# Dam Safety Program

## Technical Note 3

## Simplified Evacuation Mapping for Emergency Action Planning

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## Overview

Technical Note 3 (TN3) is provided to assist and guide engineers and professionals engaged in developing simplified evacuation maps in emergency action plans for the potential failure of high hazard dams. TN3 is intended as a procedural aid for conducting a simplified evacuation map analysis for high hazard dams regulated by the Dam Safety Program. The procedures outlined in this technical note are based on feedback from personnel responsible for initial emergency response, who may not be familiar with technical aspects of dams but who have the challenging task of quickly reading and understanding emergency action plans when the need arises and when human lives are at risk. The Dam Safety Program intends for TN3 to provide a consistent means of conducting dam breach modeling and producing evacuation mapping in a manner that is reasonably accurate and economically efficient.

TN3 is organized in a logical format to guide the user through the simplified evacuation mapping process. First an explanation is given on why simplified mapping is used and how emergency personnel use the maps. The user is then provided engineering methodologies for conducting simplified map modeling. Guidance on map development and features to include on the maps are also contained in this technical note. Methods other than those provided in TN3 can be used in map development and are briefly discussed herein.

TN3 is written primarily for earthen dams. The procedures for simulating breach failures that are included in TN3 are based on historical data from earthen dam failures.

# DAM SAFETY PROGRAM
# DAM SAFETY PROGRAM TECHNICAL NOTE 3 (TN3)
# SIMPLIFIED EVACUATION MAPPING FOR EMERGENCY ACTION PLANNING

## 1.0 INTRODUCTION

The **Montana Dam Safety Program** is pleased to provide this **Technical Note 3 (TN3), Simplified Evacuation Mapping for Emergency Action Planning**. We hope this publication is helpful in providing technical guidance to professionals engaged in dam safety analysis and emergency action planning for high hazard dams in Montana. Our intent is to provide relevant and up-to-date information, references and procedures pertinent to the Montana dam safety rules for conducting emergency action plan (EAP) evacuation mapping using a procedure that is simplified and tailored for use by emergency response personnel.

This is the third Technical Note developed by the Dam Safety Program and we want it to be a useful document for those engaged in dam safety analyses. We welcome and encourage your feedback on its contents. Please send your comments to:

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The Dam Safety Program operates within the DNRC Water Resources Division's Water Operations Bureau.

DNRC would like to acknowledge Hydrometrics, Inc. of Helena, Montana for the development and preparation of Technical Note 3. TN3 will be revised and updated as new procedures are refined and new technical references are made available.

## 1.1 TECHNICAL NOTE PURPOSE

The purpose of TN3 is to assist and provide guidance to engineers and professionals engaged in developing the evacuation maps in emergency action plans for the potential failure of high hazard dams.. TN3 is not a regulatory document and the references and procedures provided can be modified to suit the needs of the user. Some of the technical resources referenced in TN3 are specific to Montana dams, using data gathered and compiled in Montana. The procedures outlined in this technical note are based on feedback from personnel responsible for initial emergency response, who may not be familiar with technical aspects of dams but who have the challenging task of quickly reading and understanding emergency action plans when the need arises and when human lives are at risk. The Dam Safety Program intends for TN3 to provide a consistent means of conducting dam breach modeling and producing evacuation mapping in a manner that is reasonably accurate and economically efficient. The Dam Safety Program recognizes that professionals may use other technical resources and procedures, accompanied with relevant reasons for their use that are not mentioned in TN3. Because they constitute the majority of high hazard dams in Montana, TN3 is written primarily for earthen dams. The procedures for simulating breach failures that are included in TN3 are based on historical data from earthen dam failures.

## 1.2 FOCUS AND LIMITATIONS

TN3 is intended as a procedural aid for conducting a simplified evacuation map analysis for high hazard dams regulated by the Dam Safety Program. Dams regulated by the Dam Safety Program are required by their operation permits to have emergency action plans that contain evacuation mapping in the event of a failure of the dam. Evacuation mapping typically shows the downstream area inundated by failure of a dam and identifies affected infrastructure and possible escape routes. Evacuation mapping for dams not regulated by the Dam Safety Program can be developed under the guidance suggested in TN3, but should be consistent with regulations of the appropriate regulatory agency.

## 1.3 TARGET AUDIENCE

TN3 is for use by engineers and professionals experienced in dam safety issues and evacuation mapping for dam failures. Professional judgment is sometimes required in developing evacuation mapping, regardless of guidance provided by TN3. Users of TN3 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 TN3 contents.

## 2.0 PURPOSE OF SIMPLIFIED EVACUATION MAPPING

For many Montana high hazard dams, evacuation mapping includes two inundation boundaries representing two different breach scenarios for the dam. These two scenarios include a clear-weather breach (failure of a dam for reasons not related to a storm inflow flood) and a flood-induced breach (failure caused by overtopping during a storm inflow flood). Various amounts of other information are typically placed on the map to provide emergency personnel pertinent data for making notification and evacuation decisions. While these maps have generally served their purpose, they contain information that tends to be confusing and hard to read, especially by response personnel during an actual emergency or an exercise.

Emergency response personnel may spend precious time trying to determine which boundary is correct for the actual breach situation – time that could have been effectively spent in notifying and evacuating downstream residents. Information provided on the maps, such as "wave height" or "flood wave travel time," may not be meaningful to an emergency response personnel, especially if the basis for the information is not given. Again, confusion may waste valuable time. These types of maps also require significant engineering effort to generate the needed hydrologic information and modeling results, and thus become expensive for dam owners.

In light of the concerns surrounding these inundation and evacuation maps, the challenge for dam owners and their engineers is to develop reasonably accurate inundation and evacuation maps that are useful, relatively inexpensive, and not confusing to the average emergency responder. Accordingly, the Dam Safety Program is moving toward simplifying the process for developing evacuation mapping. Lemieux and Robinson (2008) suggest a simplified method consisting in part of four basic changes to what has typically been done in the past:

1. Provide only one inundation boundary on the map.
2. Generate the single boundary by modeling a somewhat conservative breach of the dam with the reservoir level at the low point of the dam crest.

3. Identify and delineate areas requiring evacuation that are not within the inundation zone.
4. Provide only enough information on the maps that will be useful and understandable to emergency personnel.

The features listed above are echoed in a paper developed by the National Dam Safety Review Board Emergency Action Plan Workgroup (FEMA-NDSRB, 2009) urging the development of simplified maps in an effort to broaden the use of evacuation maps by making them more affordable to dam owners. Having more EAPs with evacuation maps will help protect citizens living downstream of dams.

The following discussion details the reasons for utilizing simplified evacuation maps.

## 2.1 NEED FOR EMERGENCY ACTION PLAN MAPS

EAPs identify the procedures for evacuation or protection of residents in the event of a disaster. In the case of dams, the EAP contains explanations of emergency hierarchy, communications, and procedures, plus a map or maps that delineate flood inundation boundaries that are expected in the event of dam failure. EAPs represent a prudent and diligent resource that can be enacted to help reduce property and personal damage, as well as save lives. In Montana, EAPs are required in order to obtain an operation permit for a high-hazard dam. Owners of high hazard dams are required to develop the plans and provide copies to appropriate response agencies that can utilize them in the event of an actual or impending dam failure.

## 2.2 INTENDED USERS OF MAPS

Evacuation maps within an EAP are useful tools in the event of an emergency. While experienced engineers with sophisticated computer modeling software generate the maps, emergency response personnel are the end users. Therefore, it becomes critically important that maps convey the intended information without confusion or misinterpretation. Typical users of evacuation maps are local police and sheriff offices, state Disaster and Emergency Service personnel, engineers familiar with the dam, and the Dam Safety Program office.

## 2.3 REASONS FOR SIMPLIFIED MAPS

While sophisticated programs used to develop inundation maps allow the calculation of many specific details relevant to the breach flood, there are many compelling reasons to simplify both the engineering model and the information shown on the maps. By "simplification," the Dam Safety Program's intention is not to make evacuation maps inaccurate or ineffective. Instead, simplified maps are intended to be generated by commonly-used computer software that is reasonably accurate within an error band expected by most modeling techniques, and with enough data on the maps to provide emergency personnel clear evacuation instructions and effective warning protocols.

### 2.3.1 Modeling Uncertainty and Data Inaccuracy

Hydrologic and hydraulic modeling of flows in the natural environment have inherent errors because of many unknown and uncertain factors in the watershed and riverine environments. While even high-level modeling using finite element analyses to estimate unsteady flow in one or two dimensions may define changes in flow accurately to the degree that input data will allow, there still remains uncertainty in the data and unpredictability of flows' interaction with the channel and surrounding areas. High force floods, such as a breach flood from a failed dam, create extreme scour occurrences that significantly change the flow channel shape and expose different material types as scour progresses downward, which change the channel and overbank cross section properties during the flood. This is demonstrated in the photos in Figure 1.

**FIGURE 1. PHOTOGRAPHS OF CHANGES IN DOWNSTREAM FLOW CHANNEL FOLLOWING A DAM BREACH**

In Figure 1, the photograph on the left is looking downstream from the dam and the photograph on the right is looking upstream toward the dam from the start of a headcut.

Also, the debris-carrying capacity of an abrupt flood wave can be tremendous. For some breach floods, the flood wave is more likely to be mud flow than water flow. If debris and sediment content in a flood wave is high enough, flow characteristics could change from fairly predictable Newtonian flow to non-Newtonian flow where standard laws of unsteady fluid conveyance no longer apply. Additionally, debris can jam bridge openings or channel constrictions, causing backwater that cannot be predicted by flood simulation models.

Watersheds and flood conveyance channels contain significant variability in soils, ground cover and debris that affect resulting flow routing. Data required to accurately capture the variability of these characteristics is overwhelming for standard prediction models. The best engineers can do, considering a reasonable time frame for gathering data at a reasonable cost, is provide sampling of the data available and propose that the samples adequately represent actual field conditions. Because samples are relied upon for data representation, inherent errors are introduced into the prediction models.

### 2.3.2 Engineering Cost Reduction

As mentioned earlier, comprehensive data gathering and sophisticated modeling techniques could require significant modeling effort and accompanying high engineering costs. High-level modeling may be warranted in certain situations as discussed in Section 6.0. But in the vast majority of areas in Montana, populations are sparse and stream channels and floodplains are well defined. Fairly straight-forward engineering models, such as HEC-HMS (USACOE, 2009), provide reasonable results and are more robust than many complex unsteady flow models. Use of a model such as HEC-HMS results in lower engineering costs because of its relatively uncomplicated application.

Simplified maps also serve to reduce engineering costs because of only one breach model used to produce the maps. Not only does this approach reduce engineering costs, but it also reduces CAD technician time for drawing the map. The simplified map technique described below ignores upstream hydrology and discharges from spillways and outlets, providing an additional cost reduction.

### 2.3.3 Less Complicated for Emergency Personnel

Consider this situation:

> A sheriff for a rural Montana county is suddenly alerted that a large high hazard earthen dam in his jurisdiction is in danger of failing. After the initial rushed effort to locate the emergency action plan filed away in the county offices, the sheriff hurriedly tries to form a mental picture of the dam and its downstream area as he refamiliarizes himself with the plan and the maps it contains after almost a year since it was updated. As he finally gets to the maps to understand the affected areas, he sees not only one flood boundary line, but two. What do they mean? Why two lines? Where are they explained? Then he spots the legend that says one of the lines conforms to a “clear-weather breach” and the other line represents a “storm-induced breach.” Ok. What do those terms mean again? Never mind, he thinks, just use the wider boundary area and assume it is better to be safe than sorry. But now there is a box pointing to a bold line drawn across the valley on the map. In the box is a table

containing terms like “Peak Discharge” and “Maximum Stage” and “Wave Height.” He is unsure about the meaning of those terms, in addition to not fully understanding the meaning of the numbers below each of the terms. But at least now he recognizes the area on the map and can even identify the houses in or near the flood boundaries.

Up to this point, the sheriff has spent all his time just trying to figure out the maps in the emergency action plan. It could have taken only a few minutes but in the event of an impending dam failure, lost minutes could mean lives lost downstream. The people placed in situations similar to the sheriff’s described above are well trained and effective in their duties. But faced with unusual information that is technical in nature and contains terminology unfamiliar to those not involved in the modeling of dam failures, personnel can get bogged down in details and confusion. It is important for engineers to understand that emergency personnel in Montana will typically not have an understanding of hydraulic modeling terminology and will be under considerable stress during an emergency. Having maps that are not complicated, easy to read and understandable will be much more effective than more complicated maps. It could help save lives.

### 2.3.4 Predominantly Sparse Population in Montana Risk Areas

The Dam Safety Program places the lives of every Montana resident as its ultimate priority and responsibility in the regulation of high hazard dams. In 1985, Montana Code Annotated (MCA), Title 85 (Water Use), Chapter 15 (Dam Safety Act) was enacted which places all dams that have the potential for only one loss of life or more in the event of failure into the category of high hazard and under the authority of the Dam Safety Program. Because of the concern for every citizen, even with Montana’s predominately rural and sparse population, modeling of breach floods have to be reasonably accurate. However, inevitable inaccuracies will be inherent in all breach flood modeling. Those inaccuracies become critical in densely populated areas where only a few feet of flood stage error could affect hundreds or thousands of lives. High-level modeling is justified in dense population centers, not only for map accuracy but for the cost and impact of evacuating large numbers of people. When 2,400 people in suburban Washington DC were evacuated below Lake Needwood Dam in 2008, detailed maps were needed to identify who could return to their homes as water levels receded. Modeling inaccuracies in sparsely populated areas can be tolerated to a point, mainly because of the few numbers of people affected. Combined with built-in model conservatism, uncertainty of a program such as HEC-HMS becomes less impactual in most areas in Montana. If only a few people who are actually safe from breach flood harm but who are shown to be within a mapped inundation area are evacuated because of model uncertainty and conservatism, then the overall impact is relatively minor. Therefore a tool like HEC-HMS is warranted in the vast majority of areas potentially affected by dams in Montana.

# 3.0 HOW MAPS ARE USED BY EMERGENCY PERSONNEL

In Section 2.3.3 of this technical note, a brief scenario was given of a rural sheriff hurriedly trying to decipher evacuation maps of a dam's emergency action plan. While the scenario reflects issues faced by responding officials during an emergency, it fails to underscore the range of purposes of evacuation maps. In this section, you will better understand how emergency personnel use evacuation maps. Much of the information presented in this section is based on feedback from Montana emergency personnel in emergency action plan exercises and other evaluation venues. The purpose of including this section in this technical note is to provide a basis for developing evacuation mapping for dam failures, considering the spectrum of personnel responsible for using the maps. As mentioned in previous sections, emergency personnel are highly qualified in their area of expertise but the technical nature in which maps are created can sometimes pose a gap between modeling and mapping development and user understanding of the data presented on the maps. This section is provided for creators of maps to assist in making them as user-friendly and effective as possible.

## 3.1 EVACUATION ROUTES AND EMERGENCY CENTER LOCATIONS

Evacuation maps not only reflect the breach flood inundation boundary but also identify areas requiring evacuation outside of the inundation boundary. In order to direct people to safety from their location within the inundation area, travel routes from the inundation and evacuation areas need to be identified. These routes would either be away from inundated areas or in inundation areas where travel could occur well in advance of the arrival of the flood wave. Routes should be clearly labeled with restrictions identified. This type of information may best be obtained from the local emergency personnel, whose input is invaluable for the development of evacuation maps (see Section 5.2).

Key to any evacuation effort are locations, or emergency centers, where evacuees would gather for food and shelter. When using the maps, emergency personnel can locate emergency centers which should be clearly identified, located outside of the evacuation area and accessible by non flooded roads. The EAP should clearly describe in the emergency action plan if the center is in an area outside of the map extents. Emergency centers are typically schools, gymnasiums, arenas, or other large public gathering places that can handle large numbers of people and some of their belongings. Emergency centers are critical to maintain evacuee counts, provide shelter and comfort to those forced to evacuate, and to establish a central location to locate friends and relatives affected by the evacuation.

## 3.2 ROAD, RAILROAD AND BRIDGE CLOSURES

One of the leading causes of death and injury during a flooding event is when vehicles travel into flood water on a road or bridge. The U.S. Bureau of Reclamation, in their ACER Technical Memorandum No. 11 (USDOI-USBR, 1988), indicates that water depths from 1.5 to 2 feet with little to no velocity endangers the safety of occupants in passenger vehicles, regardless of vehicle size. It therefore becomes critical to show road closures on clearly identified routes susceptible to flooding on evacuation maps. Emergency personnel can then close routes to vehicular traffic as soon as possible after flood warning is given. Bridges become endangered by flood flows even if overtopping does not occur. Scour around bridge piers can cause instability or failure if high flows are prolonged. Evacuation maps should clearly identify roads and bridges that emergency personnel can close during an impending or actual failure of a dam. Road closures should identify where blockages need to be placed to allow emergency personnel to detour traffic to other routes directed away from flooding danger.

Railroads are also a concern if tracks cross waterways that could carry breach flood flows. Railroad crossings should also be identified on evacuation maps to alert emergency personnel to communicate with railroad officials about impending danger and to halt rail traffic.

Emergency personnel should also be aware of walking or biking paths that may not be identified on USGS 7-minute quadrangle maps. These can be drawn in on the maps and identified as travel routes that need closures as well.

## 3.3 IDENTIFICATION OF AFFECTED INFRASTRUCTURE

Some counties desire that infrastructure affected by the breach flood wave be clearly identified on the evacuation maps. Infrastructure important to emergency personnel include roads and highways, railroads, and buildings or facilities considered critical for community services (such as hospitals, emergency or law enforcement centers, or power plants) or considered to potentially contain significant numbers of people (such as schools, government buildings, churches and large office buildings). Special handling and evacuation measures may be needed to alert and transport building occupants away from danger zones. Emergency personnel will likely need to coordinate with each facility's own emergency action plan to make sure the facility understands it is susceptible to breach flooding and to coordinate communication. Whether or not affected infrastructure is included on a map should be discussed with local emergency responders during map development (see Section 5.2).

# 4.0 SIMPLIFIED BREACH ENGINEERING ANALYSIS

The Dam Safety Program recommends specific procedures for conducting a breach analysis that will produce simplified evacuation mapping. With the goal in mind that this method will help reduce the cost of engineering analysis for dam owners, yet produce reasonably accurate and effective mapping, the procedures described herein are relatively straight forward and logical. The method recommended below includes use of the computer software HEC-HMS. As mentioned previously in this technical note, HEC-HMS is a one-dimensional hydrological modeling system that routes flood flows using quasi-unsteady flow simulations. While not as sophisticated as other flood-routing models, such as HEC-RAS (USACOE, 2010) or FLDWAV (USDOC-NWS, 2008) that use full unsteady one-dimensional flow equations, HEC-HMS is robust and not as temperamental in its computational convergence. It is also the Dam Safety Program's position that HEC-HMS provides results well within expected accuracy error bands of other modeling software. An example of a HEC-HMS routing model used to determine the inundation boundaries of a simplified evacuation map is provided in Appendix A.

## 4.1 MODEL INPUT DATA

HEC-HMS requires input data within specified model components. The first basic input component is a Basin Model, which is comprised of a watershed basin or subbasins, reservoir, dam and spillway features, and downstream channel data for flood routing. The second component is a Meteorological Model that defines precipitation that falls within the watershed. Dam breach models that are not triggered by a storm event will still include a Meteorological Model because it is required by the HEC-HMS software but no precipitation data will be entered. Then the program requires a Control Specifications component to specify run time length and time intervals. The final components of the program include Time-Series data, such as specified hydrographs and precipitation hyetographs, and Paired Data, that is used to define reservoir storage-area-elevation relationships, spillway discharge-storage-elevation data, or downstream channel cross sections for flood routing.

The following sections identify common input information needed for a HEC-HMS breach flood analysis.

### 4.1.1 Reservoir

Reservoir storage-area-elevation data is entered in the HEC-HMS Paired Data component with the Basin Model. The reservoir can be described by published data that is usually part of the reservoir system inventory. The reservoir volume is typically described in terms of storage or impoundment area related to elevation. Data is entered as a Paired Data file. If published reservoir data is not available, the user is required to estimate the reservoir volume. This can be done by numerous methods but two common methods are typically used. The first is to use the equation provided in Administrative Rules of Montana (ARM) 36.14.102, which estimates the volume of a reservoir to the level of the dam crest in the absence of better data by taking 0.4 times the height of the dam in feet from the downstream toe to the dam crest times the reservoir area in acres at the level of the dam crest. The second method uses equal elevation contours above the reservoir surface from a map. By calculating the surface area at each contour to the downstream extent of the dam, a relation can be made by regression equation or by graphical means of area versus elevation above the surface of the reservoir shown on the map. Then the area-elevation relationship can be extrapolated to the estimated bottom elevation of the dam. This can be used to develop the area-elevation relationship in the normal reservoir elevation range.

### 4.1.2 Dam, Spillways and Outlets

Descriptive information about the dam, spillway and outlets are entered in HEC-HMS with the reservoir data within the Basin Model. The only information required to describe the dam is its top elevation. In this type of analysis, the dam break option will also be selected. Input factors for the dam break option are described in Section 4.1.4. Spillway (auxiliary, emergency, or both) and outlet information can be entered as part of the reservoir data as well. However, in the simplified method, no additional flow from spillways and outlets is included in a dam break. The contribution to breach flow from spillways and outlets is often negligible.

### 4.1.3 Downstream Channel

The breach flood wave will be routed along the downstream channel. In order to do this in HEC-HMS, channel data is input in the Basin Model as a routing component. There are several routing methods available in HEC-HMS, but the most common used for natural channels is the Muskingum-Cunge method. The reason for this is two-fold: first, the Muskingum-Cunge method estimates attenuation of the breach flood peak discharge by recalculating the routing parameters at every time step of the computation process; and second, the method uses an eight-point cross section to approximate a natural channel and overbank cross section. All other routing methods in HEC-HMS use a standard shape cross section such as trapezoid, circular, triangular, etc. Each Muskingum-Cunge cross section represents a relatively homogeneous reach along the channel. Each of the eight points of the inserted cross section are identified by a station and an elevation. Manning's n friction coefficient values are assigned to the channel and overbanks. Length values represent the homogeneous reach length.

Other routing methods can be used if the channel characteristics can be reasonably estimated by a standard shape.

### 4.1.4 Breach Characteristics and Starting Conditions

The outflow hydrograph from the dam breach will be determined by the size of the breach and the time it takes to fully develop the breach. HEC-HMS does not simulate the breach by physical erosional estimation computations. Instead it uses breach parameters input by the user. Breach parameters are calculated outside the program by published empirical relationships taken from historical earthen dam failures. Progression of the breach is a factor of the reservoir hydrostatic head on the dam and the volume of water impounded. Breach flow will be dependent on the starting reservoir level at the beginning of breach simulation. For the simplified approach, the reservoir level at the beginning of the computation is at the top of the dam crest.

#### 4.1.4.1 <u>Methods for Estimating Embankment Breach Characteristics</u>

Several methods have emerged that estimate breach parameters of earthen embankments. Two of the most common methods are those developed by MacDonald and Langridge-Monopolis (1984) and Froehlich (2008). A comparison study by Wahl (2004) indicated the prediction equations developed by Froehlich (1995) had consistently low uncertainty orders of magnitude when compared with other published methods using a historical database of dam failures and comparing results to the physically-based erosional model NWS-BREACH (Fread, 1991). Based on Wahl's study, the Dam Safety Program suggests the use of Froehlich equations in determining breach parameters for earthen dams. The 2008 Froehlich equations have been changed slightly from the 1995 equations used in Wahl's study.

Froehlich's equations are as follows:

Average Breach Width: $B_{avg} = 8.239 K_o V_w^{0.32} H_b^{0.04}$

Where: $B_{avg}$ is the average breach width in feet

$K_o$ is the Failure Mode Factor

- $K_o = 1.0$ for piping
- $K_o = 1.3$ for overtopping

$V_w$ is the volume of the reservoir in acre-feet above the bottom of the breach

$H_b$ is the breach height in feet, which is the vertical distance from the dam crest to the breach invert

Breach Development Time: $T_f = 3.664(V_w/(gH_b^2))^{0.5}$

Where: $T_f$ is the breach development time in hours

g is gravitational acceleration = 32.2 ft/sec$^2$

Froehlich recommends breach sides slopes of 0.7:1 (horizontal:vertical) for piping and 1.0:1 for overtopping. However the Dam Safety Program's recommendation, based on observations from actual dam breaches in Montana, is to use vertical breach side slopes of

(0.0:1). Numerous examples have supported this recommendation, including the breach shown in Figure 2.

**FIGURE 2. PHOTOGRAPH OF AN EARTHEN DAM BREACH IN MONTANA WITH VERTICAL BREACH SIDE SLOPES**

**4.1.4.2 <u>Starting Reservoir Level</u>**

As mentioned in Section 4.1.4, the starting reservoir level for the breach analysis is at the top of the dam crest. This is conservative for both a clear weather breach and most flood induced breaches. The only situation where this is not conservative is in the unlikely situation when an extreme storm event causes the dam to overtop for a while prior to failure. As discussed in other sections of this document, this level of conservancy is acceptable, as there is no way to predict debris jams which can artificially raise water levels about what our models will predict. By using a top of dam crest starting water level, a “safety factor” against debris induced water level rises is provided.

**4.1.4.3 <u>Spillway and Outlet Restrictions</u>**

Even though the reservoir level is to the top of the dam for the breach analysis, the Dam Safety Program recommends a modeled breach of the dam without contribution of flows from the spillways or outlets. Breach modeling experience has shown that spillway and outlet flows are only a small percentage of breach flows. Ignoring them has little impact on the evacuation boundary.

#### 4.1.4.4 <u>Modeling Road Crossings With HEC-HMS</u>

For many dams it is common that much of the inundation area will be the result of ponding behind roads, rather than due to the flow area of the breach flood. While this type of backwater is commonly modeled with HEC-RAS because of its standard-step water surface profile capabilities, it is also possible to model the roads and subsequent backwater with HEC-HMS. This accomplished by modeling the road as a dam and identifying the area upstream of the road as a reservoir. The user will be required to input the road (dam) top elevation, upstream area (reservoir) elevation-area-volume data, outflow structures, and ditch flow along the road. This might require some field surveying to get appropriate data. Flow along the road ditch can be significant. The user is cautioned to model this as accurately as possible because road ditches sometimes have relatively large capacities. It may be useful to model the road ditch as the main downstream flow channel through which flow is routed. Necessary data gathering and input will depend on the applicable situation.

# 5.0 SIMPLIFIED MAP DEVELOPMENT

Once the HEC-HMS model is complete and results are available, the process of developing an evacuation map can begin. Maps can be produced on any background desired, but most typically they will be drawn on either USGS 7.5 minute quadrangle maps or aerial photographs. Technology is changing rapidly in this area and maps and aerial photography are becoming easier to access and use. Maps and aerial photography are available through the Montana Natural Resources Information System at http://nris.mt.gov/. Maps can be produced either in a computer-aided drafting format such as AutoCAD® or with a geographic information system (GIS) such as ArcGIS®. An example of a simplified evacuation map is provided in Appendix B of this technical note.

## 5.1 MAP ANNOTATION AND ATTRIBUTES

Since the goal of simplified mapping is to make the maps easier to read and more efficient to use, it makes sense that information placed on the maps is appropriate and clear to the user. The information suggested in this section is important from the perspective of emergency personnel in Montana. The Dam Safety Program recommends the annotation and attributes listed below to meet what it considers the essential properties of a simplified evacuation map. Map producers can use the following information according to their discretion. Note that each county has different ways of handling emergency preparedness. Before spending much time annotating and fine tuning your map, it is recommended you meet with local emergency management personnel to get their input (as discussed in Section 5.2).

### 5.1.1 Flood Wave Characteristics

Information describing breach flood waves should be clearly defined. For this type of application, too much flood wave information on a map would likely be counterproductive for the reasons discussed in Section 2.3.3. The most important piece of information for emergency personnel is the flood wave travel time. Travel time is important for proper notification of downstream residents and for evacuation timing.

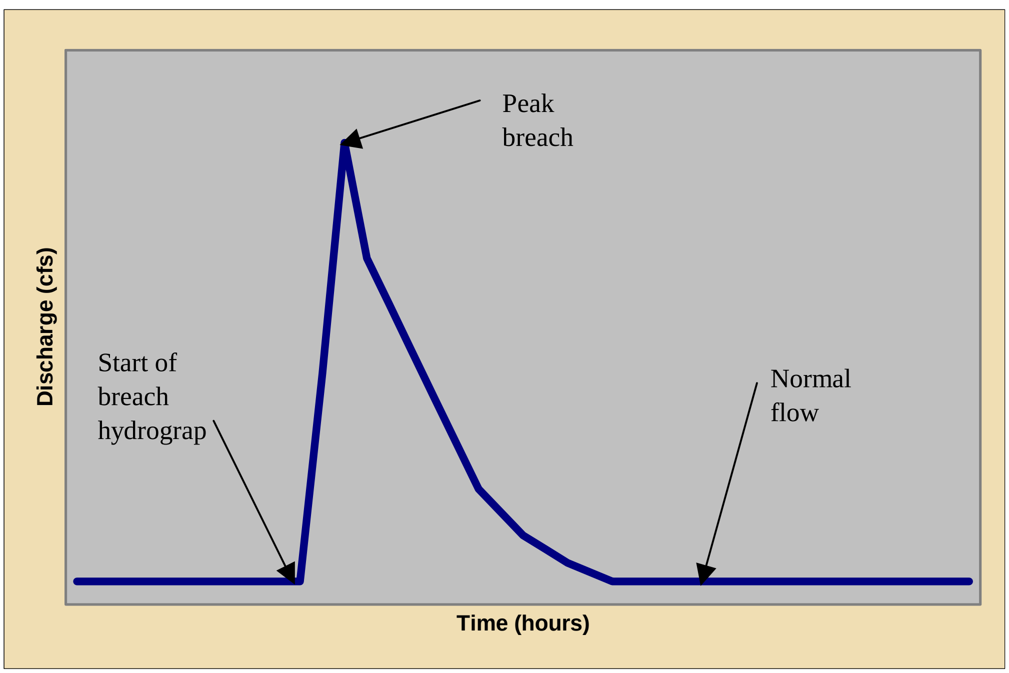
#### 5.1.1.1 Travel Time

Since a flood wave is a dynamic and unsteady phenomenon, describing it in terms of time can be ambiguous. The most important detail about a breach flood wave for emergency personnel is the time it takes for the flood wave to travel from the dam to a point of interest downstream of the dam. But many questions arise when identifying travel time, such as:

- What is considered the "start" of a failure breach? Is it the time at which the first flows leave the dam or is it the peak of the breach hydrograph at the dam?
- Is the time at which the flood wave arrives at a specified point downstream considered the time when flows first start to exceed normal base stream flows? Or is it when the peak of the traveling flood wave reaches the point?
- Can travel time start when notification to downstream residents is first given? What happens when notification is made after the dam has failed?

Understanding how a flood wave is represented and the different properties of the flood wave hydrograph are important. As shown in Figure 3, a typical flood wave or hydrograph, is defined as a graph plotting discharge (usually in units of cubic feet per second) versus time.

**FIGURE 3. TYPICAL BREACH HYDROGRAPH**



A hydrograph defines discharge at a point on a stream or river (or any channel or pipe that conveys a fluid). For normal stream flow, the hydrograph at a point would typically be relatively flat. But when the breach flood wave hits the point, flow dramatically increases to a maximum flow and then gradually reduces back to normal flow. The time at which breach flow starts at the point is the beginning of breach flow. The time at which the maximum flow arrives is peak breach flow. Breach hydrographs will vary with different dam and channel valley conditions.

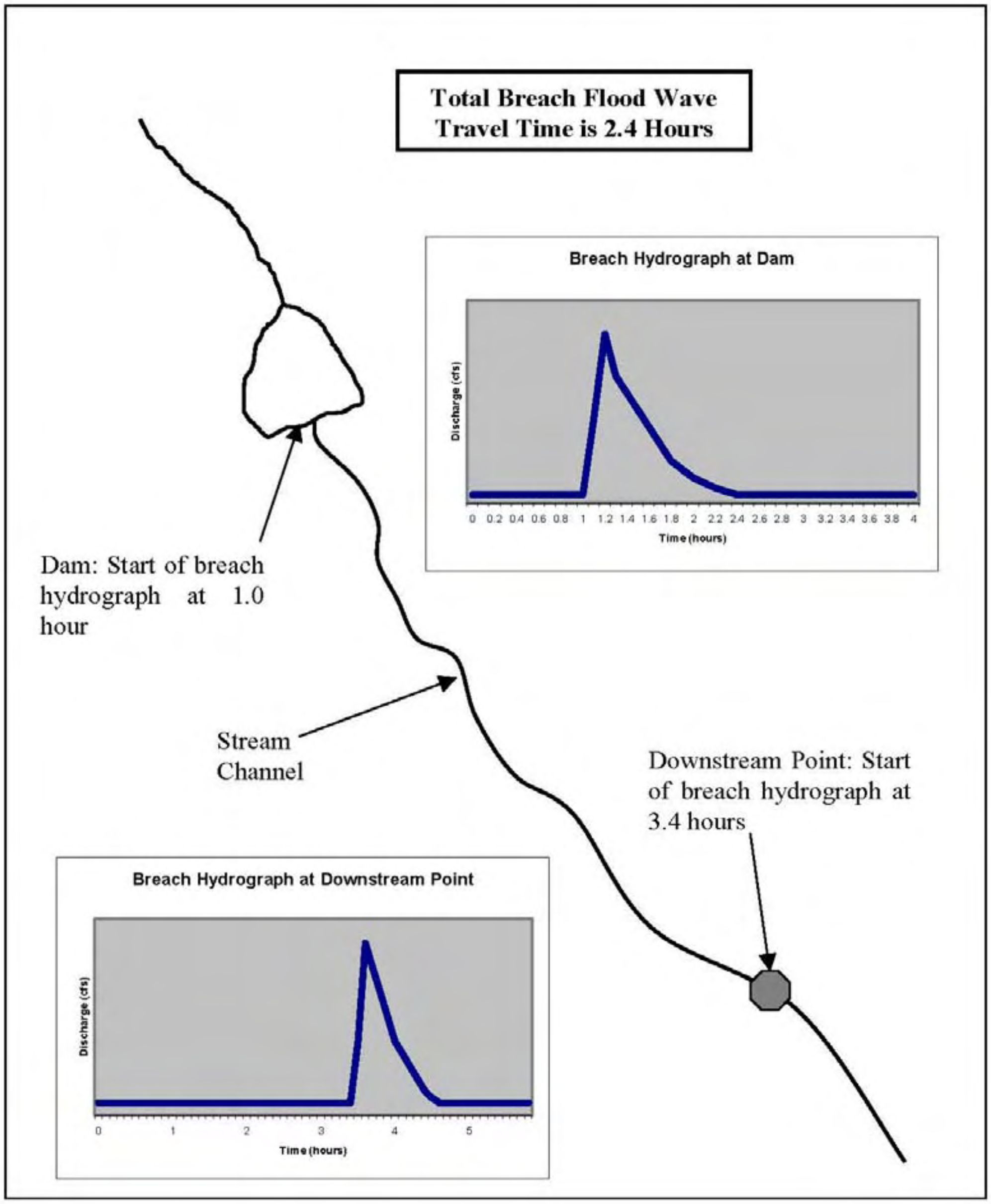
For purposes of simplified evacuation mapping, the Dam Safety Program defines breach flood wave travel time as the time from when breach flows first start at the dam to the time the breach flow arrives at a specified point downstream. This time will be determined by the HEC-HMS model results.

Figure 4 visually represents the definition of breach wave travel time according to the Dam Safety Program.

#### 5.1.1.2 <u>Caution in Displaying Wave Height</u>

Many existing evacuation maps display the height of the breach flood wave at various points along the downstream channel. While this data is descriptive and can convey the severity of a flood wave, it can also be misleading and confusing. The problem with this type of information is that the base of the flood wave at the point in question us usually not identified. Most of the time, wave height is measured from the bottom of the stream channel at the point in question but it is not always interpreted as such. A good example of how this can be misleading is described by Lemieux and Robinson (2008) where an emergency action plan tabletop exercise was conducted in a Montana community. A local newspaper covered the story. The next day it was obvious the newspaper reporter misinterpreted the data in the emergency action plan maps. Lemieux and Robinson state, "… A newspaper report after a recent tabletop exercise stated that 'the high school would see a 24-foot wall of water.' In reality, the water at the high school was only two to six feet deep. The '24-foot depth' shown on the map used by the reporter referred to wave height with respect to the stream bottom."

**FIGURE 4. DEFINITION OF BREACH FLOOD WAVE TRAVEL TIME**



The Dam Safety Program recommends not displaying wave height information on evacuation maps. The flood boundary shown on the maps represents the highest water elevation of the flood wave, which occurs during the peak breach discharge. More information than the flood boundary related to wave height could be confusing.

### 5.1.2 Flood Boundary Delineation

HEC-HMS flood routing using the Muskingum-Cunge method is accomplished by inserting stream channel and overbank cross sections with the eight-point method. As mentioned in Section 4.1.3, each cross section represents a homogeneous reach of the stream channel. But, flood wave information is generated for the cross section at the location specified. So the results show hydrograph and stage (elevation) data at the cross section location only. The maximum stage at each location determines the flood boundary on the evacuation map. But the results from HEC-HMS are only represented on a map as two points on either side of each cross section at the maximum stage or elevation from the hydrograph. It is up to the user to interpolate the flood elevation surface between the cross section locations. The most common interpolation method is to follow the elevation contours of the base map, accounting for the flood water surface slope between cross sections. This can be done digitally or manually, depending on the software resources available to the user. Backwater behind roads or bridges need to be accounted for. A discussion on this is found in Sections 4.1.4.4 and 5.1.3.5.

The flood boundary on the map should be easy to identify and clearly marked. It should be bold enough or brightly colored to avoid confusion with contours, stream lines or roads on the map.

### 5.1.3 Infrastructure Identification

The following sections discuss infrastructure that may be considered for identification on evacuation maps. Important infrastructure is generally described as roads, bridges, critical infrastructure such as hospitals, and evacuation routes. Infrastructure identification should be coordinated with local emergency personnel.

#### 5.1.3.1 <u>Inundated Roads and Bridges</u>

Maps should be clearly marked where roads and bridges are inundated. The information provided should also include road closure sections and where road blocks should be placed. In the case of road crossings over streams and rivers, even if the bridge or culvert opening is modeled as passing the breach flood, the bridge should be closed in the event of a dam failure because of the potential for pier scour and debris jams in the bridge or culvert opening. An example of an inundated road and bridge are shown in Figure 5.

#### 5.1.3.2 <u>Inundated Critical Infrastructure</u>

If facilities such as hospitals, government buildings or other places where relatively large numbers of people congregate are inundated by the breach flood, they should be identified on the evacuation maps. Information useful to emergency personnel should be included on the map as shown in Figure 6.

#### 5.1.3.3 <u>Evacuation Routes</u>

Evacuation routes for residents need to be shown on evacuation mapping. While this may seem obvious to those looking at a map, this type of information will help emergency personnel provide instructions to residents during a stressful time where many things are happening at once. It will provide directions to residents that will steer them away from danger and warn them not to travel into potentially inundated areas. An example of identification of an evacuation route is provided in Figure 7.

#### 5.1.3.4 <u>Isolated Areas Not Inundated</u>

A unique feature of simplified evacuation maps is delineation of areas that are not susceptible to inundation but require evacuation because the breach flood would isolate the area because access routes would be cut off. Typically, these areas are delineated by dashed boundaries or some other form of identification that distinguishes it from the inundation flood boundary.

An example of identifying isolated areas requiring evacuation is shown on Figure 8.

**FIGURE 5. EXAMPLE ROAD AND BRIDGE CLOSURE FOR INUNDATION MAPPING**

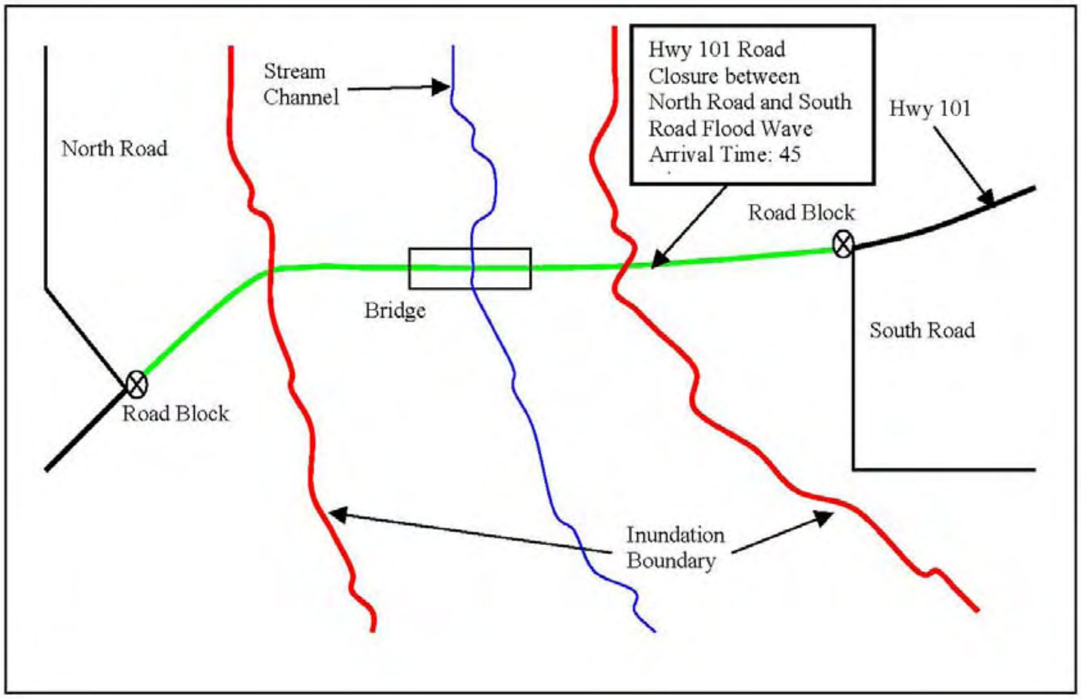


**FIGURE 6. EXAMPLE CRITICAL INFRASTRUCTURE IDENTIFICATION FOR INUNDATION MAPPING**

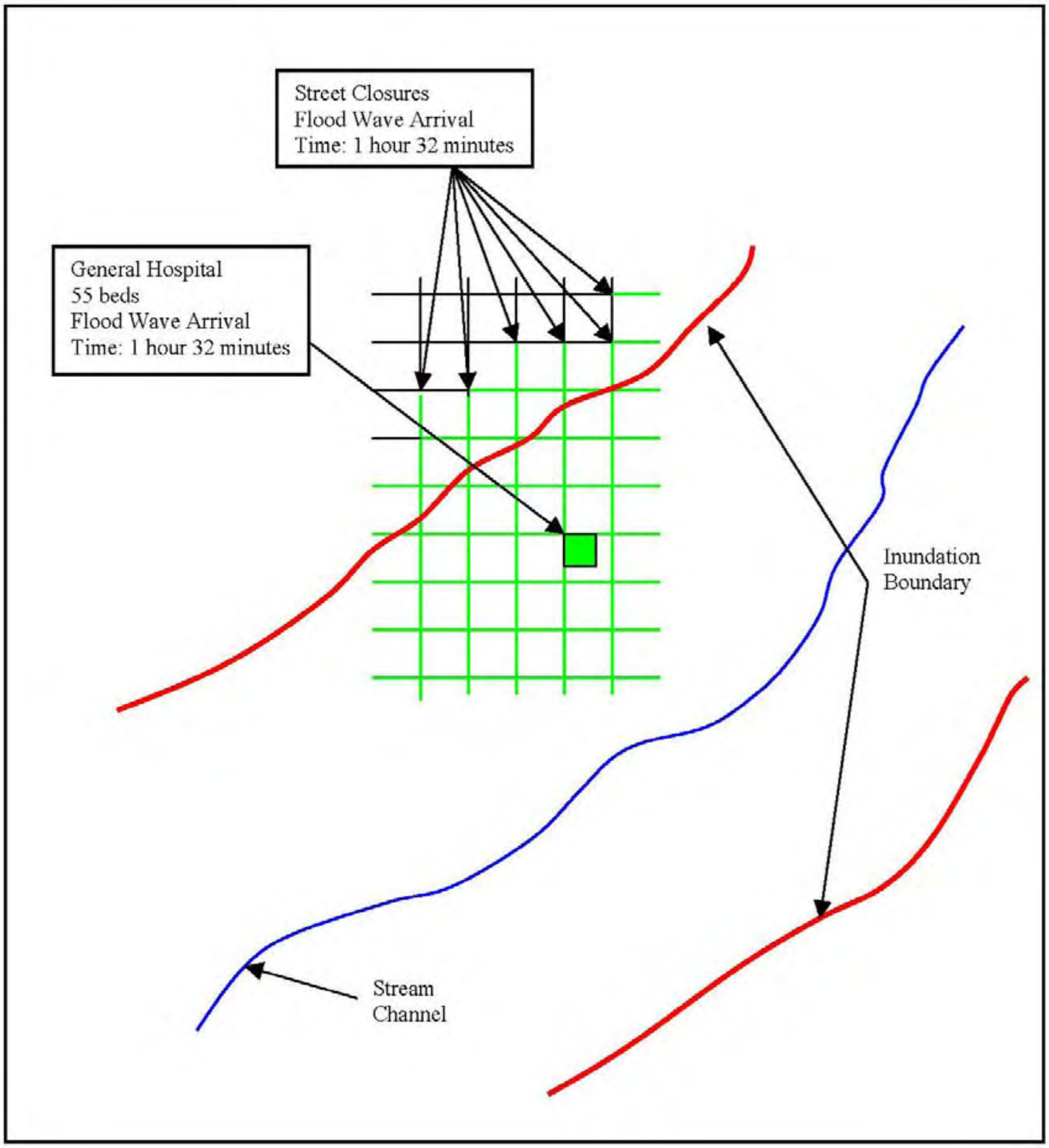


**FIGURE 7. EXAMPLE EVACUATION ROUTE IDENTIFICATION FOR INUNDATION MAPPING**

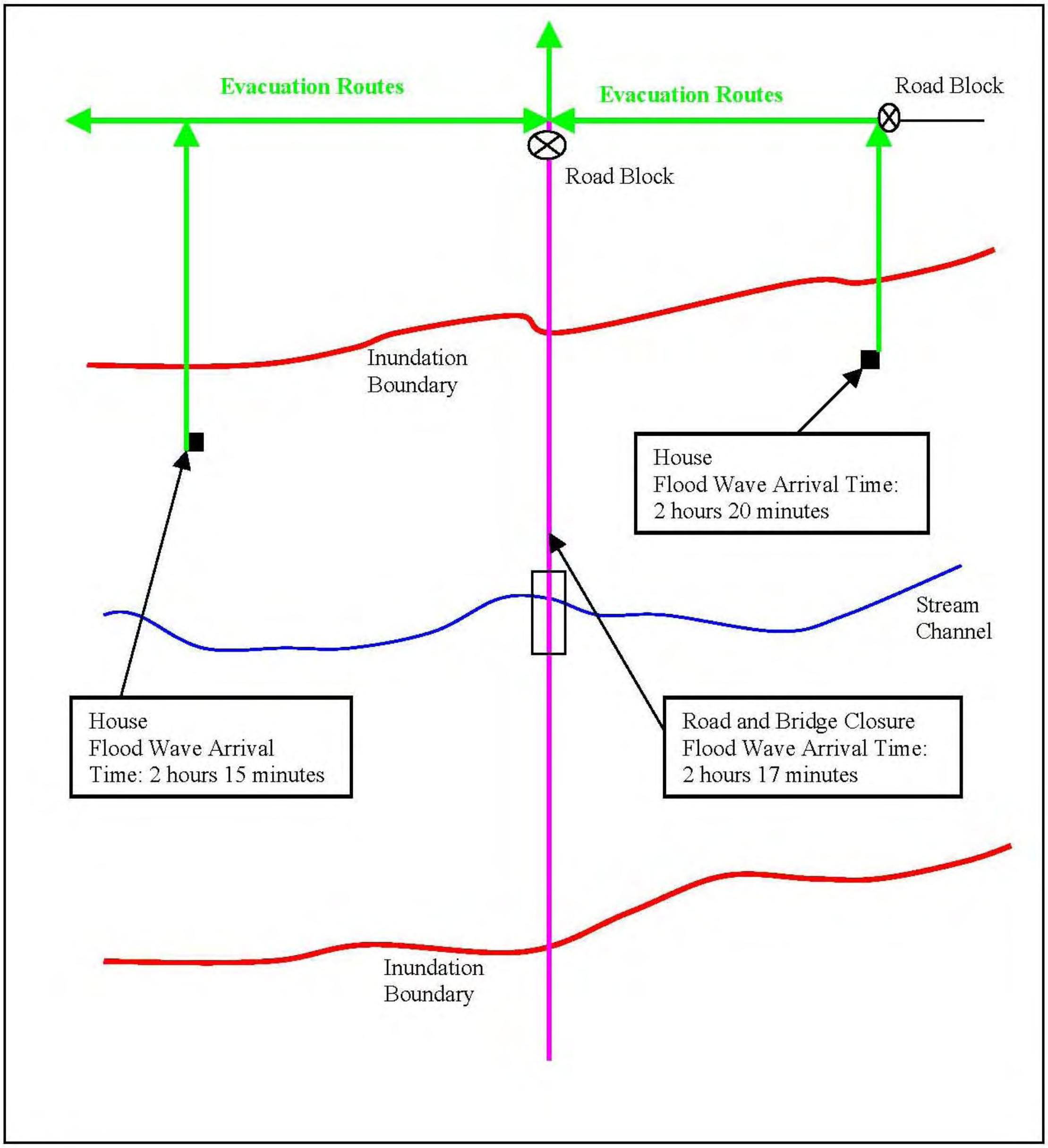
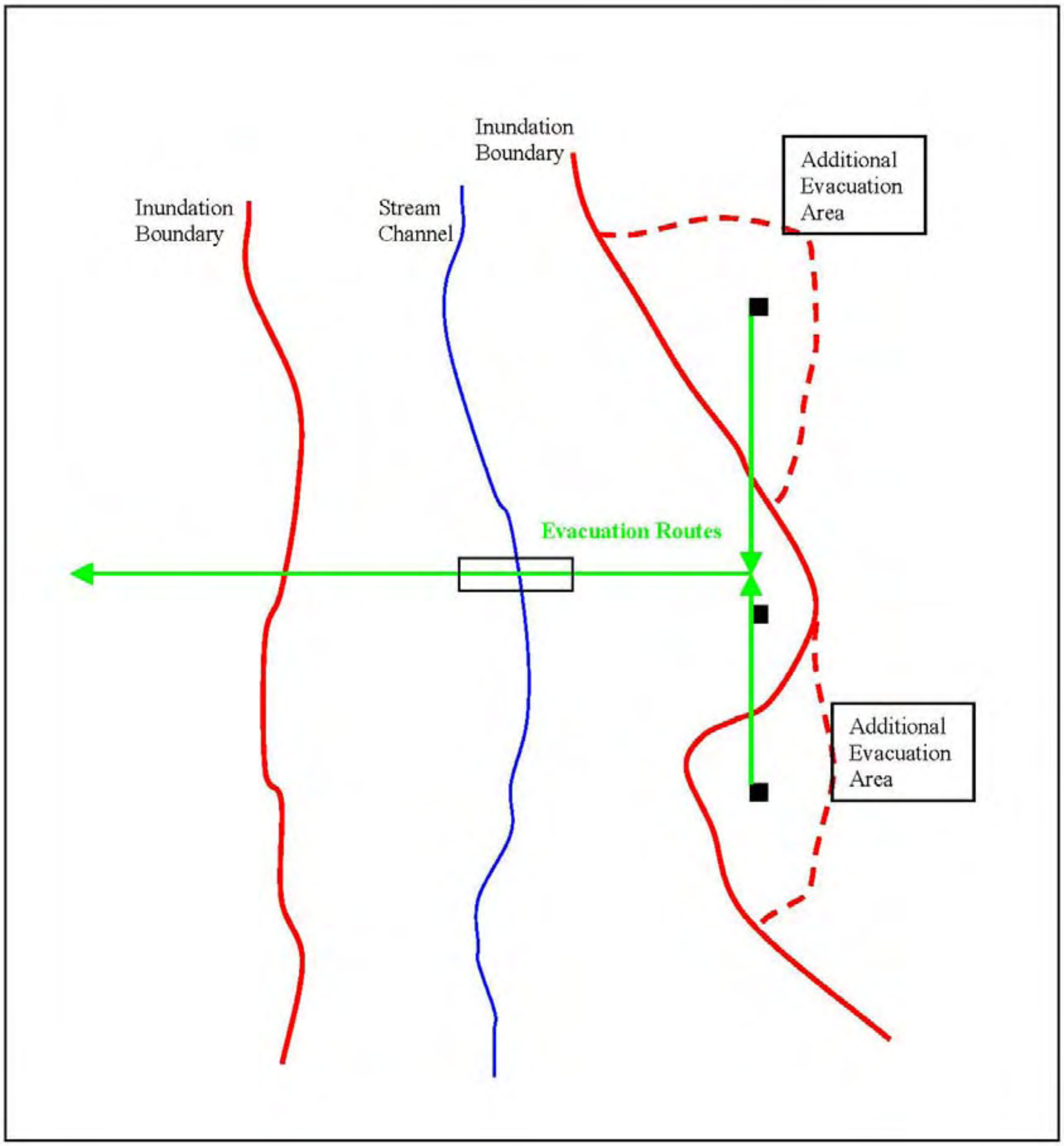


**FIGURE 8. EXAMPLE ADDITIONAL EVACUATION AREAS IDENTIFICATION FOR INUNDATION MAPPING**



#### 5.1.3.5 Other Areas Susceptible to Inundation

It is important to remember that, unlike HEC-RAS, HEC-HMS does not perform standard step water surface profile computations and will not compute backwater surface profiles due to obstructions or constrictions in the floodplain. It is possible to obtain HEC-HMS water surface elevation results at a point that are higher than upstream water surface elevations because water surface determinations are based only on data at the point only and are not affected by upstream or downstream water surface profiles. So relying only on HEC-HMS routing results may not provide inundation data for all areas potentially susceptible to flooding. Probably the most common areas for which this is true are backwater areas upstream of road crossings. For areas that have the potential for backwater, it recommended that a HEC-HMS analysis be performed to better define the backwater profile, as discussed in Section 4.1.4.4. This is accomplished by modeling the road as a dam and the upstream inundation area as a reservoir. Another way to accomplish this is to model the crossing using HEC-RAS. This is done by using the peak flow at the point from the HEC-HMS output combined with HEC-RAS cross section geometry data at the point in question. However, a HEC-RAS analysis will require more data, such as a detailed survey of the crossing and surrounding area, which will add to the cost of the analysis. If few hazards exist in a backwater area, it is acceptable to estimate backwater elevation to equal the elevation of the top cord of the bridge or road. It is also acceptable to assume the bridge is washed out (which is often the case).

Other areas, such as backwater into tributaries or other low-lying areas adjacent to the main floodplain, are also susceptible to backwater inundation.

## 5.2 INPUT FROM EMERGENCY PERSONNEL

To make simplified evacuation maps effective and usable by their target audience, it makes sense to have appropriate emergency personnel review the maps and provide input on their content. This should be done after a preliminary analysis has indicated areas most susceptible to flooding from a dam breach and indicated most infrastructure affected by flooding. Face-to-face meetings with emergency personnel are most advantageous in order to convey the goals of mapping from both the engineering and emergency response perspectives.

Emergency personnel likely to be involved include the county disaster and emergency services representative, and sheriff and police office representatives. The appropriate emergency individuals should meet with the engineer responsible for the breach flood modeling, the dam owner and possibly a representative from the Dam Safety Program.

Emergency personnel may have a wide range of comments on the maps, but input will likely be focused on identification of evacuation routes, road closures, and affected facilities, as well as notification processes and resident listings.

## 5.3 LIMITATIONS OF GIS

Be cautions with the use of GIS digital elevations model (DEM) data to draw your evacuation boundaries. For Montana, DEM's are commonly at 10 meter spacing. Using high spacing DEM's for contouring can result in erroneous boundary results. It has been the experience of the Dam Safety Program that the quickest and most accurate way of mapping evacuation boundaries in GIS is using USGS 7.5 minute quadrangle maps as a base layer and double checking elevations with a DEM.

## 5.4 MAP METADATA

Map metadata refers to data about the map data. In other words, map metadata are descriptive information about the elements of a set of data that make up the map and its contents. The Dam Safety Program has developed a simplified Metadata template shown in Appendix C. While this type of information may seem redundant or not worthwhile, it is very important that the map author provide metadata to clearly identify map contents and data sources that explain the limitations of such data and to aid in reproduction of the maps and results. This will also help engineers call on during an emergency to understand assumptions that were made in developing the maps. It is not recommended that metadata reside on or with the map; the information within metadata is not usually meaningful to emergency personnel and would likely be confusing. But footnotes that direct the user to where metadata resides will be helpful from the perspective of the modeler and the map developer. An appendix in the emergency action plan with other supporting documentation is a good place to put Metadata.

# 6.0 WHEN ADVANCED MODELING MAKES SENSE

When will simplified methods not meet the needs of an evacuation map? As much as the Dam Safety Program tries to make mapping affordable for owners and effective for emergency personnel, situations may arise where simplified mapping is not appropriate. For those cases, more complex modeling techniques are required. Owners of dams where advanced modeling are appropriate need to realize that potential effects of the breach of their dam are serious and more detailed analyses will greatly enhance the effectiveness of the mapping. This section focuses on situations where advance modeling are needed; data requirements for advanced modeling; and some of the available models for advanced mapping.

## 6.1 SITUATIONS WARRANTING ADVANCED MODELING

Some cases of breach flood modeling require modeling beyond the capabilities of HEC-HMS. The goal of evacuation mapping is to save lives in the event of a dam failure. It may require an advanced model to identify all areas susceptible to flooding, or to protect the lives of affected residents. The following are descriptions of at least some situations that warrant advanced modeling of breach flows. The following list is not comprehensive and other situations not on the list may arise that qualify for advanced modeling:

1. Dense population centers. In areas where housing or other facilities are located within close proximity to each other, it is important to define the breach flood boundary as accurately as possible to first of all include all areas potentially susceptible to breach flooding, and then to prevent unnecessary evacuations because of cost and the potential impact to emergency resources and facilities.
2. Areas of braided streams, river deltas or alluvial fans. Where flood waters are conveyed in floodplains that are relatively flat, wide-spread or concave in shape (as in the case of an alluvial fan), flood simulation is complicated and may not be adequately defined with a one-dimensional, quasi-unsteady flow model, such as HEC-HMS. Flow may extend in two dimensions and may require extensive data input for two-dimensional modeling.

3. Areas with populations located in areas of backwater. As mentioned in Section 5.1.3.5, HEC-HMS does not compute backwater effects from obstructions in the floodplain. To model this requires a program capable of backwater computations, such as HEC-RAS. Judgment may be needed to determine if more advanced modeling is warranted. More than a few houses or business in backwater zones would require a more sophisticated model.
4. Areas adjacent to critical infrastructure. For facilities that are not necessarily within large population centers, but whose function is critical for the well being of the general public, breach flood mapping should be as accurate as possible. As mentioned previously in this technical note, critical infrastructure can include hospitals, emergency government buildings such as law enforcement centers, or power plants.
5. Areas of flat topography. Slight changes in topography or minor obstructions in relatively flat areas may affect breach flood elevations to a greater extent than in areas with steeper stream channel gradients. More advanced modeling may be needed to define changes in flat topography, as well as define potential flow in two dimensions.

## 6.2 DATA REQUIREMENTS

In general, advanced modeling requires more intense and extensive topographical and ground cover data. Advanced modeling programs can be categorized in two general types of unsteady flow models: one-dimensional (1D) and two-dimensional (2D).

One-dimensional flow is only in the downstream direction on a horizontal plane. One-dimensional models typically rely on geometry data in the form of stream and floodplain cross sections, with cross section data points consisting of distance and elevation values. Accuracy depends on the number of data points, which should include ground grade breaks along the cross section.

Two-dimensional flow is in both the downstream and lateral (perpendicular to downstream) directions in a horizontal plane. Two-dimensional models use geometry data points in the form of a grid over a surface area. Grid size determines accuracy whereby smaller grids will more accurately define topography, soil and ground cover data. However, small grid sizes significantly increase the model file size and computational requirements. Most 2D models use a geographical information system (GIS) to generate the grid, or mesh, from digital topographic data. The data can sometimes come from available sources (in Montana, available GIS data can be found on the Natural Resource Information System (NRIS) website at http://nris.mt.gov/gis/) or can be generated from mapping provided by surveying or photogrammetry. GIS also has the advantage of potentially including layers of information related to soils, land use and ground cover.

## 6.3 MODEL OPTIONS

If advanced modeling is necessary, there are several software options to assist the user. Modeling can be in one dimension, meaning that computations take place only in a downstream horizontal direction, or in two dimensions, where computations are in the downstream and lateral directions in the horizontal plane. Intuitively, two dimensional (2D) modeling will add another layer of complexity to computational algorithms compared to one dimensional (1D), increasing software costs, hardware requirements, computational time, and data requirements.

### 6.3.1 One-Dimensional Models

For 1D modeling, the two most common programs are HEC-RAS and FLDWAV. HEC-RAS is more widely used than FLDWAV. HEC-RAS, developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center, is a 1D water surface profile program that has steady and unsteady flow capabilities. Breach flood routing would take advantage of the program's unsteady flow capabilities and also offers the advantage of performing backwater analysis for obstructions in the floodplain.

FLDWAV, developed by the National Weather Service (NWS), is very similar to the unsteady flow modeling of HEC-RAS. FLDWAV combines two NWS programs: DAMBRK, and unsteady flow model specifically designed for dam breach analysis; and

DWOPER, a water surface profile model used widely to conduct backwater analysis at bridges.

Both HEC-RAS and FLDWAV require considerable operator skill at performing unsteady flow analyses without causing computational rejection. Within each program, computational convergence is necessary to fulfill the equations for unsteady flow. Breach flows in particular have such rapidly varying flow that the programs have a tendency to stop the computational process without convergence.

### 6.3.2 Two-Dimensional Models

A number of programs are available to conduct 2D unsteady flow analysis. The following are two of the common 2D programs used currently:

- Storm Water Management Model (SWMM) (USEPA, 2009) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas, including the capability to conduct 2D modeling of unsteady flow for flood analyses.
- Finite Element Surface Water Modeling System (FESWMS) (USDT-FHWA, 2003) is a multi-dimensional modeling system that is used for one and two dimensional analysis of surface water flow. The system supports modules FST1DH and FST2DH (Flow and Sediment Transport in one and two dimensions, respectively) used in floodplain and bridge hydraulic modeling. FESWMS can be used with the commercially-available graphical interface Surface Modeling System® (SMS) available from Environmental Modeling Systems, Inc.
- FLO-2D is “a dynamic flood routing model that simulates channel flow, unconfined overland flow and street flow. It can simulate a flood over complex topography and roughness while reporting on volume conservation; the key to accurate flood distribution. The model uses the full dynamic wave momentum equation and a central finite difference routing scheme with eight potential flow directions to predict the progression of a flood hydrograph over a system of square grid elements” (FLO-2D, 2010).

## 7.0 DEFINITIONS

The following definitions are offered for terms used in Technical Note 3:

**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.

**Clear-Weather Breach –** Failure of a dam due to causes not related to storm inflow flooding. Also called sunny-day breach.

**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 Action Plan Exercise –** An exercise conducted with local and state officials to evaluate the effectiveness of a dam's an emergency action plan. Exercises can vary in length and complexity, from tabletop level to full simulated events.

**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.

**FLDWAV –** A computer program (Flood Wave) developed by the National Weather Service that a generalized flood routing program with the capability to model flows through a single stream or a system of interconnected waterways. Modeling of steady and unsteady flows is possible, including dam breach flows.

**Flood-Induced Breach –** Failure of a dam caused by overtopping during storm inflow flooding.

**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.

**Inundation Boundary –** A map boundary depicting the extent of flooding from a dam failure, corresponding to the maximum flood wave elevation.

**Newtonian Flow –** Fluid flow, in this case for water, characterized by a viscosity that is independent of strain rate; the rate of strain is directly proportional to the shearing stress. Shearing stress, or frictional head loss, increases with flow discharge and velocity.

**Non-Newtonian Flow –** Fluid flow whose properties are not described by a single constant value of viscosity and the relation between the shear stress and the strain rate is nonlinear, and can even be time-dependent. Therefore a constant coefficient of viscosity cannot be defined. Non-Newtonian flow occurs only when a minimum force applied to the fluid is exceeded.

**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.

**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.

**Wave Height –** The vertical height of the peak of a flood wave. For a breach flood, wave height is the peak of the flood wave at a point along the downstream channel below a dam.

# 8.0 REFERENCES

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# APPENDIX A

# EXAMPLE HEC-HMS BREACH ROUTING MODEL

# APPENDIX B

# EXAMPLE SIMPLIFIED EVACUATION MAP

# APPENDIX C

# SIMPLIFIED EVACUATION MAP METADATA TEMPLATE

# METADATA Documentation for Emergency Action Plan Maps

## Identification Information

| | |
|---|---|
| Map Title: | |
| Geographic Area Covered | |
| Purpose: | |
| Rules for use | |
| Last update date | |

## Data Quality Information

| | |
|---|---|
| Engineering model(s)<br>*(Include dates)* | |
| Unit of measure | |
| Description of Storm Event (s)<br>*(Include citation of reports used to develop storm events)* | |
| Starting reservoir water surface elevation(s) | |
| Source of cross section data<br>*(USGS topo maps, surveyed data)* | |
| Accuracy of cross section data<br>*(40 ft contours, survey grade, etc.)* | |
| Source of reservoir characteristic data<br>*(estimated off USGS topo maps, detailed survey, original design etc.)* | |
| Accuracy of reservoir characteristic data<br>*(rough estimate, detailed survey etc.)* | |
| Other engineering assumptions<br>*(range of mannings n, antecedent conditions, spillway discharge, etc.)* | |
| Engineer (s)<br>*(Firm or engineer who completed analysis. Include contact information if appropriate)* | |
| Location of data, reports, model runs | |
| Modification(s)<br>*(Summary of modifications to maps, include dates and who made modifications)* | |

## Spatial Data Organization Information and Spatial Reference

*(if maps are in a GIS database, cite location of database and organization that maintains the database.  If maps are not in a GIS, leave this section blank)*

| |
|---|
| |

## Entity and Attribute Information

*(describe units and reference for measurement)*

| | |
|---|---|
| Channel distance | |
| Flow | |
| Wave height | |
| Travel time initial | |
| Travel time peak | |
| Velocity | |
| Other | |

## Distribution Information

| | |
|---|---|
| Contact Information: | |
| Available Formats: | |
| Disclaimer: | |