



**Dam Safety Program
Technical Note 2
Estimating Loss of Life for
Determining the Minimum Inflow Design Flood Recurrence Interval**

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1.0 OVERVIEW

Technical Note 2 (TN2) provides guidance to engineers and dam safety professionals in understanding the basis for estimating loss of life (LOL) to determine the minimum inflow design flood (IDF) recurrence interval for high hazard dams that are regulated by the [Montana Dam Safety Program \(DSP\)](#). The purpose for TN2 is to provide a reference describing how loss of life studies are to be performed in Montana

TN2 is organized to lead the user through the basis for estimating LOL and defining the minimum acceptable LOL (and hence the IDF) for high hazard dams in Montana. TN2 provides an overview of Montana's Dam Safety rules for determining the minimum IDF, followed by the concepts of Population at Risk (PAR) and LOL. The user is then pointed to the Bureau of Reclamation's *Consequence Estimating Methodology (RCEM)*, which is the current state-of-the-practice industry guidance document for performing LOL analyses.

TN2 is intended for use by engineers and professionals experienced in dam safety issues and hydrologic analyses, and who are familiar with the design, analysis, and rehabilitation of dams. Professional judgment is required when performing loss of life analyses, regardless of the guidance provided in TN2 or other references.



2.0 PURPOSE

The purpose of TN2 is to provide guidance to engineers and dam safety professionals when conducting a loss of life study to determine the minimum acceptable IDF for high hazard dams in Montana that are regulated by the MT DSP. TN2 is not a regulatory document; depending on the specific dam and downstream setting being evaluated the dam safety professional may propose to use an alternate method for estimating LOL. The case for an alternate method must be reviewed and accepted by the MT DSP. DNRC and the Dam Safety Program are not responsible for the use and interpretation of TN2 contents.

3.0 OVERVIEW OF RISK BASED DESIGN STANDARDS

It is important for users of this Technical Note to have a basic understanding of past and current dam safety statutes and rules to appreciate the intent of the current spillway standards. This section presents a brief overview of the standards and their history up to the current risk-based standards. A more detailed discussion of Montana Dam Safety standards is found in [Technical Note 1, Determination of the Inflow Design Flood for High Hazard Dams in Montana](#).

In Montana, the dam safety rules for high hazard dams are part of the [Administrative Rules of Montana \(ARM\) and the Montana Code Annotated \(MCA\)](#). Among other important concepts, these rules and regulations require the IDF for a high hazard dam to be determined based on the estimated loss of life that would result from a failure of the dam. Hence, understanding the basis for hazard classification is essential for a dam owner and dam safety professionals in Montana. [Technical Note 6](#) provides information and guidance on completing Hazard determinations.

3.1 History

Development of the current dam safety rules began as an organized effort to identify potentially hazardous dams and to implement appropriate design, maintenance, and operation procedures to protect downstream citizens. In the United States, the first federally funded effort to address the safety of dams was initiated in 1972 by the National Dam Inspection Act, Public Law 92-367, which authorized the Secretary of the Army, through the Corps of Engineers, to conduct safety inspections of non-federal dams throughout the United States. The Corps of Engineers spearheaded efforts to conduct a two-phased study for investigating and evaluating dams. Phase I inspections were conducted in the late 1970s and early 1980s, and their results were



presented to state agencies responsible for dams and reservoirs. States were responsible for implementing the Phase I recommendations, the more detailed Phase II investigations, and evaluations of dams to better identify specific safety concerns. In response to the Phase I reports for Montana dams, the Montana Legislature passed the Montana Dam Safety Act in 1985, which is currently part of the [Montana Code Annotated \(MCA\), Title 85 \(Water Use\), Chapter 15 \(Dam Safety Act\)](#). In 1988, DNRC developed the Dam Safety Rules in the Administrative Rules of Montana (ARM) Chapter 36.14.

The original Dam Safety Rules established standards for high hazard dams based on reservoir volume and dam height. The minimum inflow design flood for an existing dam impounding less than 100 acre-feet and less than 20 feet in height was the 100-year flood. The inflow design flood increased in magnitude for larger impoundments by fractions of the Probable Maximum Flood (PMF) to a maximum of the full PMF for dams impounding 50,000 acre-feet or greater and with heights of 100 feet or higher. It became evident that in many cases the required spillway size was disproportionate to the level of downstream development (i.e., consequences). This was particularly true for large dams located in rural areas (i.e., lower consequences) and for smaller dams that have dense downstream development (i.e., higher consequences).

In response, DNRC in 1999 developed new hydrologic standards that provide a uniform level of downstream protection by relating the IDF to the consequences of a dam failure (estimated LOL), rather than to the size of the dam. The magnitude, or relative size, of the IDF is determined by LOL, which in turn dictates the spillway capacity needed to safely pass the IDF.

Current standards require that an IDF for LOL of 0.5 or less must have a minimum recurrence interval of 500-years. For LOL greater than 0.5 and less than or equal to 5, the minimum recurrence interval used for determining the IDF is calculated by multiplying the LOL by 1,000. For LOL greater than 5 and less than 1,000, the minimum IDF is based upon the amount of runoff that is predicted to occur from an amount of precipitation calculated using equations that interpolate rainfall depths between the 5,000-year event and the probable maximum precipitation (PMP). The full PMP is used to determine the IDF, called the probable maximum flood (PMF), when the LOL is greater than or equal to 1,000.



3.2 Steps In Determining the Minimum Acceptabl Inflow Design Flood

Determining the minimum acceptable IDF for high hazard dams involves three primary steps: determining the dam breach hydrograph, flood routing characteristics, and inundation boundary; estimating LOL; and developing the IDF hydrologic model. The following is a brief summary of these three primary steps:

Step 1. Determine the Dam Breach Hydrograph, Flood Routing Characteristics, and Inundation Boundary. Refer to [Technical Note 6 – Downstream Hazard Classification Procedures for Montana Dams](#) for a description of the concepts and acceptable procedures for developing the breach flood hydrograph and routing it downstream. The results of this step will be used to estimate the loss of life. **Note an important exception:** Loss of Life determination must be based on an inundation boundary from a failure of the dam with the starting water surface at the top of the dam, commonly referred to as a top of dam breach. Hazard classifications are based on an inundation boundary from a clear weather breach.

Step 2. Estimate Loss of Life. Step 2 is the subject of this technical note (TN2).

Step 3. Develop the Hydrologic Model. This is the final step in developing the IDF. A full discussion of this step is found in [Technical Note 1 – Determination of the Inflow Design Flood for High Hazard Dams in Montana](#). For an LOL less than or equal to 5, the IDF is calculated as a return interval, or exceedance probability of occurrence. The IDF return interval is equal to $LOL \times 1,000$. For example, an LOL of 2.5 (LOL is a statistical concept and, hence, is not necessarily an integer) requires the dam to safely pass the 2,500-year flood. For an LOL greater than 5 and less than 1,000, IDF is between the 5,000-year flood and the probable maximum flood (PMF). For LOL greater than 1,000, the IDF is the PMF.

4.0 LOSS OF LIFE AND THE POPULATION AT RISK CONCEPT

Dams exist all across Montana, and the areas downstream from these dams varies widely in topography, land cover, development, and population density. The LOL that could result from failure (breach) of a dam is dependent on many factors, but is primarily a function of the population at risk (PAR) that is (or may be) in the breach flood inundation area. LOL is then estimated (calculated) by applying an estimated fatality rate to the PAR. Fatality rates are estimated by accounting for factors that influence the susceptibility of the PAR, such as the



travel time of the breach flood wave, public warning of the impending flood, the depth and velocity of flooding, and many other factors.

LOL is rarely equal to, and normally substantially lower than, the PAR. This is due to two general facts: (1) populations are somewhat mobile and people rarely inhabit all available structures that are located in the breach flood area; and (2) there is usually some form of warning that a breach flood is coming so that people can move out of harm's way. Historic catastrophic dam failures were mostly due to a lack of warning time or the failure happening late at night or early in the morning.

5.0 POPULATION AT RISK

Since the Montana Dam Safety rules for determining the IDF are based on the estimated LOL that could result from a dam breach, it is important to develop as accurate a population estimate as possible for the anticipated dam breach inundation area.

5.1 Aerial Extent of the PAR

When developing the PAR for an LOL analysis, the area that contributes to the PAR is the area from the dam to the location at which there will be three hours of warning time in advance of the dam breach flood wave arrival. If the dam has an on-site dam tender, the warning time is measured from the time the breach begins. If the dam is unattended, warning time begins at the first downstream residence.

5.2 Determining the PAR

The PAR is the theoretical number of people that could be in the dam breach inundation area. The most practical and efficient way to estimate PAR is to apply GIS (geographic information systems) overlays for aerial imagery, roads, and [census blocks](#) to the anticipated dam breach inundation boundary (census data, including shapefiles, are available through the United States Census Bureau). Refer to *Technical Note 6 – Downstream Hazard Classification Procedures for Montana Dams* for guidance on developing a dam breach model and routing the dam breach hydrograph downstream to determine the dam breach flood inundation boundary.

Note that Loss of Life determination for PAR determination must be based on an inundation boundary from a failure of the dam with the starting reservoir water surface at the top of the dam, commonly referred to as a top of dam breach. Hazards classifications discussed in



Technical Note 6 are based on an inundation boundary from a clear weather breach, with a starting water surface elevation at normal pool, which generally is **NOT** conservative. The purpose of using a top of dam breach is to account for a flood induced failure, the effects of debris, and other uncertainties that have the potential to increase the inundation area and put additional people at risk.

By superimposing GIS data on the inundation area mapping and performing a careful review of inundation area, the dam safety professional can derive a reasonably accurate estimate for the PAR. Also, while it is typically impractical to conduct project specific census surveys, the dam safety professional should perform a physical reconnaissance to ground truth the PAR map.

5.3 DSP Required PAR Estimates by Feature Type

The Montana Dam Safety Program considers any structure with the potential for human occupancy within the breach flood area to have a “population” at risk of fatality. Table 5.1 provides pre-defined population at risk estimates for a variety of features.

Table 5.1: Population at Risk Estimates by Feature Type

Feature Type	Estimated PAR
Residence	3
Farm shop building	2
Commercial building	10
Hospital	100
School	100
Municipal park	10
Campground	30
Golf course	30
Airport	30
Paved road	2
Railroad	2

While populations are known to fluctuate by time of day, day of the week, and season of the year, dam failures can happen at any time. Inundation of the features listed in Table 5.1 will incrementally contribute to the cumulative PAR by the values identified in the table. The



cumulative PAR is the sum of the incremental PAR from the entire area anticipated to be inundated by the dam failure breach flood wave.

Note that there may be situations where a detailed population study is warranted. A case can be made where a hospital or school has lower population at risk than identified in Table 5.1. This approach has been taken when evaluating an existing dam for hydrologic standard compliance.

5.4 Consideration for Population Growth

Development and home sites near streams are highly sought-after locations. Regardless of how remote a dam may be, it is common for development to occur below the dam. Often, developers and/or residents are unaware of the potential risk they're exposing themselves to. Montana Dam Safety statutes place responsibility on the dam owner to provide an adequate level of protection (i.e., flood capacity) to the downstream PAR.

As development within the breach flood inundation boundary occurs, the PAR increases and, hence, the estimate for LOL increases commensurately; the tendency for LOL to increase over time is sometimes referred to as "hazard creep." Because of hazard creep, when designing a new dam, rehabilitating an existing dam, or evaluating an existing dam for compliance with Montana's dam safety rules, it is essential that dam owners and dam safety professionals account for the potential for future development below the dam. It is usually prudent account for future population growth by selecting a larger IDF than the minimum required for the current population. It is for this reason that the MT DNRC guidelines describe determination of the "**minimum**" IDF – in most cases the design basis IDF should be larger (i.e., less frequent) than the minimum IDF.

Statutorily, to remain in compliance with the operating permit for a high hazard dam, and receive the associated statutory protection, the dam must pass the LOL based IDF (as well as satisfy the other permit requirements). From a dam owner's perspective, the incremental construction cost to accommodate a larger IDF during rehabilitation or construction of a new spillway is much less than the cost of a future construction project to increase the spillway capacity in response to downstream development.



6.0 ESTIMATING LOSS OF LIFE

Over the years, a number of methods for estimating LOL have been developed that correlate observed fatalities to estimates of the PAR and other considerations, such as warning time and flood depth and velocity. The current standard-of-practice in the dam safety industry is the Bureau of Reclamation's [Consequence Estimating Methodology](#), or RCEM. Older methods for estimating LOL are no longer generally accepted by the MT DSP; exceptions for using other methods for estimating LOL may be approved by the DSP if they are shown to produce better estimates for LOL.

The RCEM for estimating LOL supersedes DSO-99-06, which was commonly referred to as "the Graham Method." Similar to DSO-99-06, RCEM is used to estimate fatality rates that are applied to the PAR. However, while DSO-99-06 is a tabular approach, RCEM is a graphical approach that more fully incorporates data from the dam failure case history. RCEM is a comprehensive document that includes background on the development and application of the process, including examples demonstrating how the process has been applied to several real-world situations. Users of this Technical Note are directed to RCEM for additional description in the application of the methodology and example LOL calculations.

6.1 Situations Where LOL is Mandated

Loss of life is assumed likely to occur, and the dam is classified as a High Hazard dam and subject to DSP regulation, when specific features (or "hazards", [ARM 36.14.206\(2\)\(a\)](#)) are identified to be within the inundation boundary resulting from a "sunny day" dam breach. If any of the hazards listed below are determined to be within the "sunny day" dam breach flood boundary, then the dam is classified as high hazard with a **minimum** IDF equal to the 500-year flood - even if the estimated LOL is less than 0.5.

- occupied houses and farm buildings;
- stores;
- gas stations;
- parks;
- golf courses;
- stadiums;
- ball parks;



- developed campgrounds (note that dispersed camping in primitive campsites are excluded from this hazard category);
 - railroads; and
 - interstate, principal, and other paved highways, highway rest areas and RV areas.
- Excluded from this hazard category are unpaved county roads and all private roads.

7.0 UNCERTAINTY

The DSP provides the guidance in this technical note only as an aid to help estimate loss of life for determining the minimum acceptable IDF. It is fully understood that there is uncertainty in every step of the process, and that judgment is necessary in performing these types of analyses. Conservatism (i.e., factors that result in greater PAR and fatality rates) should be incorporated into LOL analyses to account for the uncertainty of the estimates. It is important that users understand that loss of life estimates are just that – estimates.

As shown in [Figures 1 and 2 of RCEM](#), fatality rates range by two or more orders of magnitude for a given DV (depth times velocity) – regardless of the adequacy and timing of the warning. Selection of an appropriate fatality rate within the suggested (or overall) limits contributes greatly to the overall uncertainty and conservatism in LOL estimates.

Professional engineering judgment cannot be understated in this process. The Montana Dam Safety Program encourages all users of this technical note to gather as much data as possible and to communicate with as many officials in the study area as possible to arrive at estimates that best fit the dam and downstream setting.

8.0 FINAL WORD OF CAUTION

Legal counsel has concluded that strict liability for dam failure is not the law in Montana. Dams are lawful business, so unless a dam owner is negligent, the owner is unlikely to be held liable. However, based on Montana case law, the flip side is that if a dam fails and someone is damaged, a court is likely to find negligence. Thus, it is of critical importance that dam owners and their engineers closely follow Montana Dam Safety Program guidance with awareness that the guidance lays out *minimums*.....and it may be prudent, as described above, to exceed the minimums.



9.0 DISCLAIMER

This is the second Technical Note developed by the Montana Dam Safety Program. We welcome and encourage your feedback on its contents. Please send your comments to:

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DNRC would like to acknowledge Hydrometrics, Inc. and DOWL for the development and update of Technical Note 2, respectively. TN2 will continue to be revised and updated as new technical references are made available and the state-of-the-practice advances.



10.0 DEFINITIONS

The following list of terms and definitions are common when discussing dam safety and loss of life concepts, and including them in this section may provide clarification for users of Technical Note 2 that are new to the dam safety industry:

Breach – Failure of a dam caused by an opening through the dam.

Emergency Personnel – Officials involved in the notification, evacuation and assisting of the public in the event of an emergency.

Evacuation Mapping – Maps for an emergency action plan that show the anticipated inundation zone of a dam failure and identify evacuation routes, affected infrastructure, dam breach travel time, evacuation areas outside of the inundation area, other data helpful in the event of a dam failure.

Flood Wave Travel Time – The time for a flood wave to travel between two specified points. For breach flood routing referred to in this technical note, flood wave travel time is the time from the start of the breach at the dam to the time that the beginning of the breach flood wave arrives at a specified point.

High Hazard Dam – In Montana, a dam that impounds 50 acre-feet or more in reservoir volume and whose failure would likely cause a loss of life. High hazard dams are under the authority of the Montana Dam Safety Program, a part of the Montana Department of Natural Resources and Conservation.

Hydrograph - A graphical representation of stage, flow, velocity, or other characteristics of water at a given point as a function of time.

Inundation map - Maps that show the anticipated inundation zone of a dam failure, dam breach travel time, velocity and depth.

Loss of Life – Actual or predicted number of human lives expected to lost in the event of a dam failure. Predicted loss of life (LOL) is based on empirical methodologies derived from historical dam failure data. Typically, LOL is a much lower number than the population at risk (PAR) within a dam breach flood area.

normal operating pool:

- (a) means the elevation of lowest uncontrolled principal spillway for on-stream reservoirs;
- (b) means the elevation of the emergency spillway for flood control structures; and
- (c) is defined on a case-by-case basis according to reservoir operation for off-stream reservoirs

Population at Risk – Actual or predicted number of human lives at risk of injury or death in the event of a dam failure. Population at risk (PAR) is determined by the number of humans within a dam breach flood area. Predicted PAR is based on estimated numbers of humans



inhabiting the dam breach flood area at any time of day or season, and is dependent on the infrastructure or features within the flooded area.

Simplified Evacuation Mapping – Evacuation mapping that is made simpler than complex mapping by defining only on inundation boundary, limiting information on the maps, and modeling the dam failure and flood routing with quasi-unsteady flow models.

Spillway – A hydraulic structure associated with a dam that discharges flow. A spillway can be categorized as principal (discharges normal flows from reservoir); auxiliary (discharges flow in excess of the principal spillway capacity); or emergency (discharges flows in excess of the principal and/or auxiliary spillway capacities). Spillways are designed to either regulate flow from the reservoir or provide overtopping protection during extreme flood conditions.

Warning Time – the time period from when communication warning of a dam failure or impending dam failure reaches a specific population at risk (PAR) to when the breach flood arrives at the location of the specific PAR. In other words, it is the amount of time for people to evacuate a breach flood zone after they receive notification of a dam failure and before the flood failure wave arrives.



11.0 REFERENCES

1. Montana Department of Natural Resources and Conservation Dam Safety Program
(<http://dnrc.mt.gov/divisions/water/operations/dam-safety>)
2. Montana Dam Safety Program Technical Notes
(<http://dnrc.mt.gov/divisions/water/operations/dam-safety/technical-references-and-links/technical-notes>)
3. Administrative Rules of Montana (ARM) and the Montana Code Annotated (MCA)
(<http://dnrc.mt.gov/divisions/water/operations/dam-safety/rules-and-regulations>)
4. United States Census Bureau – Maps and Data
(<https://www.census.gov/geo/maps-data/>)