DAM SAFETY PROGRAM

TECHNICAL NOTE 2

LOSS OF LIFE DETERMINATION FOR SPILLWAY CAPACITY ANALYSIS

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DAM SAFETY PROGRAM
TECHNICAL NOTE 2 (TN2)
LOSS OF LIFE DETERMINATION FOR SPILLWAY CAPACITY ANALYSIS

Overview

Technical Note 2 (TN2) is provided to assist and guide engineers and professionals in conducting a loss of life determination for determining the capacity requirements of spillways for Montana high hazard dams. The Dam Safety Program intends TN2 to provide a consistent means of conducting loss of life analyses, but recognizes that professionals may use other technical resources, accompanied with relevant reasons for their use, that are not mentioned in TN2. TN2 is primarily for earthen dams because they constitute the majority of high hazard dams in Montana and because procedures herein are based on historical data from earthen dam failures.

TN2 is organized to lead the user through logical steps of conducting a loss of life determination. TN2 first provides a clear overview of spillway hydrologic standards according to Montana Dam Safety rules. Then TN2 discusses the concept of loss of life risk based on population within a dam failure flood zone. The user is then led through a thorough explanation of loss of life prediction methodologies, including detailed procedural steps for the Bureau of Reclamation's Graham Method, which is the preferred method of the Montana Dam Safety Program.

TN2 is for use by engineers and professionals experienced in dam safety issues, hydrologic analyses and familiar with design and rehabilitation of spillways and dams. Professional judgment is sometimes expected and required in loss of life estimates, regardless of guidance provided by TN2.

DAM SAFETY PROGRAM
TECHNICAL NOTE 2 (TN2)
LOSS OF LIFE DETERMINATION FOR SPILLWAY CAPACITY ANALYSIS

1.0 INTRODUCTION

The **Montana Dam Safety Program** is pleased to provide this **Technical Note 2 (TN2), Loss of Life Determination for Spillway Capacity Analysis**. We hope this publication is helpful in providing technical guidance to professionals engaged in the analysis and design of spillways for high hazard dams in Montana. Our intent is to make available relevant and up-to-date information, references and procedures relevant to the dam safety rules for Montana for determining spillway capacity requirements based on estimated loss of life downstream of a high hazard dam.

This is the second Technical Note developed by the Montana Dam Safety Program and, as such, we are interested in making it the best we possibly can. 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. of Helena, Montana for the development and preparation of Technical Note 2.

TN2 will be revised and updated as new technical references are made available.

1.1 PURPOSE

The purpose of TN2 is to assist and provide guidance to engineers and professionals for conducting a loss of life determination in determining the capacity requirements of spillways for Montana high hazard dams. TN2 is not a regulatory document and the references and procedures provided can be modified to suit the needs of the user. TN2 references technical resources that are recognized as applicable to Montana dams and recommended by the Dam Safety Program in determining the capacity requirements of spillways. The Dam Safety Program intends for TN2 to provide a consistent means of conducting loss of life analyses, but recognizes that professionals may use other technical resources, accompanied with relevant reasons for their use, that are not mentioned in TN2. TN2 is primarily for earthen dams because they constitute the majority of high hazard dams in Montana and because procedures herein are based on historical data from earthen dam failures.

1.2 FOCUS AND LIMITATIONS

TN2 is intended as a procedural aid for estimating loss of life for determining spillway capacity for high hazard dams regulated by the Montana Dam Safety Program. Dams regulated by the Montana Dam Safety Program are the only ones in Montana whose spillway capacity is based on risk of failure and the potential consequences of a breach flood. Guidelines for spillway capacity determinations on other Montana dams are dictated by the appropriate regulating agency or by accepted design standards.

TN2 does not address spillway analysis procedures (which is covered in *Technical Note 1, Analysis of Spillway Capacity in Montana*). It does not provide guidance on spillway design, armoring, erosion control, energy dissipation, or maintenance and operation procedures.

1.3 TARGET AUDIENCE

TN2 is for use by engineers and professionals experienced in dam safety issues, hydrologic analyses and familiar with design and rehabilitation of spillways and dams. Professional

judgment is sometimes expected and required in loss of life estimates, regardless of guidance provided by TN2. Users of TN2 are expected to be familiar with common hydrologic and hydraulic computer programs and their appropriate use. DNRC and the Dam Safety Program are not responsible for the use and interpretation of TN2 contents.

2.0 OVERVIEW OF RISK BASED SPILLWAY 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 is 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 are found in *Technical Note 1, Analysis of Spillway Capacity in Montana*. Montana Dam Safety Administrative Rules govern the design, operation and maintenance of high hazard dams (dam safety rules are part of the Administrative Rules of Montana (ARM) and can be viewed at *http://dnrc.mt.gov/wrd/water_op/dam_safety/*). As described in this section, standards for Montana dams came about through a growing awareness of the potential danger of dams and the need for regular maintenance and operation procedures. This awareness started at the federal level and has become the responsibility of state agencies. The Dam Safety Program currently maintains spillway hydrologic standards based on the estimated loss of life downstream of a dam.

2.1 HISTORY

The development of current spillway hydrologic standards 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 1 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 Phase I recommendations as well as implementing more detailed Phase II investigations and evaluations of dams to better identify specific safety concerns. In response to the Phase 1 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 spillway hydrologic 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. This was particularly true for large dams located in rural areas or for smaller dams that had dense downstream development.

In response, DNRC in 1999 developed new hydrologic standards that provide a uniform level of downstream protection by relating the required spillway size to the consequences of a dam failure, or estimated loss of life (LOL), rather than to the size of the dam. The minimum inflow design flood, or IDF, is the storm runoff that enters a reservoir impounded by a dam and is routed through the spillway. The magnitude, or relative size, of the IDF is determined by LOL, which in turn dictates the spillway capacity 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 calculating the IDF is determined 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. Steps for calculating IDF magnitudes are given in the following sections.

2.2 STEPS IN DETERMINING REQUIRED INFLOW DESIGN FLOOD

Central to the evaluation of spillways is the determination of LOL and its impact on the determination of IDF and spillway size. The following is a very brief summary of the two major steps involved in determining the required IDF:

Step 1. Estimated Loss of Life Determination. This is the subject of this technical note (TN2). While determining LOL is one of the most subjective and misunderstood components of dam safety, it is the deciding factor in determining the size of the IDF for spillway design in Montana. Discussion of this step begins in Section 3.0.

Step 2. Inflow Design Flood Determination. A full discussion of this step is found in Technical Note 1. For an LOL less than or equal to 5, the spillway IDF magnitude is calculated as a return interval, or exceedance probability of occurrence. The IDF return interval is equal to LOL x 1000, i.e., an LOL of 2.5 (an LOL does not have to be an integer) requires the spillway to pass the 2500-year IDF. An LOL greater than 5 and less than 1,000 requires the IDF magnitude to be calculated by equations defined in the Montana Dam Safety Rules that determines a resulting runoff flood based on interpolated basin precipitation depths between the 5,000-year recurrence interval and the probable maximum precipitation, or PMP. PMP is defined as being the largest theoretical precipitation amount possible for a region given the optimum meteorological conditions. The IDF for an LOL equal to or greater than 1,000 is the probable maximum flood, or PMF. The PMF is runoff produced by the PMP.

3.0 LOSS OF LIFE AND POPULATION AT RISK CONCEPT

In Montana, the areas situated below, or downstream, of dams vary widely in topography and population density. The impact of a flood resulting from failure of a dam is dependent on many factors, not the least of which is the population at risk (PAR) in the zone of flooding from a breach. Since the Montana Dam Safety spillway standards are dependent on an estimated LOL resulting from breach of a dam, it is first important that reasonably accurate population estimates be determined in the dam's breach flood area. Updated mapping along with physical reconnaissance of the breach area are usually necessary to obtain an estimate of PAR of being affected by the breach flood. Then, it is important to estimate LOL based on acceptable methods that take into account various factors that influence the susceptibility of the population downstream. Factors include the PAR, travel time of the breach flood, communication of emergency personnel, topography of the valley through which the breach flood travels, and other factors that will be discussed later in this technical note.

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 harms way. Historic catastrophic dam failures were mostly due to lack of warning time or failure happening late at night or early in the morning. Other contributing factors could be short flood travel times from the dam to a population center, narrow and steep valleys, remote locations, or possibly ignorance on the part of the people that a dam exists upstream of their habitation.

Methods for determining LOL based on PAR have been developed based on empirical data from past dam failures. Two of the more common methodologies are discussed in Section 4.0 of this technical note.

4.0 LOSS OF LIFE CALCULATION METHODOLOGIES

The Montana Dam Safety Program has used two published methodologies to estimate LOL from failure of dams. The first methodology was developed by DeKay and McClelland (1993). This method, which was used by the Montana Dam Safety Program throughout the 1990s, is based on the premise that "LOL decreases exponentially with warning time and increases nonlinearly with PAR" (ibid). The second methodology was published by Graham of the U.S. Bureau of Reclamation (1999). In this method, LOL is "highly influenced by three factors: (1) the number of people occupying the dam failure flood plain; (2) the amount of warning that is provided to the people exposed to dangerous flooding; and (3) the severity of the flooding" (ibid). The Bureau of Reclamation method, commonly referred to by the Montana Dam Safety Program as the "Graham Method," is now widely used as the preferred method for estimating LOL. The following sections provide details on both methods.

4.1 DEKAY AND MCCLELLAND METHOD

Michael DeKay and Gary McClelland in 1992 developed equations to predict loss of life from dam failure flooding using data that had originally been compiled by the U.S. Bureau of Reclamation. Their final equations to predict loss of life are dependent on population at risk (PAR), warning time, and whether the floodwaters are "high force" or "low force." High force relates to flooding that is deep with high velocity, such as through a narrow steep canyon. Low force describes flooding that is shallow with low velocity, such as over a relatively flat plain. The factors describing the force of the floodwater are dichotomous (zero for low force and one for high force) without a scale of severity, so it is effectively up to the user to determine if a condition is low or high force. Loss of life predictions are based on two equations, one for low force and one for high force, with PAR and warning time as variables.

4.2 US BUREAU OF RECLAMATION GRAHAM METHOD

The Graham Method estimates loss of life based on data taken from every documented U.S. dam failure that resulted in more than 50 fatalities and every documented dam failure that

occurred after 1960 resulting in at least one fatality. Graham found that loss of life resulting from dam failure is highly influenced by three factors: (1) the number of people occupying the dam failure floodplain; (2) the amount of warning that is provided to the people exposed to dangerous flooding; and (3) the severity of the flooding. The method proposed by Graham is composed of seven steps given below:

1. Determine dam failure scenarios to evaluate.
2. Determine time categories for which loss of life estimates are needed.
3. Determine when dam failure warnings would be initiated.
4. Determine area flooded for each dam failure scenario.
5. Estimate the number of people at risk for each dam failure scenario and time category.
6. Apply empirically based equations or methods for estimating the number of fatalities.
7. Evaluate uncertainty.

For use in determining LOL for Montana Dam Safety Program purposes as shown in this technical note, each of Graham's steps are addressed but not necessarily in the order provided above. Section 5.0 of this technical note provides steps normally taken by engineers to arrive at LOL values used in determining Montana spillway design capacity.

5.0 LOSS OF LIFE DETERMINATION USING THE GRAHAM METHOD

As the preferred method of estimating loss of life, the Graham Method has distinctive procedural steps that have to be followed sequentially to come to a final loss of life estimate. In this section, the procedural steps are presented in detail.

5.1 POPULATION AT RISK (PAR) DETERMINATION

Population at risk (PAR) is the theoretical number of people potentially exposed to risk of death in the event of a dam failure. It is impractical to conduct population counts in the zone of flooding due caused by dam failure. Therefore, the following sections provide suggested methods of making reasonable estimates of PAR.

5.1.1 Flooded Area Determination - Evacuation Maps

Use of maps is the most cost effective and practical method of determining PAR. It is therefore important that maps are up to date and with enough detail to depict potential structures where humans may congregate. Typically, evacuation maps are drawn on 1:24,000 scale, or 7.5-minute quadrangle maps, produced by the U.S. Geological Survey. Most quadrangle maps in the United States are in digital format, which aids in the development of evacuation maps.

Dam failure flood boundaries are delineated on maps to depict the expected extent of flooding. Flood boundary maps are useful to emergency response personnel in determining where people may be affected and the location of important escape routes. Boundaries of the flood depend on the modeled failure mode of the dam. For the purpose of this technical note, only one method of mapping will be discussed: the simplified breach flood map. While other flood boundaries resulting from other types of dam failure simulations (overtopping, piping failure, etc.) may be important in certain applications, the simplified breach flood map is used in the determination of PAR for the Montana Dam Safety Program.

5.1.1.1 Simplified Breach Flood Map

In an effort to adequately protect the public and still allow engineers to make reasonable and cost effective breach maps, the Montana Dam Safety Program encourages the use of simplified breach flood maps. The simplified approach uses only one breach boundary on the map. Any structures within the boundary are considered in determining PAR for the breach flood. For determining spillway capacity requirements, which is dependent of PAR and subsequently loss of life, Montana Dam Safety rules (ARM 36.14.502) dictate that loss of life is estimated by a "spillway failure." The Montana Dam Safety Program interprets this to mean that the spillway fails with the reservoir level at the top of the dam. For this type of breach analysis, spillway flows are not considered (the spillway is not allowed to flow in the breach model). Failure of the dam is modeled using breach parameters calculated by methods approved by Dam Safety and widely used in industry. This step addresses Steps 1 and 4 of the Graham Method (see Section 4.2 of this technical note).

In general, simplified breach flood maps are developed using the following basic concepts, which are covered in *Technical Note 3, Simplified Evacuation Mapping for Emergency Action Planning*:

- Use HEC-HMS computer model (USACOE-HEC, 2009);
- Starting reservoir surface elevation at top of dam;
- No routed flood through reservoir;
- Ignore spillway and outlet flow – usually insignificant in dam breach;
- Dam breach estimation by accepted methods;
- Route breach flood flows a maximum of 3 hours warning time from start of breach;
- Use high Manning's n to estimate and account for debris/mud flow;
- Use Muskingum Cunge routing with 8-point cross sections for natural channels; and
- Ignore backwater effects at bridges unless deemed significant.

5.1.2 PAR Estimates for Inundated Structures

For the Montana Dam Safety Program, any structure with the potential for human occupancy within the breach flood area is considered to have population at risk of fatality. The only

exception would be in areas of shallow water depth and very low flow velocities, as discussed in Section 5.1.3. The Table 5-1 gives population at risk estimates for structures typically expected to be within a breach flood area.

TABLE 5-1. POPULATION AT RISK ESTIMATES FOR STRUCTURES OF HUMAN HABITATION

Structure	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

It is important to note that for the Montana Dam Safety Program, inundation of the structures listed in Table 5-1 will count as contributing to the PAR regardless of the time of day, day of the week or season of the year. While populations may fluctuate in a particular location, dam failures can happen any time. Loss of life is considered possible if any of the structures in Table 5-1 are within the breach flood area. This step addresses Step 2 of the Graham Method (see Section 4.2 of this technical note).

5.1.3 Water Depth and Velocity

Flooding danger to humans is dependent on the depth and velocity of water. While determination of a strict delineation is very subjective and nebulous between what combination of depth and velocity of flowing water is fatal and what is not, the Dam Safety Program has general rules of thumb to aid in loss of life determinations.

A conservative approach would be to include all structures within the breach flood boundary as having the potential for causing loss of life, and thus included in the estimation of PAR. This approach is simple and straightforward, allowing less time to conduct a determination. The disadvantage to this approach is that it may significantly increase PAR and subsequent LOL estimates. However in low-force areas ("force" will be discussed in Section 5.2) additional PAR does not make a significant difference on LOL.

Another approach would be to divide the breach flood area into zones that represent various levels of danger to humans. This approach requires a fairly detailed examination of the breach flood area with attention to estimating variations in depth and velocity across the entire flooded zone. To do this may require sophisticated software. Normal flood routing is accomplished with HEC-HMS, which does not have the capability to determine velocity variations across a modeled cross section. However later versions of HEC-RAS (River Modeling System) (USACOE-HEC, 2010) with unsteady flow capability can separate cross section channel and overflow areas with average flow velocity estimates in each.

Appendix A contains guidelines for identifying hazards with suggestions for evaluating danger zones in flooded areas, as published in ACER Technical Memorandum No. 11 by the U.S. Bureau of Reclamation (USDOI-USBR, 1988). Guidelines are provided to estimate high, judgment and low danger zones related to houses on foundations, mobile homes, passenger vehicles, and pedestrian adults and children. Danger zones are based on combinations of depth and velocity of flood flows.

5.1.4 Location Within Flood Inundation Area

As with water velocity and depth discussed in the previous section, the location of a structure within the flooded area dictates the danger to human occupants. Structures located within the main channel of flow will likely be subject to high flood forces that pose significant danger to humans. Structures on the flooded fringe or in backwater areas upstream of road crossings or other obstructions are typically not subject to dangerous flow velocities if they

are away from main flow channels, but they may be in areas where the depth of water can be significant. All conditions have to be considered and evaluated on a case-by-case basis.

5.1.5 Extent of Determination

In conducting LOL estimations, the extent downstream to which the breach flood is routed can affect the PAR estimates. Until recently, the Montana Dam Safety Program required breach flood routing to be extended downstream to the point at which the breach flood peak discharge was equal to or less than the drainage 100-year flood peak discharge. While this is still the routing extent for the Dam Safety Program in conducting hazard classification determinations, it is no longer the preferred method for PAR determinations. The Dam Safety Program now prefers to extend the routed breach flood downstream to a point on the drainage that is three hours warning time from the dam. 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 first downstream residence. Warning time is discussed in more detail below in Section 5.2. The basis for this method is that it has been shown through research that LOL falls to near zero with three hours warning time (DeKay and McClelland, 1993).

5.1.6 Considerations for Future Population Growth

In developing spillway standards for dams, engineers are wise to consider future population growth. If populations move into the breach flood boundary after spillway modifications have been completed, the dam owner may be faced with the requirement to enlarge the spillway again. Taking into account projected future growth estimates will undoubtedly increase PAR and possibly LOL, unless projections are for population decreases, in which case the current PAR is used in the LOL analysis. Population growth projections should be based on reliable sources and coordinated with the dam owner because they may affect the size of the spillway and cost for construction.

This section addresses PAR determination, which is Step 5 of the Graham Method (see Section 4.2 of this technical note).

5.2 WARNING TIME

In general, warning time as it relates to dam failure is the time period from when communication warning of a dam failure or impending dam failure reaches a specific 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. However, warning time depends on many factors. For instance, warning time may be zero or very short for a PAR in the downstream flood area near an unattended dam in a remote location where knowledge of a dam breach is not known until it reaches or is very near the affected PAR. On the other hand, warning time may be relatively long in a densely populated area below a dam that has a sophisticated early warning system where warning can come directly from the warning system and also from personal communication among the affected residents. The following discussion addresses several factors related to warning time.

5.2.1 When Does Warning Time Start?

This step in the Graham Method may be the most important part of estimating loss of life due to dam failure. The premise in this step is that lives may be saved if adequate warning of a dam failure is given to downstream inhabitants. Since warning time plays such a significant role in determining LOL, it is important to define when warning time starts. Each dam has to be considered individually, taking into account its size, location and PAR downstream. In order to help define when warning time likely would be given, Graham developed a table that offers various scenarios in choose the start of the warning time period. Graham broke the decision factors down to five options. It is up to the user to decide which of the options best fits the dam in question. The five factors are as follows:

1. Dam type (earthfill is the only option given – concrete dams present significantly different warning time values).
2. Cause of failure (overtopping, piping, or seismic).
3. Special considerations that include drainage area size, immediate failure or delayed failure.
4. Time of day when failure occurs.

5. Observers at the dam – if the dam is attended, there are “many observers” at the dam; if the dam is unattended, there are “no observers” at the dam.

This table used in Graham’s publication is provided in Figure 5-1 on the next page. Graham clearly points out that each dam and scenario has to be evaluated individually and special circumstances need to be taken into consideration. Figure 5-1 is provided for guidance only and each case study should consider if using Graham’s guidance is appropriate. This step addresses Step 3 of the Graham Method (see Section 4.2 of this technical note).

5.2.2 Time When First Flood Wave Arrives (Travel Time)

On evacuation maps developed using a model such as HEC-HMS, travel time is defined as being from the start of the dam breach to the time that the start of the flood hydrograph reaches a certain location downstream of the dam. This is different than warning time discussed in the previous section. Travel time is considered as part of warning time, but as shown in Figure 5-1, warning time can start prior to or after the actual beginning of dam failure. A detailed discussion of travel time is provided in *Technical Note 3, Simplified Evacuation Mapping for Emergency Action Planning*.

5.2.3 Warning Time Categories

In determining LOL, Graham suggests using one of three categories for warning time. The warning time categories are as follows:

1. No warning means the media nor official sources issue no warning in the particular area prior to the flood water arrival; only the possible sight or sound of the approaching flooding serves as a warning.
2. Some warning means officials or the media begin warning in the particular area 15 to 60 minutes before floodwater arrival. Some people will learn of the flooding indirectly when contacted by friends, neighbors or relatives.
3. Adequate warning means officials or the media begins warning in the particular area more than 60 minutes before the floodwater arrives. Some people will learn of the flooding indirectly when contacted by friends, neighbors or relatives.

FIGURE 5-1. TABLE 2 OF USBR DS0-99-06 (GRAHAM), ESTIMATES FOR WHEN WARNING TIME BEGINS

Table 2. Guidance for Estimating When Dam Failure Warnings Would be Initiated (Earthfill Dam)

Dam Type	Cause of Failure	Special Considerations	Time of Failure	When Would Dam Failure Warning be Initiated?	
				Many Observers at Dam	No Observers at Dam
Earthfill	Overtopping	Drainage area at dam less than 100 mi^2 (260 km^2)	Day	0.25 hrs. before dam failure	0.25 hrs. after fw reaches populated area
		Drainage area at dam less than 100 mi^2 (260 km^2)	Night	0.25 hrs. after dam failure	1.0 hrs. after fw reaches populated area
		Drainage area at dam more than 100 mi^2 (260 km^2)	Day	2 hrs. before dam failure	1 hr. before dam failure
		Drainage area at dam more than 100 mi^2 (260 km^2)	Night	1 to 2 hr. before dam failure	0 to 1 hr. before dam failure
	Piping (full reservoir, normal weather)		Day	1 hr. before dam failure	0.25 hrs. after fw reaches populated area
			Night	0.5 hr. after dam failure	1.0 hr. after fw reaches populated area
	Seismic	Immediate Failure	Day	0.25 hr. after dam failure	0.25 hr. after fw reaches populated area
			Night	0.50 hr. after dam failure	1.0 hrs. after fw reaches populated area
		Delayed Failure	Day	2 hrs. before dam failure	0.5 hrs. before fw reaches populated area
			Night	2 hrs. before dam failure	0.5 hrs. before fw reaches populated area

Notes: "Many Observers at Dam" means that a dam tender lives on high ground and within site of the dam or the dam is visible from the homes of many people or the dam crest serves as a heavily used roadway. These dams are typically in urban areas. "No Observers at Dam" means that there is no dam tender at the dam, the dam is out of site of nearly all homes and there is no roadway on the dam crest. These dams are usually in remote areas. The abbreviation "fw" stands for floodwater.

5.3 FLOOD SEVERITY

Graham developed a new way of looking at the severity of flooding based on data from previous dam failures. Severity relates to the force of the flood and the ability of humans to survive the flood. It also considers a population's understanding of a flood's severity that affects the ability of those affected by the flood to evacuate. The following discussion focuses on Graham's definitions of the three categories of severity and how it relates to loss of life, and the two categories of flood severity understanding.

5.3.1 Low Severity

If a flood is classified as having low severity, it has the ability to wash buildings off their foundations. However, it also implies the building remains relatively intact and humans within the building have a reasonable chance for survival.

5.3.2 Medium Severity

Medium severity applies to floods that destroy homes but certain features like trees or mangled homes remain in the flooded area where people can seek refuge.

5.3.3 High Severity

This is the least likely form of severity, but certainly the deadliest. High severity refers to a flood of such magnitude that the flooded zone is swept clean to the ground and nothing remains. This type of flooding has occurred only a few times in recorded history, but it has the potential for happening in certain geographical areas. In Graham's study, data for high severity failures was not well represented and guidance is not given for estimating loss of life for this case.

5.3.4 Severity Understanding

Flood severity understanding is the last factor related to severity that has an impact on the ultimate estimation of LOL. According to Graham (USDOI-USBR, 1999):

> "The relative understanding of the flood severity is a function of the distance or time from the dam failure or the source and origination of flooding. The farther one is

from the source of the flooding, the greater the likelihood that the warning will be precise and accurate. This is because people have seen the flooding in upstream areas, they understand the damage potential of the flooding and the warnings are adjusted to reflect the actual danger. Similarly, the people receiving the warning should obtain a better understanding of the danger to which they are exposed. A warning of potential flooding, before it actually occurs (because a dam has not yet failed or during a flash flood in which the true flood magnitude is often not known until after the event is over), may not be understood by the warning issuers and would therefore be difficult to describe. Recipients of this warning will therefore not get an accurate picture of the flooding about to occur and may not evacuate at all or not as quickly as they should. This factor will come into consideration only when there is some or adequate warning. The flood severity understanding categories are as follows:

1) Vague Understanding of Flood Severity means that the warning issuers have not yet seen an actual dam failure or do not comprehend the true magnitude of the flooding.
2) Precise Understanding of Flood Severity means that the warning issuers have an excellent understanding of the flooding due to observations of the flooding made by themselves or others."

So, to summarize, there are three categories of flood severity (low, medium and high) and two categories of flood severity understanding.

5.4 LOSS OF LIFE FATALITY RATES DETERMINATION

Graham summarized his findings in a table that lists recommended fatality rates for estimating LOL for dam failures. His table (published as Table 7 in his study (USACOE-USBR, 1999) is listed in this technical note as Figure 5-2. Figure 5-2 shows 15 different combinations of factors for flood severity, warning time and flood severity understanding. The rates listed were determined by examination of the data from dam failures used in Graham's study.

FIGURE 5-2. TABLE 7 FROM DS0-99-06 (GRAHAM) RECOMMENDED FATALITY RATES FOR LOL ESTIMATION

Table 7 Recommended Fatality Rates for Estimating Loss of Life Resulting from Dam Failure				
Flood Severity	Warning Time (minutes)	Flood Severity Understanding	Fatality Rate (Fraction of people at risk expected to die)	
			Suggested	Suggested Range
HIGH	no warning	not applicable	0.75	0.30 to 1.00
	15 to 60	vague	Use the values shown above and apply to the number of people who remain in the dam failure floodplain after warnings are issued. No guidance is provided on how many people will remain in the floodplain.	
		precise		
	more than 60	vague		
		precise		
MEDIUM	no warning	not applicable	0.15	0.03 to 0.35
	15 to 60	vague	0.04	0.01 to 0.08
		precise	0.02	0.005 to 0.04
	more than 60	vague	0.03	0.005 to 0.06
		precise	0.01	0.002 to 0.02
LOW	no warning	not applicable	0.01	0.0 to 0.02
	15 to 60	vague	0.007	0.0 to 0.015
		precise	0.002	0.0 to 0.004
	more than 60	vague	0.0003	0.0 to 0.0006
		precise	0.0002	0.0 to 0.0004

Graham also suggests ways to determine if flood severity is low, medium or high. Several of the guidelines suggested by Graham are difficult to assess, such as determining areas where "homes are destroyed but trees or mangled homes remain for people to seek refuge in or on" (ibid). In order to simplify the guidelines, the Montana Dam Safety Program suggests the following:

1. In determining whether flooding is low severity or medium severity, use low severity if most of the structures will be exposed to depths of less than 10 feet and medium severity if most of the structures will be exposed to depths of 10 feet or more. (Note that low severity flooding can be quite deadly to people attempting to drive vehicles.) (ibid)
2. Use high flood severity only for locations flooded by the near instantaneous failure of a concrete dam, or an earthfill dam that turns into "jello" and goes out in seconds rather than minutes or hours. (ibid)

Graham suggests another method that can be used to separate low severity flooding from medium severity flooding by use of the parameter DV:

$$DV = \frac{Q_{df} - Q_{2.33}}{W_{df}}$$

Where: Q_{df} is the discharge at a particular site caused by dam failure.

$Q_{2.33}$ is the mean annual discharge at the same site. This discharge can be easily estimated and it is an indicator of the safe channel capacity. As discharges increase above this value, there is a greater chance that it will cause overbank flooding.

W_{df} is the maximum width of flooding caused by dam failure at the same site.

The units of DV are d^2/s or depth (D) times velocity (V). Graham suggests low flood severity should be assumed, in general, when DV is less than 50 ft^2/s (4.6 m^2/s). Medium flood severity should be assumed, in general, when DV is more than this value (ibid).

5.5 UNCERTAINTY

The Montana Dam Safety Program provides the guidance in this technical note only as an aid to help estimate loss of life in determining spillway design capacity. It is fully understood that uncertainty enters into every step of these estimation methods. Judgment is necessary in conducting these types of analyses. Conservatism may be introduced at various levels of analysis. It is important that users understand that loss of life estimates are just that – estimates.

For discussion, the following steps produce uncertainty in this type of analysis:

- Type of failure – Dams can fail many different ways. For the purpose of this technical note, the mode of failure is limited to one with the reservoir level at the crest of the dam. The inundation mapping for this type of failure will be conservative for cases where failure is by piping with the reservoir at a lower level and it may produce slightly smaller inundation boundaries for an overtopping failure during a large runoff event.
- Failure modeling – Several different models can be used to estimate failure discharge and routing of the flood wave. Each will estimate the resulting flood differently. All models are simulations and real floods may react differently than the model. Models will have inherent errors because of simplification introduced into the calculations.
- Time of failure – When a dam fails has significant impact on loss of life downstream. Nighttime failures have been shown to be deadlier than daytime failures. Weekday daytime failures that affect residential areas could have lower fatality rates than during weekends. Other factors such as time of year could introduce uncertainty in the estimates determined by this method.
- Initiating warnings – When a warning is initiated plays significantly on the uncertainty of the LOL estimates.
- Applying fatality rates – Uncertainty in the type of force area, warning times, and other factors in the estimation process could lead to wide variability in fatality rates. By virtue of a range of suggested fatality rates in Figure 5-2, the uncertainty of applying the rates contributes to the overall uncertainty of this method.

Engineering and professional 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 come to estimates that best fit the dam and conditions.

6.0 DEFINITIONS

The following definitions are offered for terms used in Technical Note 2:

Backwater – Water in a stream channel or floodplain that is impeded from its natural flow profile and creates an area of inundation behind an obstruction. The water surface profile of backwater is much flatter than the natural flow profile.

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

Emergency Action Plan (EAP) – A written plan developed for enacting procedures during an emergency. For dams, EAPs are used for evacuation and warning of residents living in the inundation area resulting from failure of 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.

HEC-HMS – A computer program (Hydrologic Modeling System) developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center that performs rainfall-runoff and flood routing computations. Additional capabilities include dam breach and snowmelt modeling.

HEC-RAS – A computer program (River Analysis System) developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center that performs water surface profile computations for steady and unsteady flows. Additional capabilities include sediment transport and dam breach modeling.

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.

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.

Piping – The action of buried soil erosion by water movement through larger soil pores. For earthen dams, piping is generated by the hydrostatic head of the impounded reservoir. If flow continues unabated, the pore space increases and piping can accelerate rapidly.

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.

USGS 7.5 Minute Quadrangle Map – Topographic maps developed by the United States Geological Survey that are 1:24,000 in scale, or 1 inch equals 2000 feet. The range of each map covers 7.5 minutes of latitude and longitude.

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.

7.0 REFERENCES

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APPENDIX A

DEPTH-VELOCITY FLOOD DANGER GUIDELINES

HIGH DANGER ZONE - Occupants of most houses are in danger from floodwater.

JUDGEMENT ZONE - Danger level is based upon engineering judgement.

LOW DANGER ZONE - Occupants of most houses are not seriously in danger from flood water.

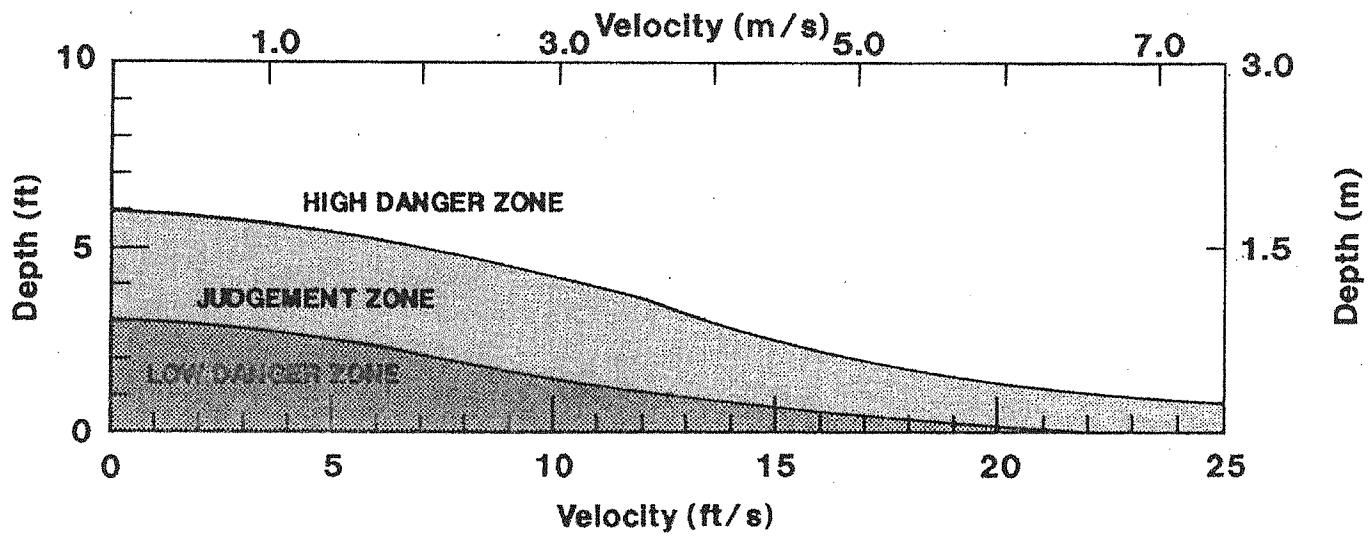

Figure 2. – Depth–velocity flood danger level relationship for houses built on foundations.

HIGH DANGER ZONE - Occupants of almost any size mobile home are in danger from flood water.
JUDGEMENT ZONE - Danger level is based upon engineering judgement.
LOW DANGER ZONE - Occupants of almost any size mobile home are not seriously in danger from flood water.

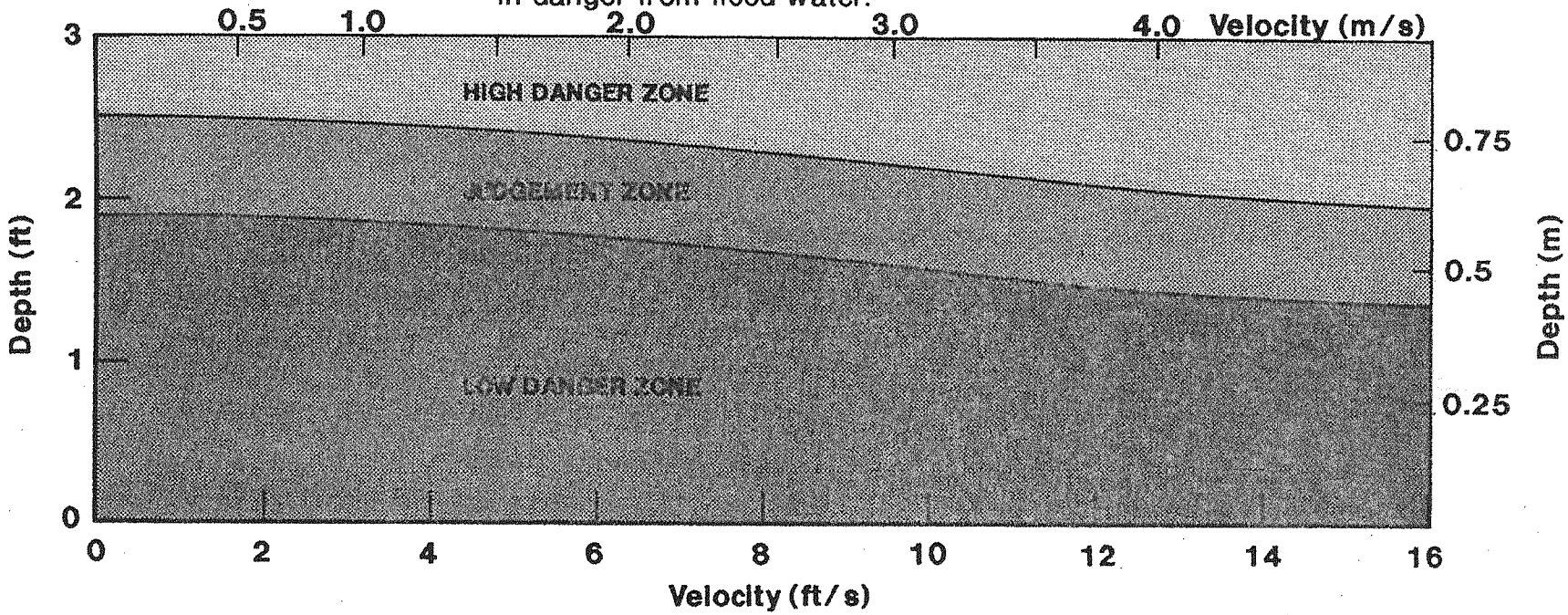

Figure 3. - Depth-velocity flood danger level relationship for mobile homes.

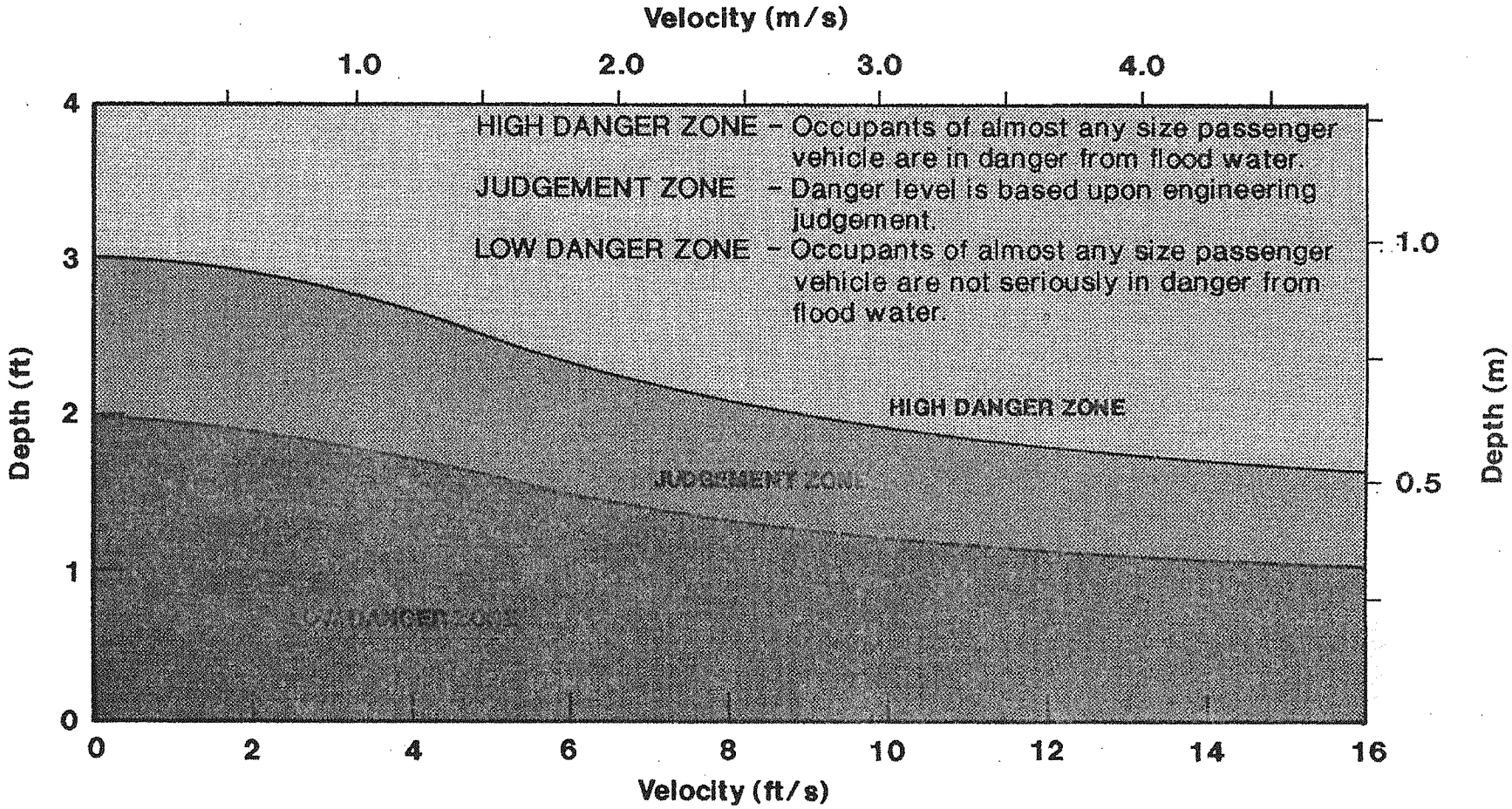

Figure 4. – Depth–velocity flood danger level relationship for passenger vehicles.

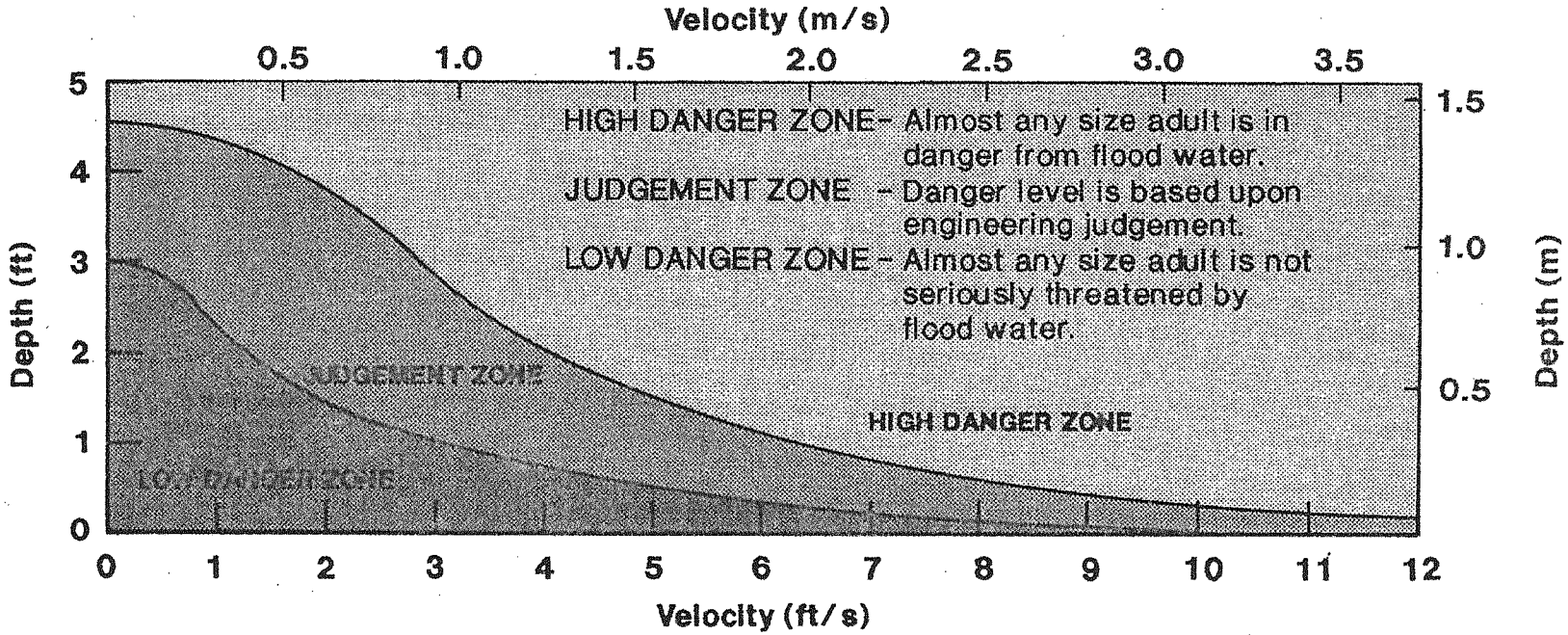

Figure 5. – Depth–velocity flood danger level relationship for adults.

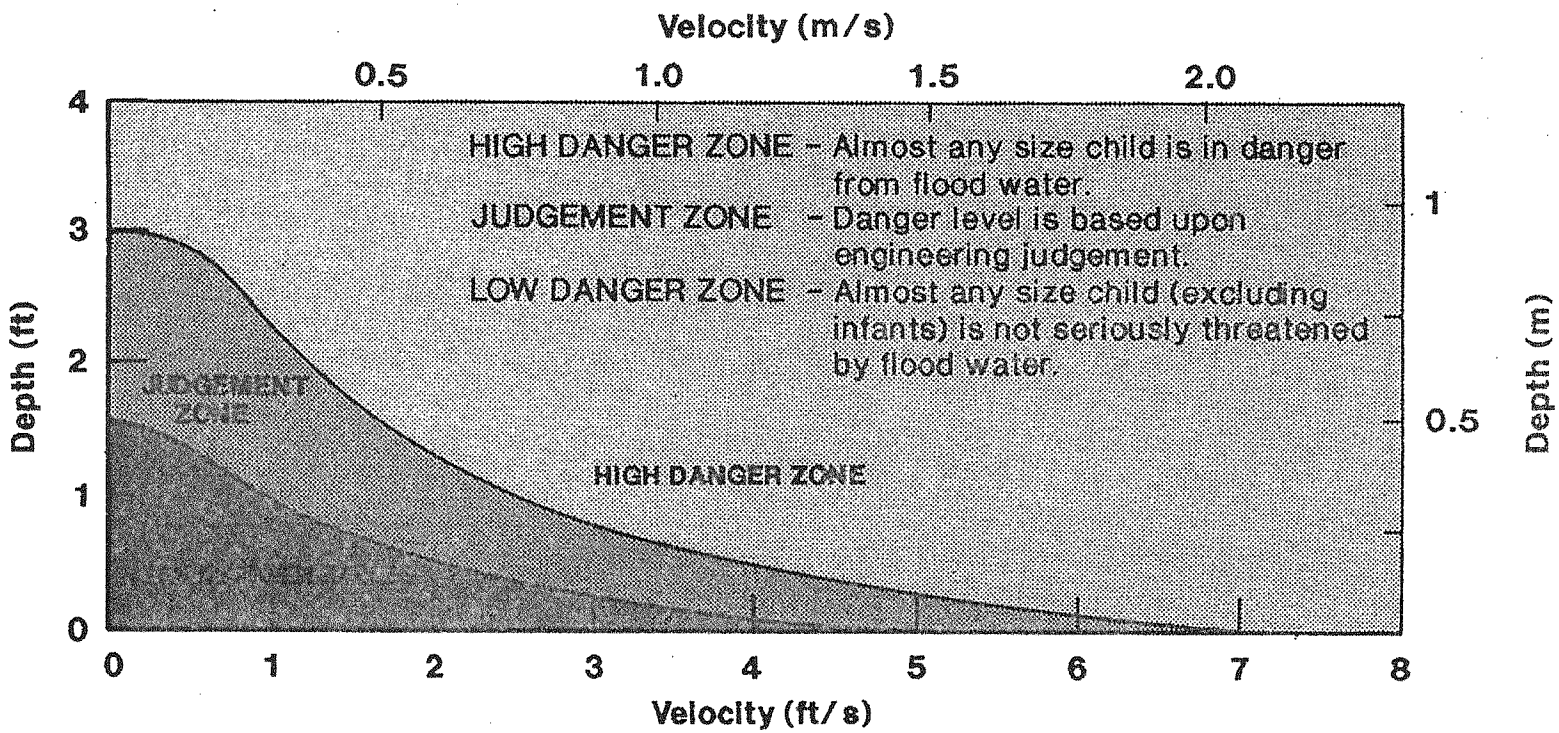

Figure 6. – Depth–velocity flood danger level relationship for children.

APPENDIX B

LOSS OF LIFE DETERMINATION EXAMPLE – FISH CREEK DAM

APPENDIX C

SPREADSHEETS FOR LOSS OF LIFE DETERMINATIONS