Dam 2, the Issue Evaluation example.

Examples

The following sections give several examples of how the 2014 empirical approach can be used to estimate life loss in the event of dam failure. As previously discussed, life loss estimation can be very complicated and contain a great deal of variables, and no template exists to cover every situation. In some situations it may be more appropriate to discuss DV and flood severity before defining reaches and PAR, while in other cases discussion of geographic reaches and PAR can be followed by discussions of DV and flood severity. The examples do provide techniques, strategies, and considerations that should be considered for any specific life loss estimation.

Example Dam 1 (CR-level evaluation)

I. General

Example Dam 1 is a zoned embankment dam with a height above streambed of 130 feet and a crest length of nearly 2,000 feet. It impounds a reservoir of approximately 50,000 acre-feet. It is a multi-purpose facility with a reservoir level that fluctuates only about 20 feet or less in a given year.

Failure of this dam would result in a flood that would travel down Little Creek and enter Big River just downstream of the city of Pleasantville. Flood waters would inundate rural areas between the dam and the city of Pleasantville, about 6.5 miles downstream from the dam. The area between the dam and Pleasantville consists of a day-use/picnic area, an 18-hole golf course and about 42 residences. The city of Pleasantville has an approximate population of 5,000. The damage to the upstream rural area and the city of Pleasantville could be severe due to the close proximity to the dam and the expected large flows through this area. Flood waters would then enter the Big River just downstream of the downtown area of Pleasantville, raising the Big River and backing it upstream for about a mile and a half. Downstream of Pleasantville on the Big River the flood flows would be mostly contained within the banks of the main river channel, with some flooding of the towns of Sunnydale, Happy Valley, Mayberry, Beanville, and Shipwreck.

An inundation study using 1D hydraulic modeling was performed in 1989 with inundation boundaries shown for one inundation scenario; dam failure during the local storm Probable Maximum Flood (PMF). The local storm PMF has a peak inflow of 55,000 ft^3/s, duration of 26 hours, and inflow volume of 18,400 acre-feet. The dam was assumed to breach when the maximum reservoir surface reached the crest of the dam, with a breach development time of 2.5 hours. The assumed breach resulted in flooding levels up to 50 feet deep immediately downstream of the dam, and flood depths typically ranging from 15 to 30 feet between the dam and the Big River. No static or seismic failure scenarios were modeled in the inundation study.

An evaluation of potential failure modes at this dam indicated three types of potential failure mode scenarios judged to be sufficiently credible to quantify risks:

1. Internal erosion of embankment under normal operations (static)
2. Overtopping or internal erosion of embankment under flood loading (hydrologic)
3. Sudden failure of embankment under earthquake loading (seismic)

Life loss for these failure mode scenarios was estimated using the Reclamation Consequence Estimating Methodology (RCEM 2014) utilizing an empirical approach featuring graphical correlations between fatality rate, flood severity (DV), and warning time.

II. Sunny Day Dam Failure Modes

There are several different static and seismic failure modes theoretically possible at Example Dam 1. All of the static and seismic failure modes listed would be considered as sunny day (or clear night) failures. One possible difference between any of these failures is that an internal erosion failure is more likely to occur at the normal high water surface elevation, while an earthquake could occur anytime, with a possible lower reservoir pool. This may mean the earthquake population at risk should be slightly smaller. However, this factor is judged to be insignificant for this study since the reservoir at this facility does not fluctuate dramatically over the course of a year, and because the dam would be less likely to fail seismically at lower reservoir levels. In terms of embankment breach development, either an internal erosion breach or a seismic overtopping breach will likely take some time to develop, given the plastic clay core and strong embankment shells. In this respect, the inundation study assumed breach development time of 2.5 hours appears reasonable.

Key factors such as the population at risk and DV values (flood severity) are thus assumed to be essentially the same for all sunny day failure modes. It is possible that warning time would be different for different failure modes. If an earthquake occurs, this could provide some potential warning that the dam may be in trouble, but may not give enough warning to residents of Pleasantville and those residents upstream of Pleasantville. Furthermore, this potential warning advantage may be eliminated if roads, bridges, and communication (phone, cell networks, internet, TV) are affected by the earthquake. Generally, downstream damage from an earthquake is difficult to predict.

Due to the many expected similarities in downstream consequences and the variables affecting them, separate discussions are not made in the text below for earthquake or static failure consequences. Rather, a general discussion is provided, and any differences due to a specific failure mode are highlighted. Separate calculations are performed for the static and seismic failure modes.

A. Population at Risk (PAR)

The most recent inundation study was performed in 1989 for the PMF overtopping failure scenario. A generalized portrayal of the 1989 inundation study is shown as Figure 1.1. For this study it is conservatively assumed that a dam breach and resulting inundation boundary downstream due to the static or seismic failure modes would be similar to the PMF failure release inundation boundary. In this case (CR life loss estimate study) it is considered acceptable to use the PMF inundation boundary because the results are slightly conservative and the inflows associated with the PMF do not significantly increase the outflows released by the dam breach. To check the reasonableness of this assumption, the 1995 Froelich equation for peak breach flows was calculated using the reservoir at normal high water surface versus the reservoir at the dam crest (simulating an overtopping condition, but without flood inflows). The predicted peak breach flows only differed by 10 percent.

The PAR was evaluated in terms of population centers, topographic conditions, and general types of flood severity (DV values) expected. Particular emphasis was placed on creating reaches where flood depths, flows, and topography were relatively consistent. This helps ensure similar DV values within a reach. For this consequences evaluation, the PAR was separated into 6 reaches. These reaches, and a brief description of the PAR within each reach, are presented in Table 1.1.

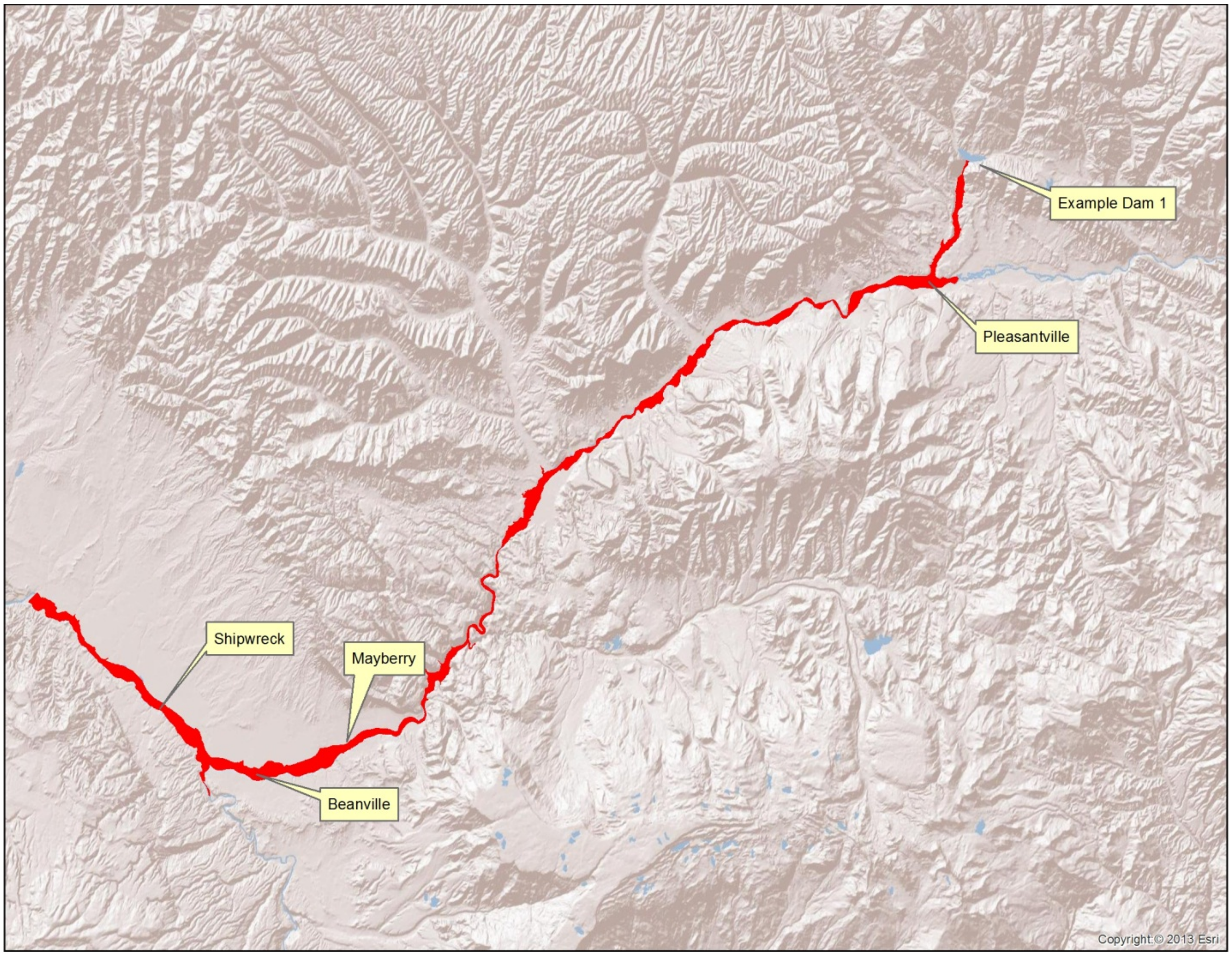


Figure 1.1 – Example Dam 1 – maximum inundation (Note: for a typical life loss study, existing inundation maps would be included rather than the simplified graphics in this Examples of Use document)

Table 1.1 – Summary of Inundated Areas Downstream of Example Dam 1

Reach	Location	River Miles from Dam	What is There?
1	Dam to Picnic Area	0	County Road 1 across dam and down to Picnic Area
2	Scattered residences and 18 Hole Golf Course	0.75 – 1.5	42 homes & Golf Course
3	Pleasantville	6.5	Main Business District/City Center, Elementary and Middle Schools, County Fair Grounds, Shopping Centers, Restaurants, City Pool
4	Scattered Homes	7.5	Multiple Residences

Reach	Location	River Miles from Dam	What is There?
5	Sunnydale & Happy Valley	24 - 52	Towns
6	Mayberry/Beanville/Shipwreck	59 - 74	Cities, Large Shopping and Business Areas

Tessel, Reclamation's GIS-based PAR mapping system, was used in combination with year 2010 census data for the entire stretch of the inundation boundary to identify permanent resident populations. The Tessel database contains the PMF maximum inundation boundary from the 1989 study in digital format. Table 1.2 shows the estimated PAR based on all the available data listed above. Different day and night PAR was estimated to reflect business operations and school attendance, with information provided by area office personnel familiar with Pleasantville. This definition of different day/night PAR was done because it is known that many students and workers reside in more rural areas, yet come to Pleasantville during the day.

Table 1.2 – Population at Risk from Sunny Day Dam Failure

Reach	River Miles from Dam	Estimated Travel Time of Leading Edge of Flood (in hours)	Population at Risk	
			Day	Night
1	0	0	4	0
2	1.5	0.1	104	126
3	6.5	0.5	4,912	4,115
4	7.5	1	22	43
5	52	3	483	868
6	74	5	4,961	4,961
		Total PAR	**10,486**	**10,113**

B. DV Values

The maximum peak breach outflow (based on the 1989 modeled hydrologic-induced failure) was estimated to be approximately 537,000 ft^3/s at the dam, and the flows gradually attenuated as the flood traveled downstream. As mentioned earlier, for the sunny day failure scenario, it was assumed that flood flows (and correspondingly, DV values) would be similar to the hydrologic inundation scenario results given the small (10 percent) difference in calculated peak breach outflows. Based on the available inundation maps, the width of the inundation plain ranges from about 1,500 to 4,000 feet in most downstream areas. DV values were estimated by dividing the breach flows at the various reaches from a dam failure by the width of the inundation plain (as scaled from the inundation maps). As an additional approach, DV was estimated by looking at the travel times (to determine velocity) and expected depths at a reach location. Both of these resulting sets of estimates are shown in the following table. For this particular dam, there was no reason to vary DV ranges within a given reach because the reaches were selected to represent relatively constant DV flows. In addition, the PAR in each reach are typically located within the broad and fairly flat floodplain (no residences are on a mesa or similarly higher land above the river).

Table 1.3 – Estimation of DV Values

Reach	DV from inundation flow/width			DV from depth x velocity		
	Flow (ft^3/s)	Flood plain width (ft)	Est. DV (ft^2/s)	Max. Depth (ft)	Est. Vel. (ft/s)	Est. DV (ft^2/s)
1	526,000	1,500	350	50	11	550
2	520,000	2,800	185	25	10	250
3	460,000	2,500	184	15	9	135
4	250,000	3,000	83	20	8	160
5	170,000	4,000	43	13	6	78
6	125,000	4,000	30	12	5	60

As shown in the table, the DV values are similar when estimated by the two approaches. This suggests a degree of confidence in the estimates. In addition, the flows attenuate as the distance downstream increases; given the consistent, reasonably wide flood plain this is expected. However, realizing there will be some variance of DV along various areas within any reach, a range is the preferred approach for specifying DV values. Using these estimated values from Table 1.3, the following range of DV values was selected for each reach:

Reach 1: 300 – 500 ft^2/s
Reach 2: 150 – 300 ft^2/s
Reach 3: 100 – 200 ft^2/s
Reach 4: 75 – 185 ft^2/s
Reach 5: 40 – 75 ft^2/s
Reach 6: 30 – 60 ft^2/s

C. Warning Time

Warning time values were evaluated by considering the rate at which a sunny day failure might develop, the likelihood of detection, the time to breach, and the flood wave travel times. In this manner, warning times were estimated for each PAR reach downstream. Warning times were estimated for both day and night failures, although for reaches with appreciable travel time there was no significant difference.

For an internal erosion failure during normal operations, there is a reasonable chance that the developing erosion would be detected so that some warning can be provided to all downstream PAR. As discussed by the team when determining intervention probability for the potential failure modes, reasons to expect some warning include the likelihood that the erosion and ultimate breach will progress slowly due to the plastic clay core and strong cobble-fill shells, the presence of an onsite damtender (8 hours/day five days a week), and the likelihood that changed seepage conditions would be noticed early in the process. However, there is always some possibility that a seepage breakout could occur suddenly or that a situation could develop overnight or on a weekend. In addition, the travel times to the first four reaches are only one hour or less. Given the uncertainty in the potential warning, varying probabilities of warning times were estimated. Considering the factors listed above, an estimate was made as to whether the PAR in the various downstream reaches would receive “little or no” warning or “adequate” warning. Those results for an internal erosion failure during normal operations are shown in Table 1.4.

Table 1.4 - Estimated Warning for Sunny Day Failure Internal Erosion

Reach	Probability of Little or No Warning	Probability of Adequate Warning
1 – 3 (day)	0.25	0.75
1 – 3 (night)	0.7	0.3
4 (day & night)	0.1	0.9
5 – 6 (day & night)	0	1.0

For the first three reaches, where flood wave travel time is no more than 30 minutes, it was judged that it is relatively likely that warning will be provided during the day. However, during the night, it is more likely that the warning will not be adequate. It was judged that "adequate" warning would be provided for the last two reaches, primarily due to the several hours of flood wave travel time and the likelihood that survivors in the upstream reaches will notify officials who will start evacuation notices.

For a seismic failure, it was judged that less warning would be provided than for the normal operations internal erosion failure mode. This is because the failure could occur much more rapidly by a catastrophic slope failure leading to overtopping, as well as because of the potential that widespread chaos and infrastructure damage following a large earthquake could complicate warning and evacuation efforts. The team believed that the impact of these widespread complications would equally affect both the day and night time warning in the first two reaches, since the flood wave would reach these areas in a matter of minutes. These considerations led to the following weighting of warning times.

Table 1.5 – Estimated Warning for Sunny Day Failure Sudden Seismic

Reach	Probability of Little or No Warning	Probability of Adequate Warning
1 – 2 (day & night)	0.7	0.3
3 (day)	0.5	0.5
3 (night)	0.9	0.1
4 (day & night)	0.25	0.75
5 – 6 (day & night)	0	1.0

D. Fatality Rates

For this evaluation, a range of fatality rates was assigned for the various DV values estimated. Both graphs for "little or no" warning and for "adequate" warning were utilized depending on the warning assumed above. The use of a range of fatality rates is believed to appropriately reflect the uncertainty in estimating the many complex variables associated with life loss resulting from dam failure. Key sources of uncertainty include breach parameters and inundation modeling results, both of which impact DV; as well as warning time estimates and the estimated success of evacuation efforts, both of which can be significantly affected by time of day or cause and speed of failure. There were no obvious case histories that closely matched the population at risk, site conditions, or potential failure modes considered at this dam. Hence, the general trends suggested by the plots were considered reasonable.

For the internal erosion failure mode during normal operations, the fatality rate ranges were generally selected from the lower to middle portions of the suggested value bounds for daytime failure and from the upper portion of the suggested and overall bounds for night time failures. This was done to reflect the case history data that shows a definite difference for fatality rates depending on the time of failure. In addition, although the DV values are rather high, an internal erosion failure mode at this well-built dam is expected to manifest as a steadily enlarging breach as opposed to releasing a sudden "wall of water" and associated rapid rate of rise in downstream water levels resulting in lower fatality rates. The selected fatality rates for the first two reaches (for this failure mode only) are depicted on Figures 1.2 and 1.3.

For the sudden seismic failure mode, slightly higher fatality rates were selected compared to the internal erosion failure. This was judged reasonable due to the expected damage that might result from an earthquake, which could trap people in cars or homes, potentially significantly affecting their ability to escape ensuing floodwaters. In addition, it is judged that the rate of rise in the downstream flood plain will be more dramatic than with the internal erosion failure mode, particularly the dam experiences a sudden slope failure and resulting crest loss due to the earthquake loading.

The fatality rates assumed for this evaluation are shown in Table 1.6 (for internal erosion under normal operations) and Table 1.7 (for sudden seismic failure). To get a "best estimate," a weighted average of 0.25 for night and 0.75 for day was assumed. In part this weighting considered the relative amount of daylight for a failure during summer (16 out of 24 hours) when the reservoir is highest and a failure most likely. However, it is also judged rather unlikely that a dam failure would develop and occur solely during the night, without first being observed at some point during the day.

E. Loss-of-Life Estimate

Tables 1.6 and 1.7 list the assumptions for all the various areas of PAR, and calculate the total estimated life loss due to the two types of sunny day failure modes (internal erosion and sudden seismic) for both daytime and nighttime failure scenarios. Using Reclamation's 2014 methodology, the estimated life loss in the event of an internal erosion failure mode under normal operations ranges from 30 to 1,600, with a resulting best estimate value (obtained using the day/night weighting described above) of 350. Using the same methodology, the estimated life loss in the event of a rapidly developing seismic failure mode ranges from 180 to 2,380, with a resulting best estimate value (described above) of 780.

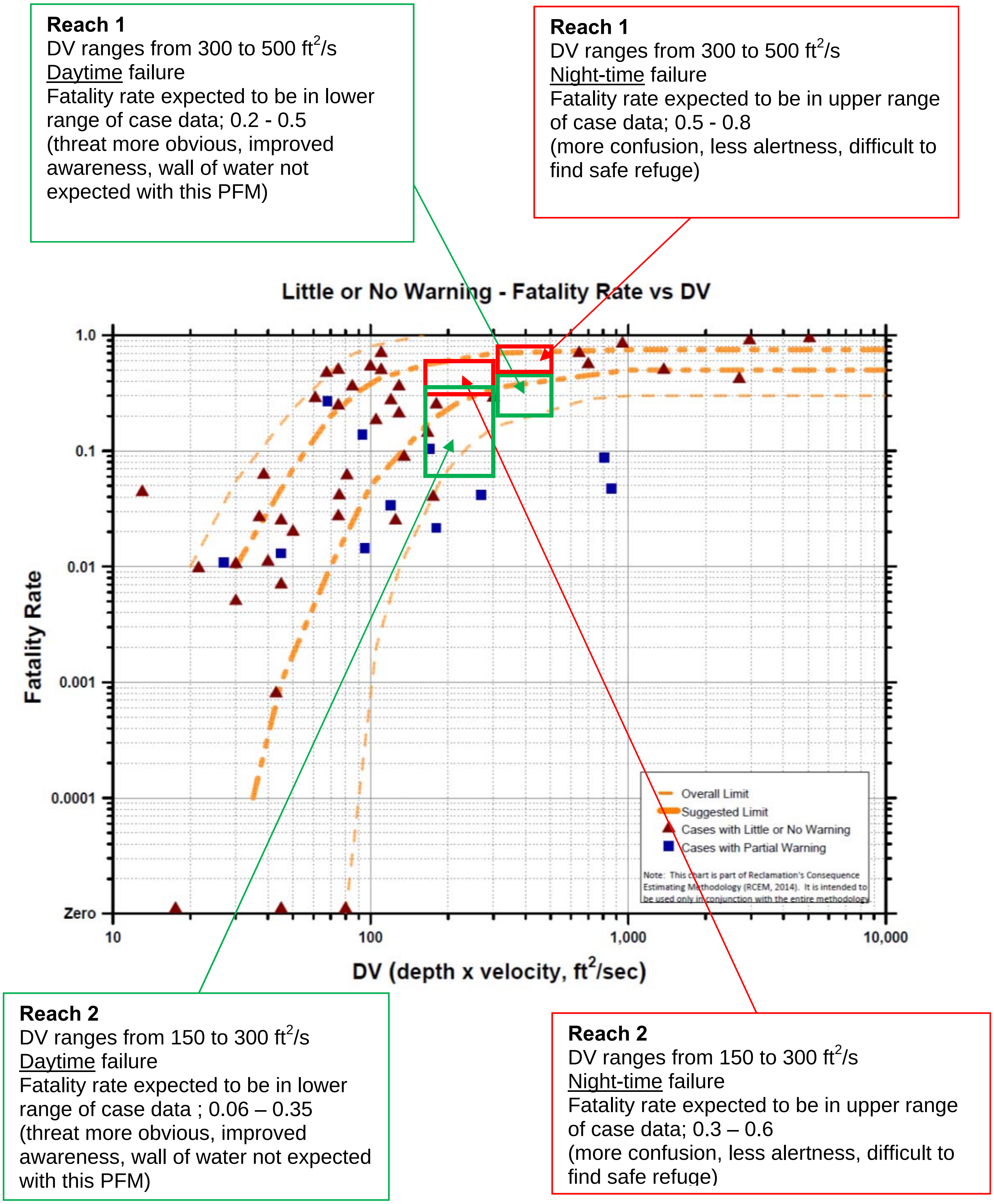


Figure 1.2. Example of selection of fatality rates when little or no warning assumed

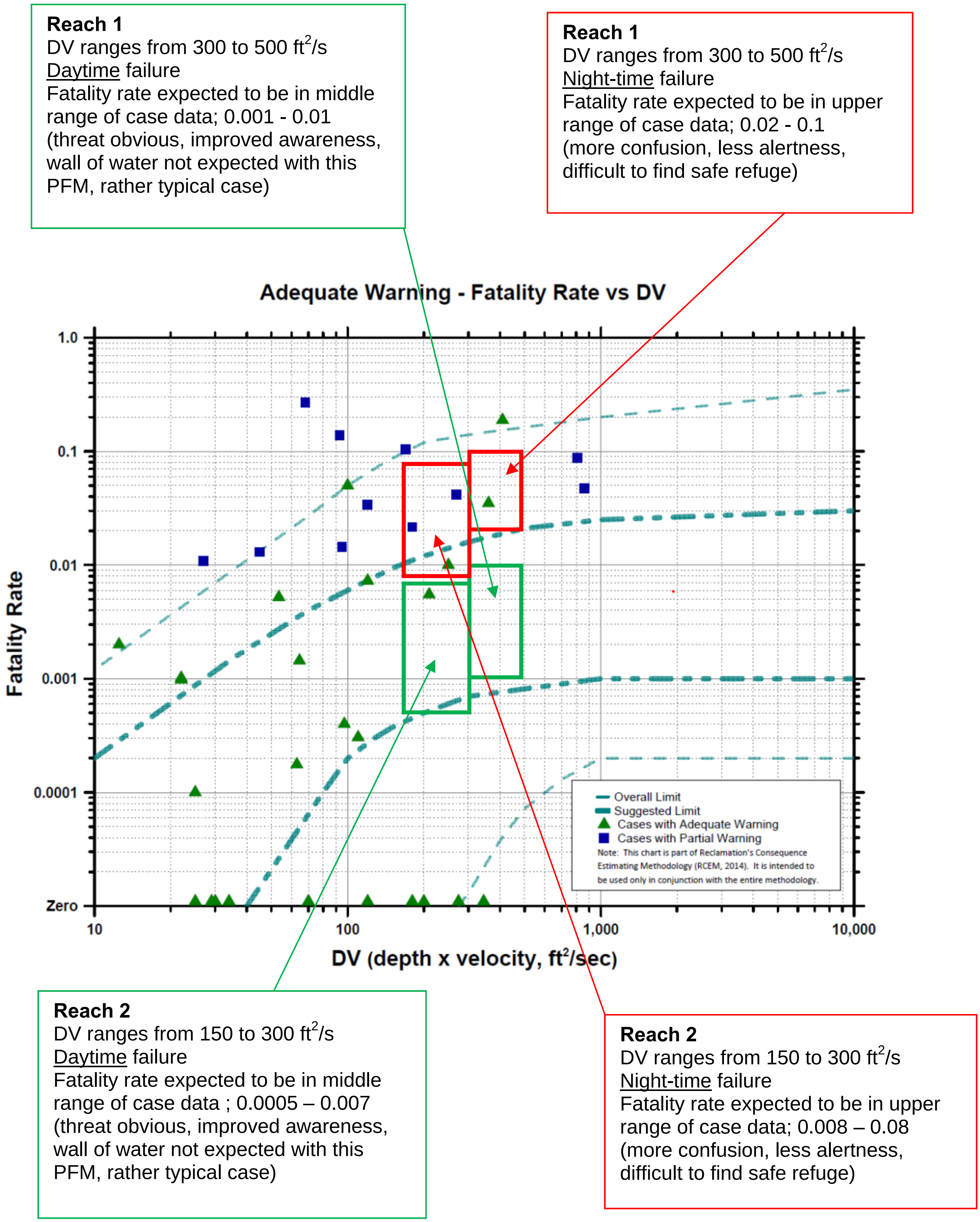


Figure 1.3. Example of selection of fatality rates when adequate warning assumed

III. Flood Related Failure Modes

The hydrologic failure modes that were evaluated included overtopping erosion of the embankment under flood loading and an internal erosion failure mode under higher hydraulic heads than previously experienced. Both are expected to result in a similar loss of life, not only because the breach would be expected to develop similarly given the strong embankment materials, but primarily because the entire downstream PAR would likely have many hours of warning.

A. Population at Risk (PAR)

Since the inundation study was for a hydrologic failure, the same PAR that was calculated for the sunny day failures from the 1989 PMF inundation mapping was also assumed for this case. Those PAR estimates are shown in Table 1.2.

B. Flood Severity

The same DV values and discussions provided under the **Sunny Day Dam Failure Modes** apply here as well.

C. Warning Time

The warning times for flood-related failures are greater than for sunny day failures, due to the available forecasting of large storms, the typical 24-hour surveillance at Reclamation dams once they experience new maximum reservoir levels, and the presence of early warning systems for hydrologic events. It is judged that warning will be issued several hours prior to breach. Thus, for all reaches, warning was assumed to be “adequate.”

D. Fatality Rates

A range of fatality rates was assigned for the various DV values estimated. For all reaches, the graph for “adequate” warning was used.

The fatality rates assumed for this evaluation are shown in Table 1.8. As with the sunny day failure scenario, both day and night time fatality rate ranges were considered. In general, the fatality rate ranges for both conditions were selected from the lower portions of the suggested value bounds. This was done because there appears to be a high probability of a lengthy warning and evacuation effort due to the slowly developing failure mode.

E. Loss-of-Life Estimate

Table 1.8 lists the assumptions for all the various areas of PAR, and calculates the total estimated life loss due to the hydrologic failure modes for daytime and nighttime failure scenarios. Using Reclamation’s 2014 methodology, the estimated life loss in the event of this failure mode ranges from 1 to 24 with a best estimate value of 8. As was done for the sunny day life loss estimates, this best estimate assumes a weighted average probabilities of 0.25 for a night failure and 0.75 for a daytime failure.

IV. Summary

Table 1.9 summarizes the life loss estimates, using RCEM 2014. As can be seen in the table, the lowest estimated life loss would occur during a hydrologic failure where the facility would be under constant surveillance and hours of warning in advance of a developing failure would be expected. A sunny day internal erosion failure could lead to a high number of fatalities, particularly if the event occurred at night. The vast majority of the life loss would occur in the city of Pleasantville, only 6.5 miles downstream from the dam and expected to experience flooding DV values ranging from 100 to 200 ft^2/s. A sudden failure of the embankment dam during an earthquake would result in even higher fatalities, since less warning would be expected and due to the general chaos following an earthquake that would complicate warning and evacuation efforts.

Table 1.9 – Life Loss Estimates for Various Failure Modes

Failure Mode Category	Estimated Daytime Life Loss			Estimated Nighttime Life Loss			Best Estimate of Life Loss (Day: 75%; Night: 25%)
	Low	Mean	High	Low	Mean	High	Best Estimate
Normal Operation Internal Erosion	30	150	270	330	960	1600	350
Hydrologic	1	6	10	2	13	24	8
Sudden Seismic	180	500	830	780	1580	2380	770

For each failure mode category, approximately 94 percent of the estimated life loss occurs in the town of Pleasantville. This appears entirely reasonable, as nearly 5,000 people reside in the town, and a dam failure flood would hit the community in only 30 minutes. Given the limited time for warning and evacuation, as well as the severity of the flooding expected in Pleasantville (DV averages from 100 to 200 ft^2/s), it is likely that a large number of residents could perish in the event of dam failure.

The relative amount of life loss for the three types of failure mode categories also appears reasonable. Given an extreme flood loading (hydrologic failure mode), many hours of warning are expected due to the dam being under 24-hour surveillance, spillway flows providing an indication of unusual releases, and the capability of the local emergency management officials. Consequently, it is reasonable to assume that most of the downstream PAR will be evacuated and life loss from a dam failure should be low.

For an internal erosion failure mode, it is judged that the failure will not proceed rapidly, since the plastic clay core and strong cobble-fill shells will provide some erosion resistance. In addition, a damtender is on site 8 hours Monday through Friday. Thus, a daytime failure should result in far less life loss than a failure during the night if emergency management officials perceive the threat and issue evacuation orders. Based on the observed conditions and layout of the town, the PAR in Pleasantville should have numerous evacuation routes available to them. However, in the event the failure occurs when the damtender is not present, the town of Pleasantville may get little advance warning, since the upstream areas are not well populated by recreationists. Life loss could be significant in this event, even if half or more of the residents manage to evacuate.

Finally, a sudden failure during an earthquake (seismic loading) poses a very serious threat to Pleasantville residents. With the chaos and widespread damage likely to occur from the earthquake, residents may have a difficult time evacuating in the event of dam failure. With the large flood wave from a sudden seismic-induced overtopping of the dam hitting Pleasantville in only 30 minutes, major life loss is possible.

Obviously, there is uncertainty when estimating the life loss that might occur from a dam failure, given the many variables and possible outcomes associated with the development of a failure mode leading to dam breach. As shown in the calculation tables, a wide range of life loss is possible. Given this possible range and the age and type of inundation study, this life loss evaluation cannot be considered to have a high degree of confidence associated with it. However, given the relatively low annualized failure probabilities associated with the credible potential failure modes at this facility, a change in the best estimate life loss by even a factor of 3 or so should not affect the conclusions of low risk at this dam. Thus, although there is significant uncertainty in the life loss estimates, there is reasonable confidence that any reasonable change life loss estimates (from new inundation studies, for example) would not change any dam safety decisions[1].

[1] This paragraph brings in the AFP risk to help establish confidence in the overall level of risk and dam safety decisions, even though there is not high confidence in the life loss estimate. This type of discussion may be added to the end of the Consequences section of a CR; however, the best location is in the DD/TROF section of the CR.

Table 1.6 – Static Internal Erosion Life Loss

Life Loss for Sunny Day Internal Erosion
Example Dam 1

Reach	Day PAR	Night PAR	DV Estimate	Warning Time Increment	Day Fatality Rate Low	Day Fatality Rate High	Night Fatality Rate Low	Night Fatality Rate High	Day Life Loss Low	Day Life Loss Mean	Day Life Loss High	Night Life Loss Low	Night Life Loss Mean	Night Life Loss High	Best Estimate Life Loss
1	1	0	300 - 500	little or no	0.2	0.5	0.5	0.8	0.2	0.4	0.5	0.0	0.0	0.0	0.3
	3	0	300 - 500	adequate	0.001	0.01	0.02	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	26	88	150 - 300	little or no	0.06	0.35	0.3	0.6	1.6	5.3	9.1	26.4	39.6	52.8	13.9
	78	38	150 - 300	adequate	0.0005	0.007	0.008	0.08	0.0	0.3	0.5	0.3	1.7	3.0	0.6
3	1228	2881	100 - 200	little or no	0.02	0.2	0.1	0.5	24.6	135.1	245.6	288.1	864.3	1440.5	317.4
	3684	1234	100 - 200	adequate	0.0004	0.004	0.005	0.04	1.5	8.1	14.7	6.2	27.8	49.4	13.0
4	2	4	75 - 185	little or no	0.01	0.1	0.005	0.3	0.0	0.1	0.2	0.0	0.6	1.2	0.2
	20	39	75 - 185	adequate	0.0002	0.003	0.002	0.03	0.0	0.0	0.1	0.1	0.6	1.2	0.2
5	483	868	40 - 75	adequate	0	0.001	0.001	0.015	0.0	0.2	0.5	0.9	6.9	13.0	1.9
6	4961	4961	30 - 60	adequate	0	0.0003	0.001	0.008	0.0	0.7	1.5	5.0	22.3	39.7	6.1
TOTAL	**10486**	**10113**							**28**	**150**	**273**	**327**	**964**	**1601**	**354**

Table 1.7 – Sudden Seismic Life Loss

Life Loss for Sudden Seismic
Example Dam 1

Reach	Day PAR	Night PAR	DV Estimate	Warning Time Increment	Day Fatality Rate Low	Day Fatality Rate High	Night Fatality Rate Low	Night Fatality Rate High	Day Life Loss Low	Day Life Loss Mean	Day Life Loss High	Night Life Loss Low	Night Life Loss Mean	Night Life Loss High	Best Estimate Life Loss
1	3	0	300 - 500	little or no	0.3	0.7	0.5	0.8	0.9	1.5	2.1	0.0	0.0	0.0	1.1
	1	0	300 - 500	adequate	0.001	0.03	0.03	0.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	73	88	150 - 300	little or no	0.1	0.5	0.4	0.7	7.3	21.9	36.5	35.2	48.4	61.6	28.5
	31	38	150 - 300	adequate	0.0008	0.004	0.01	0.08	0.0	0.1	0.1	0.4	1.7	3.0	0.5
3	2456	3703	100 - 200	little or no	0.07	0.3	0.2	0.6	171.9	454.4	736.8	740.6	1481.2	2221.8	711.1
	2456	412	100 - 200	adequate	0.0004	0.02	0.005	0.05	1.0	25.1	49.1	2.1	11.3	20.6	21.6
4	5	11	75 - 185	little or no	0.02	0.2	0.1	0.3	0.1	0.6	1.0	1.1	2.2	3.3	1.0
	17	32	75 - 185	adequate	0.0003	0.01	0.003	0.04	0.0	0.1	0.2	0.1	0.7	1.3	0.2
5	483	868	40 - 75	adequate	0.0001	0.0008	0.001	0.02	0.0	0.2	0.4	0.9	9.1	17.4	2.4
6	4961	4961	30 - 60	adequate	0	0.001	0.001	0.01	0.0	2.5	5.0	5.0	27.3	49.6	8.7
TOTAL	**10486**	**10113**							**181**	**506**	**831**	**785**	**1582**	**2379**	**775**

Table 1.8. – Hydrologic Life Loss

Life Loss for Hydrologic Overtopping
Example Dam 1

Reach	Day PAR	Night PAR	DV Estimate	Warning Time Increment	Day Fatality Rate		Night Fatality Rate		Day Life Loss			Night Life Loss			Best Estimate Life Loss
					Low	High	Low	High	Low	Mean	High	Low	Mean	High	
1	4	0	300 - 500	adequate	0.0001	0.001	0.001	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	104	126	150 - 300	adequate	0.0001	0.001	0.001	0.01	0.0	0.1	0.1	0.1	0.7	1.3	0.2
3	4912	4115	100 - 200	adequate	0.0002	0.002	0.0005	0.005	1.0	5.4	9.8	2.1	11.3	20.6	6.9
4	22	43	75 - 185	adequate	0.0001	0.001	0.0003	0.003	0.0	0.0	0.0	0.0	0.1	0.1	0.0
5	483	868	40 - 75	adequate	0	0.0001	0	0.0005	0.0	0.0	0.0	0.0	0.2	0.4	0.1
6	4961	4961	30 - 60	adequate	0	0.0001	0	0.00025	0.0	0.2	0.5	0.0	0.6	1.2	0.3
TOTAL	**10486**	**10113**							**1**	**6**	**10**	**2**	**13**	**24**	**8**

Example Dam 2 (Issue Evaluation level)

I. Background

Example Dam 2 is a zoned earthfill embankment located on Glenn River, about 16 miles northeast of Glenn City. The dam's structural height is about 250 feet and the reservoir holds about 125,000 acre-feet of active storage.

A recent CR indicated Annualized Life Loss (ALL) risks for static and hydrologic potential failure modes that were estimated to be borderline with respect to Reclamation's Public Protection Guidelines. The total ALL is above the guideline value of $1x10^{-3}$, and there is moderate confidence in the individual Annualized Failure Probability risk estimates. To address the static internal erosion potential failure mode, a SOD recommendation (2014-SOD-A) was made to evaluate the observed concentrated seepage and install a weir at the right groin to look for observations of material transport. To address the hydrologic overtopping potential failure mode, a SOD recommendation (2014-SOD-B) was made to perform a higher level hydrologic hazard study followed by a flood routing study using newly developed flood frequency hydrographs. The annualized life loss risk estimate for the hydrologic overtopping potential failure mode (from the last CR) is just above the guideline threshold value of $1x10^{-3}$. Due to conservatism in prior life loss estimates, the lack of a modern inundation study (the study was from the 1980s) and significant uncertainty in the inundation area and flood flow characteristics through Glenn City, other future recommended actions for the dam are somewhat dependent on whether a more detailed life loss evaluation would shift the total risk marker left or right. Therefore, the following SOD recommendations were made in the CR to re-evaluate the life loss consequences:

> **2014-SOD-C** Perform an updated inundation study for Example Dam 2 for static and hydrologic potential failure modes that includes 2D modeling through Glenn City. Based on the results of the inundation study, use a team approach to update the estimated life loss for static and hydrologic potential failure modes.
>
> **2014-SOD-D** After completion of the work associated with SOD recommendations A through C, perform a team risk analysis for static and hydrologic potential failure modes.

II. General

Failure of Example Dam 2 would result in a flood that would travel down Glenn River through Glenn River Canyon, entering the outlying portions of Glenn City at mile 10, eventually being contained in Mountain Lake about 22 river miles from the dam. Glenn River Canyon is heavily used for recreation and contains five specific sites with high seasonal usage. Glenn City has a relatively large, urbanized population, with suburban outskirts which extend upstream to the community of Newton at the mouth of the canyon.

To address 2014-SOD-C, an inundation study was performed using 1D and 2D hydraulic modeling. In the canyon, 1D modeling was used; and 2D modeling was used from the mouth of the canyon, through Glenn City and into Mountain Lake. The inundation study evaluated two scenarios: "sunny day" failure representing the static internal erosion potential failure mode with the reservoir at top of active conservation, and a hydrologic overtopping scenario based on a general spring storm PMF flood inflow event. Inundation maps are included in this report.

Life loss estimates for these potential failure modes were estimated using the new inundation study, updated PAR estimates, and fatality rates selected using Reclamation's 2014 Consequence Evaluation Methodology (RCEM 2014).

Since different inundation studies were performed for static and hydrologic potential failure modes, the factors relating to estimating the life loss for each potential failure mode are discussed separately below.

III. Internal Erosion Potential Failure Mode ("Sunny Day Failure")

A. Breach Parameters

Several empirical relationships were used to predict breach parameters for the static dam failure scenario at Example Dam 2. The three main breach parameters evaluated were breach width, breach side slope, and breach formation time. Selected values for breach parameters included breach side slopes of 0.25H:1V, a top breach width of 400 feet, and a breach formation time of 90 minutes. The final breach dimensions are appropriate for the internal erosion potential failure mode being considered, although the embankment erosion would likely begin at the right abutment (i.e. the area of concern with current seepage) and erode across the dam rather than develop outward from the center. During prior discussions with geotechnical staff regarding the breach parameters for the inundation study, it was concluded that because portions of the core of this dam were constructed with non-plastic silty sands and some low plasticity clays, the estimated breach formation time would be about 1.5 hours when the reservoir is at the top of active conservation. Overall the life loss evaluation team agreed with the breach parameters and the breach formation time. A 1.5 hour breach formation time would result in an estimated peak breach discharge of 1.5 million ft^3/s. Details of the breach parameter evaluation are in the inundation study report.

B. Time Categories

Reservoir operation records indicate that the reservoir typically fills during the spring months due to snow runoff and spring precipitation. The pool reaches its normal high level (at or near the top of active conservation) in early June, and is gradually drawn down during the summer months. The reservoir is normally at its low point in the months of December and January. Since case histories indicate an internal erosion failure mode is most likely to occur during high reservoir levels, it is judged that the summer season will be the critical time for internal erosion to develop and lead to a dam failure.

As mentioned above, Glenn River Canyon is a popular recreation area and contains four campgrounds and a day-use area which are heavily used in the summer. Since recreation season corresponds to the time at which the dam is most vulnerable to an internal erosion failure, a higher PAR was assumed for appropriate reaches to reflect the summer recreationists. Non-summer recreational PAR is significantly lower and is not applicable to this type of failure mode at this dam. There is a small degree of weekday/weekend variation in recreational PAR in the summer, but this is judged to be relatively minor. Thus, for purposes of this evaluation, separate weekend/weekday PAR estimates are not included.

RCEM Guidance Note:
In this example, due to the relatively short distance inundated (around 22 miles), travel times are relatively short (a few hours as opposed to days). Thus, the warning time is more likely to be influenced by the amount of advance detection and warning, and the awareness level of the affected PAR. Differences between day and night might therefore be critical. For projects with lengthy travel times to the PAR centers, travel time may dominate the warning time and make day/night differences insignificant.

In general, an internal erosion failure of the dam during the day offers a better chance of advanced warning being issued to the PAR compared to a night failure. In addition, the affected PAR will likely react more readily in the day as opposed to the night. Therefore, separate day and night time categories are considered when warning times and the warning category (little or no vs. adequate) are estimated.

C. Defined Reaches and DV Values

The new inundation maps were reviewed, and PAR location and DV values were considered to define the reaches. In general, the inundation study results indicate deep flows and relative high velocities, particularly in the canyon just downstream of the dam, which is steep and confined. Two reaches were defined in the canyon based on flood depths and topography, as described below. Figure 2-1 shows the inundation map in Glenn River Canyon for the first two reaches.

Example Dam 2

Inundation map of first 10 miles downstream of dam through Glenn River Canyon

Reach 1: dam to 7 miles
Depths range from 30 to 85 ft
Avg. velocity 18 ft/sec
DV ranges from 550 to 1,500 ft^2/sec

Reach 2: 7 to 10 miles
Depths typically 25 to 30 ft
Avg. velocity 15-18 ft/sec
DV ranges from 350 – 550 ft^2/sec

Figure 2-1 – Example Dam 2 - Inundation Map for Reaches 1 and 2

The first two reaches and flood characteristics are described below, along with the basis for selection of the reach boundaries.

- Reach 1 (dam to 7 miles): This reach includes the most severe flooding conditions. The inundation study indicates flood depths in the first seven miles of Glenn River Canyon range from 30-85 feet, with depths generally decreasing with distance downstream. Maximum velocity was calculated from the 1D model to be about 18 ft/s. The maximum DV was calculated to range from about 550 to 1,500 ft^2/s. The downstream limit (7 miles) of this reach was selected to coincide with a DV value of about 500 ft^2/s, because the curves on the RCEM fatality rate charts generally become more horizontal (i.e. have a smaller relative increase in fatality rate with higher DV values) at DV values between 300 and 500 ft^2/s. With a velocity of 18 ft/s, flood depths between 25 and 30 ft. would result in a DV of about 500 ft^2/s. Maximum flood depths of 25 to 30 ft. occur about 7 miles downstream. Similar flood depths continue to the mouth of the canyon; however velocity decreases slightly in the lower 3 miles of the canyon because the topography is not as steep in this portion. Therefore, a second reach was also defined for the canyon. It was noted that the hydraulic model indicated a rate of rise greater than 10 feet in 5 minutes in this reach, which could lead to higher fatality rates, although the estimated DV values are quite high without considering the rate of rise.

- Reach 2 (7 to 10 miles): The inundation model indicates that maximum flood depths within this reach ranged from 25 to 30 feet and flow velocity ranged from 15 to 18 ft/s. Estimated DV ranges from a high value of about 550 ft^2/s at 7 miles, to a low value of about 350 ft^2/s at 10 miles, which is the mouth of canyon at the community of Newton

At 10 miles downstream, the canyon ends and the inundated area is wider. Three reaches were selected for the area downstream of the mouth of the canyon to reflect the type and locations of the PAR as described below. Because of the relative proximity of the PAR in essentially one population center, travel time was not used to establish the reach boundaries. Figure 2-2 shows the inundation map for the three reaches downstream of Glenn River Canyon, through Glenn City, to Mountain Lake.

RCEM Guidance Note:
For cases with multiple population centers separated by some distance, it is typically appropriate to use travel time, with other factors such as flood characteristics, to differentiate between flood reaches.

Example Dam 2
Inundation map downstream of the mouth of Glenn River Canyon, through Glenn City and into Mountain Lake

Reach 3: mouth of canyon to outskirts of Glenn City, 10 to 15 miles
Variable depth and velocity from 2D inundation study

Reach 4: City center through commercial and residential areas, 15 to 19 miles
Variable depth and velocity from 2D inundation study

Reach 5: Low lying areas, agricultural use, Glenn Airport to Mountain Lake, 19-22 miles
Variable depth and velocity from 2D inundation study

Figure 2-2 – Example Dam 2 - Inundation Map for Reaches 3, 4 and 5

Reaches 3, 4 and 5 (and corresponding sub-reaches) are described below, along with the flood characteristics and the basis for selection of the reach and sub-reach boundaries. Figure 2-3 shows the sub-reaches described below.

- Reach 3 (10 to 15 miles): Beyond the mouth of the canyon for about five miles, the river channel slope decreases, and the flood waters are contained within the broad Glenn River valley, which is about 4-5,000 ft. wide. This valley contains generally residential PAR in suburban developments with parks and open space along the river. The 2D inundation modeling started at this reach because of the anticipated wide range of flood severity caused by the channel and cross-valley topography, and the location and density of the PAR approaching Glenn City. The 2D inundation model provided a more refined breakdown of flood flow characteristics and was used to establish two sub-areas within this reach. As expected, the inundation model indicated maximum depths and flow velocities vary laterally in this reach, and that the PAR located closer to the channel would experience more severe flooding than the portion of the PAR located near the fringes of the valley. Sub-reach 3a represents the main river channel area and was defined with a maximum velocity of 15 ft/s. The fringe areas are included in sub-reach 3b, with flow velocity that ranges from about 10 to 15 ft/s. Based the calculated depth range of 10 to 20 ft, the DV in sub-reach 3a is still relatively high, ranging from about 150 to 300 ft^2/s. The DV in sub-reach 3b ranges from about 50 to 150 ft^2/s, based on depths ranging from 5 to 10 ft.

- Reach 4 (15 to 19 miles): At about 15 miles, the flood inundation area expands laterally due to the flatter terrain. The width (perpendicular to the river channel) in this reach is about 1.5 to 5 miles wide. This reach includes a substantial portion of the PAR in Glenn City. The 2D inundation model provided a more refined breakdown of flood flow characteristics used to establish three sub-areas within this reach. The inundation model indicated maximum depths and flow velocities were located closest to the main river channel, with depths and velocities decreasing toward the south, away from the channel as it curves and heads westward toward Mountain Lake. The PAR located closer to the channel would experience more severe flooding than the portion of the PAR located farther south. Sub-reach 4a represents the main river channel area and was defined with a maximum velocity range of 5-10 ft/s. To the south, sub-reach 4b was also defined with a maximum velocity range of 5-10 ft/s, but with maximum depths less than 10 ft. A small area to the north of sub-reach 4a was also included in sub-area 4b because of similar depths and velocity values. Sub-reach 4c was defined as the area to the far south with velocity values of about 5 ft/s or less and maximum depths less than 10 ft. Much of this area might be inundated with "backwater" low velocity flows as the flood water extends south and enters Mountain Lake. Based the calculated depth ranges for each sub-area, the DV range in sub-reach 4a is 50-150 ft^2/s, the DV range in sub-reach 4b is 25-100 ft^2/s, and the DV range in sub-reach 4c is 25-50 ft^2/s.

- Reach 5 (19 to 22 miles, Mountain Lake): At about 19 miles, the PAR characteristics change significantly because this represents the limit of the Glenn City residential suburb areas, and the beginning of flatter, low-lying primarily agricultural areas. This reach also includes Glenn Regional Airport, which would have some non-residential PAR. To the west and south of the airport, flood flows would flow over flat or gently sloping lands then enter Mountain Lake. The flood characteristics in reach 5 are very similar to those in reach 4. Three sub-reaches were defined with the same velocity ranges established for reach 4. The most severe flooding would occur along the main river channel to the north, and depths and velocities decrease toward the south, away from the channel. Because of the similar flood characteristics, the DV ranges for sub-reaches 5a, 5b and 5c are the same as the DV ranges described previously for sub-reaches 4a, 4b and 4c. Slightly lower fatality rates could be justified for sub-reaches 5a, 5b and 5c relative to comparable sub-reaches in reach 4 due to velocities and depths likely being closer to the lower end of the estimated ranges. However, the biggest difference between reach 4 and reach 5 is the PAR; urban and suburban in reach 4 compared to rural, agricultural and non-residential (airport in sub-reach 5b) in reach 5. The PAR is discussed in a subsequent section.

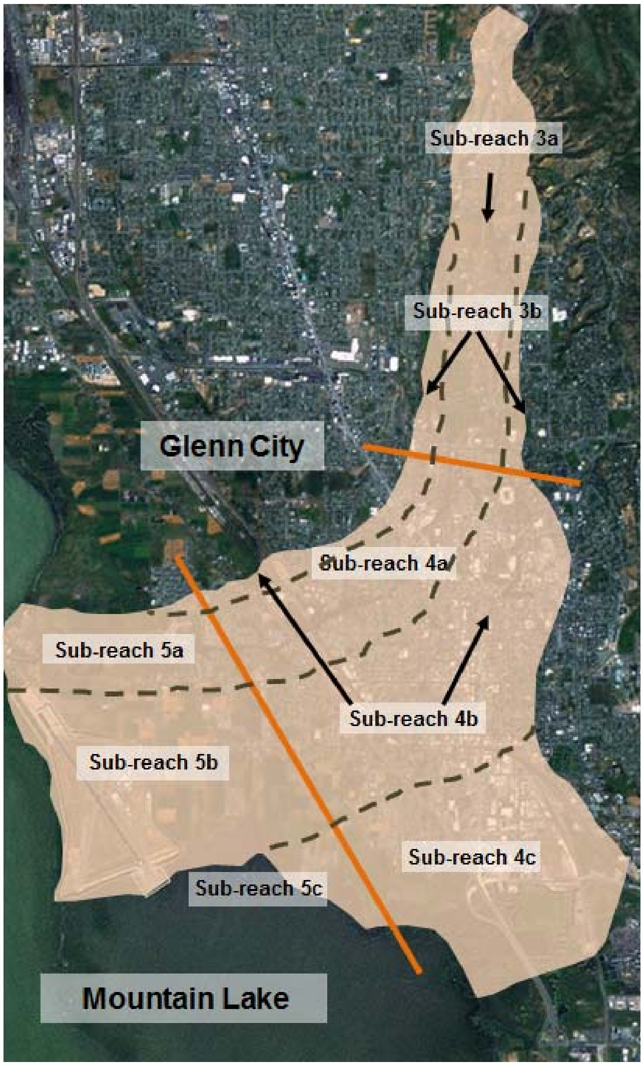


Figure 2-3 – Example Dam 2 - Inundation Map with defined sub-reaches for Reaches 3, 4 and 5

Example Dam 2
DV Subareas from 2D inundation model

Sub-reach 3a: Glenn River valley through outskirts of Glenn City
Depths range from 10 to 20 ft
Avg. velocity 15 ft/sec
DV ranges from 150 to 300 ft^2/sec

Sub-reach 3b: Fringes of Glenn River valley
Depths range from 5 to 10 ft
Velocity 10-15 ft/sec
DV ranges from 50 – 150 ft^2/sec

Sub-reach 4a: Glenn River channel through Glenn City
Sub-reach 5a: Glenn River channel through low agricultural areas
Depths range from 10 to 15 ft
Velocity 5-10 ft/sec
DV ranges from 50 – 150 ft^2/sec

Sub-reach 4b: Glenn City residential
Sub-reach 5b: low agricultural areas and Glenn Airport
Depths range from 5 to 10 ft
Velocity 5-10 ft/sec
DV ranges from 25 – 100 ft^2/sec

Sub-reach 4c: Glenn City suburbs
Sub-reach 5c: low agricultural areas
Depths range from 5 to 10 ft
Velocity ~5 ft/sec or less
DV ranges from 25 – 50 ft^2/sec

D. Population at Risk (PAR)

The residential PAR in the inundated areas was updated for this study using 2010 census data. In Glenn River Canyon, the residential PAR was obtained by overlaying the flood inundation map with the census blocks in Reclamation's GIS. The total estimated PAR in the canyon using this method was 80. During the most recent CR site exam, the Senior Engineer drove up and down the canyon and noted the location of residences in the canyon. Although the elevation of the residences varies with respect to the river, it was estimated that all of the residences observed in the canyon would be inundated by maximum dam breach outflows (i.e. none are located higher than the maximum depth of flood water). A total of 35 residential structures were noted, with 25 (70 percent) in the first 7 miles and 10 (30 percent) in the lower 3 miles. Assuming an average occupancy rate of 2.5 per house (based on county census data), the total PAR would be 88 people, which is in general agreement with the GIS approach. Based on the proportion of structures in the first 7 miles below the dam, a PAR of 56 (70% of 80) was estimated in Reach 1 and 24 (30% of 80) in Reach 2.

The canyon is used extensively in the summer for recreation. Formal recreation sites in Glenn River Canyon include four campgrounds and a formal day-use area. During summer months the campgrounds and day-use area see large visitation numbers. These recreational facilities are administered by the State Parks Department who provided ten years of seasonal visitation data for use in this study. Based on the locations and parking capacities of the recreational sites, the recreational PAR was proportioned appropriately between Reach 1 and Reach 2. The summer recreational PAR in Reach 1 was estimated to be 700 and in Reach 2 was estimated to be 185.

The PAR in Reach 3 includes Newton (at the mouth of the canyon) and the mostly residential population between Newton and the outskirts of Glenn City. Two sub-reaches were established (as described above) and the PAR in each sub-reach was obtained by overlaying the flood inundation map with the census blocks by a Reclamation GIS analyst. The total estimated PAR in Sub-reach 3a was estimated to be 1,785 and the total estimated PAR in Sub-reach 3b was estimated to be 275.

The PAR in Reach 4 includes both residential and commercial areas of Glenn City. Three sub-reaches were established (as described above) and the PAR in each sub-reach was obtained by overlaying the flood inundation map with the census blocks in Reclamation's GIS. The census block data only includes residential PAR, and does not include people in in the city for commercial purposes such as business owners, employees, or customers. The team considered increasing the daytime PAR to account for the additional people within commercial areas of Glenn City. However, after some discussion, the team also recognized that during the day, some of the residential PAR would not be at home, and could be working or attending school outside of the inundated areas. These two factors were judged to be offsetting, and no adjustment was made to the PAR in Reach 4. The total estimated PAR in Sub-reach 4a was estimated to be 2,275; the total estimated PAR in Sub-reach 4b was estimated to be 4,850; and the total estimated PAR in Sub-reach 4c was estimated to be 1,275.

The PAR in Reach 5 is predominantly rural agricultural with scattered residences, plus the Glenn Regional Airport. Based on annual traveler information obtained by local Area office representatives from the Glenn Regional Airport Authority, the average number of employees and passengers at the airport at any given time throughout the year is about 500. Three sub-reaches were established (as described above) and the residential PAR in each sub-reach was obtained by overlaying the flood inundation map with the census blocks in Reclamation's GIS.

The total estimated PAR in Sub-reach 5a was estimated to be 375; the total estimated PAR in Sub-reach 5b was estimated to be 1,185 (685 residents and 500 at the airport); and the total estimated PAR in Sub-reach 5c was estimated to be 145.

The PAR values estimated for each sub-reach are presented on Table 2.1. Although the PAR shown on Table 2.1 includes recreationists that would only be present for part of the year, that time corresponds with the time when the reservoir is most vulnerable to internal erosion potential failure modes. Therefore, the total summer PAR is equated to the total PAR for internal erosion PFMs and is used directly rather than annualizing the values for some proportion of the year.

Table 2.1 – Estimated PAR for Internal Erosion Potential Failure Modes

Reach and Description	Sub Area and DV range	Population at Risk (PAR)		
		Residential (year round)	Recreational Summer	Total PAR for Internal Erosion PFMs
1 (0-7 mi) Glenn River Canyon	No sub areas DV: 550-1500 ft^2/s	56	700	756
2 (7-10 mi) Glenn River Canyon	No sub areas DV 350-550 ft^2/s	24	185	209
3 (10-15 mi) mouth of canyon (Newton) to outskirts of Glenn City	3a: DV: 150-300 ft^2/s 3b: DV: 50-150 ft^2/s	1,785 275	No recreational PAR	1,785 275
4 (15-19 mi) Glenn City commercial and residential areas	4a: DV: 50-150 ft^2/s 4b: DV: 25-100 ft^2/s 4c: DV: 25-50 ft^2/s	2,275 4,850 1,275	No recreational PAR	2,275 4,850 1,275
5 (19-22 mi) Low lying areas, Glenn Airport to Mountain Lake	5a: DV: 50-150 ft^2/s 5b: DV: 25-100 ft^2/s 5c: DV: 25-50 ft^2/s	375 1,185 145	No recreational PAR	375 1,185 145
	Totals:	12,245	885	13,130

E. Flood Travel Time and Warning Time

Table 2.2 below summarizes the flood wave travel times from the inundation study results. The lower value represents the arrival time at the beginning of the reach, and the upper value represents the arrival time at the end of the reach.

Table 2.2 – Summary of flood travel times from inundation study

Reach and Description	Time (hrs.) to Leading Edge	Time (hrs.) to Maximum Discharge
	Range	Range
Reach 1: 0-7 mi Glenn River Canyon	0 - 0.6	1.0 - 1.6
Reach 2: 7-10 mi Glenn River Canyon	0.6 - 0.9	1.6 – 2.1
Reach 3: 10-15 mi Newton to Glenn City	0.9 - 1.4	2.1 – 2.9
Reach 4: 15-19 mi Glenn City	1.4 - 2.3	2.9 - 4.0
Reach 5: 19-22 mi Glenn City to Mountain Lake	2.3 - 3.2	4.0 - 5.2

The team that evaluated the life loss for Example Dam 2 spent considerable time discussing warning time and warning category, and all the factors that could influence warning and evacuation in the inundated areas. The most significant factors are discussed below:

Internal Erosion Potential Failure Mode: A detailed description of the primary internal erosion potential failure mode entitled, "Internal erosion of the embankment into defects in the foundation rock" was provided to the team. The team discussed factors related to the complete formation of a dam breach, and the time it would take to develop. The specific location of this potential failure mode is on the right abutment where concentrated seepage is visibly exiting near the right groin. The upper portion of the foundation rock is jointed, and although foundation treatment included a single-row grout curtain, no foundation surface treatment was performed. Foundation exploration programs indicate that rock joints are tighter and rock quality increases 10-20 feet below the embankment/foundation contact. Seepage is believed to be coming through a window in the grout curtain, through some open joints in the upper part of the foundation. Based on the current understanding of the geologic and geotechnical conditions, it is unlikely that increased seepage or erosion of embankment material would go undetected for more than a day or two. The seepage is a known concern, and any changes would likely result in detection and increased monitoring. However, the team also recognized that observation of a change in seepage conditions or evidence of material transport would not immediately result in activation of the EAP. Response and intervention activities would likely be ongoing for hours or days before notice of imminent dam failure is provided to local authorities. The team judged that in most cases this notification would be provided at least two hours before dam failure, and likely earlier than that.

Dam Staff (eyes on the dam): A dam tender is present at or near the dam, eight hours a day, five days a week. There is a small operations building with phone and internet service on the left abutment, but there is no dam tender residence. The dam tender lives in Glenn City, and drives up and down the canyon each work day. She is responsible for operating the spillway gates and outlet works as needed, as well as monitoring dam instrumentation on a monthly basis. Under normal operating conditions, formal, documented visual inspections are performed monthly. The dam is well maintained with minimal surface vegetation, increasing the effectiveness of visual observations. Based on the team's discussions with Area Office representatives, it is likely that if a significant change in seepage conditions or other unusual behavior occurred while the dam tender was on-site, she would observe and report the changed conditions.

Recreationists: As described in the PAR section, during summer months there are recreationists present daily in reservoir areas upstream of the dam and in the canyon. If a problem developed, recreationists driving the canyon road or those in the five recreation areas in the canyon might first observe unusual or suddenly increased flows in Glenn River. The likelihood of recreationists observing and reporting a problem would be much greater during summer days, both weekdays and weekends.

Year-round canyon residents: The year-round residents in the canyon are few and scattered. If a problem developed, some might be able to see or hear unusual or suddenly increased flows in the river because of the proximity of their residences to the river. Many of the canyon residents leave the canyon during the day for work or school on weekdays. On weekdays, the most likely time that unusual conditions would be noted is when they are driving up or down the canyon road. On weekends, there is greater likelihood that unusual or suddenly increased flows in the river would be observed and reported to authorities.

Residents near Newton: The small community of Newton is located at the mouth of the canyon. The Glenn River flows adjacent to the center of town and several nearby parks. Newton has several gas stations and convenience stores that are open 24-hours and are located near the road leading to the canyon. If unusual or suddenly increased flows had not been observed and reported prior to arriving in Newton, there is high confidence that someone in the residential or commercial areas of Newton would contact authorities, both in the day and at night. From Table 2.2, the leading edge of the flood would arrive in Newton in about 0.9 hours.

Emergency Management Officials: During recent EAP tabletop exercises with local emergency management officials, Glenn City law enforcement officials stated they require visual confirmation or strong assurances that the dam failed, or is in the process of failing, before they would initiate evacuations of Glenn City. They also stated that they would not put an officer's life at risk by sending one up into the canyon to warn and evacuate canyon residents if the dam was failing. Law enforcement officials would rely on visual confirmation and reporting from Reclamation officials. Land line and cell phone service is reasonably reliable in the canyon, and notifications could be made by phone and/or reverse 911. Once emergency officials are notified of the failure, they would begin warning and evacuation in Glenn City.

Based on the factors above, the best and worst case scenarios in terms of how the first observations and notifications to authorities might occur are described below. Warning category is described in more detail in the section that follows.

Best case: In the best case, the dam tender, recreationists, or canyon residents observe and report unusual dam behavior or a sudden increase in flows in the canyon.

This reporting results in Reclamation officials observing the dam and attempting intervention actions, which could continue for hours or days. Once it is decided that dam failure is likely, the EAP would be activated. Assuming EAP activation and the related notifications all occur at least two hours prior to dam failure, the PAR in the canyon would have about 2-3 hours to evacuate. The PAR in Glenn City would have about 3.5 to 4.5 hours to evacuate before the leading edge of the flood wave arrives. Peak flows would arrive about 1 hour (in the canyon) to 2 hours (in Glenn City) after the leading edge flood wave.

Worst case: In the worst case, deteriorating conditions at the dam at night go unnoticed for many hours. Unusual behavior or river flow increases are not observed by anyone in the canyon. Observations (likely in Newton) of increasing river flows result in notifications to Reclamation officials; however, the river flows might be too high to safety drive up the canyon road to confirm dam failure. Valuable warning time is lost in the resulting delays in activating the EAP. EAP activation and the related notifications may not occur until one hour after the dam has failed. In this case, the PAR in the canyon would not receive any official warning before arrival of the leading edge flood wave; successful evacuation would depend on the PAR's ability to make the decision to evacuate, and to evacuate to a safe location. The PAR in Glenn City could receive 15 minutes to 1.5 hours of warning before arrival of the leading edge flood wave, depending on their specific location. Peak flows would arrive about 1 hour (in the canyon) to 2 hours (in Glenn City) after the leading edge flood wave.

F. Warning Category

For each reach there are numerous factors that influence whether the warning time provided to the PAR in that reach would be categorized as "Little or No Warning" or "Adequate Warning" in accordance with RCEM. The team evaluating the life loss recognized there are conditions that could justify either category for most reaches under varying situations, and a weighting scheme was developed to account for the varying factors and conditions. For each reach, the best case and worst case warning time scenarios were evaluated, and a judgment was made of the percent of time that the warning category would be "Little or No" and "Adequate."

RCEM Guidance Note: *There are two ways to consider how to "weight" the two warning categories. Weighting percentages could represent either "percent of the time" or "percent of PAR." This example applies weighting percentages to represent "percent of the time" for most reaches; although "percent of the PAR" is also used. Either approach is valid as long as the explanation is clear.*

Reaches 1 and 2: In the best case warning scenario, the EAP is activated and the related notifications all occur at least two hours prior to dam failure. The PAR in the canyon would have about 2-3 hours to evacuate. The PAR could choose to drive upstream or downstream to evacuate. During the summer months, the canyon PAR is estimated to be nearly 1,000 people. If the summer canyon PAR had 2-3 hours to evacuate under best case warning conditions, the team discussed significant problems that could still develop. The canyon road is one lane in each direction, has many curves and crosses the river several times over narrow bridges. Many recreationists have camping and recreational gear, and might be driving large motor homes or towing off-road vehicles and camper trailers. The team envisioned numerous conditions that could lead to traffic problems along the evacuation route and other delays.

- Large, slow vehicles cause delays
- People delay in evacuating to pack up all their gear
- People waiting in traffic abandon their vehicles on the road
- Recreationists unfamiliar with the area are unclear on which way to go; attempt to turn around
- High flows erode portions of the roadway
- High flows make bridge crossings dangerous
- Rising water covers portions of the roadway and blocks the evacuation route, perhaps at multiple locations

The team concluded that it could take hours to evacuate the canyon, and 2-3 hours (under best case warning conditions) might not be enough to be considered "adequate" warning. Furthermore, the problems listed above could be compounded for a nighttime failure and evacuation scenario and there would be greater confusion. To capture the range of possible best case and worst case warning scenarios, two warning category conditions were considered for the summer failure scenario. A 30 percent probability weighting for the "adequate" warning category was judged to be appropriate for a best case, daytime failure with 2-3 hours of warning followed by orderly evacuation with minimal delays and traffic issues. The "little or no" warning category was given an 70 percent probability weighting to represent the more likely daytime failure scenarios where effective evacuation becomes problematic and delays occur. The "little or no" warning category was judged to be appropriate for 70 percent of the time, regardless if there was 2-3 hours of warning (best case) or less (worst case) because under both scenarios there would be insufficient time for the summer PAR to evacuate. For a nighttime failure, to account for more difficulty in warning notifications and a greater level of overall confusion, the probability weighting for "little or no" warning was estimated to be 90 percent, with only a 10 percent probability weighting for "adequate" warning at night.

> ***RCEM Guidance Note:*** *Teams should be careful not to over-conservatively account for the negative impact of a failure at night. For many situations, it is likely that a greater proportion of the PAR would receive "little or no" warning compared to a failure during the day. Case history data also indicates that fatality rates are higher at night compared to during the day (see RCEM Appendix B). In some cases the impact of a nighttime failure on fatalities could be over-conservatively estimated if a high proportion of the PAR (or high probability weighting) is given to "little or no" warning AND fatality rates are selected towards the upper end of the range on the "little or no" warning chart.*

<u>Reach 3:</u> In the best case warning scenario, by the time the leading edge arrives at the mouth of the canyon in Newton, the PAR in the five mile reach from Newton to the outskirts of Glenn City would have had about 3 to 3.5 hours warning. In the worst case warning scenario, there might be zero to a half-hour of warning. The residential PAR of just over 2,000 would have many optional driving routes for evacuation that are about a half-mile or less. The PAR could also easily walk out of the inundation area through neighborhood streets and arterials. There is no recreational PAR in this reach. The team concluded that seasonal variations (summer, non-summer) and weekday/weekend variations would have no significant impact on the life loss estimate, so the primary focus was on daytime vs. nighttime scenarios. For a daytime failure, the team judged that the best case scenario would occur 95 percent of the time due to high likelihood that someone closer to the dam would observe a problem and notify authorities, and the best case

scenario would be "adequate" warning for the PAR. However, there is more uncertainty associated with warning for a nighttime failure, and the team members varied in their judgments on the probability weightings for "little or no" and "adequate" warnings. Team members that believed the worst case scenario was more likely to occur for this PAR were focused on the fact that some of the PAR would have no warning, and a half-hour of warning would not be enough to successfully warn and evacuate this PAR. Other team members that believed the best case warning scenario was more likely to occur focused on how easy it would be to evacuate (i.e. the short distance) and the additional 1-1.5 hours of time between the leading edge and the peak of the flood wave. Consensus was reached among team members that the worst case scenario should be weighted five times greater than during the day. The "little or no" warning category was judged to be appropriate for the worst case scenario, and was given a 25 percent probability weighting. Overall, the team members were comfortable with a probability weighting of 75 percent for "adequate" warning at nighttime, mainly due to the additional time between the leading edge and peak discharge arrival time.

> ***RCEM Guidance Note:*** *In some cases the time difference between the leading edge of the flood wave and the arrival of peak flows can be a significant factor that contributes to successful evacuation and lower fatality rates. It is over-conservative to estimate fatality rates based on maximum depths and velocity (based on peak flows) and warning times based on leading edge travel times. However, in some cases, there may be little time difference between the leading edge and peak arrival times (for example, reaches closed to the dam), or the difference in arrival times may be judged insufficient to make a difference in fatality rates.*

Reach 4: Reach 4 includes all the commercial and residential areas of Glenn City, with a PAR of about 8,400. The ability to effectively warn and evacuate this large, populated area would depend on the warning time available and the effectiveness of the emergency management officials. Because the flows spread out significantly in this reach, it might not be clear to the PAR which direction would be the best choice for evacuation. The river turns west in this reach, and flows spread south; therefore, most of the PAR would have to travel east to leave the inundation area. Those that choose to travel west toward Reach 5 could be trapped between the rising water coming from the north and east, and Mountain Lake. Complications could also arise from the PAR in sub-reach 4a (nearest the river, and the first area inundated) evacuating southward into sub-reaches 4b and 4c, adding to overall road congestion and confusion on which way to evacuate. Emergency management and law enforcement officials would have to direct traffic at many locations to communicate evacuation routes. In the team's discussions with local Area office representatives, it was not clear if all the nuances of evacuation of Glenn City were known to local emergency management officials. This finding was judged by the team to be critical, and the Area office representative attending the meeting agreed to follow up with local officials.

The team's primary focus was on daytime vs. nighttime failure scenarios in this reach. The best case warning scenario in Reach 4a would provide about 3.5 to 4.5 hours of warning. Sub-areas 4b and 4c to the south would receive additional warning time, because they would not be inundated by the leading edge flood wave, and would have an additional 1.5-1.75 hours before the peak discharge arrival. For a daytime failure, the team recognized the most difficult part of estimating whether warning would be considered "little or no" or "adequate" was highly dependent on communication systems (reverse 911, emergency cell phone notifications, radio, TV, etc.), clear messages and instructions, as well as on-the-ground emergency management and law enforcement officials. With input from local Area office representatives, the team judged that during the day, the best case warning scenario with "adequate" warning would occur 90 percent of the time due to the minimum 3.5 hours of warning and the technology available to emergency management officials. A probability weighting of 10 percent "little to no" warning was judged to be appropriate for daytime failures to account for some of the difficulties mentioned above with road congestion and possible confusion on the part of some people not understanding which way to go to evacuate.

Similar to Reach 3, the team judged there is more uncertainty associated with warning for a nighttime failure, and the team members varied in their judgments on the probability weightings for "little or no" and "adequate" warnings.

Team members that believed the worst case scenario was more likely to occur for this PAR envisioned greater confusion and more difficulties evacuating at night, particularly closer to the river channel (sub-area 4a) where the PAR might only receive about 15 minutes to 1.5 hours warning. Other team members that believed the best case warning scenario was more likely to occur focused on the many available evacuation routes, and the additional 1.5-1.75 hours of time between the leading edge and the peak discharge that would greatly benefit most of the PAR in Reach 4. Consensus was reached among team members that the worst case scenario would be slightly more likely to occur in this reach at night compared to Reach 3, simply due to the greater number of people, even though there would be a little more warning time in Reach 4. The "little or no" warning category was judged to be appropriate for the worst case scenario, and was given a 30 percent probability weighting. Overall, the team members were comfortable with a probability weighting of 70 percent for "adequate" warning at nighttime, mainly due to the additional time between the leading edge and peak discharge arrival time. Team members noted that this additional time would allow the PAR to correct any mistakes made in choosing an evacuation direction before the peak flows arrive.

<u>Reach 5:</u> From a warning and evacuation viewpoint, Reach 5 is much different than the other reaches. There would be 4 to 5 hours of warning in the best case scenario (likely daytime) and 1 to 2 hours of warning in the worst case scenario (likely nighttime). The residential PAR of about 1,200 is predominantly rural agricultural; however, there are about 500 employees and passengers at the airport at any given time. The topography in Reach 5 is flat and low-lying, although the roads and buildings around the airport have been built up several feet. In addition, the airport itself is a 3-story modern building, and most of the employees and passengers are on the second and third levels (ground crews and baggage handling are on the ground level). The inundation map indicates flood depths in the vicinity of the airport would be about 5 to 10 feet. Therefore, in the event of a dam failure, the PAR at the airport could escape flood waters by simply remaining at the airport and obtaining shelter on the main concourse (second) level. With DV values between 25 and 100 ft^2/s, the modern airport building might experience some damage from flows but should be able to provide a safe haven for those that remain. Evacuation of the airport could be more problematic than simply remaining there because vehicles transporting people would have to travel east about five or six miles, possibly towards areas (Reach 4) that have deeper flooding and a significantly greater number of people trying to evacuate. The significant time before the arrival of the peak discharge could be uniquely problematic also because people may become impatient, and choose to leave the safety of the airport building after a couple hours, before the most severe floodwaters arrive. It is unlikely there would be

enough law enforcement officials at the airport to assist with this situation because they would likely be dispatched to critical areas in Reach 4.

The team discussed some warning and evacuation advantages and disadvantages that the rural PAR of 1,500 in Reach 5 has compared to those in Reach 4. During the day, the rural PAR is less likely to receive the fully warning time of 4 to 5 hours because they are likely not paying attention to various communication outlets (cell phone, radio, TV, etc.). Also, their evacuation route could involve travelling east, towards Reach 4, where there are more people and flows could be more severe as time passes. However, the team agreed that during the day, the warning and evacuation advantages would far outweigh the disadvantages. The Reach 5 PAR has the longest warning time with 4-5 hours, plus an additional 2 hours before the arrival of the peak discharge. This would enable friends and neighbors adequate time to communicate and find adequate evacuation routes toward the south and east. If some of the PAR was not adequately informed and became trapped by water flowing from the north and east, they could travel west to the airport and be safe on the second level. Considering all of the factors above related to the airport and rural PAR, the team judged that during the day "adequate" warning would be provided 95 percent of the time. A probability weighting of 5 percent "little or no" warning was judged to be appropriate to account for those that ultimately never receive warning, or those that leave the safe haven of the airport. The team recognized that assigning "little or no" warning to those that leave the airport is an indirect way of reflecting a greater likelihood of fatalities to a small portion of the overall PAR.

At night, the rural PAR is more likely to receive some warning and evacuation communication (reverse 911, cell phone, etc.) because they are in their homes. Even in the worst case warning scenario, 1 to 2 hours warning was judged to be "adequate" warning for this PAR 80 percent of the time. A probability weighting of 20 percent "little or no" warning was judged appropriate to account for greater difficulty in evacuating at night.

Table 2.3 – Estimated Travel Time, Warning Time and Warning Category

Reach and Description	Estimated Travel Time (hrs.)		Warning Time (to leading edge)		Warning Category and Weighting	
	Leading Edge	Peak	Best Case (2 hrs. before)	Worst Case (1 hr. after)	Little or no warning	Adequate warning
Reach 1: 0-7 mi Glenn River Canyon	0 - 0.6	1.0 – 1.6	2 – 2.6	None	Day: 0.70 Night: 0.90	Day: 0.30 Night: 0.10
Reach 2: 7-10 mi Glenn River Canyon	0.6 - 0.9	1.6 - 2.1	2.6 – 2.9	None	Day: 0.70 Night: 0.90	Day: 0.30 Night: 0.10
Reach 3: 10-15 mi Newton to Glenn City	0.9 - 1.4	2.1 - 2.9	2.9 – 3.4	0 – 0.4	Day: 0.05 Night: 0.25	Day: 0.95 Night: 0.75
Reach 4: 15-19 mi Glenn City	1.4 - 2.3	2.9 - 4.0	3.4 – 4.3	0.4 – 1.3	Day: 0.10 Night: 0.30	Day: 0.90 Night: 0.70
Reach 5: 19-22 mi Glenn City to Mountain Lake	2.3 - 3.2	4.0 - 5.2	4.3 - 5.2	1.3 – 2.2	Day: 0.05 Night: 0.20	Day: 0.95 Night: 0.80

G. Fatality Rates

The selection of fatality rates was based on estimates of DV and warning time and other factors specific to each reach. The team reviewed the conditions at each reach and used the appropriate fatality rate curves to select a likely range of fatality rates. Fatality rate vs. DV charts that graphically show the fatality rate ranges selected by the team for each reach are included in the Appendix. In general, for comparable DV values, the fatality rates from the "adequate" warning chart are much lower than the fatality rates from the "little or no" warning chart. Because of this, the team recognized that the selection of fatality rates for the "adequate" warning portion was not going to drive the life loss. Therefore, the team spent most of their time discussing the factors that would influence fatality rates for the little or no warning portion. The following notes for each reach capture the team's discussions on selection of fatality rate ranges for the "little or no warning" portion. A summary of the logic used to select fatality rate ranges for the "adequate warning" portion is included following the "little or no warning" portion.

Little or No Warning

Reach 1 (0-7 miles)(DV 550-1500 ft^2/s):

The terrain in upper Glenn River Canyon is steep and confined. From the time the leading edge flood wave arrives, flows would be very intense with very high DV and high rate of rise in Reach 1. The rate of rise, which is estimated to be at least 10 feet in 5 minutes, indicates that the flooding would arrive as a "wall of water." There would not be a lot of lateral variation in flood intensity due to the confined nature of the canyon at most locations. Persons who do not successfully evacuate and are caught in the flooding would be subjected to very intense flows. The characteristics of the flooding would result in the destruction of most structures. Trees would be uprooted. Areas subjected to flooding in the canyon would experience almost total destruction, except for the outmost fringes of the flood zone. Individual decisions and actions occurring in this emergency situation are likely going to influence the whether people survive or not. Similar case histories characterized by steep canyon reaches, high DV and little to no warning included Teton Dam (canyon fatality rate 0.5), St. Francis Dam (construction camp fatality rate 0.56), and Malpasset Dam (Upper Reyran fatality rate 0.7). These case histories helped the team select upper values of 0.5 for daytime failure and 0.7 for nighttime failure. The lower limits of both the day and night values were selected slightly below the suggested limit on the fatality rate vs. DV chart because of the team's belief that the PAR's likely knowledge of the need to evacuate would tend to reduce the fatality rate, even if canyon traffic or other conditions limit vehicular evacuation. The lower limit for daytime failure was estimated at 0.2, and the lower limit for nighttime failure was estimated at 0.3. These fatality rates are below the lower suggested limit, but they are above the fatality rates for cases (with similar DV values) with "partial" warning. The team recognized these fatality rates are high, but the high DV values, the rate of rise, and the potential difficulties with evacuation even with hours of warning could result in a large number of fatalities in the upper portion of the canyon.

Reach 2 (7-10 miles)(DV 350-550 ft^2/s): The terrain in lower Glenn River Canyon is not as steep as Reach 1, but it is confined. Flows would be intense with high DV values, though not as high as in Reach 1. With the lower DV values and slightly more warning, fatality rates would be lower than in Reach 1. There are no case histories with DV between 350 and 550 ft^2/s; however, the Vega de Tera Dam failure is close, with a DV of 300 ft^2/s and a fatality rate of 0.29. The nighttime fatality rate range was selected as 0.2–0.6 to bracket the Vega de Tera dam, which failed at night. The daytime fatality rate range was selected as 0.1-0.4. The upper limit of 0.4 is slightly higher than the Vega de Tera fatality rate, and approximately equal to the lower limit of the suggested range. The lower limits for both day and night ranges were selected to be well below lower limit of the suggested ranges because the PAR would likely have knowledge of the need to evacuate, unlike at Vega de Tera or St. Francis Dams. The lower limits for both day and night ranges were selected to be greater than the fatality rates associated with the 2011 Japanese tsunami because of the confined nature of the canyon, which the team judged would be a more severe situation than the coastal PAR areas inundated by the tsunami.

<u>Reach 3 (10-15 mi)(3a: DV 150-300 ft^2/s; 3b: DV 50-150 ft^2/s):</u> Downstream of the canyon mouth the DV decreases as flows enter Newton and the Glenn River valley, and the potential for warning increases. The DV has greater lateral variation in Reach 3 compared to the canyon, so different fatality rates were selected for each of the two sub-reaches. Higher DVs would occur near in sub-reach 3a, which includes the main river channel. A nighttime fatality rate range from 0.15 to 0.5 was selected, which is slightly lower than the fatality rate range in Reach 2. The PAR is higher in Reach 3a compared to Reach 2 in the canyon, but there are many more options for evacuation. A daytime fatality rate range from 0.08 to 0.3 was selected, which is also slightly lower than the fatality rate range in Reach 2. Some team members voiced concern that these fatality rate ranges were too high because of all the warning and evacuation options; however, those factors have minimal influence on the fatality rate selection (and the probability weighting) for "little or no" warning as compared to the "adequate" warning condition. For those with little or no warning, it is difficult to justify much lower fatality rates for this range of DV values based on the case history data.

Lower DVs (50-150 ft^2/s) would occur on the fringes of Reach 3, which was designated sub-reach 3b. Within this DV range, the case history data indicates a wide, overlapping range of fatality rates for day and night failures, with no clear trend. The team judged that a higher fatality rate at night would be justified, even if the case history data in this range do not support the general trend. A nighttime fatality rate range from 0.05 to 0.3 was selected, which is lower than the fatality rate range in sub-reach 3a. A daytime fatality rate range from 0.02 to 0.1 was selected, which is also lower than the fatality rate range in sub-reach 3a. The PAR in sub-reach 3b is smaller than in sub-reach 3a, and they do not have to travel as far to evacuate.

<u>Reach 4 (15-19 mi)(4a DV 50-150 ft^2/s; 4b DV 25-100 ft^2/s; 4c DV 25-50 ft^2/s):</u> Reach 4 contains dense, urbanized residential and commercial areas of Glenn City. The DV has great lateral variation in Reach 4 due to the configuration of the river channel in the north, which turns westward towards Mountain Lake. However, as floodwaters leave the river channel, they flow southward and westward, before entering Mountain Lake. Due to the topographic and flooding conditions, three sub-reaches were established, with the highest DVs in the northern sub-reach 4a. DVs generally decrease towards the south through sub-reaches 4b and 4c. The DV range of sub-reach 4a is similar to that of sub-reach 3b described above; and within this DV range, the case history data indicates a wide, overlapping range of fatality rates for day and night failures, with no clear trend. In sub-reach 4a, a nighttime fatality rate range from 0.03 to 0.2 was selected, and a daytime fatality rate range from 0.01 to 0.07 was selected. The team judged that

a higher fatality rate at night would be justified, even if the case history data in this range do not support the general trend. The nighttime fatality rates generally include the suggested limits on the fatality rate vs. DV chart, but the daytime fatality rate range is towards the lower side of the suggested limit. The team discussed the Canyon Lake Dam failure case and it's applicability to Example Dam 2. Canyon Lake Dam failed in 1972 at night, with a DV of 95 and a fatality rate of 0.014. The case was classified as a "partial warning" case because some of the PAR received warning and some did not. This case (with offsetting factors of night failure, partial warning) provided some justification for the selected lower bound daytime fatality rate of 0.01 with little or no warning. Other modern cases with nighttime failure (Shadyside flood, DV 75, fatality rate 0.027; Big Thompson flood DV 76, fatality rate 0.04) influenced the selection of the lower limit of the nighttime fatality rate of 0.03.

In sub-reach 4b the DVs are generally lower than in sub-reach 4a, but the fatality rate range corresponding to a DV range from 25-100 ft^2/s spans more than one order of magnitude. Therefore, there could be significant variability in the fatalities in this sub-reach. The suggested limits on the fatality rate vs. DV chart decrease quickly with decreasing DV in this range due to the case history evidence that suggests these floods are not as lethal as higher severity floods. A nighttime fatality rate range from 0.02 to 0.1 was selected, and a daytime fatality rate range from 0.004 to 0.04 was selected. The fatality rates were selected to be lower than those in sub-reach 4a (due to the lower DVs) and were selected to generally include the suggested limit range on the fatality rate vs. DV chart.

In sub-reach 4c, the upper estimate of the DV range is 50 ft^2/s, so the flood severity in this sub-reach is much lower and lower fatality rates are justified. A nighttime fatality rate range from 0.007 to 0.04 was selected, and a daytime fatality rate range from 0.002 to 0.01 was selected.

Reach 5 (19-22 mi)(5a DV 50-150 ft^2/s; 5b DV 25-100 ft^2/s; 5c DV 25-50 ft^2/s): Reach 5 includes the area between Glenn City and Mountain Lake, which is characterized by low lying rural agricultural areas and the Glenn Regional Airport. The three sub-reaches were established using the same DV values as the three sub-reaches in Reach 4. Compared to Reach 4, the team believed that areas in Reach 5 with similar DV values would have similar and only slightly lower fatality rates. The fact that the Reach 5 PAR is much smaller and has more warning time is reflected in a greater proportion of the PAR judged to have adequate warning (vs. little or no warning). When estimating the fatality rate, team members had to keep these factors separate to avoid giving additional credit to factors that influenced the probability weighting of adequate warning.

In sub-reach 5a, a nighttime fatality rate range from 0.02 to 0.1 was selected, and a daytime fatality rate range from 0.007 to 0.05 was selected. In sub-reach 5b (which includes the airport), the nighttime fatality rate range from 0.005 to 0.04 was selected, and a daytime fatality rate range from 0.001 to 0.01 was selected. It was recognized that the PAR at the airport would likely have warning about the flooding because of airport public address announcements and cell phones. Although some team members argued for a fatality rate of zero for sub-reach 5b, overall the team thought a low, non-zero fatality rate was more appropriate to reflect poor judgment on the part of those few that might choose to leave the safety of the airport. Sub-reach 5c is a relatively small area adjacent to Mountain Lake. A nighttime fatality rate range from 0.002 to 0.02 was selected, and a daytime fatality rate range from 0.001 to 0.005 was selected.

Adequate Warning

For each reach, the team selected fatality rates from the "adequate" warning chart that were generally within the "suggested limit" curves. The daytime fatality rate ranges were generally towards the lower part of the suggested limit, and the nighttime fatality rate ranges were generally towards the upper part of the suggested limit. The selected daytime and nighttime fatality rate ranges overlapped, but the team selected the upper limit for each of the daytime fatality rate ranges to be consistently lower than the upper limit for the nighttime fatality rate range, for the same reach. In the canyon, the team believed there would probably be high fatality rates for those that do not evacuate (either by choice or by circumstance). Selected fatality rates in Reach 1 in the canyon ranged from 0.001 (day, lower) to 0.02 (night, upper). The adequate warning assumption implies a significantly higher rate of evacuation when compared to the little to no warning category. Evacuation from the canyon by vehicle would require driving along the canyon, either to below the canyon mouth or to a location above the dam. People could climb to safety on the steep canyon hillsides such as some did during the Big Thompson flood. Selected fatality rates in Reach 2 in the canyon were slightly lower than in Reach 1 due to the lower DV values, which would enable the PAR to more easily escape by climbing compared to Reach 1. Selected fatality rates in Reach 2 ranged from 0.0007 (day, lower) to 0.015 (night, upper).

Selected fatality rates in sub-reaches 3a and 3b were generally within the suggested limits for given DV values, with fatality rates ranging from 0.0002 (Reach 3b, day, lower) to 0.01 (Reach 3a, night, upper). Selected fatality rates in sub-reach 4a were within or slightly below the suggested limits for given DV values, with fatality rates ranging from 0.00015 (day, lower) to 0.003 (night, upper). Selected fatality rates for sub-reach 5a (with flow conditions similar to sub-reach 4a) were close to but slightly lower than those selected for sub-reach 4a, ranging from 0.0001 (day, lower) to 0.001 (night, upper).

For the remaining sub-reaches (4b, 4c, 5b and 5c) the team selected the day upper fatality rate generally in the middle of the suggested range, and the night upper fatality rate generally towards the upper end of the suggested range. The team selected zero as the lower limit for daytime fatalities in these sub-reaches due to the warning time and flooding severity. Several dam failure case histories with zero fatalities with comparable DV and warning include Quail Creek Dike, Teton Dam (Roberts) and Lawn Lake Dam (Fall River / Estes Park). These comparable cases provided justification for low (or zero) fatality rates for reaches 4b, 4c, 5b, and 5c.

Table 2.4 – Fatality Rates – Internal Erosion PFM ***[Format A – see RCEM Guidance Note]***

Reach and Description	DV Range by Sub-reach	Warning Category and Probability Weighting	Fatality Rate Range	
			Day	Night
Reach 1: 0-7 mi Glenn River Canyon:	550-1500 ft^2/s	Little or No 0.70	0.2 – 0.5	0.3 – 0.7
		Adequate 0.30	0.001 – 0.01	0.003 – 0.02
Reach 2: 7-10 mi Glenn River Canyon:	350-550 ft^2/s	Little or No 0.70	0.1 – 0.4	0.2 – 0.6
		Adequate 0.30	0.0007 – 0.007	0.002 – 0.015
Reach 3: 10-15 mi Newton to Glenn City	3a: 150-300 ft^2/s 3b: 50-150 ft^2/s	Little or No Day: 0.05 / Night: 0.25	3a: 0.08 – 0.3 3b: 0.02 – 0.1	3a: 0.15 – 0.5 3b: 0.05 – 0.3
		Adequate Day: 0.95 / Night: 0.75	3a: 0.0006 – 0.005 3b: 0.0002 – 0.001	3a: 0.002 – 0.01 3b: 0.0006 – 0.005
Reach 4: 15-19 mi Glenn City	4a: 50-150 ft^2/s 4b: 25-100 ft^2/s 4c: 25-50 ft^2/s	Little or No Day: 0.10 / Night: 0.30	4a: 0.01 – 0.07 4b: 0.004 – 0.04 4c: 0.002 – 0.01	4a: 0.03 – 0.2 4b: 0.02 – 0.1 4c: 0.007 – 0.04
		Adequate Day: 0.90 / Night: 0.70	4a: 0.00015 – 0.0007 4b: 0 – 0.0004 4c: 0 – 0.0002	4a: 0.0004 – 0.003 4b: 0.0002 – 0.002 4c: 0.0001 – 0.001
Reach 5: 19-22 mi Glenn City to Mountain Lake	5a: 50-150 ft^2/s 5b: 25-100 ft^2/s 5c: 25-50 ft^2/s	Little or No Day: 0.05 / Night: 0.20	5a: 0.007 – 0.05 5b: 0.001 – 0.01 5c: 0.001 – 0.005	5a: 0.02 – 0.1 5b: 0.005 – 0.04 5c: 0.002 – 0.02
		Adequate Day: 0.95 / Night: 0.80	5a: 0.0001 – 0.0005 5b: 0 – 0.0002 5c: 0 – 0.0001	5a: 0.0002 – 0.001 5b: 0.0001 – 0.001 5c: 0 – 0.0002

RCEM Guidance Note:
There are many ways to tabulate and arrange row and column information to present fatality rates. Select a format that allows for side-by-side comparison of fatality rates to enable quick consistency reviews and "relative" checking.

Table 2.4 – Fatality Rates – Internal Erosion PFM ***[Format B – see RCEM Guidance Note]***

Reach Description and Sub-reach	DV Range (ft^2/s)	Warning Category	Warning Category Probability Weighting		Fatality Rate Range			
					Day		Night	
			Day	Night	Lower	Upper	Lower	Upper
1 (0-7 mi)	550-1500	Little or No	0.70	0.90	0.2	0.5	0.3	0.7
		Adequate	0.30	0.10	0.001	0.01	0.003	0.02
2 (7-10 mi)	350-550	Little or No	0.70	0.90	0.1	0.4	0.2	0.6
		Adequate	0.30	0.10	0.0007	0.007	0.002	0.015
3a (10-15 mi)	150-300	Little or No	0.05	0.25	0.08	0.3	0.15	0.5
		Adequate	0.95	0.75	0.0006	0.005	0.002	0.01
3b (10-15 mi)	50-150	Little or No	0.05	0.25	0.02	0.1	0.05	0.3
		Adequate	0.95	0.75	0.0002	0.001	0.0006	0.005
4a (15-19 mi)	50-150	Little or No	0.10	0.30	0.01	0.07	0.03	0.2
		Adequate	0.90	0.70	0.00015	0.0007	0.0004	0.003
4b (15-19 mi)	25-100	Little or No	0.10	0.30	0.004	0.04	0.02	0.1
		Adequate	0.90	0.70	0	0.0004	0.0002	0.002
4c (15-19 mi)	25-50	Little or No	0.10	0.30	0.002	0.01	0.007	0.04
		Adequate	0.90	0.70	0	0.0002	0.0001	0.001
5a (19-22 mi)	50-150	Little or No	0.05	0.20	0.007	0.05	0.02	0.1
		Adequate	0.95	0.80	0.0001	0.0005	0.0002	0.001
5b (19-22 mi)	25-100	Little or No	0.05	0.20	0.001	0.01	0.005	0.04
		Adequate	0.95	0.80	0	0.0002	0.0001	0.001
5c (19-22 mi)	25-50	Little or No	0.05	0.20	0.001	0.005	0.002	0.02
		Adequate	0.95	0.80	0	0.0001	0	0.0002

H. Loss-of-Life Evaluation Results

Estimated Life Loss Range

Based on the fatality rate ranges for daytime and nighttime failure scenarios, the estimated life loss for internal erosion potential failure modes is presented in Table 2.5 below.

Table 2.5 – Estimated Life Loss – Internal Erosion PFM

Reach and Sub-reach	PAR	Estimated Life Loss Range			
		Day		Night	
		Lower	Upper	Lower	Upper
Reach 1 (0-7 mi)	756	106	267	204	478
Reach 2 (7-10 mi)	209	15	59	38	113
Reach 3 (10-15 mi)					
3a	1785	8	35	70	236
3b	275	0	1	3	22
Reach 4 (15-19 mi)					
4a	2275	2	17	21	142
4b	4850	2	21	30	153
4c	1275	0	1	3	16
Reach 5 (19-22 mi)					
5a	375	0	1	2	8
5b	1185	0	1	1	10
5c	145	0	0	0	1
Sub-Totals:		134	405	372	1178
Sub-Totals (65% Day; 35% Night)		87	263	130	412
Lower Weighted Estimate of Life Loss:		217			
Upper Weighted Estimate of Life Loss:		675			
Minimum Estimate of Life Loss:		134			
Maximum Estimate of Life Loss:		1178			

The estimated life loss for the worst case scenario is 1,178, which is based on the upper range of fatality rates for nighttime failure. The estimated life loss for the best case scenario is 134, which is based on the lower range of fatality rates for a daytime failure. Overall, the life loss estimate range spans an order of magnitude, which seems appropriate given the range of possible warning category and flood severity conditions that could occur in the downstream areas.

> ***RCEM Guidance Note:*** *Life loss estimates should always be presented as a range. Weighted average or "seasonalized" life loss estimates should be calculated based on the time categories (e.g. seasonal, day/night, etc.) used in the life loss evaluation. However, it is also appropriate to report the overall minimum and maximum values that could occur for the best case and worst case scenarios so the entire range of possible life loss calculated using RCEM is represented.*

Based on the DV values from the inundation study and the fatality rate ranges selected by the team, the estimated life loss range for a daytime failure is 134 to 405, and the estimated life loss range for a nighttime failure is 372 to 1178. The team judged that for either day or night, there would be equal likelihood of fatalities being at the lower end, the upper end, or any value in between. Therefore, a probability distribution for a daytime failure would be a uniform distribution between 134 and 405, and a probability distribution for a nighttime failure would be a uniform distribution between 372 and 1178. The daytime life loss estimate was judged to be representative of 65 percent of the time, and therefore nighttime would be 35 percent of the time.

The two uniform distributions of life loss (normalized to a total probability of 1.0, ignoring the small overlapping area) are represented on Figure 2-4.

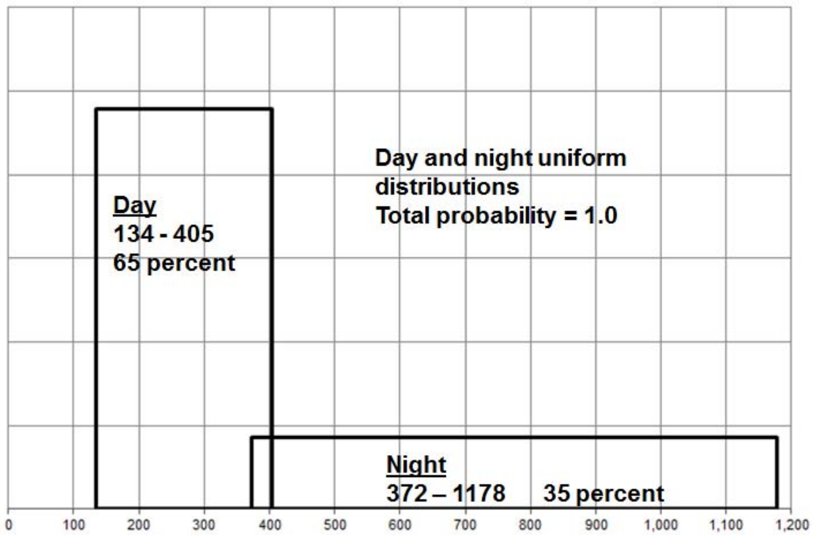


Figure 2-4. Normalized Uniform Distributions for Day and Night Failure Scenarios

The estimated life loss for a "weighted average" condition ranges from 217 to 675. This weighted average range accounts for daytime conditions representing 65 percent of the time, and nighttime conditions representing 35 percent of the time. The lower average estimate of 217 was calculated by adding 65 percent of the lower daytime life loss (0.65*134=87) and 35 percent of the lower nighttime life loss (0.35*372=130). Similarly, the upper average estimate was calculated by adding 65 percent of the upper daytime life loss (263) and 35 percent of the lower nighttime life loss (412).

> ***RCEM Guidance Note:*** *In this example a "weighted average" life loss is reported rather than an "annualized" life loss because the presence of the higher summer recreational PAR in the canyon also corresponds to the time when the dam is most vulnerable to internal erosion PFMs. Annualizing life loss by accounting for lower non-summer PAR would inappropriately underestimate the PAR for this particular failure mode.*

Confidence in Factors used to Estimate Life Loss

The summary table below was prepared to document the team's thoughts on the level of confidence in each aspect or factor that was used to estimate the life loss.

Table 2.6 – Summary of Confidence in Life Loss Estimate

Factor Considered in the Life Loss Estimate	Level of Confidence	Basis for Confidence Level
Breach parameters	Moderate to high	Numerous published relationships used; results seem consistent with similar past studies of comparable dams
Hydraulic model output; depth, velocity	High	The evaluation included both 1D and 2D models. Current topography was used in the model, and state-of-the-art modeling software was used. Depths and velocities seem reasonable, and model output indicates they decrease as the flood waters exit the canyon and continue to spread downstream, as would be expected. Reaches could be defined differently (different depth or velocity limits) but this

		would not be expected to have a significant impact on the total life loss estimate.
PAR	High	Updated census data was included. PAR was obtained by overlaying flood inundation maps with census blocks in a GIS. In the canyon, the PAR was visually confirmed by counting residences. Summer recreational PAR is high in the canyon, and was estimated from official visitation data. Some uncertainty regarding Glenn City PAR changing location from night to day (residences to commercial areas), was discussed, but the team felt the net change to the PAR would not be significant enough to differentiate.
Warning time and Warning category	Moderate to High	The team spent significant effort discussing warning time and possible scenarios. This involves prediction of human interactions, decision-making, and many inter-related factors, and it is difficult to have high confidence in these predictions. There are conditions that could justify either warning category in each reach. Team member opinions varied, but a team consensus estimated a percent weighting for each warning category in each reach to account for this uncertainty. Originally team members had low to moderate confidence that the estimated weighting percentage would be correct, but the sensitivity study results (discussed below) increased the team's overall level of confidence.
Fatality rates	Moderate	The confidence in the selected fatality rates varied, depending on the reach and warning category. Generally, there is higher confidence in the fatality rates for all reaches in the "little to no" warning category; whereas confidence is lower for reaches with higher DV values in the "adequate" warning category (in part, due to the lack of case history information on this part of the chart). There is higher confidence in the low fatality rates in reach 5 with adequate warning due to the low DV values, long warning, and several case histories with zero fatalities.

Sources of Uncertainty

Based on the team's discussions during the multi-day life loss estimating meeting, it was apparent that the primary source of uncertainty is the weighting percentage given to "little or no" warning vs. "adequate" warning. There were two specific reaches (3a and 4b) with relatively high PAR values where team member opinions varied widely for the nighttime failure scenario, and considerable discussion was required to reach consensus. During the meeting team members agreed that these areas of uncertainty should be documented in the report.

Sensitivity Studies

To address the primary sources of uncertainty, sensitivity studies were performed using simple spreadsheet analysis to determine how sensitive the overall life loss estimate is to variations in the warning category probability weighting for nighttime failure scenarios in Reaches 3a and 4b. With Reach 3a being located close to the river and at the mouth of the canyon, team members debated the probability weighting for "little to no" and "adequate" warning category scenarios (see discussion in Warning Category section above). A sensitivity study was performed to vary the probability weighting for the warning category. Although consensus was reached at 25% little or no warning (75% adequate), the sensitivity study evaluated a range from 10% to 40% probability of little or no warning. For Reach 4b, some team members expressed concern about the evacuation ability of this relatively large population center at night, even with the additional time provided between the arrival of the leading edge and the peak flow. In this reach, consensus was reached at 30% little or no warning (70% adequate), and the sensitivity study evaluated a range from 15% to 45% probability of little or no warning. The team members agreed on the bounds of the sensitivity studies, which were believed to represent likely (but not absolute) minimum and maximum values. The day/night probability weighting of 65 percent day and 35 percent night was not varied.

> ***RCEM Guidance Note:*** *This example selected the warning category probability weighting as the factor that had significant uncertainty that was evaluated using a sensitivity analysis. Any of the other input factors such as depth, velocity, PAR and fatality rate could be identified as a primary source of uncertainty and could be evaluated in a sensitivity study. Teams should evaluate uncertainty and perform sensitivity studies specific to each case, particularly for Issue Evaluation level studies.*

The lower weighted estimate of life loss using the team consensus values (25 percent little or no warning in 3a; 30 percent little or no warning in 4b) is 217. The sensitivity study found this value did not vary significantly, even when extreme values of probability weighting are used. Figure 2-5 below shows the variability of the total lower weighted life loss estimate (198 to 236) for different values of probability weighting in Reaches 3a and 4b. Similarly for the upper weighted life loss estimate, there is not significant variability in the results (604 to 746), depending on the probability weighting for little or no warning in Reaches 3a and 4b. The sensitivity analysis results indicate the life loss evaluation is not particularly sensitive to the parameter that the team felt was a source of considerable uncertainty.

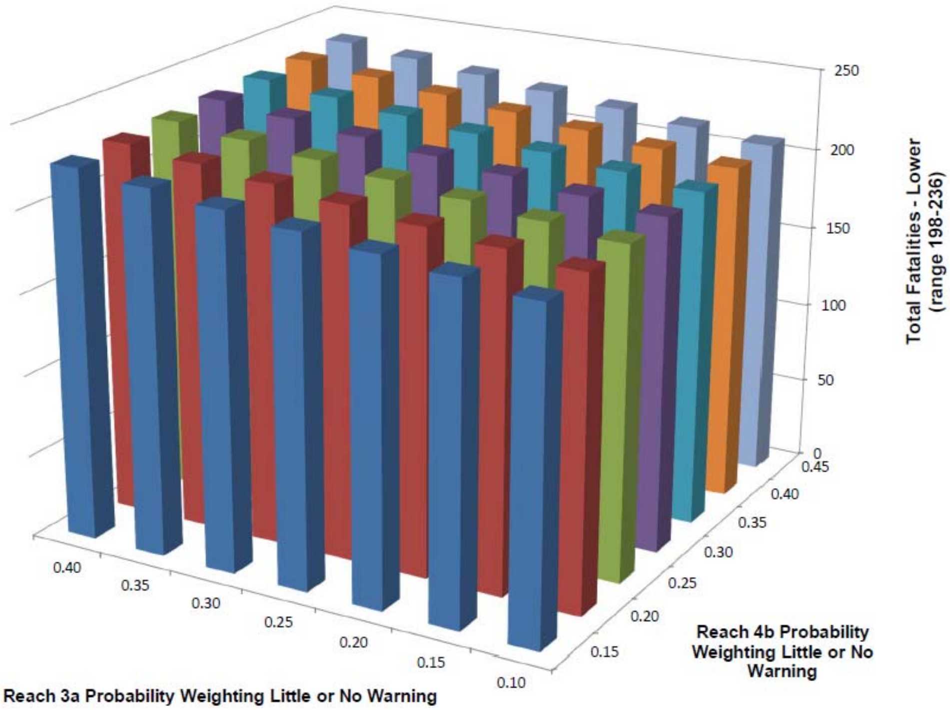


Figure 2-5 Sensitivity Study Results – Lower Estimate of Total Fatalities for variable probability weighting for little or no warning category at night

Confidence in the Overall Life Loss Estimate

Prior to initiating this life loss study for Example Dam 2, there was uncertainty in the inundation area and flood flow characteristics, which were based on older 1980s studies. This uncertainty led to a lack of confidence in the life loss estimate that was potentially driving Annualized Life Loss risk close to Reclamation's Public Protection Guidelines. The new inundation study, PAR evaluation and multi-day team life loss analysis have combined to significantly increase the overall confidence in the life loss estimate. This is based on relying on state of the art studies, the most current information on the population at risk, and a thorough evaluation of the assumptions and variables used in estimating life loss. In addition, a sensitivity study was performed to evaluate uncertainty in the warning time category distribution for two key reaches downstream of the dam. Since the sensitivity study indicated that this variable did not have a significant impact on the overall life loss range, the confidence in the life loss estimates was increased further. Overall, confidence in the life loss estimate for the internal erosion potential failure mode is judged to be moderate

> ***RCEM Guidance Note:*** *For cases where sensitivity studies indicate significant differences in life loss outcomes, teams are encouraged to re-evaluate on the reasons why there could be variation in the parameters being considered. Even with a team Issue Evaluation study, it is possible to have low to moderate confidence in the life loss estimate due to factors the team believes might result in reasonably large variations.*

> ***RCEM Guidance Note:*** *In most cases for Reclamation projects, there will be a separate Decision Document / Technical Report of Findings (DDTROF) that describes the dam safety decisions being made related to a specific issue, and documents the findings from all studies that support that decision. The discussion on uncertainty and confidence included in this section should be captured in the Findings and Dam Safety Case portion of the DD/TROF. A discussion on how uncertainty and confidence in the consequence estimates affects the total risk estimates and the overall findings should also be included.*

to high, based on the higher level of the evaluations and the results of the sensitivity studies.

Recommended Life Loss Estimate for Annualized Life Loss Risk Calculations

Since Issue Evaluation studies typically include a detailed risk analysis that utilizes Monte Carlo simulations to sample probability distributions for loadings and/or event tree nodes, teams might elect to represent the life loss estimate for each PFM as a distribution. In this way, the Annualized Life Loss output would reflect the uncertainty of the individual PFM life loss estimates, similar to how the output AFP reflects the uncertainty of the input conditional probability estimates. Some example distributions are discussed below.

> ***RCEM Guidance Note:*** *Distributions are frequently not used in CR-level studies, which instead tend to utilize point estimates. Selection of an appropriate distribution is not a simple task, and should be carefully evaluated and discussed by teams to ensure that the selected distribution is reflecting the numerical range of values (as well as the calculated mean) intended by the team.*
>
> *The remaining portion of this Example 2 life loss evaluation provides some examples of probability distributions that teams might consider without recommending a particular distribution.*

Trapezoidal Distribution

For the internal erosion PFM, the reasonable low value of potential life loss was estimated to be 134, representing the low estimate for a daytime failure. The reasonable high value of life loss was estimated to be 1,178, corresponding to the high estimate for a night time failure. The “best estimate” was judged to range from 217 to 675 (with equal likelihood that the value could fall anywhere within this range), which reflects the weighted day/night estimate described above. This “best estimate” range might be considered a mode, in that the team expects that given an internal erosion failure, the life loss would most likely fall somewhere within this band.

One way to attempt to incorporate all of the above information into a single PFM life loss distribution is a trapezoidal life loss distribution, as shown by the schematic in Figure 2-6.

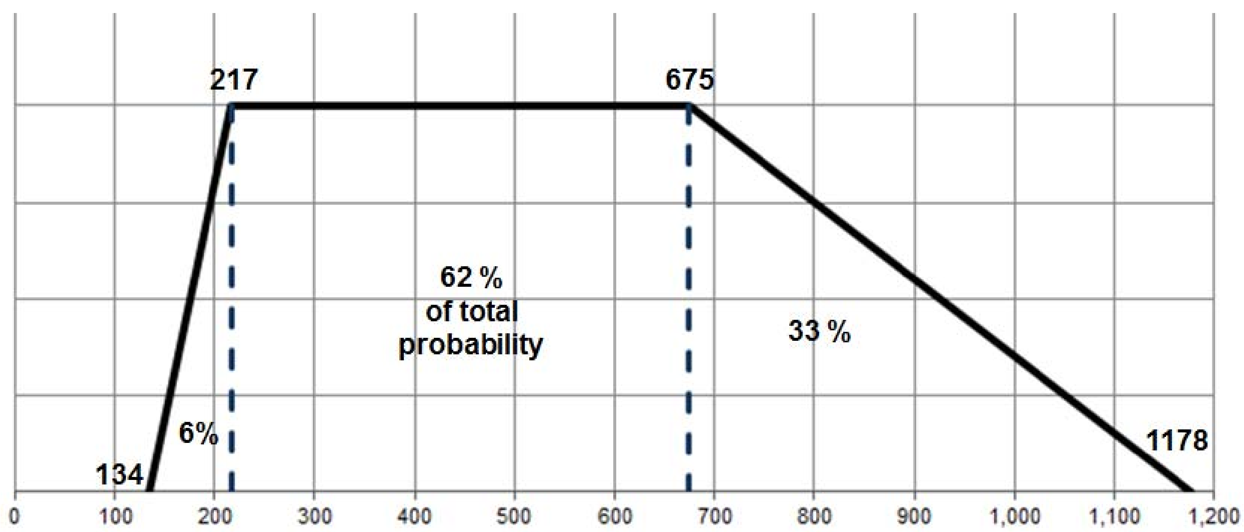


Figure 2-6 Schematic of a trapezoidal probability distribution. Such a distribution can be programmed using the @risk software “riskgeneral” function.

As shown, any given Monte Carlo trial would have about a 62 percent chance of hitting a life loss estimate within the "best estimate" or mode range identified. The overall mathematical mean life loss of this trapezoidal distribution is calculated to be approximately 565. If a simple uniform or "boxcar" distribution was assumed between 217 and 675, the calculated mean life loss would be 446. These values are similar, and based on the mean, little difference would result in estimated annualized life loss risks, particularly considering that such risks are plotted on a log-log scale.

Double Boxcar Distribution

The trapezoidal distribution allocates weight differently than the "double boxcar" shown in Figure 2-4. Because of this, teams might believe it would be more appropriate to identify a distribution which better reflects the intent of the day-night weighting. One way to accomplish this is to use the "double boxcar" shown in Figure 2-4 directly as a distribution. In order to do this, the overlap between the daytime and nighttime distributions (between x values 372 and 405) first needed to be idealized. Once an x-value of 390 had been selected as a reasonable average cutoff, the double-boxcar was programmed using the @risk "riskcumul" function. The resulting distribution, shown in Figure 2-7, appears crude, but precisely reflects the day/night weighting discussed above.

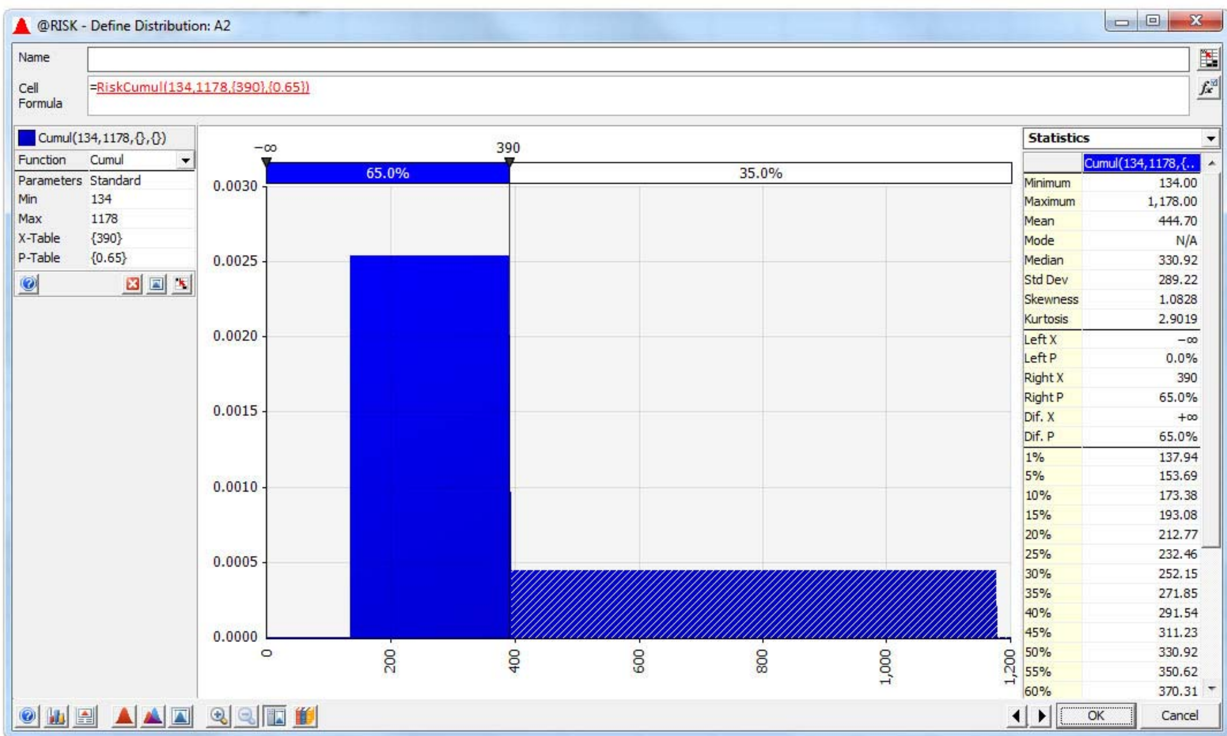


Figure 2-7 Double boxcar distribution, as defined in @risk software using "riskcumul" function.

There are some drawbacks to be aware of by selecting the double boxcar distribution. First, if the overlap is significant, the idealization of the distribution would reduce the impact of the overlap area on the simulation results. Also, when the results are depicted on an f-N scatter plot, the point cloud would be bi-modal in the Annualized Life Loss direction. This portrayal would need to be explained in the risk report (and at a DSAT presentation where decision makers need to understand the individual PFM risk portrayal).

Triangular Distribution

A classic triangular distribution might also be considered. With an x-value of 390 (equal to the average day/night cutoff) selected as a trial mode, 75 percent of the distributional weight was allocated to life loss values greater than 390. Since in this case, approximately 65 percent of the weight should end up below the cutoff value in order to correctly reflect the intent of the team's day/night judgment, the mode can be shifted to the left, with the shape beginning to approach that of a right triangle. When the mode could be shifted no further left (Figure 2-8), 57 percent of the weight still remained to the right of the cutoff value. For this particular example, a triangular distribution would not precisely reflect the intended day/night weighting. The findings from other cases will vary.

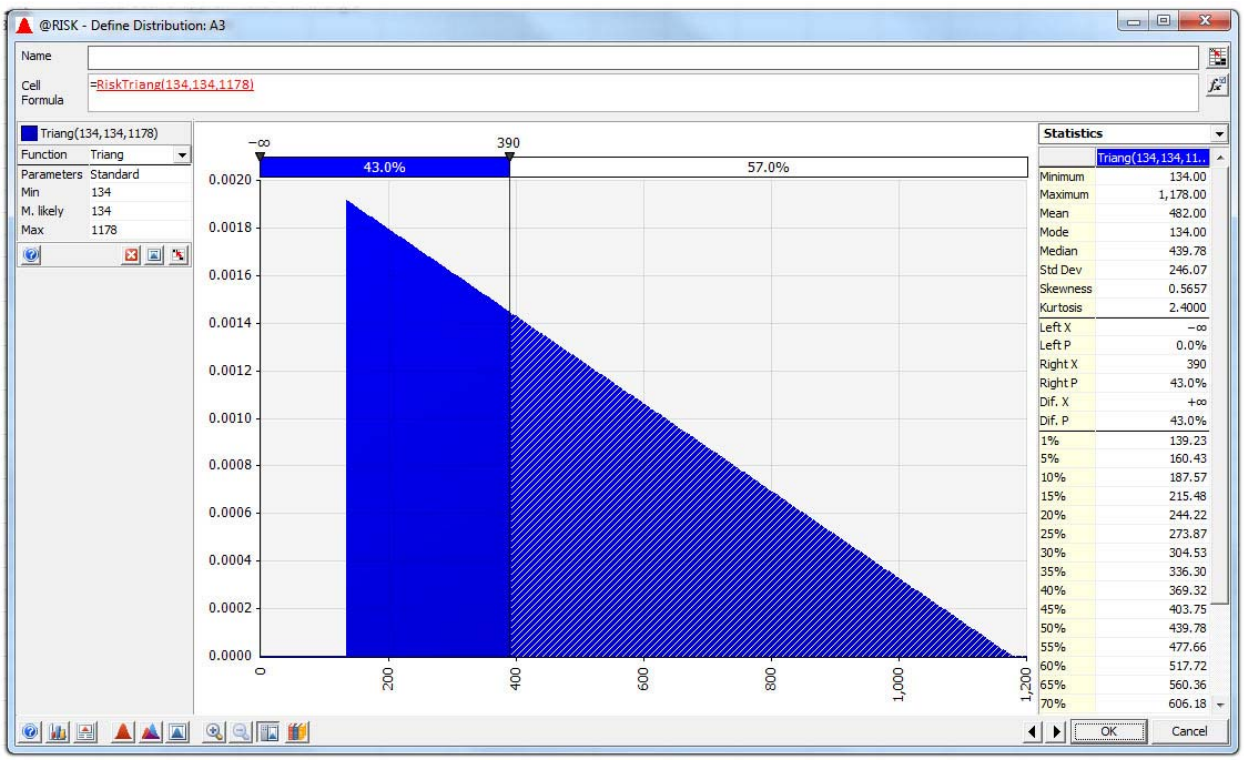


Figure 2-8 Classic triangular distribution, with the mode equal to the minimum value

PERT Distribution (alternate parameters using 65th percentile)

Another alternative to consider is a distribution that has the continuity and basic shape of the triangular distribution, but one that allocated less weight to the long side of the triangle. A PERT distribution might be selected to achieve the desired results. Much like the triangular distribution, the PERT requires three parameters, typically a min, max, and mode. For example, using the "alternate parameters" formulation in @risk, a team might select a minimum value of 134, a maximum value of 1178, and a 65th percentile of 390. The resulting distribution is shown on Figure 2-9, and features both the continuity desired and the day/night weighting implied by

Figure 2-4. In terms of weighting, the distribution in Figure 2-9 might be more consistent with both the results of the RCEM process and the intentions of the team.

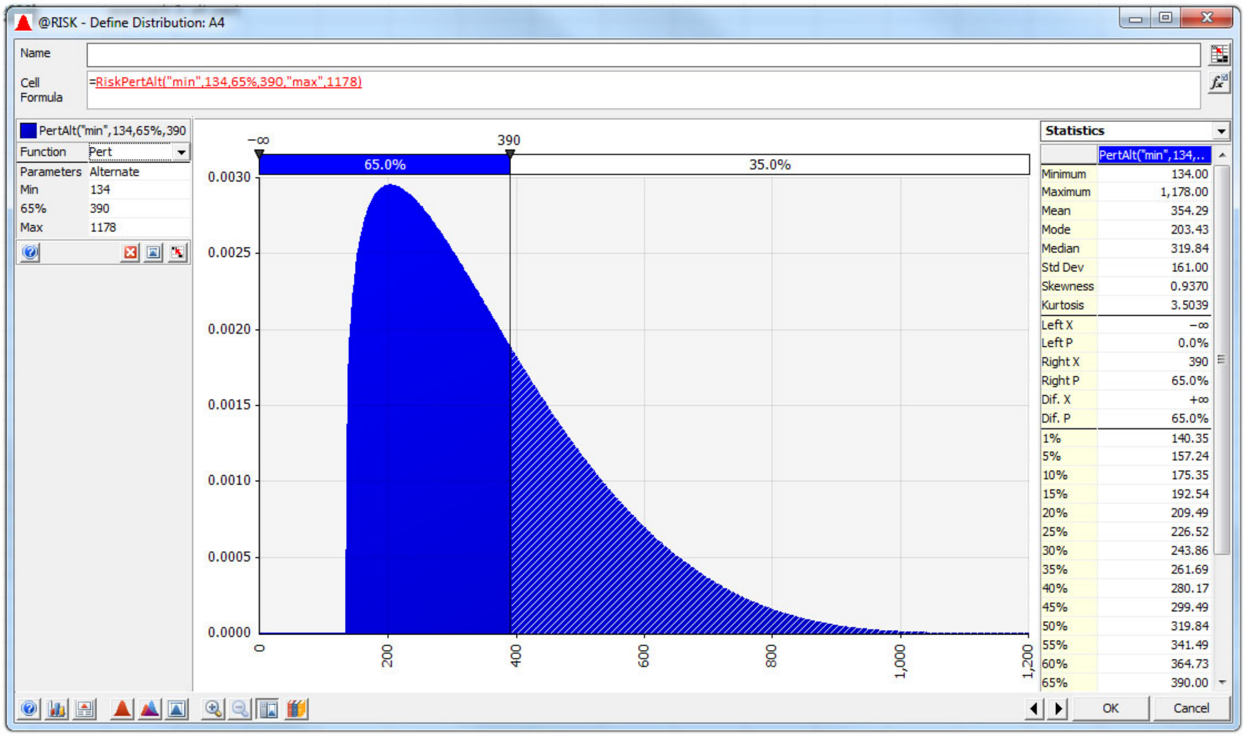


Figure 2-9 PERT distribution, specified in terms of the min, max, and 65-percentile. Note similarity to the overall shape of the triangular distribution in the preceding figure.

PERT Distribution (standard min, max and mode parameters)

For this situation, a limitation of the PERT distribution with alternate parameters was observed; i.e. the calculated mean value of 354 is lower than the mean of the double-boxcar distribution, 445 (this might not be the case for other situations). This could lead to concerns that the life loss coordinate of the f-N chart PFM marker would be lower than intended. For this reason, the standard version of the PERT (with the min, max, and mode as parameters), might provide an optimal balance between weighting and mean through trial and error. As the initial mode for the PERT, a value of 390 (the day/night cutoff value) could be initially specified. This trial resulted in only 36 percent of the weight being allocated to the daytime side of the cutoff. The mode was then reduced to 300, which resulted in 390 becoming the median and 418 the mean. Although a mean of 418 seems reasonable, if it is desired to have more weight end up on the daytime side of 390, the mode could be further reduced to 270. This resulted in 390 becoming the 55 percentile (55 percent of the weight on the daytime side of the cutoff) and in a mean of 399. While neither the mean nor the day/night weighting were identical to those of the double-boxcar, for the purposes of depicting the range of life loss possible given an internal erosion failure, the distribution shown in Figure 2-10 might provide a good balance (as well as a smooth change in probability density) for this particular case.

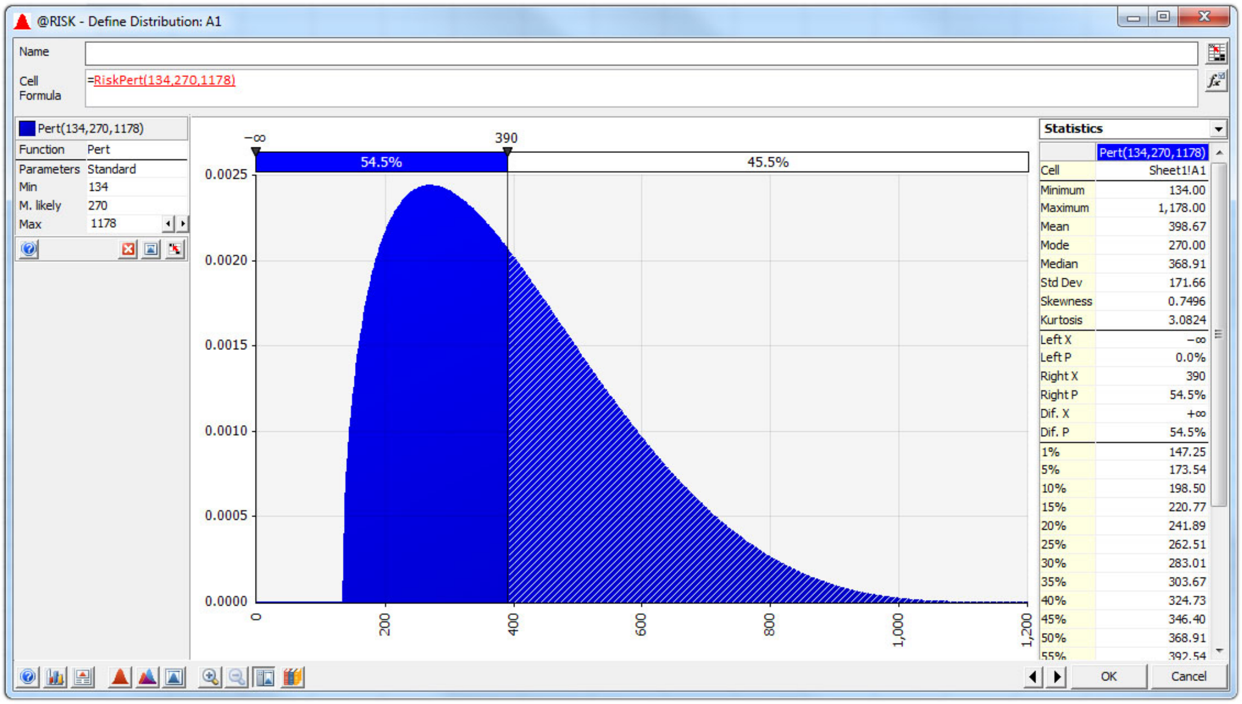


Figure 2-10 PERT distribution, specified in terms of the min, max, and mode. Compared with Figure 2-9, more of the weight ends up on the right side of the day-night cutoff (390)

IV. Flood Related Failure Modes

A. Breach Parameters

Several empirical relationships were used to predict breach parameters for the flood-related dam failure scenario at Example Dam 2, similar to the static dam failure scenario describe above. The only difference with the flood scenario is the estimated peak breach discharge of 1.9 million ft^3/s, which is 0.4 million ft^3/s (about 25%) greater than the static failure scenario. The hydrologic breach is assumed to initiate at one foot of overtopping, and the breach is assumed to be fully formed in 1.5 hours. The life loss evaluation team agreed with the breach parameters and the breach formation time. Details of the breach parameter evaluation are in the inundation study report.

B. Time Categories

The critical flood loading for this type of hydrologic failure is the spring general storm. The summer thunderstorm does not lead to dam overtopping. Reclamation hydrologic loading specialists indicate that the critical general storm is likely to occur between the months of March to mid-June. This time period includes both a low and high recreational season, indicating it would be appropriate to consider both summer and non-summer recreationists in the PAR. For this example, it is assumed that summer recreationists will be present for about 25 percent of the time that this type of flood would occur (May and half of June), while much fewer, non-summer recreationists are most likely representative of the recreational PAR for the remaining 75 percent of the time. This weighting will be applied to the recreational PAR for the general storm failure.

At Reclamation dams, it is standard practice to institute 24-hour surveillance when a reservoir reaches and exceeds historical high elevations (i.e. in a first-filling situation). In the case of a general storm, this would mean physical presence of staff at the dam for several days prior to an overtopping failure. In addition, weather system and precipitation monitoring would be used constantly to estimate inflows and reservoir levels. This suggests that the PAR would be given many hours (or days) of warning well before overtopping occurs, plus emergency evacuation warnings would be issued when there is a high probability of overtopping. Consequently, warnings are expected to be adequate, effective and timely. Because of the timing and effectiveness of the likely warning, the difference in fatalities between a day and night failure is judged to be insignificant. Therefore, separate day and night fatality rates were not estimated for this particular failure mode, but rather day and night conditions were considered as part of the range of fatality rates for each inundated area.

C. Defined Reaches and DV Values

When compared to the static inundation map, the flood inundation depths for the hydrologic failure mode are somewhat greater in the canyon downstream of the dam, but the lateral extent of flooding is not significantly different from the sunny day failure due to the relatively steep canyon walls. Below the mouth of the canyon, the flooding extent is both broader and deeper when compared to the sunny day scenario. For consistency purposes, the reaches and sub-reaches that were established for the static failure scenario were also used for the flood failure scenario. General descriptions of the five reaches are included in the discussion for static potential failure modes and are not repeated here.

The five reaches and flood characteristics are described below:

- Reach 1 (dam to 7 miles): For the flood failure scenario, the inundation study indicates flood depths in the first seven miles of Glenn River Canyon range from 40-100 feet, with depths generally decreasing with distance downstream. Maximum velocity was calculated from the 1D model to be about 20 ft/s. The maximum DV was calculated to range from about 800 to 2,000 ft^2/s. The downstream limit (7 miles) of this reach corresponds to a DV value of about 800 ft^2/s. It was noted that the hydraulic model indicated a rate of rise greater than 10 feet in 5 minutes in this reach, which could lead to higher fatality rates, although the estimated DV values are quite high without considering the rate of rise.

- Reach 2 (7 to 10 miles): The inundation model indicates that maximum flood depths within this reach ranged from 30 to 40 feet and flow velocity ranged from 18 to 20 ft/s. Estimated DV ranges from a high value of about 800 ft^2/s at 7 miles, to a low value of about 550 ft^2/s at 10 miles, which is the mouth of canyon at the community of Newton.

- Reach 3 (10 to 15 miles) (start of 2D inundation model): The 2D model results were comparable to the static failure scenario results. Sub-reach 3a represents the main river channel area and was defined with a maximum velocity of 18 ft/s. The fringe areas were included in sub-reach 3b, and were characterized by a flow velocity of about 15 ft/s. Based the calculated depth range of 15 to 25 ft, the DV in sub-reach 3a is still relatively high, ranging from about 250 to 450 ft^2/s. The DV in sub-reach 3b ranges from about 150 to 250 ft^2/s, based on depths ranging from 10 to 15 ft.

- Reach 4 (15 to 19 miles): Similar to the static failure scenario, the flood failure inundation model indicated maximum depths and flow velocities were located closest to the main river channel, with depths and velocities decreasing toward the south, away from the channel as it curves and heads westward toward Mountain Lake. Sub-reach 4a represents the main river channel area and was defined with a maximum velocity range of about 10 ft/s. To the south, sub-reach 4b was defined with a maximum velocity range of 5-10 ft/s, but with maximum depths less than 12 ft. Sub-reach 4c was defined as the area to the far south with velocity values of about 5 ft/s or less and maximum depths less than 12 ft. Much of this area might be inundated with "backwater" low velocity flows as the flood water extends south and enters Mountain Lake. Based the calculated depth ranges for each sub-area, the DV range in sub-reach 4a is 80-200 ft^2/s, the DV range in sub-reach 4b is 50-120 ft^2/s, and the DV range in sub-reach 4c is 25-60 ft^2/s.

- Reach 5 (19 to 22 miles, Mountain Lake): The flood characteristics in reach 5 are very similar to those in reach 4. Three sub-reaches were defined with the same velocity ranges established for reach 4.

D. Population at Risk (PAR)

When evaluating the PAR for the flood overtopping failure condition, the team considered the impacts of spillway releases on evacuation and the location of the PAR. Because of the size of the storm being considered, spillway releases would be occurring for days prior to overtopping of the dam. An inundation map representing the maximum spillway release was used to estimate the PAR that could be affected by spillway release flows. Once the spillway releases begin to produce flooding that exceeds safe channel capacity, evacuations would be required, particularly for the canyon and other low lying areas in sub-reaches 3a, 4a, and 5a. Based on flood routing results, the initial evacuations are estimated to occur at least 12 hours (and as much as 24 hours, depending on precipitation and runoff prediction models) in advance of a breach initiation. Local emergency management officials have an evacuation plan that designates flood shelters that are located outside of the dam failure inundation flood zone.

> ***RCEM Guidance Note:***
> *From a life loss estimating perspective, the evacuation of the PAR to shelters outside of the flood inundation area many hours or days before dam breach means the PAR is decreased. This is the one condition where it is appropriate to consider evacuation using RCEM. Fatality rates from the fatality rate vs. DV curves are applied directly to the reduced PAR that remains.*
>
> *If the PAR evacuates to shelters that are located beyond the spillway release flood zone but within the dam failure flood area, higher fatality rates may be considered because that PAR would have to evacuate again to reach safety if the dam fails. In addition, the warning category for PAR in shelters that would have to evacuate again might change from "adequate" to "little or no." This scenario is complex and makes it very difficult to estimate life loss from dam failure. A key finding from such a study should be that different evacuation shelters outside of the dam inundation area need to be identified in local evacuation plans.*

As previously described, the residential PAR in the inundated areas was updated for this study using 2010 census data. In Glenn River Canyon (Reaches 1 and 2), it was judged that 90 percent of the residential and recreational PAR would evacuate due to the high flows from spillway releases. The team believed that 10 percent of the PAR would remain because there may be a few residents not willing to leave their homes, and there might be a few recreationists (e.g. kayakers) seeking thrills from the high river flows.

The inundation study indicates that downstream of the canyon for the flood condition, the flood depths are slightly greater and the inundated area is slightly broader compared to the static condition inundation. Therefore, the PAR would increase slightly around the perimeter of the inundated areas because the flooded extent is broader. The flood failure condition PAR in Reach 3 includes Newton (at the mouth of the canyon) and the mostly residential population between Newton and the outskirts of Glenn City. Two sub-reaches were established and the PAR in each sub-reach was obtained by overlaying the flood inundation map with the census blocks in Reclamation's GIS. The total estimated PAR in Sub-reach 3a was estimated to be 1,900 and the total estimated PAR in Sub-reach 3b was estimated to be 300. However, the PAR in the low-lying areas near the river in sub-reach 3a would have been evacuated due to the spillway releases. Based on the maximum spillway release inundation map, the inundated PAR in sub-reach 3a is about 150. The team believed most people in sub-reach 3a affected by spillway release flows would evacuate. Therefore, the adjusted PAR in sub-reach 3a is 1,750, assuming 100 percent of the PAR inundated by spillway discharges evacuates. Even if a few people remain, there is not a significant impact on the overall life loss estimate for this reach.

The PAR in Reach 4 includes both residential and commercial areas of Glenn City. The PAR in sub-reach 4a does not increase for the flood failure condition because it does not include any perimeter areas. The PAR in sub-reaches 4b and 4c was obtained by overlaying the flood inundation map with the census blocks in Reclamation's GIS. The total estimated PAR in Sub-reach 4a remains the same at 2,275; the total estimated PAR in Sub-reach 4b was estimated to be 5,100; and the total estimated PAR in Sub-reach 4c was estimated to be 1,350. However, the PAR in the low-lying areas near the river in sub-reach 4a would have been evacuated due to the spillway releases. Based on the maximum spillway release inundation map, the inundated PAR in sub-reach 4a is about 220. Similar to sub-reach 3a, the team believed most people in sub-reach 4a affected by spillway release flows would evacuate. Therefore, the adjusted PAR in sub-reach 4a is 2,055, assuming 100 percent of the PAR impacted by spillway releases evacuates. Even if a few people remain, there is not a significant impact on the overall life loss estimate for this reach.

The PAR in Reach 5 does not increase for the flood failure condition because most of Reach 5 is surrounded by Mountain Lake. A slight increase in the inundated area of sub-reach 5a would occur, but the area inundated is rural agricultural land with few scattered residences. From the static inundation PAR evaluation, the total estimated PAR in Sub-reach 5a was estimated to be 375; the total estimated PAR in Sub-reach 5b was estimated to be 1,185 (685 residents and 500 at the airport); and the total estimated PAR in Sub-reach 5c was estimated to be 145. The low lying areas near the river in sub- reach 5a are primarily agricultural fields, so no adjustment was made to reduce the PAR for spillway releases in this reach.

The PAR values estimated for each sub-reach are presented on Table 2.7. The PAR shown on Table 2.7 includes both summer and non-summer recreationists that would likely be present when the reservoir is most vulnerable to a large general storm event that could lead to overtopping. Therefore, the total weighted PAR includes weighted recreational PAR to account for the possibility that the overtopping could occur either when the recreational PAR is present or not.

Table 2.7 – Estimated PAR for Flood Overtopping Potential Failure Modes

Reach and Description	Sub Area and DV range	Population at Risk (PAR)			
		Residential (year round)	Recreational Summer (25%)	Recreational Non-summer (75%)	Weighted PAR for Flood Overtopping PFMs
1 (0-7 mi) Glenn River Canyon	No sub areas DV: 800-2000 ft^2/s	6	70	3	26
2 (7-10 mi) Glenn River Canyon	No sub areas DV 550-800 ft^2/s	2	19	1	8
3 (10-15 mi) mouth of canyon (Newton) to outskirts of Glenn City	3a: DV: 250-450 ft^2/s 3b: DV: 150-250 ft^2/s	1,750 300	No recreational PAR	No recreational PAR	1,750 300
4 (15-19 mi) Glenn City commercial and residential areas	4a: DV: 80-200 ft^2/s 4b: DV: 50-120 ft^2/s 4c: DV: 25-60 ft^2/s	2,055 5,100 1,350	No recreational PAR	No recreational PAR	2,055 5,100 1,350
5 (19-22 mi) Low lying areas, Glenn Airport to Mountain Lake	5a: DV: 80-200 ft^2/s 5b: DV: 50-120 ft^2/s 5c: DV: 25-60 ft^2/s	375 1,185 145	No recreational PAR	No recreational PAR	375 1,185 145
	Totals:	**12,268**	**89**	**4**	**12,294**

E. Flood Travel Time and Warning Time

The inundation study indicates flood wave travel times are slightly faster for the flood overtopping failure scenario. Flood wave travel times and the time to maximum discharge at each reach are documented in the inundation study. However, flood wave travel times ranging from zero to about 5 hours are not significant factors in the life loss estimate for a flood overtopping failure because of the long warning time of many hours, or days. Well before the dam fails by overtopping, there would be a much greater awareness of the failure potential due to the heavy rainfall, spillway releases which produce localized flooding, continuous monitoring of physical conditions at the dam as well as a focus on weather forecasting, reservoir inflows and elevations. Flood wave travel times for a flood overtopping failure are comparable to (but slightly less than) the travel times in Table 2.2 for the static failure condition. For reference, actual values are presented in the inundation study.

F. Warning Category

Because of the high confidence in the long warning time, the team felt strongly that all downstream reaches would have “adequate” warning. During a large storm event, Reclamation officials would be continuously monitoring the dam and the weather conditions. As the reservoir continues to rise, officials would be in contact with local emergency management officials about a pending dam failure, and pre-evacuation notices would likely go out to PAR in the canyon and PAR in low lying areas along the river, including sub-reaches 3a, 4a, and 5a. If and when it becomes apparent that dam overtopping cannot be avoided, Reclamation officials would activate the EAP and local emergency management officials would begin evacuation. Based on current precipitation models, the available storage below the crest of the dam and the topography of the upstream basin, it is likely that Reclamation officials would be able to provide at least 12 to 24 hours notice before overtopping and dam failure.

G. Fatality Rates

The selection of fatality rates was based on estimates of DV and other factors related to pre-failure flooding and evacuation specific to each reach. The team reviewed the conditions at each reach and used the “adequate” warning fatality rate curves in all cases to select an estimated range of fatality rates.

Reach 1 (0-7 miles)(DV 800-2,000 ft^2/s):

Pre-failure spillway releases in Glenn River Canyon would be significant, and would likely inundate the recreation areas and could erode some portions of the canyon road. Failure flows would be very intense with very high DV and high rate of rise in Reach 1. Anyone who did not successfully evacuate would be subjected to very intense flows that would almost certainly result in the destruction of most structures and trees. There are no case histories of flooding this severe where adequate warning was provided to the PAR. The team selected a fatality rate range within the suggested limits of 0.002 to 0.01.

Reach 2 (7-10 miles)(DV 550-800 ft^2/s): Conditions in Reach 2 would be similar to Reach 1. There are no case histories of flooding this severe where adequate warning was provided to the PAR. The team selected a fatality rate range within the suggested limits of 0.001 to 0.007.

Reach 3 (10-15 mi)(3a: DV 250-450 ft^2/s; 3b: DV 150-250 ft^2/s): Downstream of the canyon mouth the DV decreases as flows enter Newton and the Glenn River valley, although the DV values are still high. For sub-reach 3a, the team selected a fatality rate range within the suggested limits of 0.0007 to 0.005. For sub-reach 3b, the team selected a fatality rate range within the suggested limits of 0.0005 to 0.004. The team noted the fatality rates at two locations downstream of the 1889 South Fork Dam failure (at E. Conemaugh DV 210 ft^2/s fatality rate 0.0055; at South Fork DV 250 ft^2/s fatality rate 0.01) and considered those cases as upper bound limits of fatality rates that would not be exceeded with a modern day dam failure. The upper limit of the fatality rate range for both reaches was selected to be below these values.

Reach 4 (15-19 mi)(4a DV 80-200 ft^2/s; 4b DV 50-120 ft^2/s; 4c DV 25-60 ft^2/s): Reach 4 contains dense, urbanized residential and commercial areas of Glenn City. Although there will be plenty of warning time, some people in the large urban area may not evacuate or may return to the inundated area and be unable to escape later. The fatality rates selected by the team reflect these factors. For sub-reach 4a, the team selected a fatality rate range of 0.0003 to 0.003. For sub-reach 4b, the team selected a fatality rate range of 0.0001 to 0.001. Some team members suggested the lower fatality rate limit for these sub-reaches could be zero, and they cited two modern case histories of flooding through towns with zero fatalities (Lawn Lake Dam, Estes Park; Teton Dam, Sugar City) to support this judgment. However, other team members pointed out other similar cases (Arno River Flood, Florence; Teton Dam, Rexburg) with non-zero life loss. The team reached consensus by selecting a low but non-zero lower limit because the value is very small, it makes very little difference in the life loss estimate. For sub-reach 4c, the team selected a fatality rate range of zero to 0.0006.

Reach 5 (19-22 mi)(5a DV 50-150 ft^2/s; 5b DV 25-100 ft^2/s; 5c DV 25-50 ft^2/s): The team believed that areas in Reach 5 with similar DV values would have the same fatality rates as Reach 4.

Table 2.8 – Fatality Rates – Flood Overtopping PFM

Reach Description and Sub-reach	DV Range (ft^2/s)	Fatality Rate Range	
		Lower	Upper
1 (0-7 mi)	800-2000	0.002	0.01
2 (7-10 mi)	550-800	0.001	0.007
3a (10-15 mi)	250-450	0.0007	0.005
3b (10-15 mi)	150-250	0.0005	0.004
4a (15-19 mi)	80-200	0.0003	0.003
4b (15-19 mi)	50-120	0.0001	0.001
4c (15-19 mi)	25-60	0	0.0006
5a (19-22 mi)	80-200	0.0003	0.003
5b (19-22 mi)	50-120	0.0001	0.001
5c (19-22 mi)	25-60	0	0.0006

H. Loss-of-Life Evaluation Results

Estimated Life Loss Range

Based on the weighted PAR (25% summer; 75% non-summer) and the fatality rate ranges for the flood overtopping failure scenario, the estimated life loss is presented in Table 2.9 below.

Table 2.9 – Estimated Life Loss – Flood Overtopping PFM (weighted PAR)

Reach and Sub-reach	Weighted PAR	Estimated Fatality Rate		Estimated Loss of Life	
		Lower	Upper	Lower	Upper
Reach 1 (0-7 mi)	26	0.002	0.01	0	0
Reach 2 (7-10 mi)	8	0.001	0.007	0	0
Reach 3 (10-15 mi)					
3a	1,750	0.0007	0.005	1	9
3b	300	0.0005	0.004	0	1
Reach 4 (15-19 mi)					
4a	2,055	0.0003	0.003	1	6
4b	5,100	0.0001	0.001	1	5
4c	1,350	0	0.0006	0	1
Reach 5 (19-22 mi)					
5a	375	0.0003	0.003	0	1
5b	1185	0.0001	0.001	0	1
5c	145	0	0.0006	0	0
			Totals:	**3**	**24**

The life loss was also estimated for the highest and lowest PAR in the canyon (accounting for evacuation), to obtain the complete range of possible fatalities if the flood overtopping occurs during the summer season or if it occurs during a non-summer period. Table 2.10 below presents the alternate high and low life loss estimate results for Reaches 1 and 2 (the only reaches with recreational PAR).

Table 2.10 – Estimated Life Loss – Flood Overtopping PFM (separate summer and non-summer PAR)

Season and Reach	PAR	Estimated Fatality Rate		Estimated Loss of Life	
		Lower	Upper	Lower	Upper
Summer Condition					
Reach 1 (0-7 mi)	76	0.002	0.01	0	1
Reach 2 (7-10 mi)	21	0.001	0.007	0	0
All other reaches (Table 2.9)				3	24
			Summer Total:	**3**	**25**
Non-Summer Condition					
Reach 1 (0-7 mi)	9	0.002	0.01	0	0
Reach 2 (7-10 mi)	3	0.001	0.007	0	0
All other reaches (Table 2.9)				3	24
			Non-Summer Totals:	**3**	**24**

Two sub-reaches 3a and 4a have the highest estimated life loss, and combined represent over half of the total estimated life loss, even when evacuation of low lying areas subject to spillway release flows is counted. These sub-reaches are the two areas closest to the river channel with significant PAR that would experience the most severe flooding conditions. DV values are very high and there would be few, if any, structures or trees remaining on the fringes of these reaches for people to seek refuge from the floodwaters. Rescue would be very difficult if not impossible in these reaches. Flooding in the canyon would be more severe, but the PAR is much lower and most, if not all, would be evacuated by the time of failure. The highest PAR (mostly residential) is in sub-reach 4b, but the flooding would not be as severe. For any PAR in sub-reach 4b that did not evacuate, they might be able to seek refuge in structures that are two stories high, or in trees, since the maximum flood depth is 12 feet and the estimated DV values (50-120 ft^2/s) would not be high enough to cause complete destruction. Overall the results indicate the life loss estimate range spans about an order of magnitude, which seems appropriate given the uncertainty in the case history database for flooding characterized by very high DV values with adequate warning.

Confidence in Factors used to Estimate Life Loss

Table 2.11 below was prepared to document the team’s thoughts on the level of confidence in each aspect or factor that was used to estimate the life loss.

Table 2.11 – Summary of Confidence in Life Loss Estimate

Factor Considered in the Life Loss Estimate	Level of Confidence	Basis for Confidence Level
Breach parameters	Moderate to high	Numerous published relationships used; results seem consistent with similar past studies of comparable dams
Hydraulic model output; depth, velocity	High	The evaluation included both 1D and 2D models. Current topography was used in the model, and state-of-the-art modeling software was used. Depths and velocities seem reasonable, and model output indicates they decrease as the flood waters exit the canyon and continue to spread downstream, as would be expected. Reaches could be defined differently (different depth or velocity limits) but this would not be expected to have a significant impact on the total life loss estimate.
PAR	Moderate to high	Updated census data was included. PAR was obtained by overlaying flood inundation maps with census blocks in a GIS. In the canyon reaches 1 and 2 and in sub-reaches 3a and 4a along the river, maximum spillway release inundation maps were used to account for likely evacuation of some PAR prior to dam failure. PAR values in these reaches were reduced to account for evacuation, but overall this does not significantly impact the life loss because of the large percentage of the PAR that would not be affected by spillway releases.
Warning time and Warning category	High	For a flood overtopping PFM, warning time would be significant and the warning category would be “adequate.” There was high confidence in this judgment due to the amount of time required for the reservoir to fill and overtop the dam.
Fatality rates	Moderate to high	The confidence in the selected fatality rates was generally moderate to high, with higher confidence in the lower DV areas where there are more case histories to support the values compared to the reaches with higher DVs. In general, confidence was high due to the numerous benefits associated with a very long warning.

Sources of Uncertainty

Unlike the internal erosion failure scenario, the weighting percentage given to “little or no” warning vs. “adequate” warning was not a source of uncertainty because of the strong belief that there would be adequate warning everywhere. For the flood overtopping scenario, the team felt the greatest source of uncertainty would be related to activation of the EAP, timing of the warnings and evacuation notifications, and overall effectiveness of communication to the PAR in Glenn City. The Area Office representative planned to follow up with local officials on this key finding from the life loss study.

Confidence in the Overall Life Loss Estimate

The new inundation study, PAR evaluation and multi-day team life loss analysis have combined to significantly increase the overall confidence in the life loss estimate. This is based on relying on state of the art studies, the most current information on the population at risk, and a thorough evaluation of the assumptions and variables used in estimating life loss. Overall, confidence in the life loss estimate for the flood overtopping potential failure mode is judged to be moderate to high, based on the significant amount of warning time and the overall higher level of the life loss evaluations.

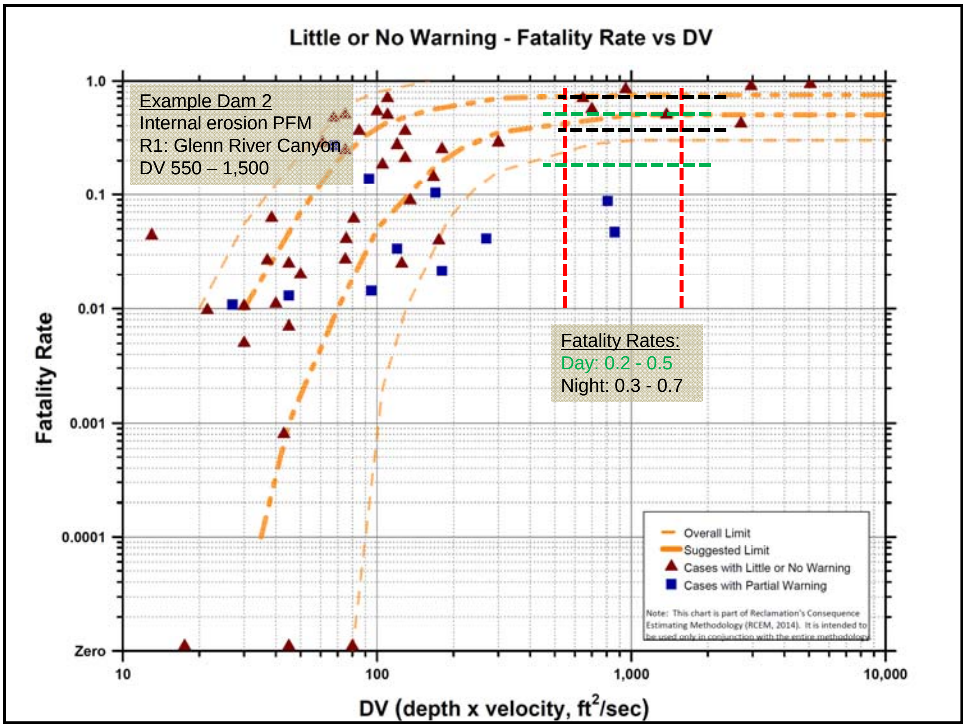
Recommended Life Loss Estimate for Annualized Life Loss Risk Calculations

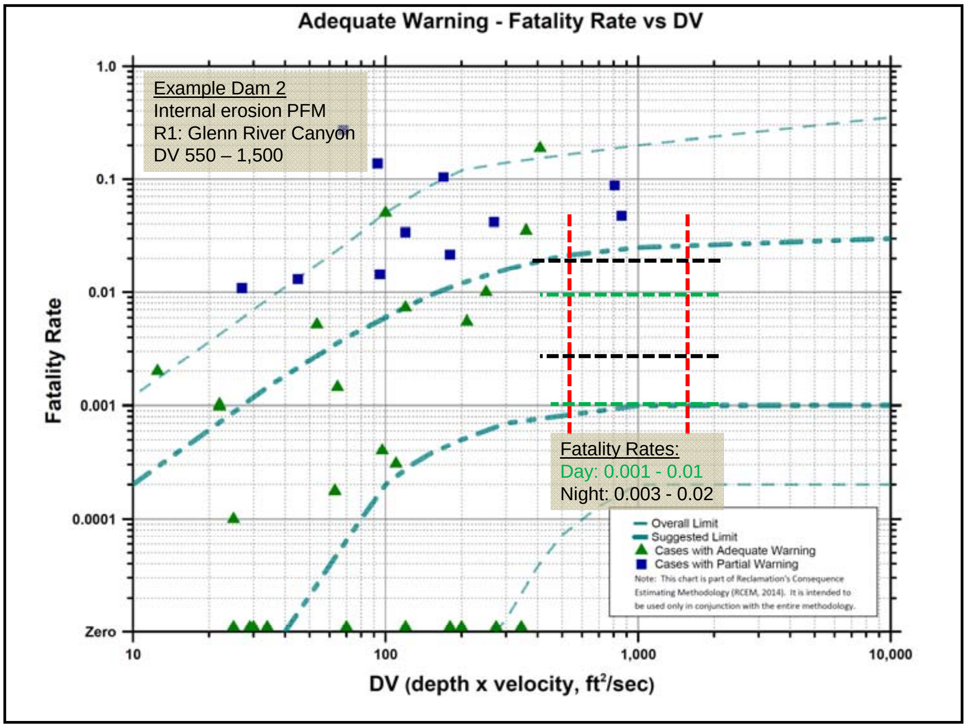
The overall results indicate there is not a significant difference in the upper life loss estimate if it is obtained using the overall maximum PAR (life loss 25) or the seasonally weighted PAR (life loss 24). There is no significant difference in the lower life loss estimate if it is obtained using the overall minimum PAR or the seasonally weighted PAR (life loss 3). Therefore, for the purpose of portraying risks, a range of 3 to 25 is used as a uniform distribution, with a mean value of 14.

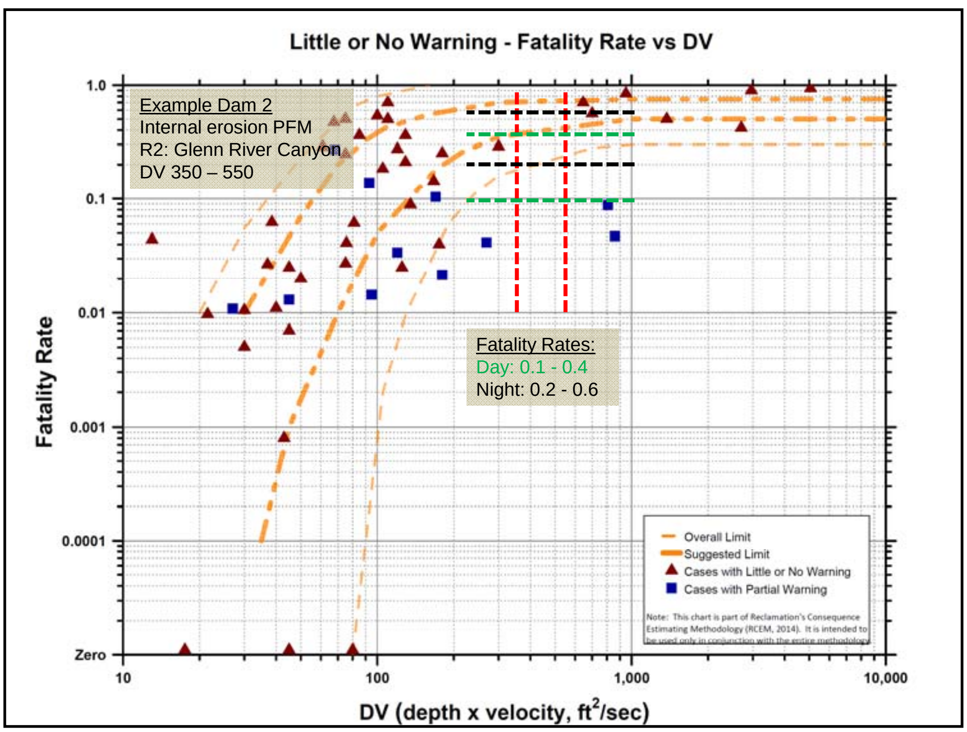
Appendix

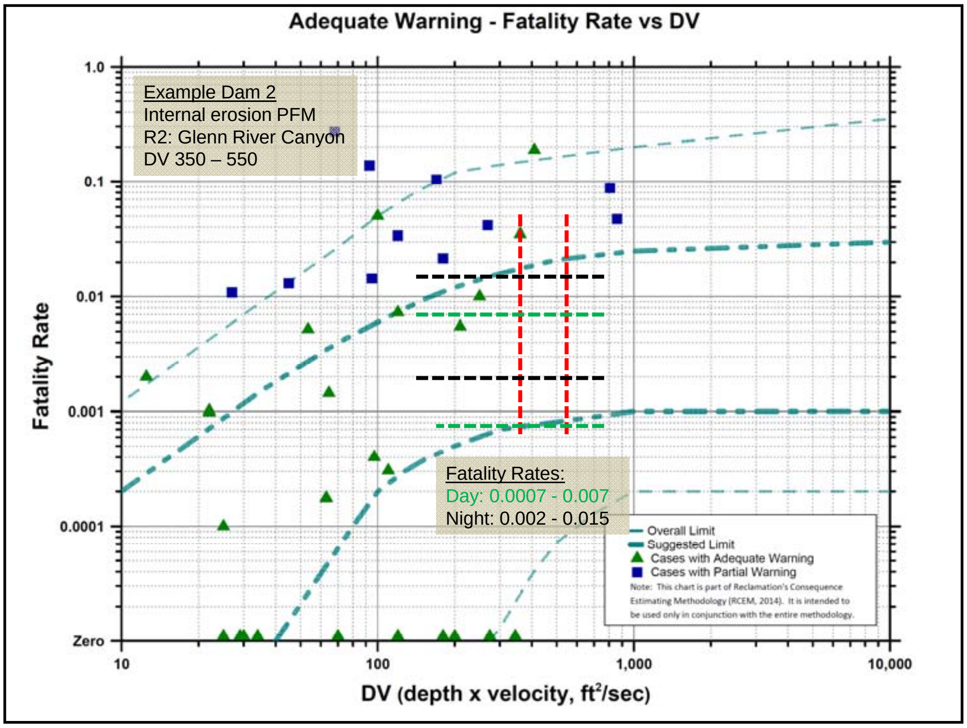
**Fatality Rate vs. DV Charts
portraying the fatality rates selected by the team for
given DV ranges in each reach.**

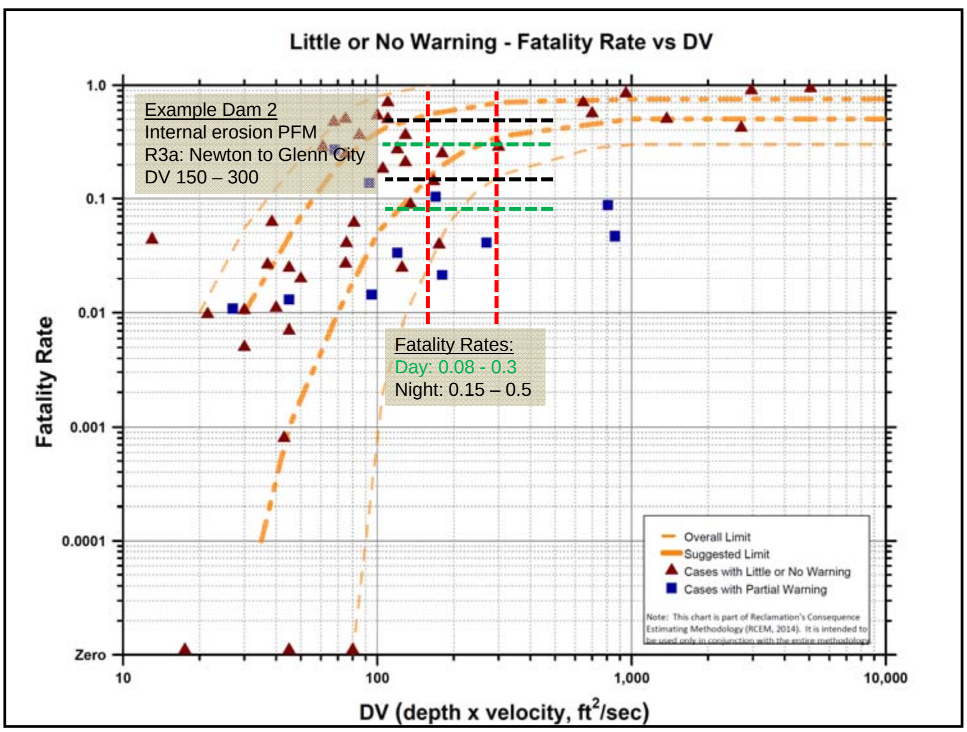
Example Dam 2
Graphical Fatality Rate Evaluation
Internal Erosion PFM

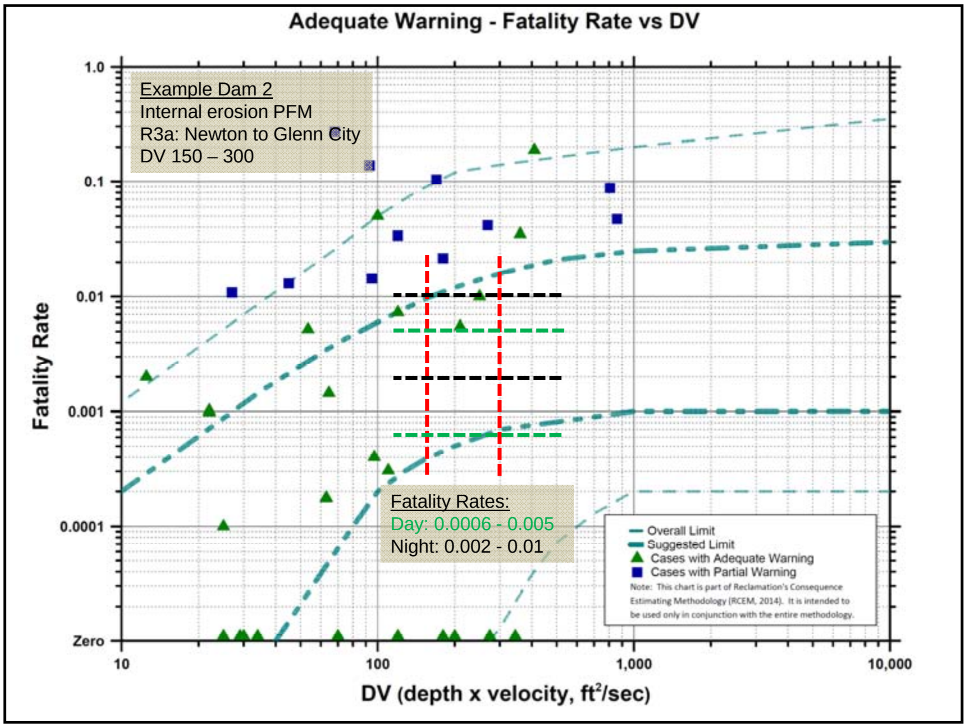


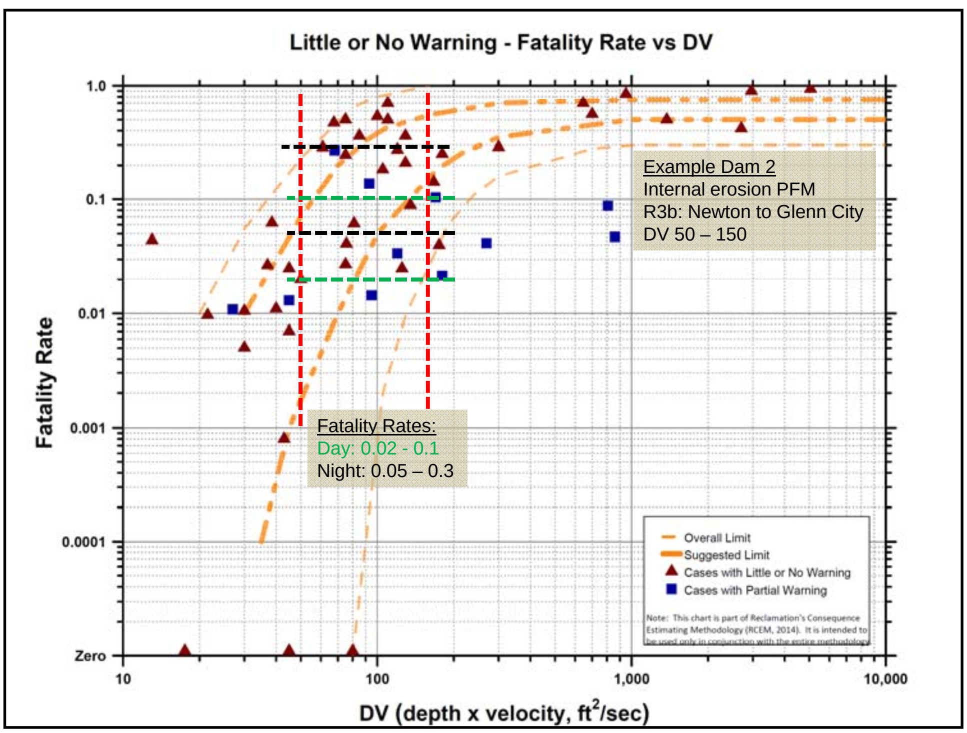

Adequate Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R1: Glenn River Canyon
DV 550 – 1,500
Fatality Rates:
Day: 0.001 - 0.01
Night: 0.003 - 0.02
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.
Fatality Rate
DV (depth x velocity, ft²/sec)

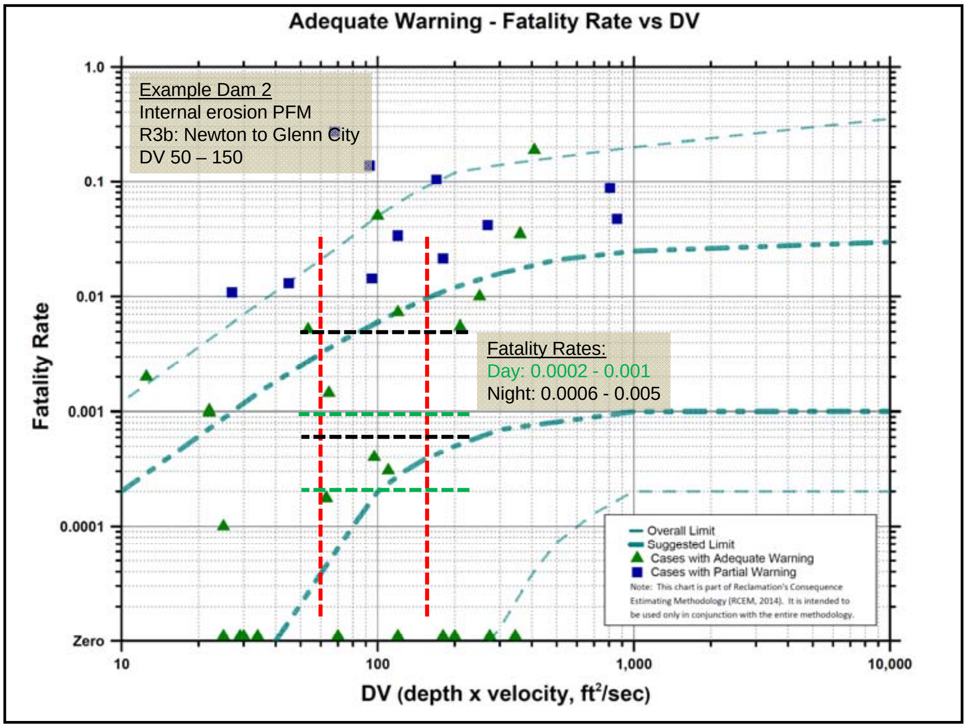

Little or No Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R2: Glenn River Canyon
DV 350 – 550
Fatality Rates:
Day: 0.1 - 0.4
Night: 0.2 - 0.6
Overall Limit
Suggested Limit
Cases with Little or No Warning
Cases with Partial Warning
Fatality Rate
DV (depth x velocity, ft²/sec)

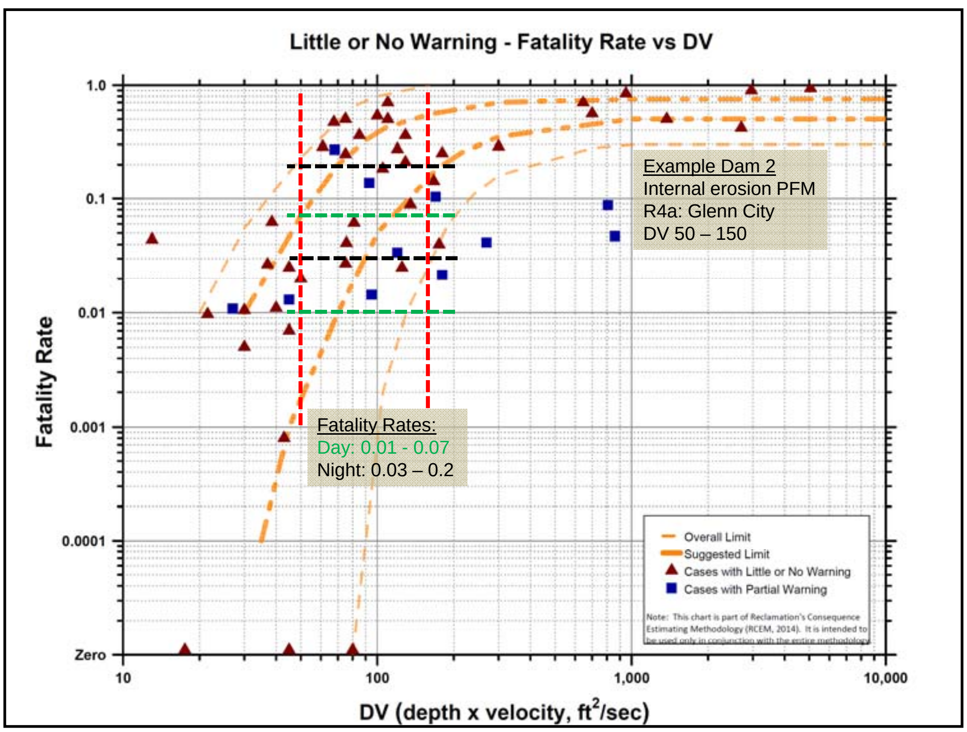

Adequate Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R2: Glenn River Canyon
DV 350 – 550
Fatality Rates:
Day: 0.0007 - 0.007
Night: 0.002 - 0.015
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Fatality Rate
DV (depth x velocity, ft²/sec)

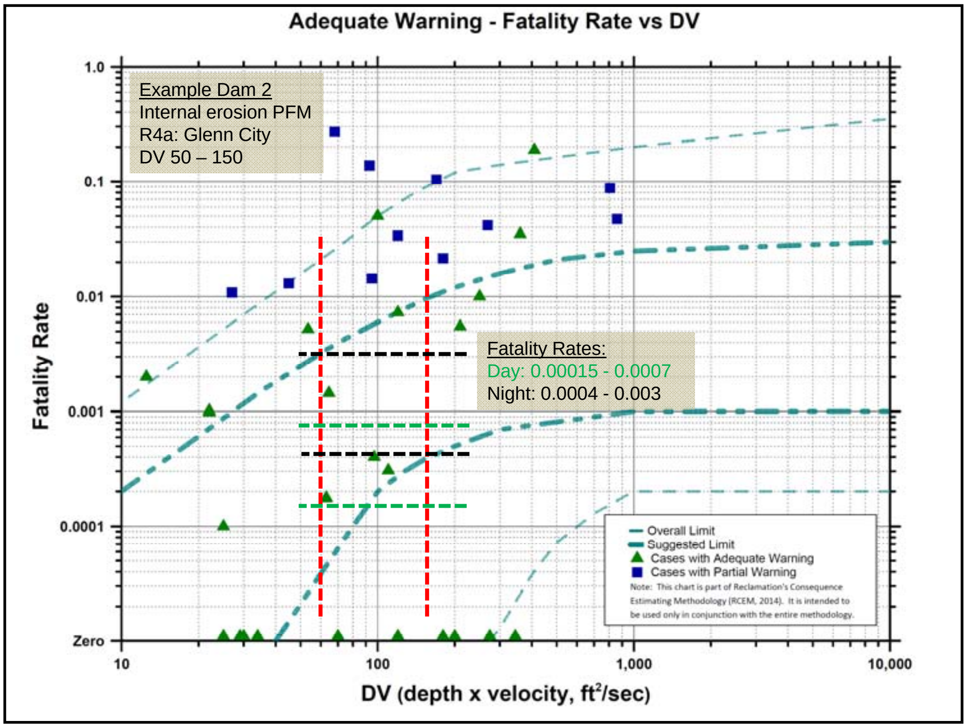

Little or No Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R3a: Newton to Glenn City
DV 150 – 300
Fatality Rates:
Day: 0.08 - 0.3
Night: 0.15 – 0.5
Overall Limit
Suggested Limit
Cases with Little or No Warning
Cases with Partial Warning
Fatality Rate
DV (depth x velocity, ft²/sec)

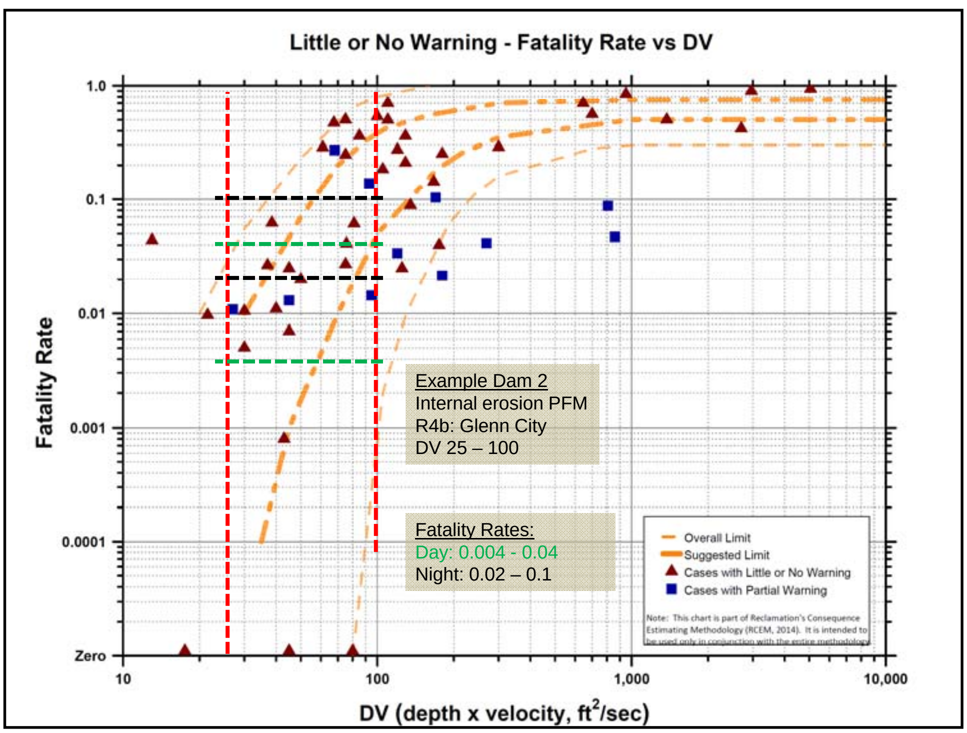

Adequate Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R3a: Newton to Glenn City
DV 150 – 300
Fatality Rates:
Day: 0.0006 - 0.005
Night: 0.002 - 0.01
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.
Fatality Rate
1.0
0.1
0.01
0.001
0.0001
Zero
10
100
1,000
10,000
DV (depth x velocity, ft²/sec)

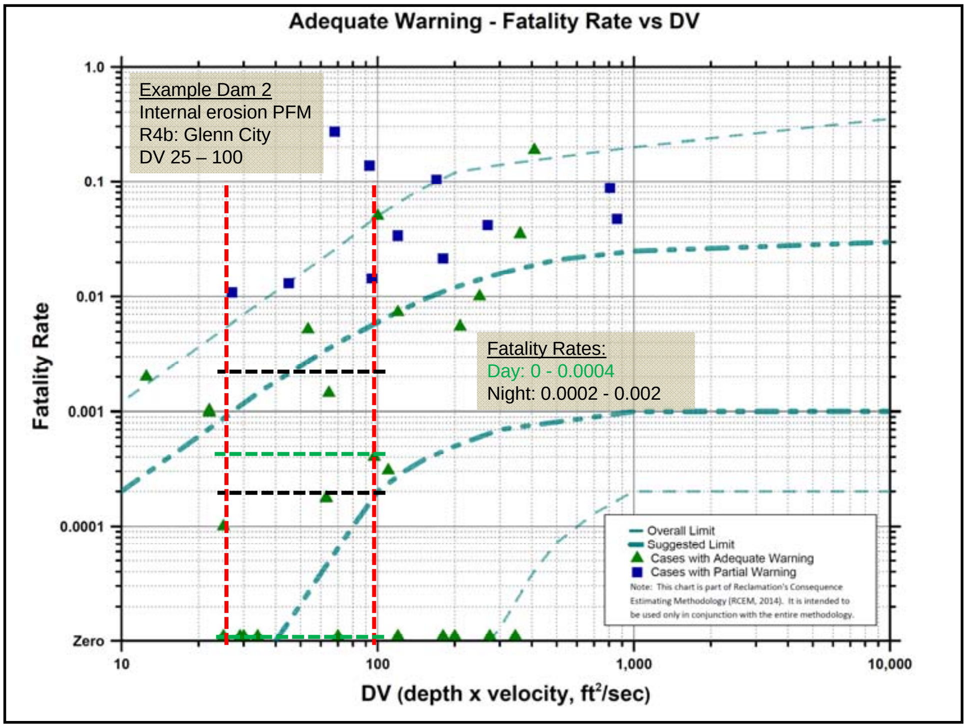

Little or No Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R3b: Newton to Glenn City
DV 50 – 150
Fatality Rates:
Day: 0.02 - 0.1
Night: 0.05 – 0.3
Overall Limit
Suggested Limit
Cases with Little or No Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.
Fatality Rate
1.0
0.1
0.01
0.001
0.0001
Zero
10
100
1,000
10,000
DV (depth x velocity, ft²/sec)

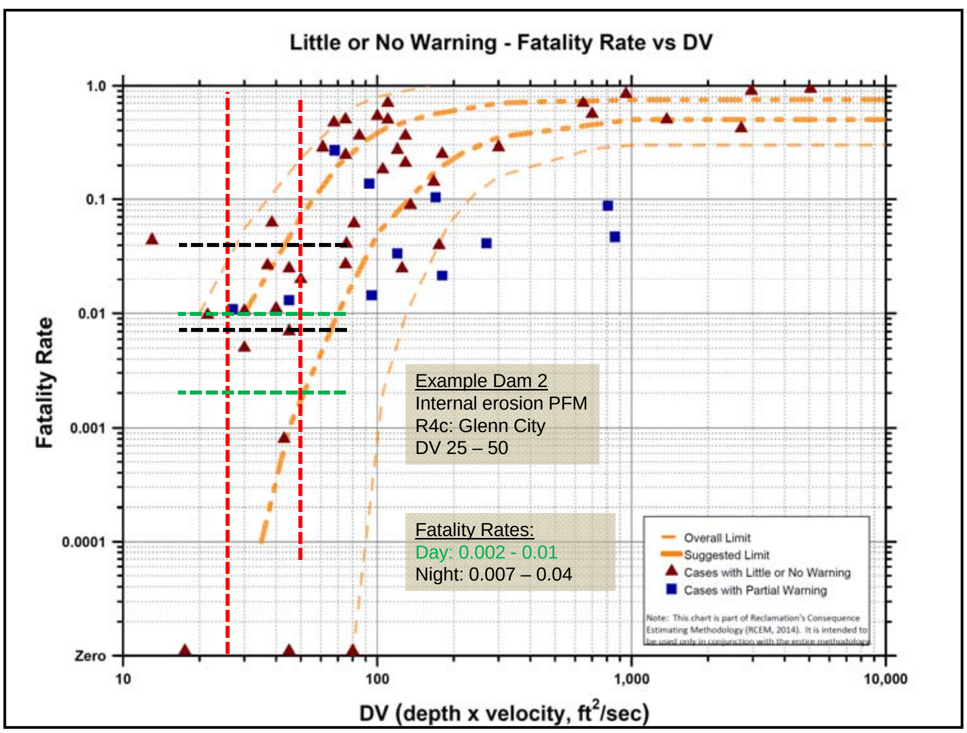

Adequate Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R3b: Newton to Glenn City
DV 50 – 150
Fatality Rates:
Day: 0.0002 - 0.001
Night: 0.0006 - 0.005
Fatality Rate
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.

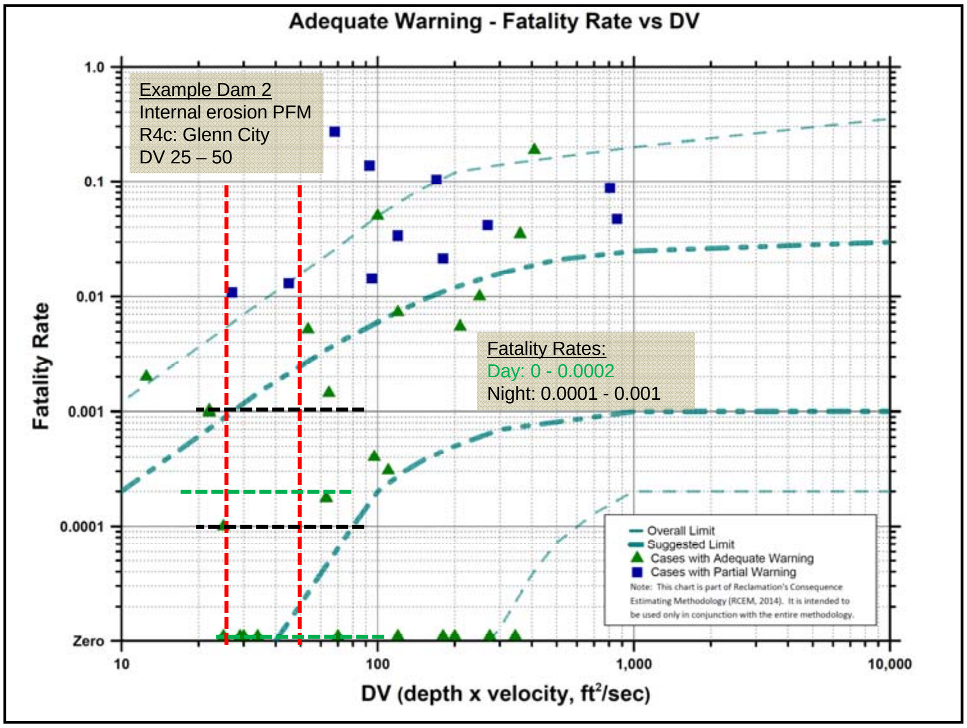

Little or No Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R4a: Glenn City
DV 50 – 150
Fatality Rates:
Day: 0.01 - 0.07
Night: 0.03 – 0.2
Fatality Rate
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Little or No Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.

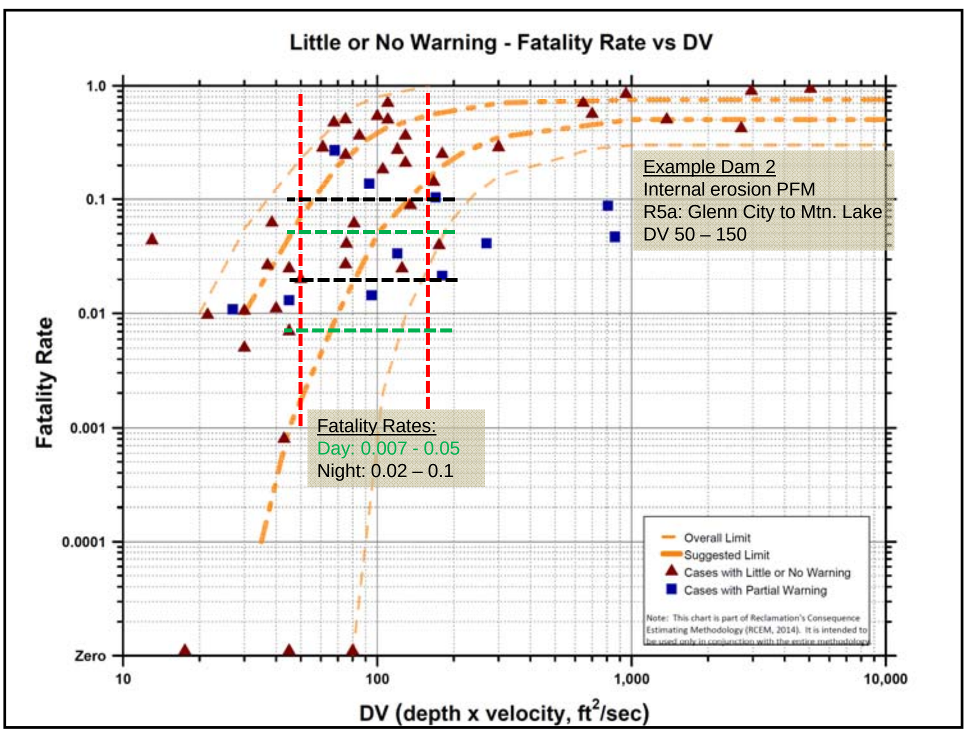

Adequate Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R4a: Glenn City
DV 50 – 150
Fatality Rates:
Day: 0.00015 - 0.0007
Night: 0.0004 - 0.003
Fatality Rate
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.

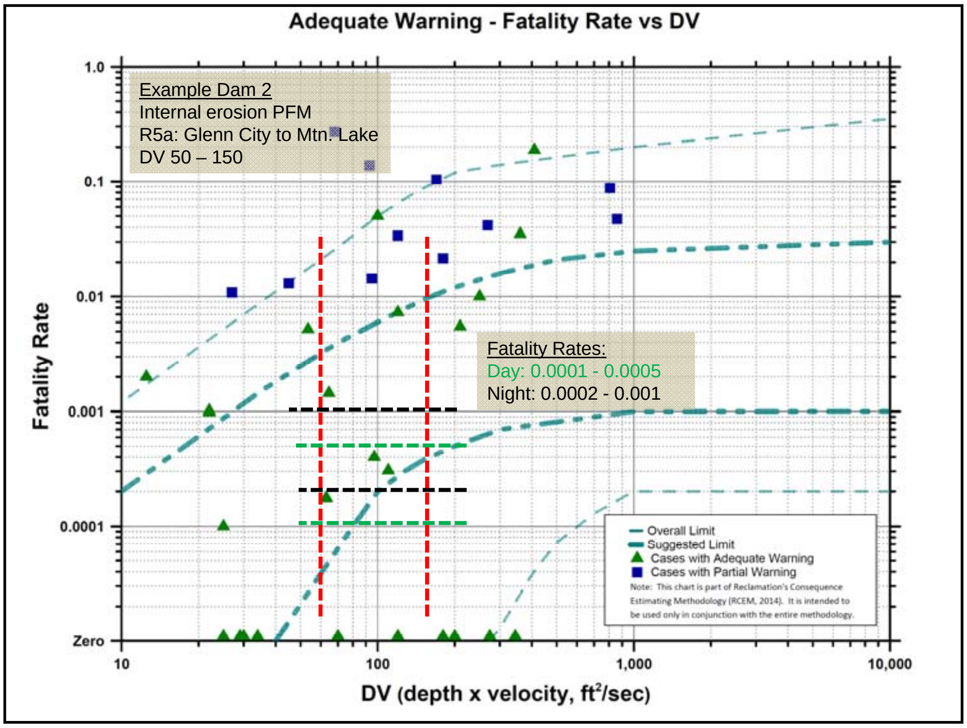

Little or No Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R4b: Glenn City
DV 25 – 100
Fatality Rates:
Day: 0.004 - 0.04
Night: 0.02 – 0.1
Fatality Rate
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Little or No Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.

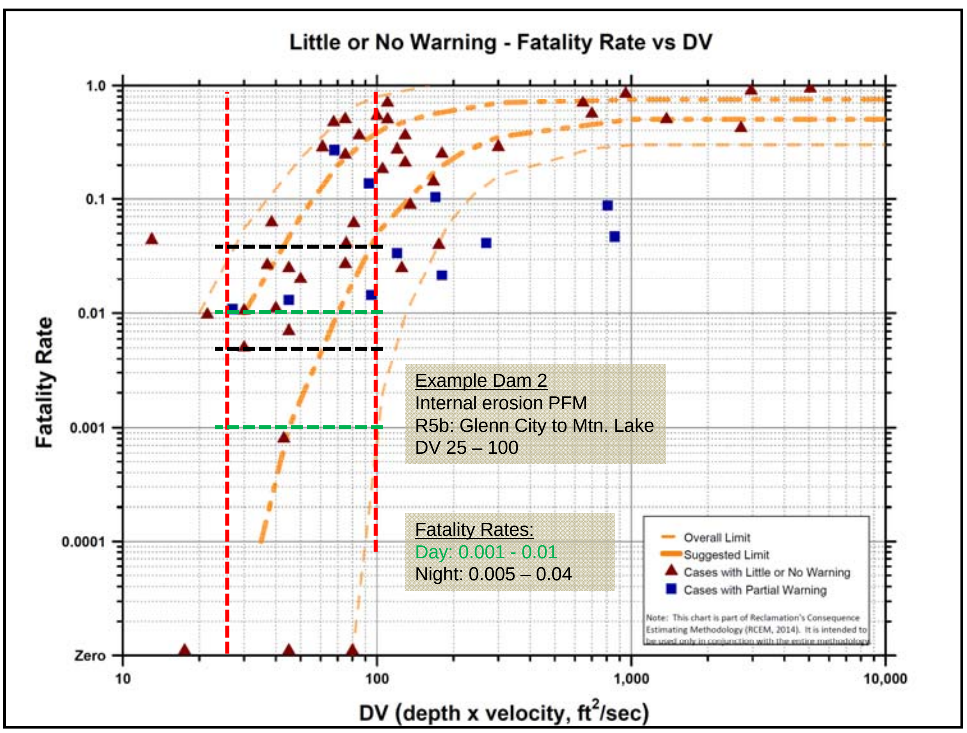

Adequate Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R4b: Glenn City
DV 25 – 100
Fatality Rates:
Day: 0 - 0.0004
Night: 0.0002 - 0.002
Fatality Rate
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.

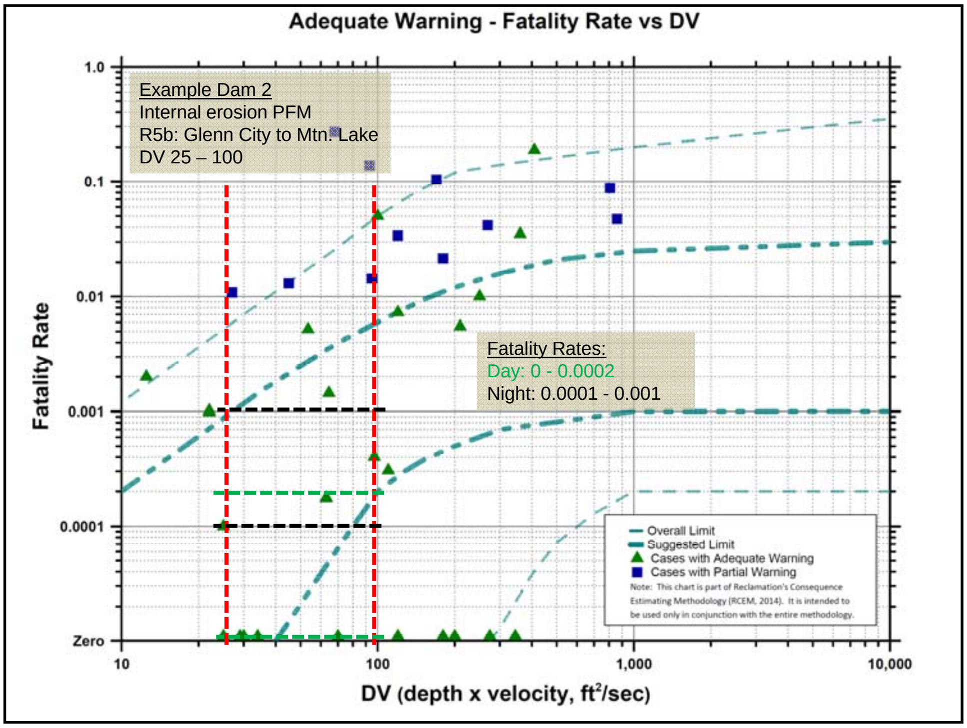

Little or No Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R4c: Glenn City
DV 25 – 50
Fatality Rates:
Day: 0.002 - 0.01
Night: 0.007 – 0.04
Fatality Rate
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Little or No Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.

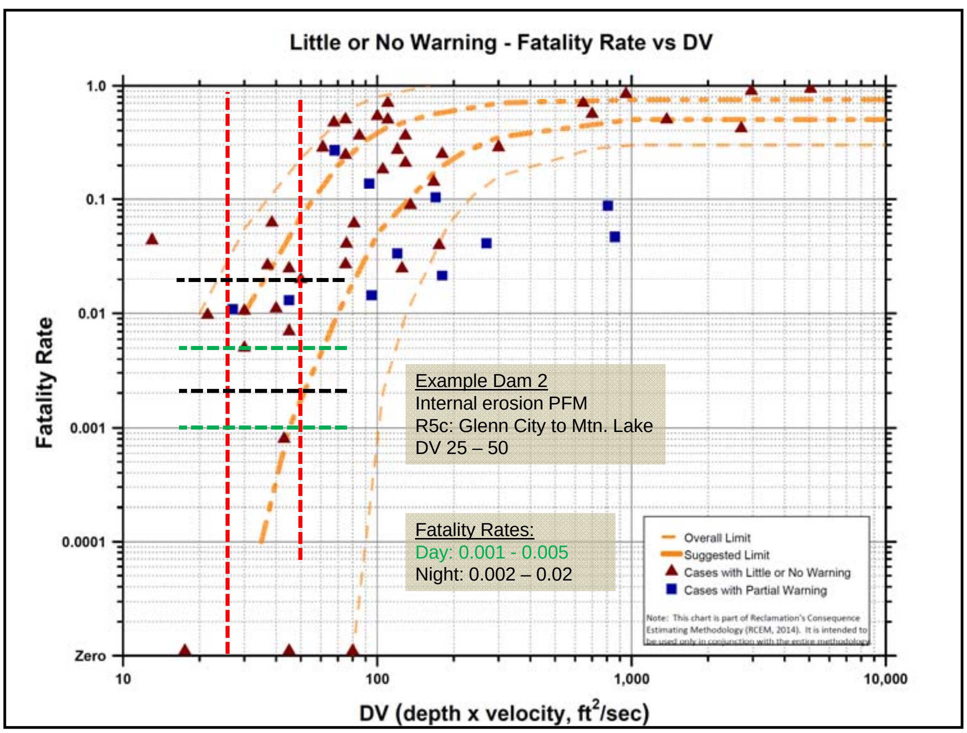

Adequate Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R4c: Glenn City
DV 25 – 50
Fatality Rates:
Day: 0 - 0.0002
Night: 0.0001 - 0.001
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Fatality Rate
DV (depth x velocity, ft²/sec)

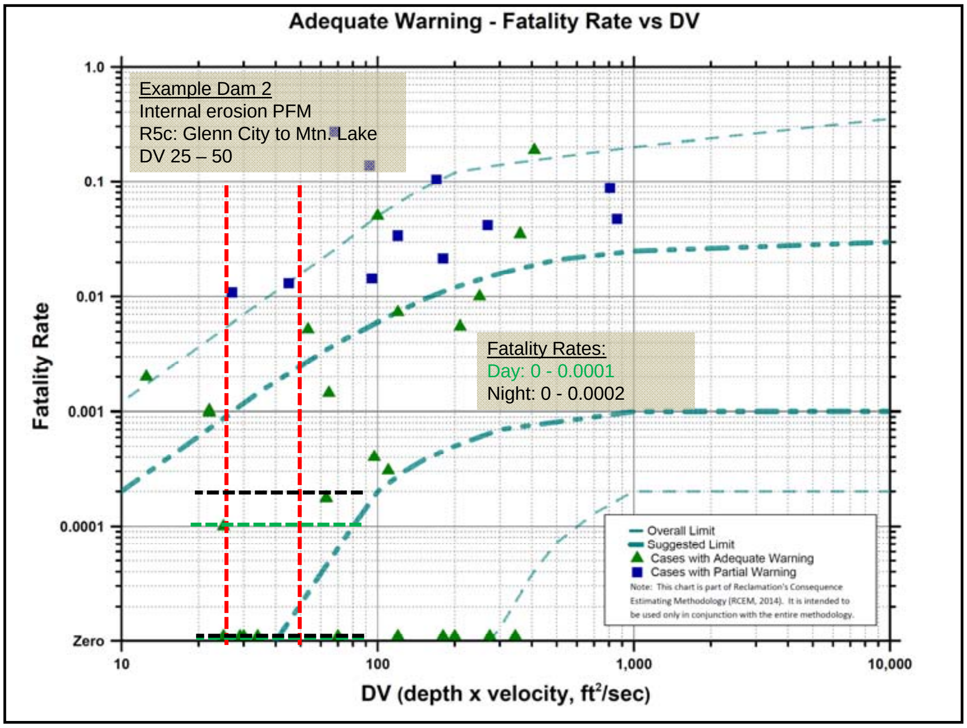

Little or No Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R5a: Glenn City to Mtn. Lake
DV 50 – 150
Fatality Rates:
Day: 0.007 - 0.05
Night: 0.02 – 0.1
Overall Limit
Suggested Limit
Cases with Little or No Warning
Cases with Partial Warning
Fatality Rate
DV (depth x velocity, ft²/sec)


Adequate Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R5a: Glenn City to Mtn. Lake
DV 50 – 150
Fatality Rates:
Day: 0.0001 - 0.0005
Night: 0.0002 - 0.001
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.
Fatality Rate
DV (depth x velocity, ft²/sec)

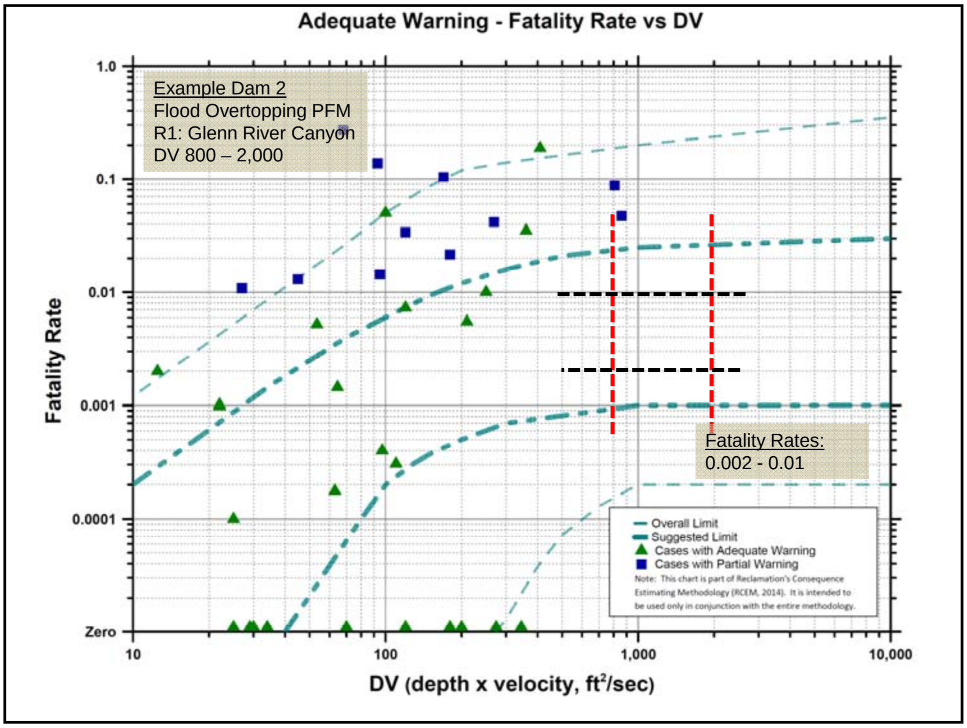

Little or No Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R5b: Glenn City to Mtn. Lake
DV 25 – 100
Fatality Rates:
Day: 0.001 - 0.01
Night: 0.005 – 0.04
Overall Limit
Suggested Limit
Cases with Little or No Warning
Cases with Partial Warning
Fatality Rate
DV (depth x velocity, ft²/sec)

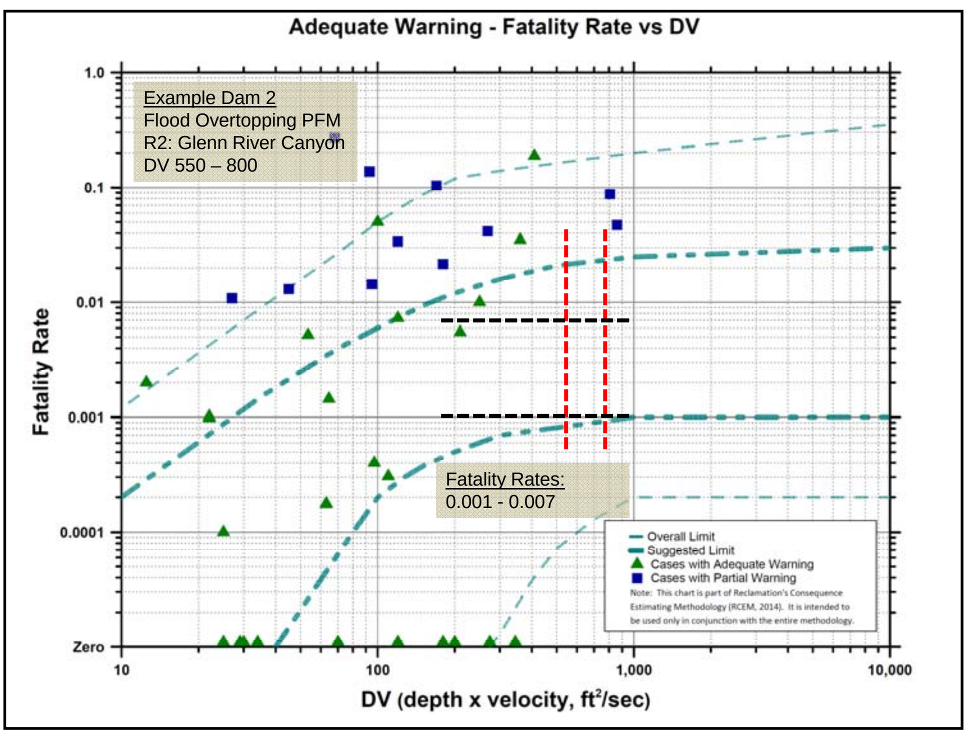

Adequate Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R5b: Glenn City to Mtn. Lake
DV 25 – 100
Fatality Rates:
Day: 0 - 0.0002
Night: 0.0001 - 0.001
Fatality Rate
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.

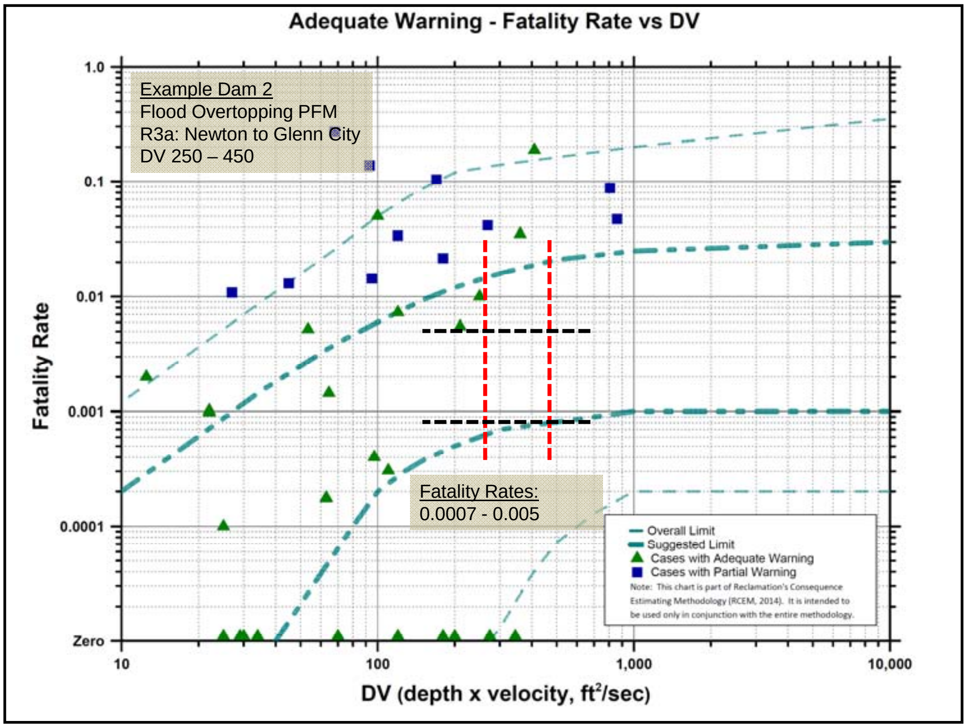

Little or No Warning - Fatality Rate vs DV
Example Dam 2
Internal erosion PFM
R5c: Glenn City to Mtn. Lake
DV 25 – 50
Fatality Rates:
Day: 0.001 - 0.005
Night: 0.002 – 0.02
Fatality Rate
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Little or No Warning
Cases with Partial Warning



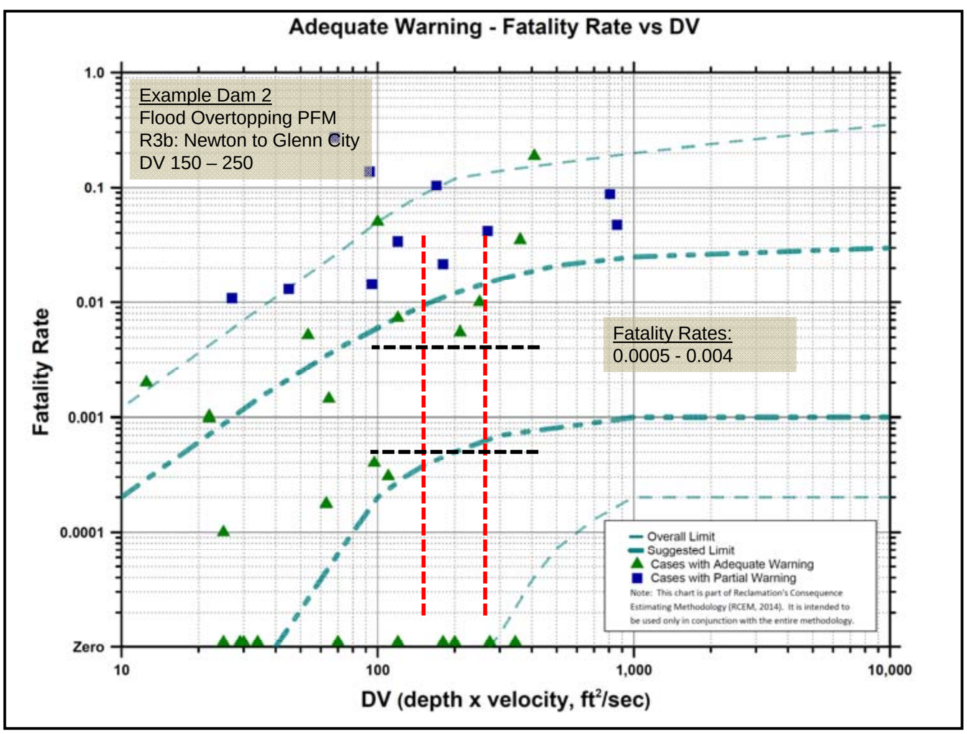
Example Dam 2
Graphical Fatality Rate Evaluation
Flood Overtopping PFM


Adequate Warning - Fatality Rate vs DV
Example Dam 2
Flood Overtopping PFM
R1: Glenn River Canyon
DV 800 – 2,000
Fatality Rates:
0.002 - 0.01
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.
Fatality Rate
DV (depth x velocity, ft²/sec)

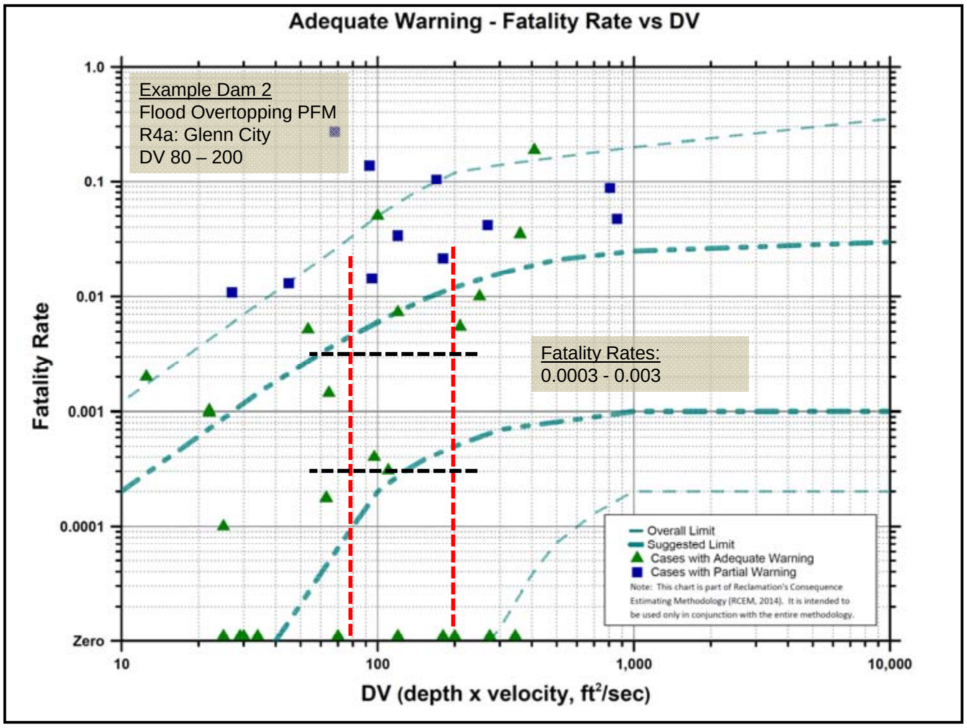

Adequate Warning - Fatality Rate vs DV
Example Dam 2
Flood Overtopping PFM
R2: Glenn River Canyon
DV 550 – 800
Fatality Rates:
0.001 - 0.007
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.
Fatality Rate
DV (depth x velocity, ft²/sec)

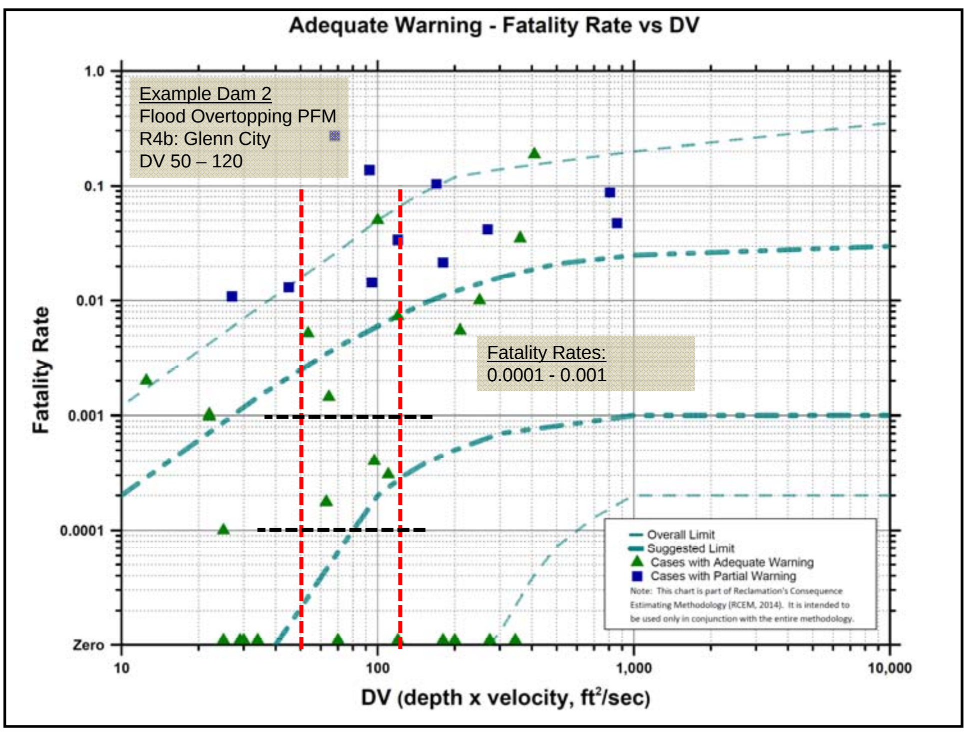


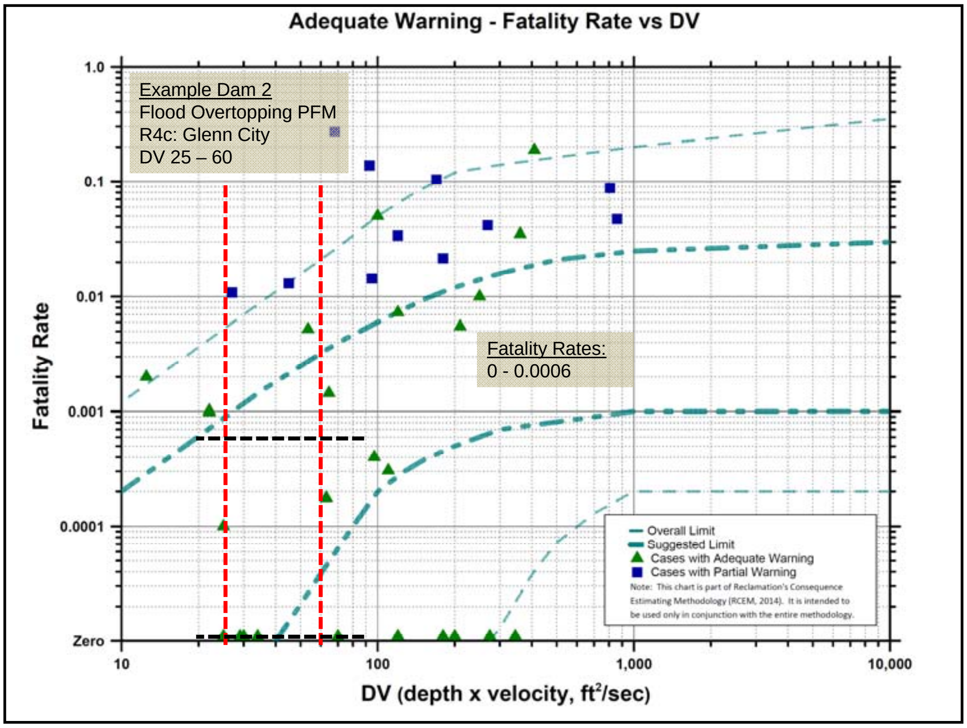
Adequate Warning - Fatality Rate vs DV
Example Dam 2
Flood Overtopping PFM
R3a: Newton to Glenn City
DV 250 – 450
Fatality Rates:
0.0007 - 0.005
Fatality Rate
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.

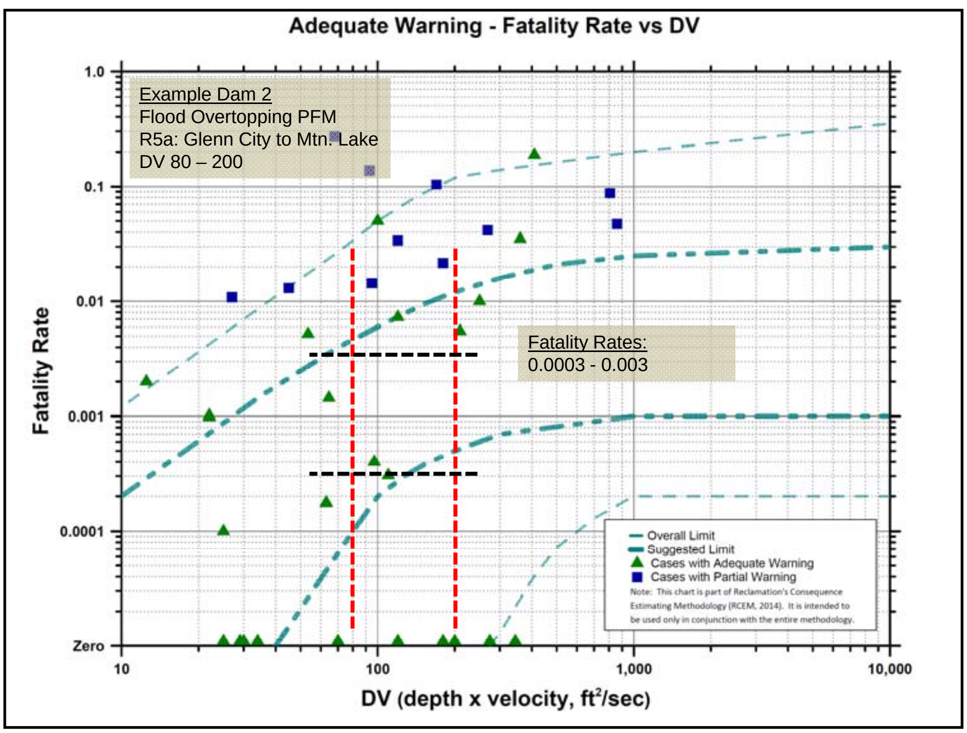


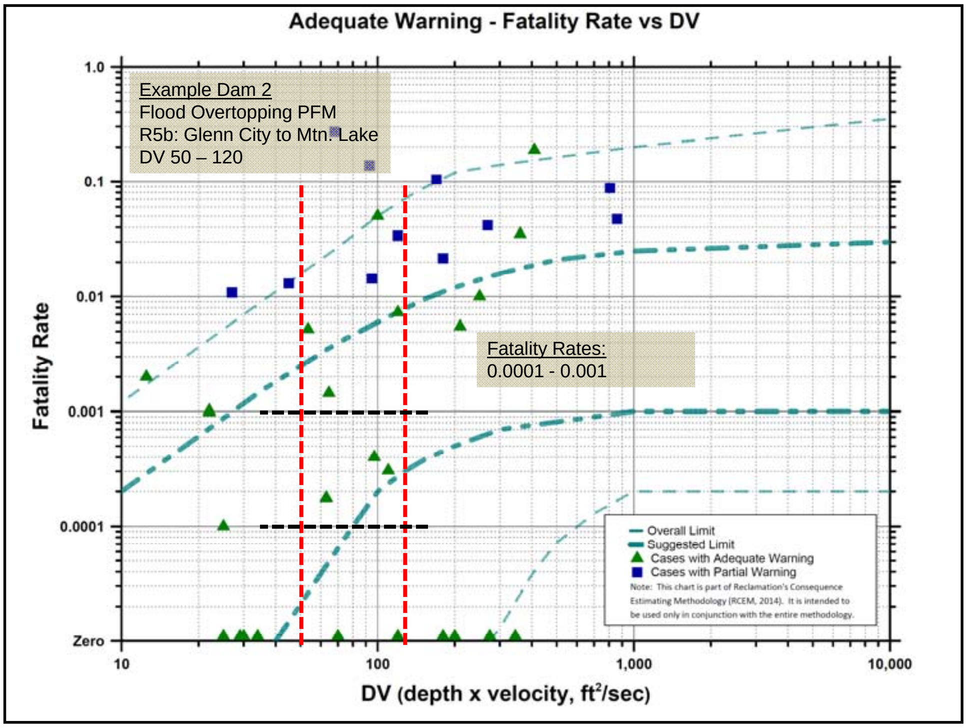
Adequate Warning - Fatality Rate vs DV
Example Dam 2
Flood Overtopping PFM
R3b: Newton to Glenn City
DV 150 – 250
Fatality Rates:
0.0005 - 0.004
Fatality Rate
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.


Adequate Warning - Fatality Rate vs DV
Example Dam 2
Flood Overtopping PFM
R4a: Glenn City
DV 80 – 200
Fatality Rates:
0.0003 - 0.003
Fatality Rate
DV (depth x velocity, ft²/sec)
1.0
0.1
0.01
0.001
0.0001
Zero
10
100
1,000
10,000
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning

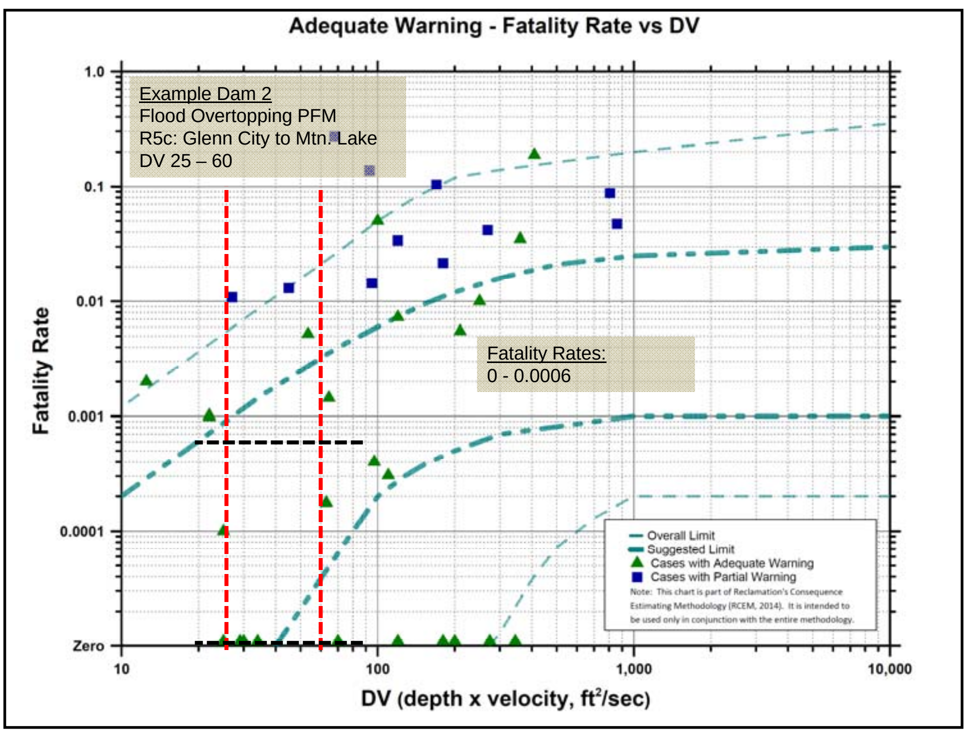

Adequate Warning - Fatality Rate vs DV
Example Dam 2
Flood Overtopping PFM
R4b: Glenn City
DV 50 – 120
Fatality Rates:
0.0001 - 0.001
Fatality Rate
DV (depth x velocity, ft²/sec)
1.0
0.1
0.01
0.001
0.0001
Zero
10
100
1,000
10,000
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning


Adequate Warning - Fatality Rate vs DV
Example Dam 2
Flood Overtopping PFM
R4c: Glenn City
DV 25 – 60
Fatality Rates:
0 - 0.0006
Fatality Rate
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.


Adequate Warning - Fatality Rate vs DV
Example Dam 2
Flood Overtopping PFM
R5a: Glenn City to Mtn. Lake
DV 80 – 200
Fatality Rates:
0.0003 - 0.003
Fatality Rate
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.



Adequate Warning - Fatality Rate vs DV
Example Dam 2
Flood Overtopping PFM
R5b: Glenn City to Mtn. Lake
DV 50 – 120
Fatality Rates:
0.0001 - 0.001
Fatality Rate
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.



Adequate Warning - Fatality Rate vs DV
Example Dam 2
Flood Overtopping PFM
R5c: Glenn City to Mtn. Lake
DV 25 – 60
Fatality Rates:
0 - 0.0006
Fatality Rate
DV (depth x velocity, ft²/sec)
Overall Limit
Suggested Limit
Cases with Adequate Warning
Cases with Partial Warning
Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.

Example Dam 3 (CR–Level Evaluation)

I. General

Example Dam 3 is a large concrete gravity dam with a storage capacity of 32,000 acre-feet. The dam has a structural height of 292 feet and a crest length of 2,650 feet. A 1D inundation study was performed in 1987, for the occurrence of the PMF with and without dam failure, using the National Weather Service Dam-Break Flood Forecasting model. For the failure of the dam during the 1985 PMF, it was assumed that the dam would fail when the reservoir reached the top of the dam, elevation 8182 (this could represent a hydrologic sliding failure of the dam along the foundation contact). An average breach width of 400 feet was assumed to develop over a period of 1.5 hours for the dam failure case, with a maximum depth of 195 feet and a peak breach outflow of 514,000 ft^3/s. The inundation maps also reflect flood flows from a major flood. The inundation maps only indicated the peak breach outflow from the dam. Flows at downstream reaches were not provided. Travel times to various downstream locations were provided.

Inundation studies were not prepared for a sunny day failure of Example Dam 3. The peak breach outflows are not expected to be appreciably lower for a sunny day failure given that the normal water surface elevation is only ten feet below the dam crest. If the reservoir was full at the time of a sunny day failure, the head through the dam breach would only be about 3 percent less than what was assumed for the flood inundation scenario which would translate to a reduction in peak discharge of about 6 percent (since discharge is a function of the flow depth raised to the 3/2 power. Downstream flood flows during a flood event would be expected to have less attenuation than a sunny day flood since flood inflows would sustain the breach outflows to a degree. But, since there is limited information on flood wave flow attenuation downstream (assumptions had to be made) the differences in attenuation are believed to be captured in the range of attenuation values that were assumed (discussed under Section II.B. DV Values).

Safe channel capacity in Granite Creek downstream of the dam is estimated to be 2300 ft^3/s. The population at risk (PAR) includes scattered rural residences, a dude ranch and a number of campgrounds along Granite Creek within 8 miles of the dam (breakdown of these PAR is shown in Tables 3.1 and 3.3), and the communities of Sagan, Garderen, Froome, and King located between 36 and 85 miles downstream of the dam along the Sagan River. Granite Creek terminates in the Sagan River, just downstream of the town of Sagan. With a population of approximately 1700, Sagan is the only major community affected by the failure flood, and is shown to be almost entirely inundated by dam failure flows. During a large flood event, large spillway releases (up to 80,000 ft^3/s) would inundate a portion of the town and about 20 to 30 percent of the population of 1700 people would likely be driven out of the flood plain by the spillway releases. The lower value of 20 percent was used to account for the fact that some of the people leaving their homes because of spillway releases may relocate within the boundaries of the dam failure inundation. The reduced PAR in Sagan was 1360 people for a flood induced failure. For the remaining towns of Garderen, Froome and King the spillway releases would not be expected to force people from their homes. Inundation maps from the Standing Operating Procedures (SOP) were used and the maximum inundation is shown on Figure 3.1. Dam failure

would result in extensive flood damage and potential loss of life along an 85-mile reach of the Sagan River.
All of the credible potential dam failure modes for Example Dam 3 involve the dam foundation. Risk estimates were developed for the following potential failure modes:

- Static – sliding on horizontal features in the dam foundation.
- Static – sliding along the foundation contact.
- Flood Related – sliding along horizontal features in the dam foundation due to spillway erosion.
- Seismic - sliding on horizontal features in the dam foundation.
- Seismic - sliding along the foundation contact.

All of the potential failure modes involve sliding either on shallow horizontal foundation features or sliding along the foundation contact, so the bottom of the final breach configuration is not expected to vary much between potential failure modes. The critical section of the dam for all the potential failure modes is the maximum section of the dam. The profile of the dam foundation contact is relatively flat over the central section of the dam (extending over 8 concrete monoliths, which each having a width of 50 feet). The assumption of a 400 foot breach width is a reasonable assumption for all potential failure modes.

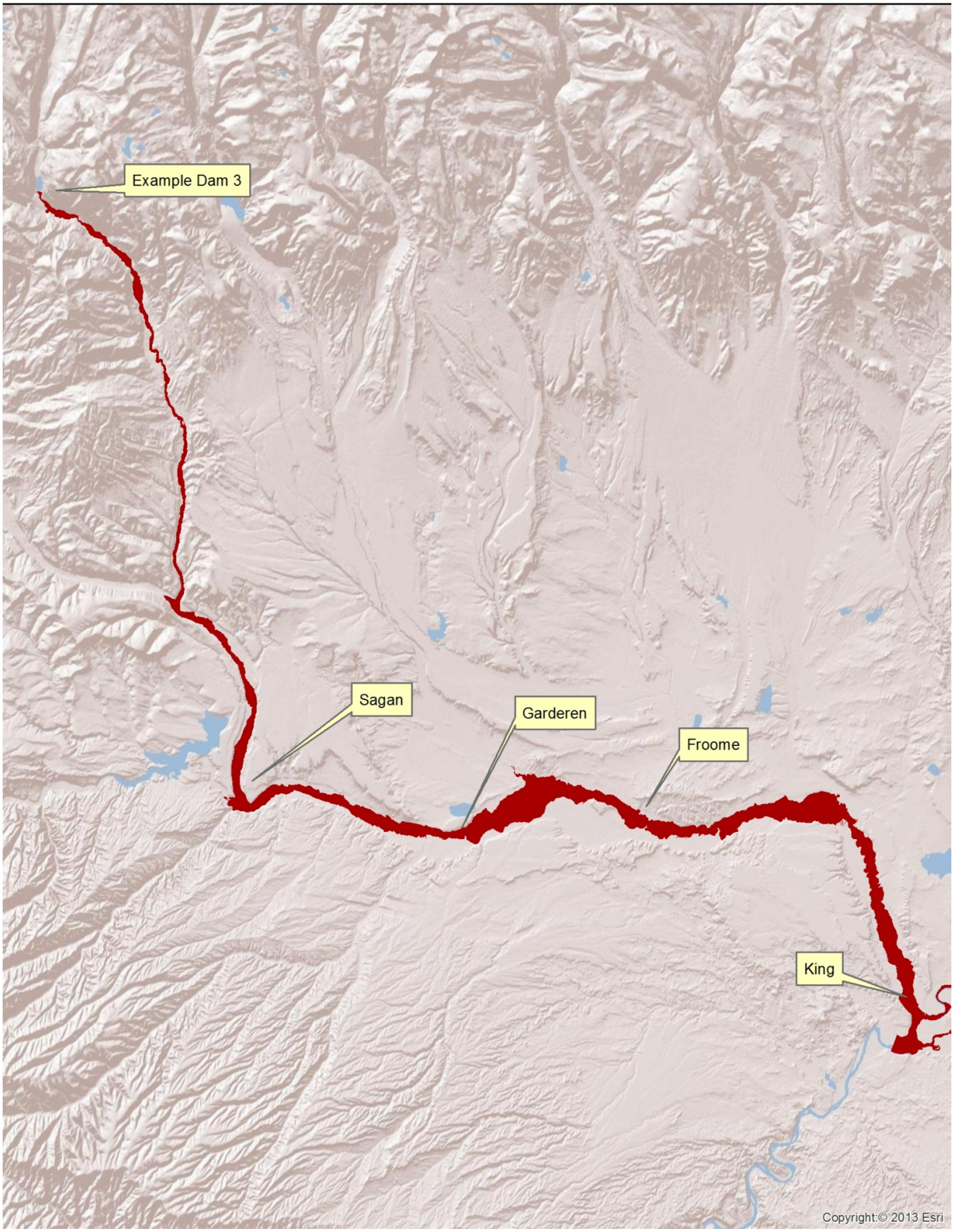


Figure 3.1 – Example Dam 3 – maximum inundation (Note: for a typical life loss study, existing inundation maps would be included rather than the simplified graphics in this Examples of Use document)

II. Flood Related Failure Modes

Flood related failure modes are judged to be less lethal than sunny day failure modes even though the failure event would result in more significant flooding downstream. The threat would likely be less because water district personnel, Reclamation personnel (who would be onsite continuously during a major flood event), local emergency response officials and the downstream population would have a heightened awareness of the high water levels prior to a dam failure. Downstream populations would be put on alert during a major flood event and warnings of dam failure would likely be initiated before dam breach actually occurred. At least for the town of Sagan, it is likely that large spillway releases would force the evacuation of some of the town's population.

A. Population at Risk (PAR)

Population at risk estimates for the areas downstream from Example Dam 3 were obtained from the estimates made in the last CR (and confirmed by overlaying 2010 census data onto the inundation maps; no significant differences were noted). Overall PAR estimates are smaller than those for a sunny day failure mode because inundation from flood releases prior to dam failure would cause some portions of the downstream population to leave prior to failure. The PAR in the first 8 miles downstream of the dam is largely comprised of campers and recreationalists. The population in the first 8 miles is broken down and provided in Table 3.1. The recreation populations are less than those for a sunny-day failure, because a flood event would be expected to occur in the springtime (the critical flood is a rain on snow event), when recreational visits are much lower than they would be in the summer and fall months. Population at risk estimates for flood related conditions reflect spring time recreational visits and are broken down by day and night values. These estimates were based on records and conversations with county authorities (who manage the campgrounds) and with the owner of Ralston Ranch.

Table 3.1 – Example Dam 3 – PAR Upstream of Sagan (first 8 miles), Flood Related Failure

Location	Distance from Dam (miles)	Population at Risk (Flood Related) Day/Night
Upper Coldwater Campground	0	15/10
Granite Creek (Campground)	1	25/20
Blue Spruce Campground	4	10/10
Prospector's Gulch Campground	5	4/4
Ralston Ranch (Dude Ranch)	6	8/8
Lower Coldwater Parking Area	8	8/8
Totals		70/60

The total PAR for all downstream reaches is provided in Table 3.2. Population at risk values were reduced from the full PAR in the town of Sagan. An adjustment was made to the PAR to remove those people whose homes would be inundated by spillway releases prior to the dam breach flows occurring. This reduced the overall PAR and reflects the incremental PAR that would be subjected to dam breach flows. The percentage of the PAR that would likely be evacuated by spillway releases in Sagan was estimated to be 20 to 30 percent of the full PAR in Sagan. The lower value of 20 percent was used, since it is uncertain whether people evacuated by spillway releases would leave the area defined by the dam failure inundation boundaries.

Table 3.2 − Population at Risk from Example Dam 3 - Flood Related Failure

River Reach	Distance from Dam (in miles)	Estimated Travel Time of Leading Edge of Flood (in hours)	Population at Risk Day/Night
Dam to Lower Coldwater Parking Area (Total)*	0 to 8	0 to 0.4	70/60
Sagan	36	2	1360/1360
Garderen	48	3	200/200
Froome	58	4	100/100
King	85	18	200/200
Total			1,930/1,920

*For details of PAR in first 8 miles see Table 3.1

B. DV Values

The primary basis for calculated DV values was to divide the range of assumed dam breach flows at various downstream reaches by the measured top of flow width from the inundation maps. The range of breach flows was established by assuming no attenuation of the peak breach outflows all the way to King (case 1) and assuming the flows attenuated to 25 percent of the peak breach outflow at the dam by the time the flow reached King (case 2, with a uniform rate of attenuation calculated between no attenuation at the dam to 75 percent at King). For cases where a range of breach flows and a range of breach widths were available, the low estimate of the breach outflow was divided by the high estimate of the breach width and the high estimate of the breach outflow was divided by the low estimate of the breach width to arrive at the widest possible range of DV values. Once this range of DV values was calculated, end points were chosen that consisted of rounded values of DV. The DV calculations are shown in Table 3.6. As a check on the reasonableness of the DV values, depths and velocities at downstream reaches were calculated. Velocities at each downstream town were calculated from the flood wave travel times. The DV values that were calculated as described above were than divided by the velocities to obtain a range of average depths. The velocities and depths at each reach are shown in Table 3.6 and were judged to be reasonable.

C. Warning Time

For a flood-induced failure, it was assumed that warning would be issued to downstream residents 1 hour prior to the dam failing, for both day and night conditions. Even though warnings would be issued, it was judged that not all residents could be contacted and as a result a small percentage of residents would receive little or no warning. The potential failure mode under flood conditions involves erosion of the foundation downstream of the overflow (spillway) portion of the dam, which allows horizontal bedding planes in the foundation to daylight and a sliding failure to initiate. Erosion of the dam foundation downstream of the spillway is something that staff onsite would be able to observe and recognize. Flow would become more turbulent at the downstream toe of the dam and the flow would become discolored as foundation material was removed. During a major flood that exceeded the flood of record, Reclamation staff (who would be monitoring the dam 24 hours a day) and management and local officials would be closely monitoring the situation and updating key decision makers on developments. Once the potential failure mode initiated, decision makers would be prepared to initiate warnings without significant delay.

Warning time was not varied between day and night, since the dam would be well monitored during a flood event and local officials would be well aware of a developing situation. Warning times at each location downstream of the dam were assumed to be equal to the flood wave travel times at these locations plus one hour.

Based on the available warning time for downstream populations, a decision was made for each reach on which fatality rate chart to use (Little or No Warning or Adequate Warning). For some reaches, the population was distributed between the two warning categories. Table 3.7 provides the warning time assumptions for each of the downstream reaches. As an example, for the reach from 0 to 8 miles downstream of the dam, under day conditions, it was assumed that 10 percent of the population at risk would receive little or no warning and 90 percent would receive adequate warning. Fatality rates were chosen from the appropriate chart for the two cases. As the available warning time increased, it was assumed more of the downstream populations at risk would receive adequate warning. For nighttime conditions, it was assumed that the people receiving adequate warning would decrease. This would be related to the difficulty in contacting individuals at night (residents would be asleep and it may be difficult to get people to respond). This would be especially true of the recreation populations in the first 8 miles downstream of the dam, where it may also difficult to locate individuals. For nighttime conditions in the first reach, the percentage of the population receiving little or no warning was increased from 10 to 30 percent.

D. Fatality Rate Selection

The selected fatality rates for the downstream reaches under both day and night conditions are shown in Table 3.7. The highest fatality rates chosen for a daytime failure applied to the reach including the first 8 miles downstream of the dam, for the little or no warning case. Even though some warning time would be available (1 to 1.4 hours), because the populations consisted of recreationists, it was assumed that 10 percent of the population at risk would not be able to be located and the little or no warning chart was used for this population. A fatality rate range of 0.2 to 0.5 was used (see Figure 3.2 for a graphical depiction of the fatality rates chosen). These values were chosen based on the low and high DV values and were selected from the lower end of the suggested fatality rate range because of the daytime conditions. The remainder of the population at risk in this reach was assumed to have adequate warning and a fatality rate range of 0.002 to 0.009 was used (see Figure 3.3), both of which reflect values between the suggested values for the range of DV estimates in this reach.

For a nighttime failure in the first reach, the fatality rate range for the population assumed to receive little or no warning was chosen to be 0.3 to 0.7 (see Figure 3.2). This was based on the fact that nighttime conditions would exist, where higher fatality rates are generally seen and reflects values that extend up to the top of the suggested range. For the population receiving adequate warning in the first reach, a fatality rate range of 0.003 to 0.015 was used (increased from 0.002 to 0.009 for daytime conditions; see Figure 3.3). These rates extend from a rate between the suggested values to a rate near the upper suggested value.

For reaches downstream of the first 8 miles (starting with the town of Sagan – see Figures 3.4 and 3.5), fatality rates were decreased to reflect the increased warning times. The range of fatality rates was selected closer to the lower suggested value at locations further downstream. After the town of Sagan, all fatality rates were chosen from the adequate warning chart. The fatality rates for nighttime conditions were always greater than those for the same reach under daytime conditions. For the downstream most location (at the town of King) fatality rate ranges were selected that were below the lower suggested value curve. This reflected the very long warning times (over 18 hours).

E. Loss of Life Estimate

Table 3.7 summarizes the above assumptions and estimates for all the downstream reaches and provides the range of life loss estimates as well as the best estimate. The day and night estimates were weighted two-thirds and one-third, respectively, when calculating a composite mean loss of life estimate.

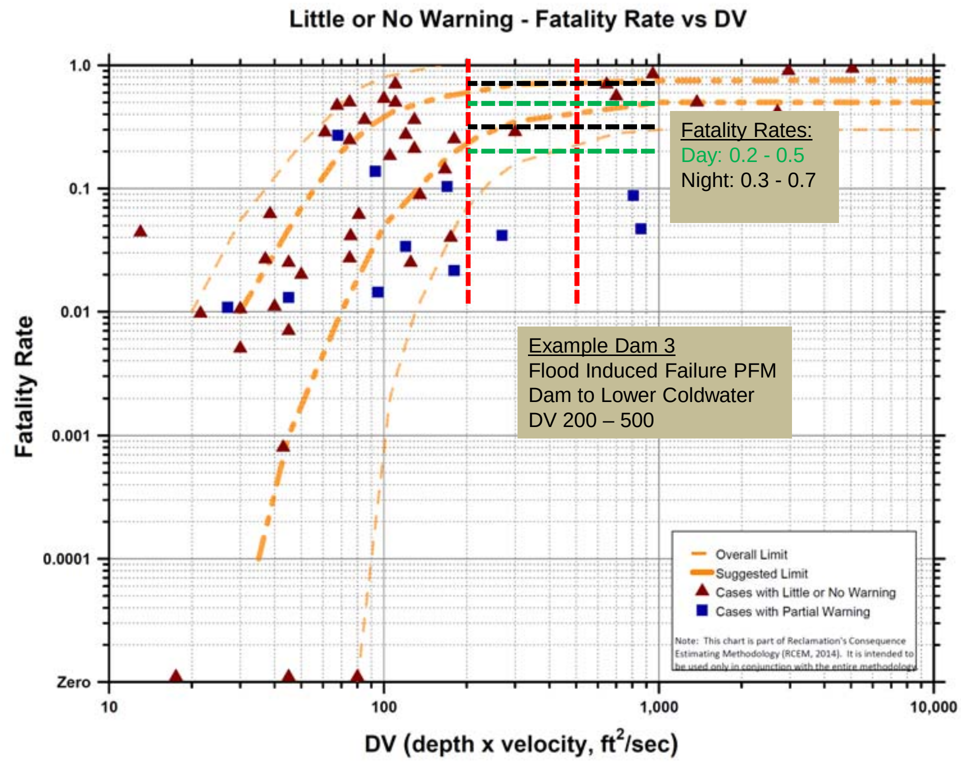


Figure 3.2. Fatality Rate Selection for Dam to Lower Coldwater Parking Reach, Little or no Warning

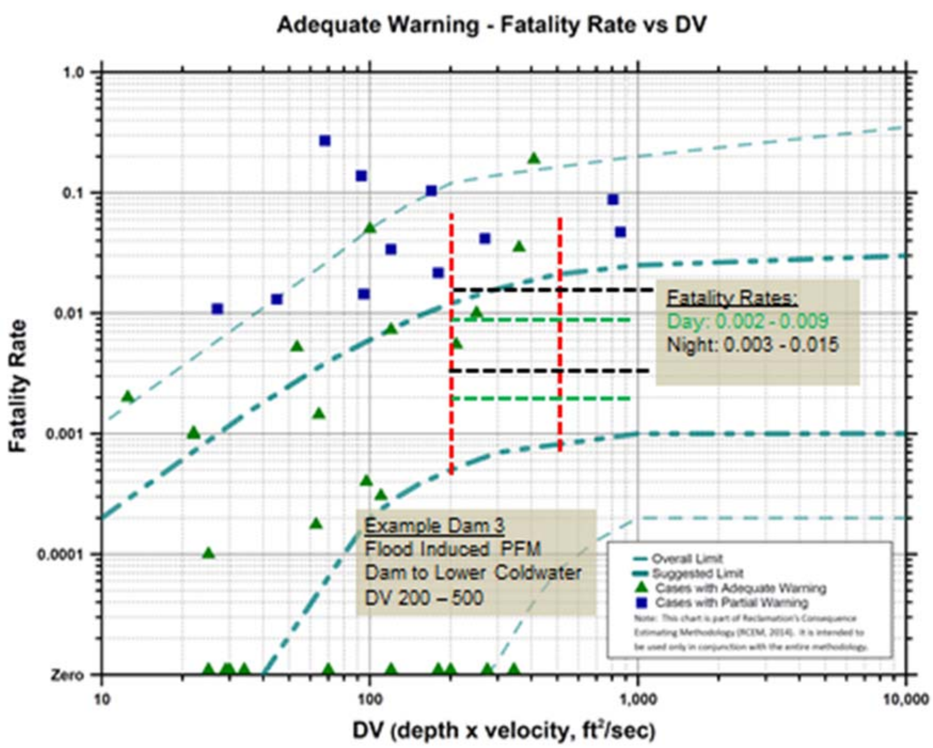


Figure 3.3. Fatality Rate Selection for Dam to Lower Coldwater Parking Reach, Adequate Warning

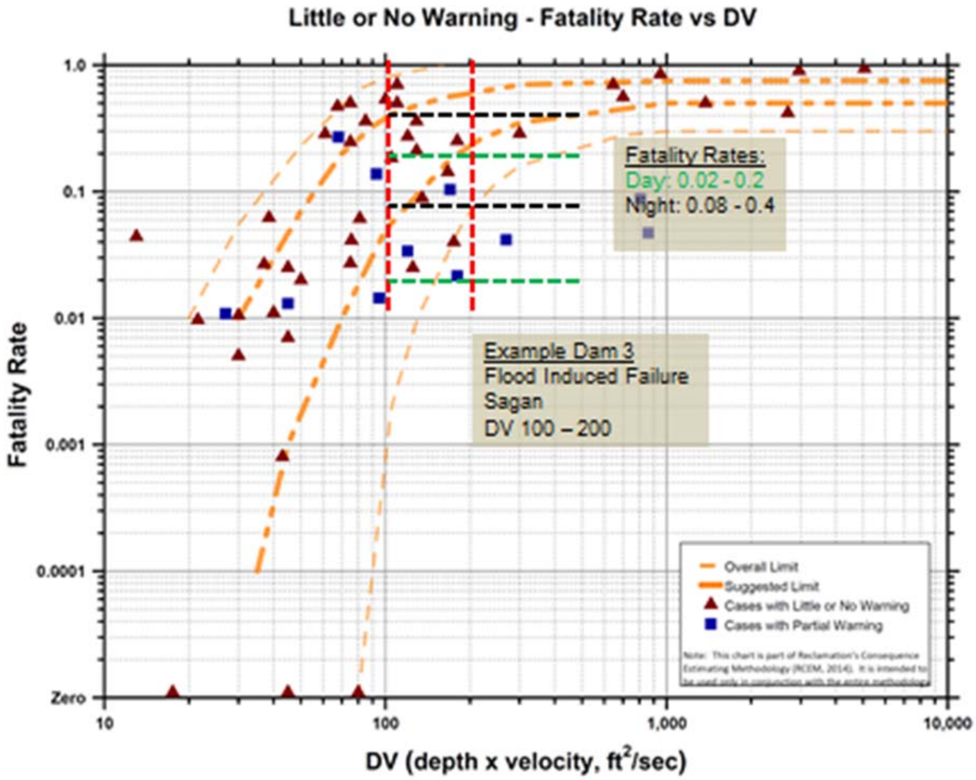


Figure 3.4. Fatality Rate Selection for Sagan Reach, Little or no Warning

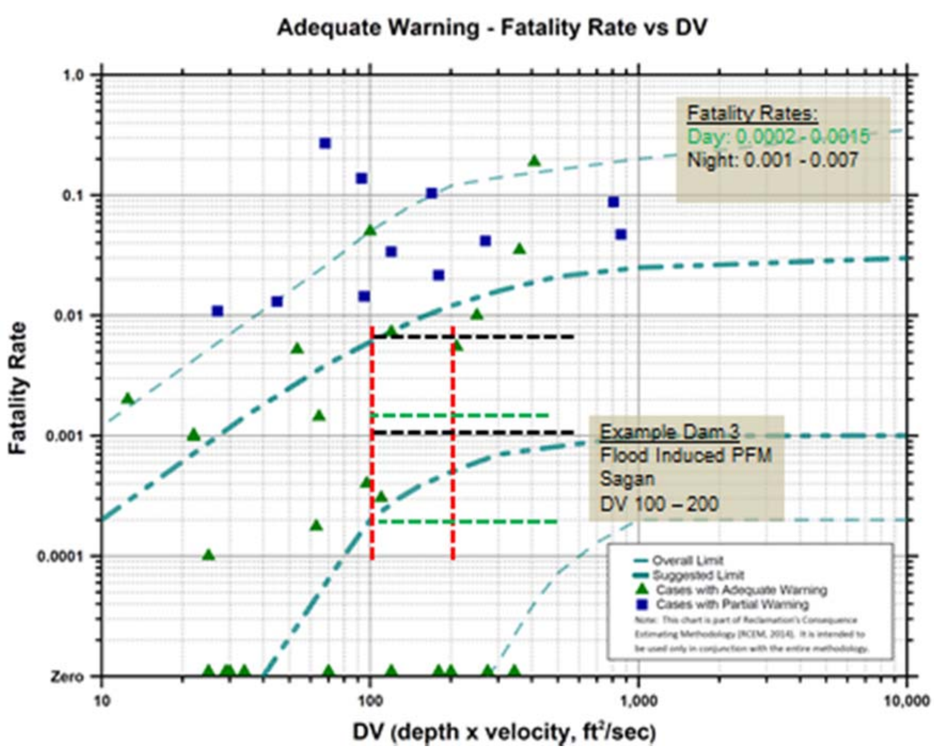


Figure 3.5. Fatality Rate Selection for Sagan Reach, Adequate Warning

The estimated life loss in the event of a hydrologic dam failure ranges from 2 to 34, with a weighted value of 11.

About 40 to 50 percent of the loss of life is expected to occur in the first 8 miles while this portion of the inundation area accounts for less than 4 percent of the PAR for the hydrologic failure. This is driven by the fact that a portion of the PAR in these first 8 miles would likely be difficult to locate, especially for a nighttime failure and would be expected to have minimal warning time. Some people in the town of Sagan may also be difficult to contact and this contributed to some loss of life in this area as well. For other downstream locations, the PAR would be expected have warning times in excess of 1 hour and would be much more likely to be able to evacuate the inundation area prior to arrival of the flood wave.

III. Sunny Day Dam Failure Modes

Sunny day dam failure modes include those that could occur during normal operations (static) or seismic conditions. Since the potential failure modes are the same for static and seismic loading conditions (and the breach would be expected to develop in the same way) only one set of estimates was prepared. Sunny day dam failure modes are inherently more lethal than failure modes that occur during hydrologic events since they can occur without warning and the downstream population would not be anticipating the possibility of high water levels. The failure of Example Dam 3 would be expected to occur rapidly with limited indicators that the failure was in progress.

While the peak breach outflow from the dam would be similar to what could occur during a hydrologic failure of the dam (the normal water surface is only 10 feet below the dam crest, which represents a head difference of about 3 percent and which would equate to about a 6 percent reduction in discharge), the flows would likely attenuate less downstream during a flood event due to the flood inflows into the reservoir. There is, however, limited information that can be used to take this effect into account. There is not available information on the attenuation of the flood inundation scenario. Assumptions were made on the amount of attenuation that might occur. A range of attenuation from no attenuation at the town of King, to 75 percent attenuation of the peak breach outflows at King, was assumed. Given this uncertainty, no attempt was made to reduce the flows for a sunny day failure. The same inundation conditions were assumed as those for the flood-induced failure.

A. Population at Risk (PAR)

Population at risk estimates for the areas downstream from Example Dam 3 were obtained from the estimates made in the last CR (and confirmed by overlaying 2010 census data onto the inundation maps). The inundation map for dam failure during a PMF was used for a sunny day failure even though it was recognized that this would overstate the inundated area to a degree.

Overall PAR estimates are larger than those for a flood-induced failure mode because the full PAR in the town of Sagan was used (in the flood case, the population was reduced to account for PAR removed as a result of pre-failure spillway releases). The PAR in the first 8 miles downstream of the dam is largely comprised of campers and recreationalists. The population in the first 8 miles is broken down and provided in Table 3.1. The recreation populations are more than those for a flood-induced failure, because the sunny day PAR was based on year round averages which are influenced by the large number of visitors in the summer and fall. Population at risk estimates for flood related conditions reflect spring time recreational visits and were broken down by day and night values. The recreational PAR estimates were based on records and conversations with county authorities (who manage the campgrounds) and with the owner of Ralston Ranch.

A summary of the PAR in the first 8 miles downstream of the dam is shown in Table 3.3.

Table 3.3 – Example Dam 3 – PAR Upstream of Sagan (first 8 miles), Sunny-day Failure

Location	Distance from Dam (miles)	Population at Risk (Sunny Day) Day/Night
Upper Coldwater Campground	0	35/32
Granite Creek (Campground)	1	60/55
Blue Spruce Campground	4	65/52
Prospector's Gulch Campground	5	35/25
Ralston Ranch (Dude Ranch)	6	30/30
Lower Coldwater Parking Area	8	30/10
Totals		255/204

The total PAR for all downstream reaches is provided in Table 3.4.

Table 3.4 − Population at Risk from Example Dam 3 Sunny Day failure

River Reach	Distance from Dam (in miles)	Estimated Travel Time of Leading Edge of Flood (in hours)	Population at Risk Day/NIght
Dam to Lower Coldwater Parking Area (Total)*	0 to 8	0 to 0.4	255/204
Sagan	36	2	1,700/1700
Garderen	48	3	200/200
Froome	58	4	100/100
King	85	18	200/200
Total			2,455/2304

*For details of PAR in first 8 miles see Table 3.3

B. DV Values

The DV values for the sunny day failure scenario are the same as those used for the flood related failure (since the same breach outflow and inundation boundaries were used). The calculation of DV values is shown in Table 3.6.

C. Warning Time

Warning was assumed to be initiated 0.5 to 1 hour after failure for a daytime failure and 1 to 1.5 hours after failure for a nighttime failure. Warning time estimates were made considering that water district personnel are at the dam 5 days per week (at least 2 days per week in the winter). Failure of the dam should be detected quickly if it occurs during the day on a weekday, but would be more difficult to detect if it occurred at night or on the weekend. There is an alarm that will alert district and Reclamation personnel if the reservoir level drops quickly, but it will take some time for district personnel to travel to the site and confirm that failure has occurred (several district employees live within 15 minutes of the dam). Flood wave travel times at each location downstream of the dam were reduced by the range of times after dam failure occurred to arrive at the warning time for each population center.

D. Fatality Rate Selection

Fatality rates for a sunny-day failure were adjusted from the flood induced failure case (this case was estimated first). Since warning times for the sunny-day failure are assumed to be less than for a flood-induced failure, fatality rates were increased for the sunny-day failure. The highest fatality rate chosen was that for the reach in the first 8 miles downstream of the dam. No warning time was assumed for all people in this reach, so the chart with little or no warning was used. For daytime conditions, the fatality rate for the flood induced failure (0.2 to 0.5) was increased to 0.3 to 0.7 to account for the fact that there would be no warning instead of 1 to 1.8 hours for a flood induced failure and due to the consideration that it would be difficult to locate and warn recreation populations (see Figure 3.6 for a graphical depiction of the fatality rate selection). For nighttime conditions, the fatality rate for a sunny day failure was increased from 0.3 to 0.7 for a flood-induced failure to 0.5 to 0.9 (see Figure 3.6).

For the town of Sagan, the fatality rate from the flood-induced failure and daytime conditions (0.02 to 0.2) was increased to 0.05 to 0.3 for the little or no warning case (see Figure 3.7). The increase was made to account for the reduced warning time. For nighttime conditions and little or no warning, the fatality rates from the flood case (0.08 to 0.4) was increased to 0.08 to 0.5 (see Figure 3.7). For the town of Sagan, the fatality rate from the flood-induced failure (0.0002 to 0.0015) for daytime conditions and adequate warning was increased to 0.0003 to 0.006 to account for the decrease in warning from 3 to 6.5 hours to 1 to 5 hours (see Figure3.8). For nighttime conditions, the fatality rate for adequate warning and the flood case (0.001 to 0.007) was increased to 0.001 to 0.01 in Sagan (see Figure 3.8). For the populations downstream of Sagan, the same trends that were applied to the flood-induced failure applied to the fatality rates selected for the sunny day failure. As warning time increased, lower fatality rates were chosen and the values moved closer to the lower suggested values. The fatality rates chosen for nighttime failures were increased from those for daytime failures.

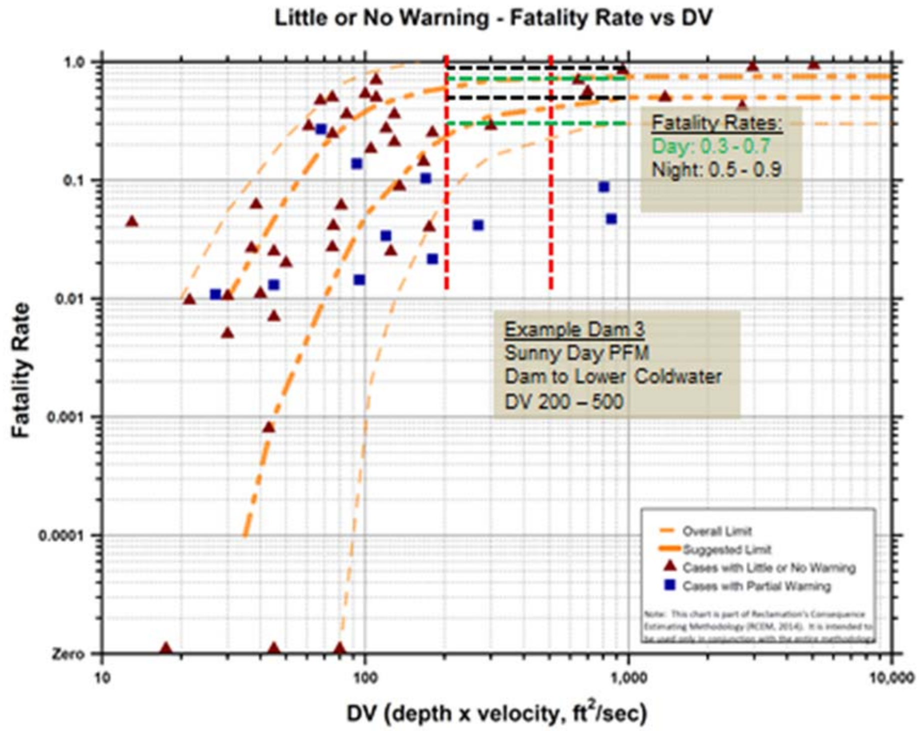


Figure 3.6. Fatality Rate Selection for Dam to Lower Coldwater Parking Reach, Little or no Warning

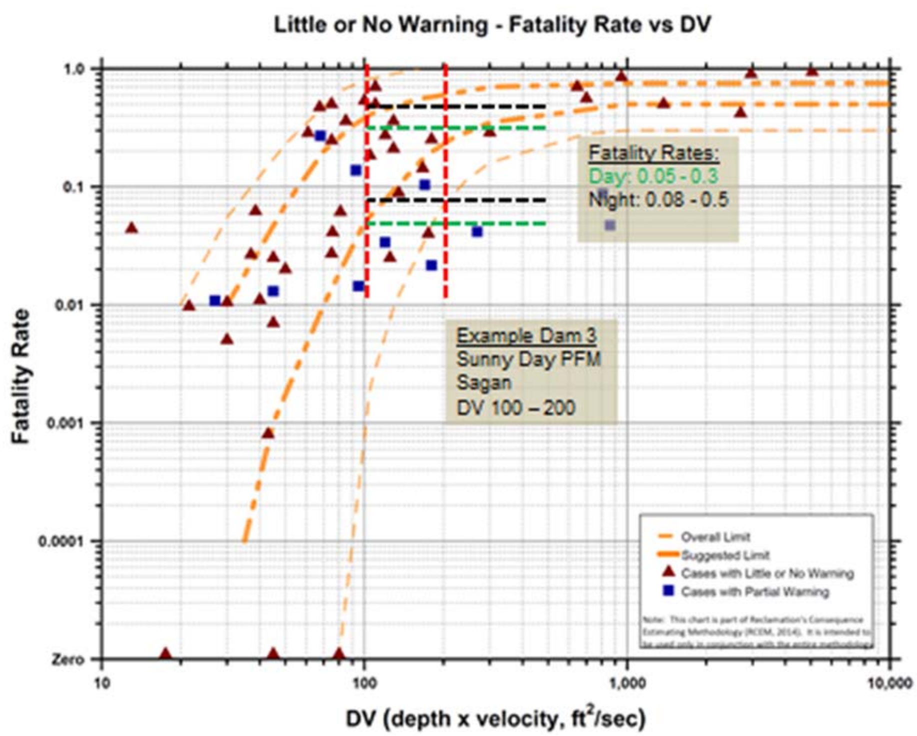


Figure 3.7. Fatality Rate Selection for Sagan, Little or no Warning

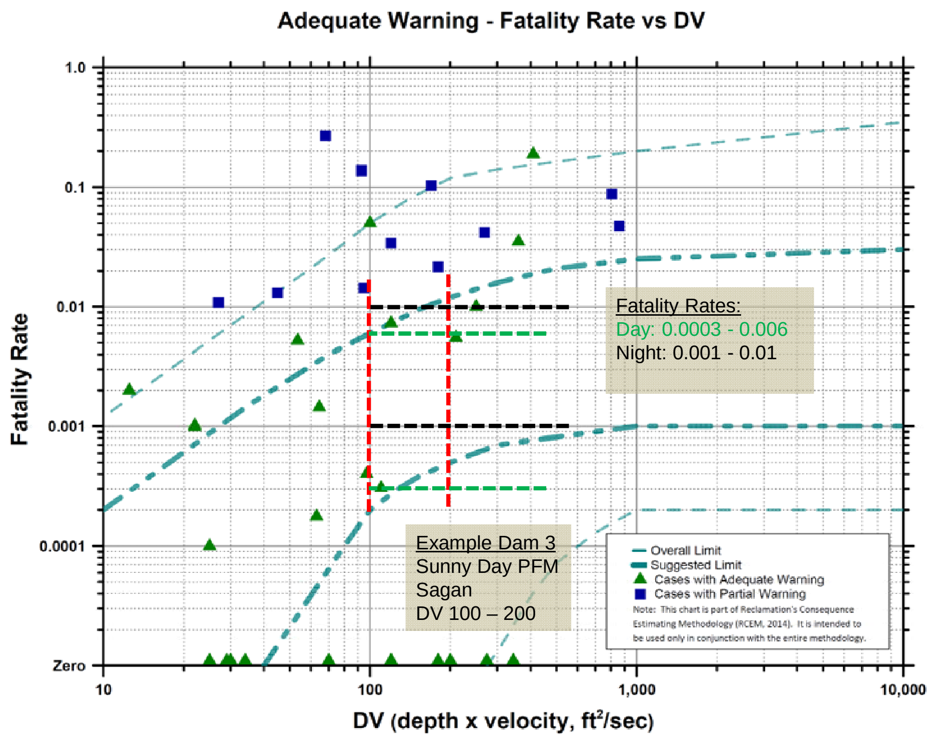


Figure 3.8. Fatality Rate Selection for Sagan, Adequate Warning

E. Loss of Life Estimate

Table 3.8 summarizes the above assumptions and estimates for all the downstream reaches and provides the range of life loss estimates as well as the best estimate. The day and night estimates were weighted two-thirds and one-third, respectively, when calculating a composite mean loss of life estimate. Using RCEM, the estimated life loss in the event of a hydrologic dam failure ranges from 78 to 231, with a weighted estimate of 147.

About 80 to 90 percent of the loss of life is expected to occur in the first 8 miles while this portion of the inundation area accounts for about 10 percent of the PAR for the sunny day failure. This is driven by the fact that the PAR in these first 8 miles would likely receive no warning. Those people in the town of Sagan and other downstream locations would have warning times in excess of 1 hour for daytime conditions and from 0.5 to 4.5 hours under nighttime conditions and would be much more likely to be able to evacuate the inundation area prior to arrival of the flood wave.

IV. Summary

Table 3.5 provides a summary of the life loss estimates for the cases analyzed. The loss of life estimate for a sunny-day failure is estimated to be much higher than the estimated life loss for a flood-induced failure. This makes sense for a number of reasons. A sunny day failure will occur with no advanced indication that the failure was about to occur. Downstream populations, especially those in the first 8 miles downstream of the dam would be oblivious to the developing failure and there would likely be no chance of warning those individuals since it is anticipated that warning would not be issued until the dam had already failed. These conditions are reflected in the high loss of life that is estimated to occur in this first reach (80 to 90 percent of the life loss is expected to occur in the first 8 miles). For the sunny day case, there is also some contribution of life loss from the town of Sagan. For daytime conditions, the life loss in Sagan is estimated to range from 2 to 15 people and for nighttime conditions, the life loss in Sagan is estimated to range from 6 to 42 people. For daytime conditions, this reflects the large number of people in Sagan which results in some life loss even with a low fatality rate. For nighttime conditions, most of the life loss in Sagan is expected to result from a small percentage of the PAR (3 percent) receiving little or no warning. This acknowledges that it would be difficult to contact and warn all individuals in a large town for an unanticipated failure occurring at night. For these individuals, a relatively high fatality rate was used.

In contrast to the sunny day failure, loss of life for a flood induced failure is expected to be much lower. The biggest factor is that a major flood that would be needed to initiate a hydrologic failure of the dam and this event would initiate continuous monitoring of the dam. Reclamation staff would be watching the dam closely for signs of the foundation failure mode initiating. Communications with downstream emergency management officials would be constant and everyone would be on alert and ready to respond to a developing situation. The downstream populations would also recognize the flood as something unprecedented and would likely be following news of the flood closely. All of this would improve the chance of timely warnings being initiated and also the chance of a quick response on the part of emergency management officials and downstream populations that would be impacted by a dam breach.

The case history data was considered when selecting fatality rates. In general, rates were selected closer to the upper suggested limit when considering nighttime conditions and closer to the lower suggested limit when considering daytime conditions. This is consistent with the data plots in Appendix B of the RCEM Methodology document. For a sunny day failure (under both daytime and nighttime conditions), the largest contributor of life loss was in the first 8 miles where no warning is expected and DV values are estimated to range from 200 to 500 ft^2/s. The closest case histories to this situation are data points from Malpasset Dam. This was a concrete dam that failed suddenly due to a foundation failure, which is a similar failure to what is expected for Example Dam 3. Three different data points are provided on the Little or No Warning Fatality Rate plot. The DV values range from less than 150 ft^2/s to over 600 ft^2/s. Fatality rates range from 0.2 to 0.7. This is consistent to what was used in this example (range of 0.3 to 0.7 during the day and 0.5 to 0.9 at night). For a flood induced failure, more warning would be expected. There was, however, a percentage of the population that would be estimated to receive little or no warning. For these people, a fatality rate range of 0.2 to 0.5 was assumed for daytime conditions and a range of 0.3 to 0.7 was assumed for nighttime conditions. These estimates are consistent with the Malpasset data.

For the flood-induced failure, the two significant areas were the first reach (within the first 8 miles downstream of the dam) and the reach including the town of Sagan. DV values for these two areas range from 100 to 500 ft^2/s. The data points closest to these DV values on the Adequate Warning Fatality Rate Plot are three South Fork Dam points (East Conemaugh, South Fork and Mineral Point), which have DV values ranging from about 200 to 400 ft^2/s and fatality rates ranging from about 0.005 to 0.03. The ranges of values used in this example were 0.002 to

0.009 (first 8 miles) and 0.0002 to 0.0015 (Sagan) for daytime conditions and 0.003 to 0.015 (first 8 miles) and 0.001 to 0.007 (Sagan) for nighttime conditions. These rates are generally consistent with the South Fork case history data but do reflect slightly lower fatality rates. This is a reflection of the improved communication and emergency management available today.

Table 3.5 - Example Dam 3 – Loss of Life Estimates Summary

Scenario	Loss of Life Estimates			Overall Fatality Rate	Percent of Life Loss	
	Low	Best	High		First 8 miles	Sagan
Sunny Day Daytime	18	136	194	0.055	93	6
Sunny Day Nighttime	108	170	231	0.071	84	14
Sunny Day Overall	78	147	231			
Flood Daytime	2	6	9	0.003	55	45
Flood Nighttime	8	21	34	0.011	45	55
Flood Overall	6	11	21			

There is significant uncertainty in the loss of life estimates, primarily because the inundation study is an older 1D study, with limited documentation. It is not expected that further refinements to the flood-induced failure scenario inundation would change the findings to a significant degree. Loss of life for this case is low and it is not envisioned that refinements would significantly change the estimates. If anything, the estimates would be expected to be lowered, since the effects of flood attenuation in downstream communities may have been underestimated. The sunny-day loss of life estimates would be more likely to change if an inundation scenario was developed for this case. The effects of attenuation would be expected to be more pronounced than what was assumed. The overall loss of life may not change significantly, however. This is because most of the life loss occurs in the first 8 mile reach and attenuation would have less of an effect closer to the dam. The flow conditions in the town of Sagan may have been overstated for this loss of life study, but even if they were reduced and the loss of life estimates reduced for this reach, this area only contributes about 5 to 15 percent of the total life loss estimated.

The previous discussion in this Summary section provides information that should be summarized in the Findings and the Dam Safety Case discussion in the Decision Document/Technical Report of Findings document. The discussion above includes a discussion of uncertainty but does not discuss confidence, because confidence has to be considered in a larger context of the overall findings, which should focus on the annualized loss of life estimates. The following additional discussion on confidence is something that would be added to the Findings and the Dam Safety Case discussion:

The total annualized failure probability at Example Dam 3 is 3.2 E-06, which is well below the threshold value in Reclamations Public Protection Guidelines for increasing justification to reduce or better understand risks. The total annualized life loss estimate is 4.8 E-4, which is also below the threshold value for increasing justification to reduce or better understand risks. The weighted life loss estimate is 150 people, which is very close to the expected life loss value of 147 people for static or seismic potential failure modes. This makes sense, since these potential failure modes are the major contributors to the both the total annualized failure probability and the total annualized life loss. The range of life loss for the static and seismic potential failure modes extended from 78 people to 231 people. This range encompasses the low loss of life estimate for a day time failure (78 people) to the high loss of life estimate for a night time failure (231 people). As a sensitivity study, the high loss of life value for all potential failure modes (including the one hydrologic potential failure mode) was used as the loss of life estimate and was multiplied by the mean annualized failure probability. This resulted in a revised total annualized life loss value of 7.5 E-4, which is still below the threshold value for increasing justification to reduce or better understand risks. For this reason and the fact that refined studies for the loss of life estimates (which most likely would focus on the inundation studies for this type of failure) would be expected to reduce the life loss estimates, if the estimates change at all, there is moderate to high confidence in the life loss estimates for Example Dam 3.

Table 3.6 – DV Calculations for Example Dam 3

EXAMPLE DAM 3 - LIFE LOSS ESTIMATES River Reach	Distance from Dam, miles	Travel Time, hrs	Average Velocity, ft/sec	Breach Flow, ft3/s	Top Width of Flow, ft	DV, ft^2/s	Ave D, ft	Comments
Dam to Lower Coldwater Parking /	0 to 8	0 to 0.8	15	514,000	1000 - 2500	200 to 500	5 to 33	scattered residences, camprounds
Sagan	36	2 to 5.5	15	350,700 - 514,000	2600 - 3500	100 to 200	7 to 13	most of town inundated
Garderen	48	3 to 8	12	293,600 - 514,000	2600	100 to 200	8 to 16	most of town inundated; homes spread out
Froome	58	4 to 11	10	250,950 - 514,000	4000	60 to 130	6 to 13	only portions of town inundated
King	85	17.5 to 19	4	128,500 - 514,000	1,500	80 to 300	20 to 150	scattered residences
Total								

Table 3.7 – Loss of Life Estimates for Flood-Induced Failure

Warning Issued I hour before failure

FLOOD INDUCED FAILURE - EXAMPLE DAM 3 (Daytime)		Warning Time, hrs					
River Reach	**Distance from Dam, mi**	**Chart Used**	**Population at Risk**	**DV, ft^2/s**	**Fatality Rates**	**Loss of Life Est**	**Notes**
Dam to Lower Coldwater Parking /	0 to 8	1 to 1.8/NW	7 (10%)	200 - 500	0.2 - 0.5	1 to 4	lower limit based on low DV and rate just below low sug value; upper limit based on high DV and midpt of suggested values
Dam to Lower Coldwater Parking /	0 to 8	1 to 1.8/AW	63 (90%)	200 - 500	0.002 - 0.009	0 to 1	lower limit based on low DV and rate btwn sug values; upper limit based on high DV and rate btwn suggested values
Sagan	36	3 to 6.5/NW	7 (0.5%)	100 - 200	0.02 - 0.2	0 to 2	lower limit based on low DV and rate btwn low sug and lower overall; upper limit based on high DV and rate just below low sug value
Sagan	36	3 to 6.5/AW	1353 (99.5%)	100 - 200	0.0002 - 0.0015	1 to 2	lower limit based on low DV and lower suggested rate; upper limit based on high DV and rate btwn suggested values
Garderen	48	4 to 9/NW	0	100 - 200		0	
Garderen	48	4 to 9/AW	200	100 - 200	0.0001 - 0.001	0	lower limit based on low DV and rate just below lower sug; upper limit based on high DV and rate btwn suggested values
Froome	58	5 to 12/AW	100	60 - 130	0.00003 - 0.0005	0	range based on low DV and rate just below low sug value; upper limit based on high DV and rate just above low sug value
King	85	18.5 to 20/AW	200	80 - 300	0.00005 - 0.0015	0	lower limit based on low DV and value btwn low sug value and low overall; upper limit based on high DV and rate btwn sug values
Total						2 to 9 (6)	

Overall Fataility Rate = 6/1930 = 0.3 percent

Warning Issued I hour before failure

FLOOD INDUCED FAILURE - EXAMPLE DAM 3 (Nightime)		Warning Time, hrs					
River Reach	**Distance from Dam, mi**	**Chart Used**	**Population at Risk**	**DV, ft^2/s**	**Fatality Rates**	**Loss of Life Est**	**Notes**
Dam to Lower Coldwater Parking	0 to 8	1 to 1.8/NW	18 (30%)	200 - 500	0.3 - 0.7	5 to 13	lower limit based on low DV and rate just above low sug value; upper limit based on high DV and upper sug rate
Dam to Lower Coldwater Parking	0 to 8	1 to 1.8/AW	42 (70%)	200 - 500	0.003- 0.015	0 to 1	lower limit based on low DV and btwn sug values; upper limit based on high DV and near up sug value
Sagan	36	3 to 6.5/NW	27 (2%)	100 - 200	0.08 - 0.4	2 to 11	lower limit based on low DV and rate btwn sug values; upper limit based on high DV and rate btwn sug values
Sagan	36	3 to 6.5/AW	1333 (98%)	100 - 200	0.001 - 0.007	1 to 9	lower limit based on low DV and rate btwn suggested values; upper limit based on high DV and rate below upper sug value
Garderen	48	4 to 9/NW	0	100 - 200		0	
Garderen	48	4 to 9/AW	200	100 - 200	0.0002 - 0.001	0	lower limit based on low DV and low sug value; upper limit based on high DV and rate btwn sug values
Froome	58	5 to 12/AW	100	60 - 130	0.00004 - 0.0007	0	range based on low DV and low sug value; upper limit based on high DV and rate btwn sug values
King	85	18.5 to 20/AW	200	80 - 300	0.00007 - 0.002	0	lower limit based on low DV and value below low sug value; upper limit based on high DV and rate btwn sug values
Total						8 to 34 (21)	

Overall Fataility Rate = 21/1920 = 1.1 percent

Weighted Average Life Loss + 2/3 (6) + 1/3 (21) = 11 people, with a range of 2 to 34

Table 3.8 – Loss of Life Estimates for Sunny Day Failure

SUNNY DAY FAILURE - EXAMPLE DAM 3 (Daytime)		Warning Time, hrs					
River Reach	**Distance from Dam, mi**	**Chart Used**	**Population at Risk**	**DV, ft^2/s**	**Fatality Rates**	**Loss of Life Est**	**Notes**
Dam to Lower Coldwater Parking	0 to 8	0/NW	255	200 - 500	0.3 - 0.7	76 to 178	lower limit based on low DV and just above lower sug value; upper limit based on high DV and upper sug value
Sagan	36	1 to 5/NW	17 (1%)	100 - 200	0.05 - 0.3	1 to 5	lower limit based on low DV and low sug value; upper limit based on high DV and rate btwn sug values
Sagan	36	1 to 5/AW	1683 (99%)	100 - 200	0.0003 - 0.006	1 to 10	lower limit based on low DV and rate just above low sug value; upper limit based on high DV and rate btwn sug values
Garderen	48	2 to 7.5/NW	0	100 - 200		0	
Garderen	48	2 to 7.5/AW	200	100 - 200	0.0002 - 0.005	0 to 1	lower limit based on low DV and lower sug value; upper limit based on high DV and rate btwn sug values
Froome	58	3 to 10.5/AW	100	60 - 130	0.00005 - 0.001	0	lower limit based on low DV and rate just above lower sug value; upper limit based on high DV and rate btwn sug values
King	85	16.5 to 18.5/AW	200	80 - 300	0.0001 - 0.001	0	lower limit based on low DV and low sug value; upper limit based on high DV and rate just above low sug value
Total						78 to 194 (136)	
			Overall Fataility Rate = 136/2455 = 5.5 percent				

Warning Issued 1 to 1.5 hours after failure

SUNNY DAY FAILURE - EXAMPLE DAM 3 (Nightime)		Warning Time, hrs					
River Reach	**Distance from Dam, mi**	**Chart Used**	**Population at Risk**	**DV, ft^2/s**	**Fatality Rates**	**Loss of Life Est**	**Notes**
Dam to Lower Coldwater Parking	0 to 8	0/NW	204	200 - 500	0.5 - 0.9	102 to 184	lower limit based on low DV and rate btwn suggested values; upper limit based on high DV and rate close to upper limit
Sagan	36	0.5 to 4.5/NW	51 (3%)	100 - 200	0.08 - 0.5	4 to 26	lower limit based on low DV and rate btwn sug values; upper limit based on high DV and rate btwn sug values
Sagan	36	0.5 to 4.5/AW	1649 (97%)	100 - 200	0.001 - 0.01	2 to 16	lower limit based on low DV and rate btwn suggested values; upper limit based on high DV and upper sug value
Garderen	48	1.5 to 7/NW	2 (1%)	100 - 200	0.06 - 0.4	0 to 1	lower limit based on low DV and rate just above low sug value; upper limit based on high DV and rate btwn sug values
Garderen	48	1.5 to 7/AW	198 (99%)	100 - 200	0.002 - 0.02	0 to 4	lower limit based on low DV and rate btwn suggested values; upper limit based on high DV and rate just above up sug value
Froome	58	2.5 to 10/NW	0	60 - 130		0	
Froome	58	2.5 to 10/AW	100	60 - 130	0.0001 - 0.003	0	lower limit based on low DV and rate btwn suggested values; upper limit based on high DV and rate btwn sug values
King	85	16 to 18/AW	200	80 - 300	0.0001 - 0.001	0	lower limit based on low DV and low sug value; upper limit based on high DV and rate just above low sug value
Total						108 to 231 (170)	
			Overall Fataility Rate = 170/2404 = 7.1 percent				
			Weighted Average Life Loss + 2/3 (136) + 1/3 (170) = 147 people, with a range of 78 to 231				

Example Dam 4 (CR-Level Evaluation)

A. General

Example Dam 4 is a zoned earthfill dam on Jewel Creek with a hydraulic height of 225 feet. The dam impounds about 125,000 acre-feet at the top of active storage and has a flood surcharge capacity of about 15,000 acre-feet.

The failure of Example Dam 4 would cause flooding in the narrow and winding valley flowing eastward from the dam to the western outskirts of Jewel City. The dam failure would inundate the small town of Rockton and cause the overtopping and failure of Willow Lake Dam downstream. Central Jewel City would be flooded, including businesses, residential developments and parks before floodwaters exit Jewel City on its eastern side and pass through less populated areas east of the city.

A severe flash flood occurred downstream from Example Dam 4 in 1974. Heavy rains of up to 8 inches fell in a period of three hours and caused flash flooding. Most of the damage occurred in Jewel City and was compounded by failure of Willow Lake Dam. The peak breach discharge at Willow Lake Dam was 32,000 ft^3/s. Because of this event, Jewel City has developed an advanced flood warning system that has been considered in this life loss evaluation.

A 1D dam failure inundation study was performed and inundation maps were prepared in 1982 for two PMF inflow scenarios; one where the PMF is passed through the spillway and one where the dam fails at the top of flood storage elevation 3621.5 feet (10 feet of freeboard), which corresponds to about 140,000 acre-feet of water (15,000 acre-feet, or 12 percent, more volume than at the top of active storage). The breach was assumed to be trapezoidal with a base width of 300 feet, extend vertically for 220 feet, have 1H:1V side slopes, and take 1.8 hours to fully form. The peak discharge obtained with the National Weather Service Dam-Break computer model was 1,750,000 ft^3/s. The study indicates that at Ruby Boulevard in downtown Jewel City, the dam failure flood boundary is about 2,600 feet wide, and the inflow design flood (without dam failure) boundary is about 1,700 feet wide (about 65% of 2,800 feet). The maximum inundation area is shown on Figure 4.1.

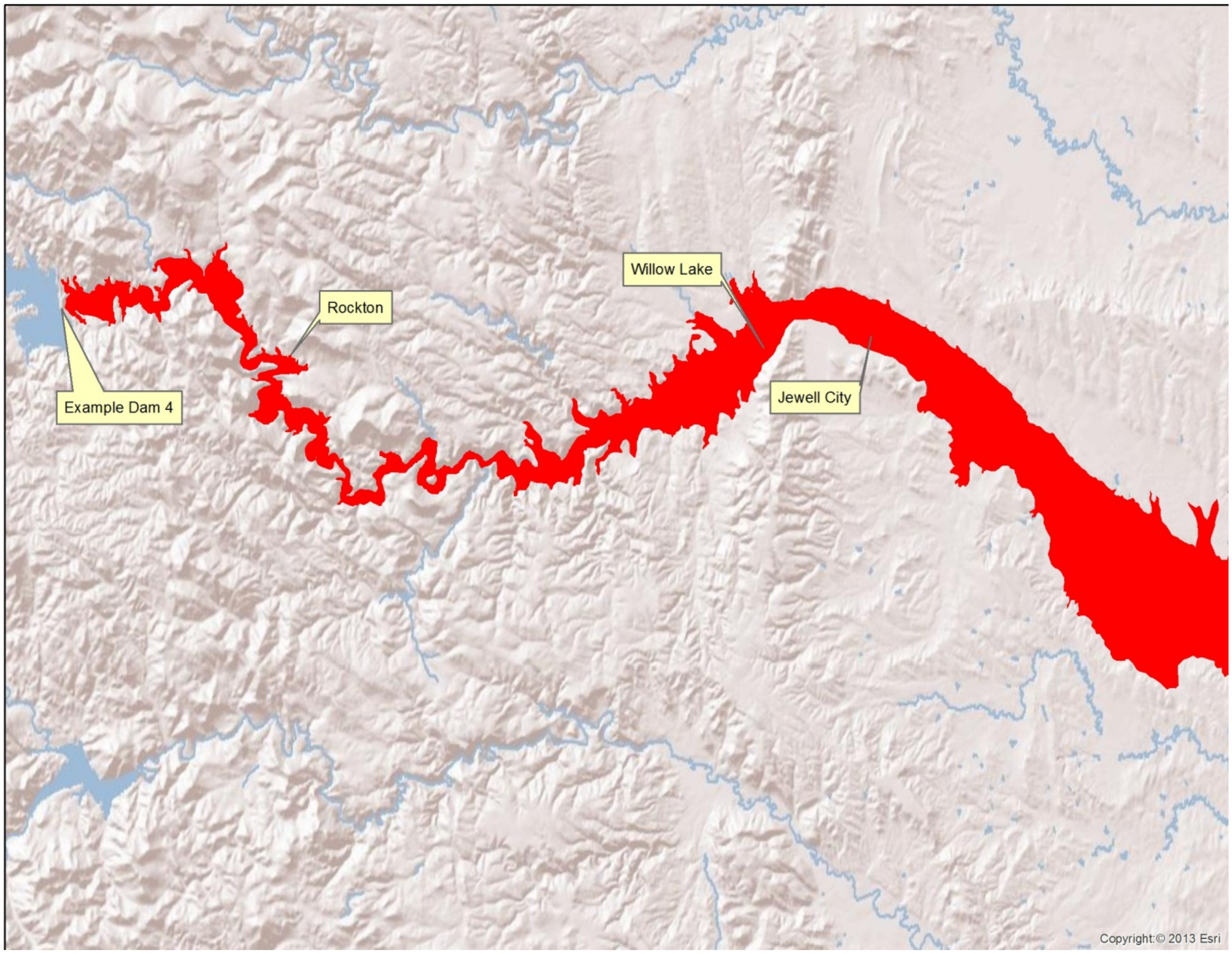


Figure 4.1 – Example Dam 4 – maximum inundation (Note: for a typical life loss study, existing inundation maps would be included rather than the simplified graphics in this Examples of Use document)

An evaluation of potential failure modes at this dam indicated two types of potential failure mode scenarios judged to be sufficiently credible to quantify risks:

- Static - internal erosion of embankment under normal operating conditions
- Hydrologic - internal erosion of embankment under flood loading

No seismic potential failure modes were judged to be sufficiently credible to quantify risks.

For this CR level study, life loss estimates for these two potential failure mode scenarios were determined using Reclamation's Consequence Estimating Methodology (RCEM) 2014. Most of the factors considered when evaluating the life loss are very similar for the two types of potential failure mode scenarios. Therefore, to avoid repetition, the factors considered in the life loss estimates are discussed together (rather than providing separate discussions) for different potential failure mode scenarios. Differences in flood volume and inundation area were also accounted for in the evaluation by using judgment.

B. Population at Risk (PAR)

The PAR was estimated by overlaying 2010 census data onto the inundation map corresponding to failure of the dam at the top of flood storage elevation. In this manner, the total number of people in the flood plain was estimated for two conditions; (1) static loading with the reservoir at the top of active conservation capacity, and (2) internal erosion under hydrologic loading at reservoir elevation 3621.5 (which is what the inundation map was based on). It is recognized that the inundation area for a breach under normal operating conditions would be smaller than what is shown on the 1982 inundation map. A general review of the downstream topography and relative location of the PAR indicates that reductions in the volume of water released from a dam failure would likely inundate a smaller area; however, the amount of reduced area might vary depending on the topography. To estimate the PAR for the static failure condition, the PAR within the inundation plain was reduced by 20 percent to account for the smaller reservoir volume and somewhat diminished levels of flooding. There is no strong quantitative basis for selecting a 20 percent reduction; the 20 percent is a judgment value that was arrived at by considering that a 50 percent reduction seemed excessive given a 12 percent reduction in reservoir volume, and a 10 percent reduction did not seem sufficient given the topography. Based on this line of reasoning, a reduction in PAR between 15 and 35 percent could likely be supported, and a reduction of 20 percent was selected as a best estimate.

A key assumption is that no life loss would occur more than 5 miles downstream from Jewel City. The number of people at risk downstream from Jewel City is small in comparison to the number of people at risk from the dam through the Jewel City metropolitan area. In addition, people in the downstream areas would generally receive less severe flooding and would likely receive warning that would be equal to or better than that in Jewel City. The number of fatalities anticipated in downstream areas would be very small (if any) compared to the number in and upstream from Jewel City.

Table 4.1 summarizes the PAR estimates.

Table 4.1 – **Estimated Population at Risk**

Location (river miles)	Reservoir Elevation 3580.2 (Static Internal Erosion PFM)	Reservoir Elevation 3621.5 (Hydrologic Internal Erosion PFM)
	Day and Night	Day and Night
Dam to Rockton (0-4)	120	150
Rockton to Willow Lake Dam (4-30)	620	780
Willow Lake Dam to Ruby Blvd. in downtown Jewel City (30-35)	1,050	1,300
Ruby Blvd. to Opal St. (35-38)	1,150	1,430
Opal St. to about 5 miles downstream (38-45)	1,200	1,500
Total	**4,140**	**5,160**

C. DV Values

DV was first estimated using travel time and depth information from the 1982 inundation maps. Flow velocities calculated using distance and arrival time information were in the range of 35 to 55 ft/s - which is unrealistically high. Corresponding DV values are also very high, as shown in Table 4.2 below. Adjustments were made to the velocity values based on the justification in the following paragraph to arrive at what is considered a more realistic DV range.

Table 4.2 – **Estimate of DV from 1982 Inundation Study Information (DV values are unrealistically high)**

Location	Distance (mi)	Arrival Time (hr)	Velocity (ft/s)	Depth (ft)	DV (ft^2/s)
Dam to Rockton	4	0.1	45	100	4500
Rockton to Willow Lake Dam	12	0.4	42	120	5040
Willow Lake Dam to Ruby Blvd. in downtown Jewel City	30	0.8	55	40	2200
Ruby Blvd. to Opal St.	35	1.4	38	35	1330
Opal St. to about 5 miles downstream	40	1.7	34	22	748

The computed velocity values are unusually high, particularly when compared to historic dam failure cases. For example, the sudden failure of St. Francis Dam in 1928 [1], produced estimated maximum velocities at Powerhouse No. 2 of about 25-30 ft/s (i.e. about 5 minutes to travel 1.4 miles). This case could be considered a high end value for flow velocities from dam failure. A closer look at the 1982 inundation study indicates that it was performed using the NWS DAMBRK model with only 8 cross sections for the entire downstream reach. Many newer 1D inundation models using MIKE11 with many more cross sections have produced much slower travel times when compared to studies from the 1980s that have a limited number of cross sections. Therefore, the DV values obtained directly from the 1982 study are likely unrealistically high. For the purposes of this consequence study, in lieu of performing a new inundation study, a maximum velocity of 25 ft/s was selected for the third reach where the maximum back-calculated 1982 velocity was 55 ft/s. This corresponds to a reduction ratio of about 45%. This reduction ratio was applied to the other 1982 velocities to estimate the maximum (high) velocity in each reach. The lower limit of the velocity was estimated to be half of the high value. The high end of the velocity range is likely an upper bound value because breach flows from failure of this earth embankment will likely be slower than the flows from the sudden failure of St. Francis Dam (although without doing the necessary studies, there is some uncertainty). By performing these adjustments to the velocity values, velocities ranging between 8 and 25 ft/s were selected to estimate DV rather than using travel time and distances from the 1982 inundation study. A new inundation study might result in different computed velocities; however, the present adjusted velocities are more realistic than values obtained from the 1982 inundation study. Results of the DV adjustment analysis are shown below.

Table 4.3 – Adjusted DV Estimates for Life Loss Evaluation

Location	Depth (ft)	Velocity (ft/s)		DV (ft^2/s)	
		Low	High	Low	High
Dam to Rockton	100	10	20	1000	2000
Rockton to Willow Lake Dam	120	9	19	1100	2300
Willow Lake Dam to Ruby Blvd. in downtown Jewel City	40	12	25	500	1000
Ruby Blvd. to Opal St.	35	9	17	300	600
Opal St. to about 5 miles downstream	22	8	15	170	340

The calculated "Low" DV values (on Table 4.3) might be more representative of flood severity on the fringes of the inundation area, and the "High" DV values might be more representative of the flood severity closer to the channel. Failure of Willow Lake Dam could cause a sudden surge in the flow and DV value if the reservoir is released rapidly. Flood severity in terms of DV might be higher for a hydrologic internal erosion potential failure mode compared to an internal erosion potential failure mode occurring under normal operating conditions. By considering a range of velocities (a factor of 2) it is judged that the estimated range of DV in Table 4.3 encompasses the two different reservoir levels as well as any surge in flow that might occur, and the larger PAR associated with the estimated wider inundation area is accounted for in Table 4.1. The estimated DV range for each reach is used to estimate the fatality rate range using the appropriate DV vs. fatality rate chart.

D. Warning Time

A full-time dam tender lives just downstream of the dam and visits the dam regularly to perform normal O&M activities and read instruments. It is judged that there would be sufficient opportunity to detect a developing dam failure during daylight hours. For a static internal erosion failure, it is estimated that warning would be initiated at least 1 hour before dam failure during the day, and perhaps 0 to 1 hour after dam failure at night. For a hydrologic internal erosion failure, there would be much more warning (at least 6 hours) because of visual monitoring of the dam associated with the ongoing flood event.

Flood wave travel time to the downstream PAR will further increase the available warning. Travel time to each location was estimated using the adjusted velocities rather than the travel times from the 1982 inundation study, which were based on unrealistic velocities. Between the dam and Rockton, travel time would be about a half hour (~15 minutes to the mid- point of this reach). The travel time to Willow Lake Dam would be about 2-3 hours, and travel time to Jewel City would be about 3 hours. The estimated warning times were added to the flood wave travel times to get the estimated warning for each PAR reach. The resulting warning times are shown in Table 4.4 below, along with the warning category.

Table 4.4 – Warning Time and Warning Category

Location	Reservoir Elevation 1580.2 (Static Internal Erosion PFM)		Reservoir Elevation 1621.5 (Hydrologic Internal Erosion PFM)	
	Day	Night	Day	Night
Dam to Rockton	1-1.5 hrs Little/No	0-1 hr Little/No	6+ hrs Adequate	6+ hrs Adequate
Rockton to Willow Lake Dam	3-4 hrs Adequate	2-3 hrs Adequate	Adequate	Adequate
Willow Lake Dam to Ruby Blvd. in downtown Jewel City	4+ hrs Adequate	3+ hrs Adequate	Adequate	Adequate
Ruby Blvd. to Opal St.	4+ hrs Adequate	3+ hrs Adequate	Adequate	Adequate
Opal St. to about 5 miles downstream	5+ hrs Adequate	4+ hrs Adequate	Adequate	Adequate

For static failures, the reach between the dam and Rockton was estimated to have 1-1.5 hours of warning for a daytime failure, and 0-1 hour for a nighttime failure. The “little or no warning” category was judged to be appropriate for both day and night failure scenarios in this reach. Generally these areas just downstream of the dam are more remote, dispersed residences. Warnings to the PAR in this reach would most likely depend on the dam tender initiating the EAP through established procedures, with local emergency management personnel becoming involved through the EAP activation. If the dam tender does not provide the initial notification, rising water would most likely be first observed by downstream residents and those travelling the roadway along the river. Most of the roads go up and down the canyon so those choosing to evacuate the area by car could be caught by floodwaters in their vehicles. Those that choose to walk to higher ground could have a better chance of survival, but it could be strenuous for many people since the area is mostly wooded. It is difficult to envision emergency management and law enforcement agencies being very effective with notification and evacuation in this first reach, particularly compared to further downstream. Therefore, because of the estimated difficulties associated with warning and evacuation in this reach, the estimated fatality rates would likely be high, particularly at night. Figure 4.2 shows a portion of the typical inundated reach between the dam and Rockton.

Figure 4.2 – Example Dam 4 – typical inundation area between the dam and Rockton where residences are remote and scattered, vehicular escape routes are up and down the canyon, and there would be little to warning for both day and night scenarios.

Between Rockton and Willow Lake Dam, the topography becomes flatter and less forested. The primary access road does not follow the canyon in this reach, and therefore portions of the road are not inundated, allowing for closer areas for the PAR to quickly escape the flood waters. Also, there are more escape routes in this reach, and emergency management actions are likely to be more effective because the residences are closer compared to farther upstream. Because of these factors, and the estimated 2-4 hours of warning in this reach, the warning category was judged to be "adequate" for both daytime failures and nighttime failures. The exact amount of warning would depend on day vs. night failure and the speed with which the breach develops, and nighttime fatality rates would generally be higher than daytime fatality rates. Figure 4.3 below shows a typical portion of the inundated area between Rockton and Willow Lake dam that would receive adequate warning.

Figure 4.3 – Example Dam 4 – typical inundation area between Rockton and Willow Lake Dam. Note the primary access road is not inundated, and topography is flatter and less forested, allowing for more effective warning and evacuation. Lower velocity, backwater flows are also present in some areas, as shown on the top of the figure.

Downstream of Willow Lake Dam, the floodwaters would first enter residential areas of Jewel City, before flowing through the downtown commercial areas. Jewel City would have at least 3-4 hours warning, and this is considered "adequate" to warn a PAR of thousands, particularly considering the advanced warning system that exists with the local emergency management officials. Figure 4.4 shows the typical inundation map of Jewel City. From the map it is apparent that there are plenty of vehicular and easy walking escape routes. The residential and commercial PAR would only have to travel 4-5 blocks, or about a half mile, to escape the inundation area.

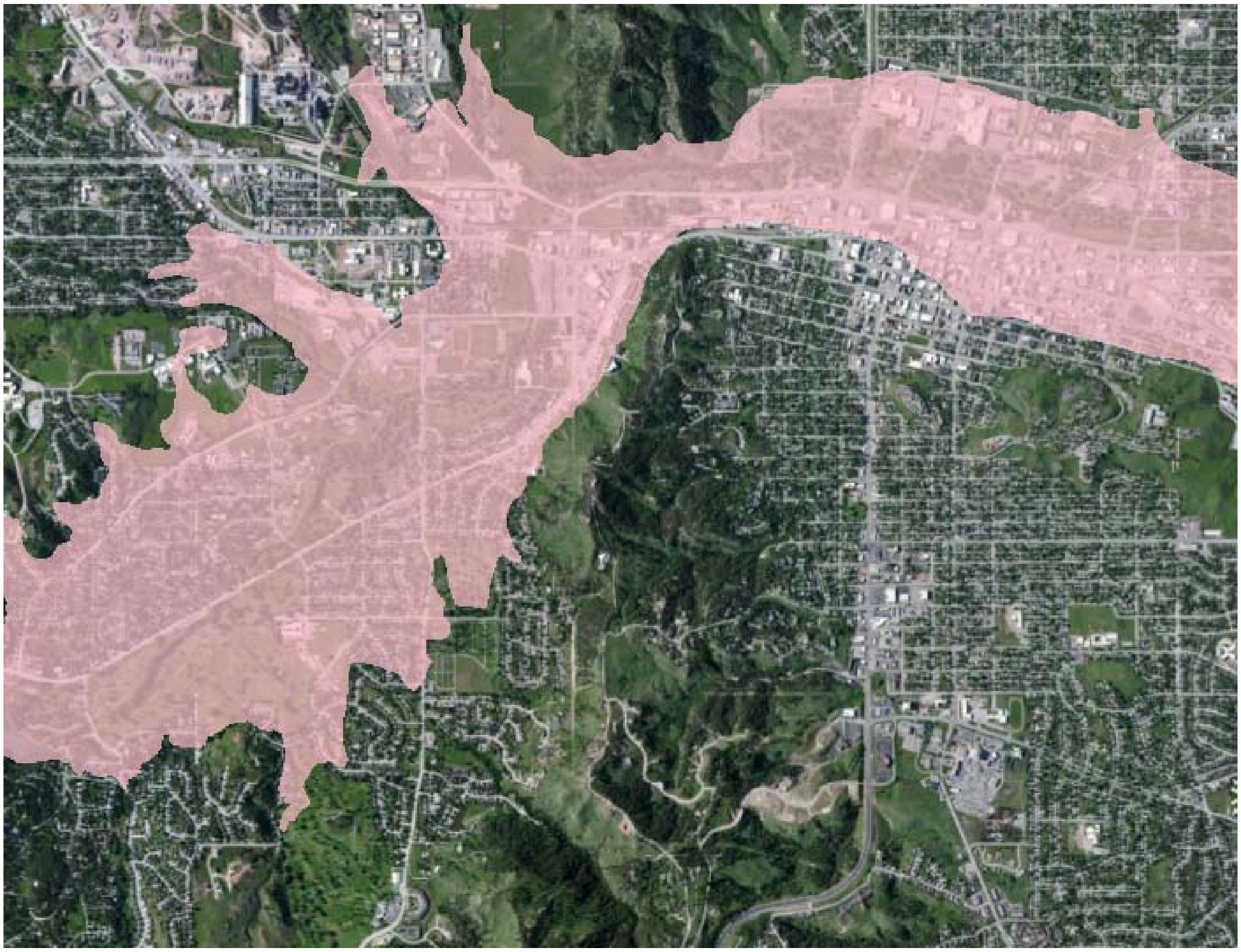


Figure 4.4 – Example Dam 4 – inundation map of residential and commercial areas in Jewel City. Note the large number of escape routes and relatively short distances that the PAR would have to travel to leave the inundation area.

For areas downstream of Ruby Blvd in Jewel City, there would be at least 3-4 hours of warning for day and night failure scenarios, and the warning category is considered "adequate" because of the advanced flood warning system that is in place as a result of the 1974 flood event. For comparable warning times, daytime fatality rates were judged to be lower than night time fatality rates due to the many positive factors associated with daytime failures such as people being awake, visual confirmation of flooding, media coverage and more efficient communications.

E. Fatality Rates and Loss of Life Estimate

For static PFMs, fatality rates between the dam and Rockton are estimated to be somewhat high and range from 0.2 (low estimate, daytime) to 0.6 (high estimate, nighttime). The lower bound daytime fatality rate of 0.2 is lower than the overall limit of 0.3 on the little or no warning chart because it is judged that most of the PAR in this reach will see or hear the signs of flooding, even if no formal warning is received. The upper bound night time fatality rate of 0.6 is between the suggested limits of 0.5 and 0.7. In general, these high fatality rates are due to the little or no warning and difficulties with evacuation (as described above) that are expected for the PAR in this reach. Although this reach has the lowest PAR (120 to 150), the high fatality rates result in this reach having the most fatalities (mean 48 of 65). This is driven by the judgment that the PAR in this reach would receive little or no warning and could encounter evacuation difficulties, so overall the results seem reasonable.

The PAR further downstream is much higher, but the fatalities are lower because of the adequate warning that would be received. Daytime fatality rates between Rockton and Willow Lake Dam were estimated in the middle of the suggested range, whereas for areas downstream of Willow Lake Dam daytime fatality rates were estimated between the middle and lower limit of the suggested range. Nighttime fatality rates were similar, but slightly higher, for these reaches. Figure 4.5 below shows the selected fatality rates relative to the suggested range for the Willow Lake Dam to Ruby Blvd reach for day and night failure scenarios.

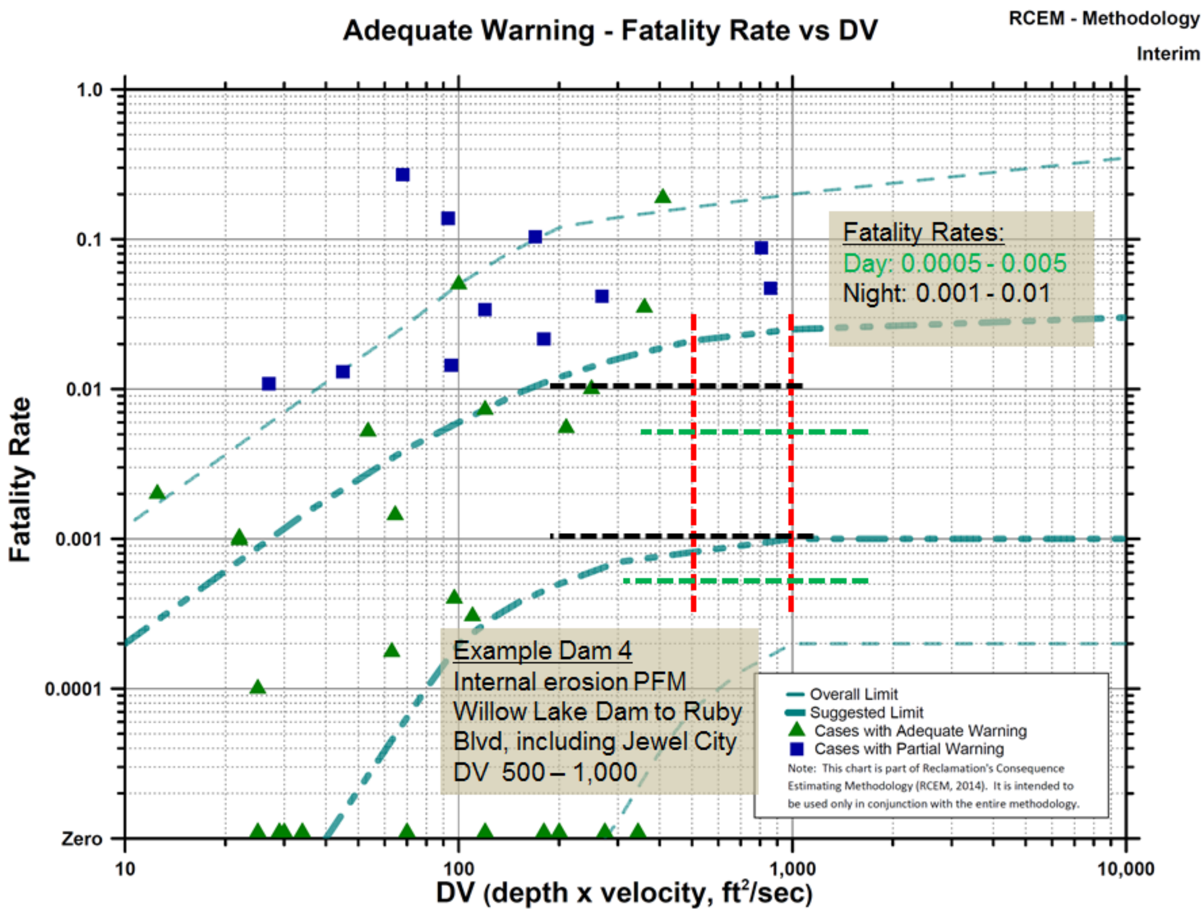


Figure 4.5 – Example Dam 4- Selected fatality rates for Willow Lake to Ruby Blvd reach for day and night, static internal erosion PFM.

One important aspect that was factored into selecting fatality rates toward the lower end of the suggested ranges is the flood severity understanding, which is a qualitative judgment of how clearly the PAR will comprehend the warning and threat of flooding. For reaches below Willow Lake Dam, it was judged that the PAR would have a very good understanding of the potential danger, while those further upstream may have a vague understanding, particularly at night. This is particularly important for the PAR in Jewel City, which has strong emergency management procedures as a result of the 1974 flood event. The life loss estimate was weighted assuming

65% of the daytime value and 35% of the nighttime value to reflect the possibility of people being awake even if it is night, particularly in the winter. Table 4.5 summarizes the estimated loss of life for the static internal erosion PFM.

For hydrologic loading conditions, given the expected long warning time (6+ hours) of potential dam failure, the life loss was estimated to be small. The breach outflow and DV values were assumed to be the same as for the static failure condition, although it is recognized the flows would be higher. A higher PAR was included for hydrologic conditions, although it could be argued that spillway releases would result in evacuation of some of the PAR. However, for the purpose of this evaluation, the significant warning time and associated low fatality rates are judged to adequately account for any evacuation resulting from spillway releases. Table 4.6 summarizes the estimated loss of life for the hydrologic internal erosion PFM.

Table 4.5 – Estimated Loss of Life for Static Internal Erosion Potential Failure Mode

Reach/ Location (miles)	PAR	DV Range	Warning Category and Estimated Time (hours)	Estimated Fatality Rate		Weighted Loss of Life (D: 65% N: 35%)		
				Low	High	Low	Mean	High
Dam to Rockton (0-4)	120	1000-2000	D: Little/No Warning (1-1.5) N: Little/No Warning (0-1)	D: 0.2 N: 0.4	D: 0.5 N: 0.6	32	48	64
Rockton to Willow Lake Dam (4-30)	620	1100-2300	D: Adequate (3-4) N: Adequate (2-3)	D: 0.002 N: 0.003	D: 0.02 N: 0.03	1	8	15
Willow Lake Dam to Ruby Blvd. in downtown Jewel City (30-35)	1050	500-1000	D: Adequate (4+) N: Adequate (3+)	D: 0.0005 N: 0.001	D: 0.005 N: 0.01	1	4	7
Ruby Blvd. to Opal St. (35-38)	1150	300-600	D: Adequate (4+) N: Adequate (3+)	D: 0.0003 N: 0.0006	D: 0.003 N: 0.006	0	3	5
Opal St. to about 5 miles downstream (38-45)	1200	170-340	D: Adequate (5+) N: Adequate (4+)	D: 0.0001 N: 0.0004	D: 0.002 N: 0.004	0	2	3
					Totals:	34	65	94

Table 4.6 – Estimated Loss of Life for Hydrologic Internal Erosion Potential Failure Mode

Reach/ Location (miles)	PAR	DV Range	Warning Category and Estimated Time (hours)	Estimated Fatality Rate		Weighted Loss of Life (D: 65% N: 35%)		
				Low	High	Low	Mean	High
Dam to Rockton (0-4)	120	1000-2000	D: Adequate (6+) N: Adequate (6+)	D: 0.001 N: 0.002	D: 0.005 N: 0.01	0+	0.5	1
Rockton to Willow Lake Dam (4-30)	620	1100-2300	D: Adequate N: Adequate	D: 0.001 N: 0.002	D: 0.005 N: 0.01	1	3	5
Willow Lake Dam to Ruby Blvd. in downtown Jewel City (30-35)	1050	500-1000	D: Adequate N: Adequate	D: 0.0005 N: 0.001	D: 0.002 N: 0.005	1	2.5	4
Ruby Blvd. to Opal St. (35-38)	1150	300-600	D: Adequate N: Adequate	D: 0.0002 N: 0.0004	D: 0.002 N: 0.004	0.5	2	4
Opal St. to about 5 miles downstream (38-45)	1200	170-340	D: Adequate N: Adequate	D: 0.0001 N: 0.0002	D: 0.001 N: 0.002	0+	1	2
					Totals:	3	9	16

F. Summary and the Consequences Case

A 1982 inundation analysis indicates failure of Example Dam 4 under hydrologic loading conditions would result in a breach outflow of 1,750,000 ft^3/s. The flow velocity values were adjusted to be more consistent with observations from dam failure case histories. The PAR is estimated to be about 4140 with a normal reservoir and 5160 under flood loading. Although there are no major cities in the first 25 miles (i.e. upstream of Jewel City), there are many residential areas along the river. It is estimated that most fatalities would occur in the first reach downstream of the dam due to the PAR having little or no warning and difficulties associated with warning and evacuation.

Flood Severity and the DV Estimate

Past consequences evaluations assigned a "medium" flood severity to the inundated areas downstream of the dam. However, estimated DV values are greater than 160 ft^2/s (typically considered the upper limit of medium severity flooding) for most of the inundation area. The calculated DV estimates are reasonable but not well-founded on any updated hydrologic analysis. The estimated DV ranges from about 500 to 2300 ft^2/s through most of the canyon upstream of Jewel City. In Jewel City, the flood plain widens slightly and the flood flows attenuate somewhat, although estimated DV values still exceed 300 ft^2/s, indicating significant damage or destruction of most buildings. There is low to medium confidence in the range of estimated DV values. An updated inundation study might reveal higher estimated DV values in areas close to the river channel, and much lower DV values in the fringes of the flooding in Jewel City, possibly resulting in lower fatality rates in some areas.

There are no case histories with adequate warning and flood severity parameters (i.e. DV greater than about 400 ft^2/s) comparable to what would be expected in the event of failure of Example Dam 4. Modern communications and emergency management procedures would result in lower fatality rates than those associated with the South Fork Dam failure in 1889. Some modern cases such as Big Bay Dam (, Baldwin Hills, and Teton Dam Sugar City with zero fatalities provide support for selecting lower fatality rates.

Warning Time and Warning Category

The warning time for most of the PAR downstream of this dam was judged to be adequate. A significant amount of credit for the adequate warning category is attributed to the advanced flood warning system that is in place as a result of the 1974 flood event. Without this warning system, and without the PAR's knowledge and experience from the 1974 flooding, there could be justification to assign some percentage of some or all of the reaches in the little/no warning category, which would result in much higher fatality rates.

In general, the results of this consequence evaluation indicate that the life loss estimate is sensitive to the available warning, and the selected warning category. The adequate warning category is judged to be appropriate for most of the reaches downstream of Rockton, however between the dam and Rockton, the PAR is expected to receive little or no warning, resulting in this reach (with the lowest PAR) having the highest estimated fatalities. This reach includes remote, dispersed residences and it is difficult to envision emergency management and law enforcement agencies being very effective with notification and evacuation in this reach. In addition, because the primary evacuation route from this area involves travel on the road in the valley, those choosing to evacuate by car could be caught by floodwaters in their vehicles. It seems reasonable to assume that because of the estimated difficulties associated with warning to evacuation in this reach, the estimated fatality rates would likely be high, particularly at night. Additional modern inundation studies could result in better estimates of DV and flood wave travel times (and therefore warning times); however, the factors described above that influenced the judgment of little or no warning for the PAR in the first reach are not likely to change with new inundation studies.

Summary of Results

Using RCEM 2014, the estimated life loss range for the static internal erosion PFM varies from 34 to 94, with a mean estimate value of 65. Most of the life loss is in the first reach between the dam and Rockton, where the PAR would have little to no warning time to evacuate. Downstream of Rockton, the warning time is longer and fatality rates are correspondingly lower.

A hydrologic internal erosion PFM would only occur after a long duration of precipitation in the basin. Because of the anticipated close observation of the dam under hydrologic conditions, all PAR would have at least 6 hours of warning. This long warning time results in lower life loss estimates in the range from 3 to 16, with a mean value of 9.