EVACUATION vs. INUNDATION:

WHICH MAP SHOULD YOUR EMERGENCY ACTION PLAN CONTAIN?

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INTRODUCTION

This article makes a case for using simple conservative evacuation maps in dam emergency action plans instead of the detailed inundation maps that are commonly used. Six "lessons learned" from Montana's experiences with tabletop exercises and a survey of local emergency responders are used to make the case.

ONE SIZE DOES NOT FIT ALL

It is important to clarify what is meant by "inundation map" in terms of emergency action planning. There are several levels of inundation mapping:

- Inundation mapping for design or rehabilitation must be detailed, often including an inflow design storm.
- Excess conservatism is not desired. Inundation mapping for subdivision planning may require a smaller more frequent inflow design storm.
- Inundation mapping for hazard classification is often based on a clear weather breach, which is non-conservative for other uses.
- In contrast, inundation mapping for emergency action planning must conservatively estimate who should be evacuated in a dam emergency, understanding that our current analysis techniques cannot take into account debris or other uncertainties that might raise flood water levels.

In the remainder of this paper, the terms "inundation mapping" refers to inundation mapping for emergency action planning.

LESSONS LEARNED

Existing Montana Emergency Action Plan (EAP) maps show two inundation boundaries, one from a clear weather breach and a second from a flood-induced breach. Included at downstream cross-sections is a variety of information, such as peak flow, wave height, time to peak and velocity. Tabletop exercises conducted throughout the state revealed many problems with the early maps. A survey of local emergency managers yielded additional feedback about the EAP maps. The tabletop exercises and the survey led to six key points that justify using simple conservative evacuation maps instead of the existing detailed inundation maps.

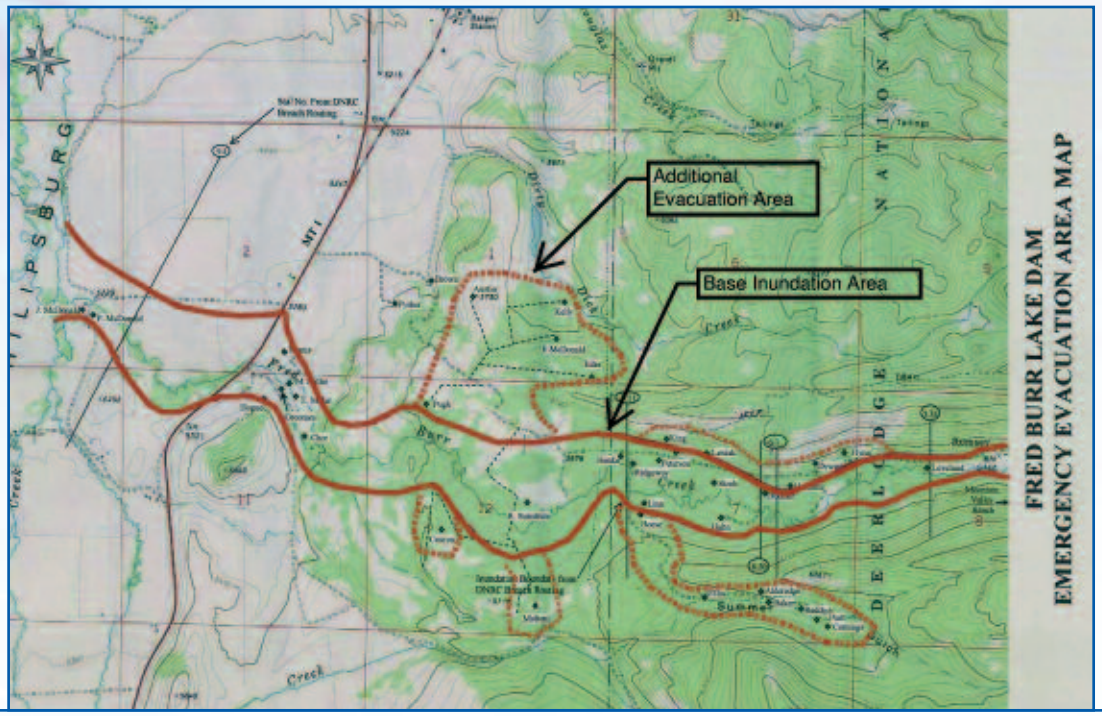

FIGURE 1: Evacuation map showing base inundation area and additional evacuation areas

Lesson 1: Include only one evacuation line on EAP maps. Multiple boundaries are a source of confusion.

Emergency planners may need to act decisively in a short period of time. An engineer is not always readily available to assist emergency managers in interpreting complex maps, especially in rural areas. The original intent of including a clear weather breach and a flood induced breach is to provide emergency managers with best and worst case boundaries for evacuation purposes. However, Montana has found that having more than one line on the map leads to confusion over the proper area to evacuate for the situation at hand. The assumptions behind the various inundation lines are not well documented and often not apparent to local county responders. In addition, the accuracy of the engineering models used to delineate inundation boundaries is typically low. Most dam owners do not have the resources required for detailed surveying of downstream areas. In many cases some of the data is taken from USGS topographic maps with 40-foot contours. The models also do not take into account the effects of debris jams. As a result, flood water levels calculated by engineering models can be off by several feet. Showing a variety of "inundation areas" on a map implies a certain level of accuracy that often does not exist.

In response to these concerns, Montana is opting to include only one evacuation line on the maps, so that knowledge of the assumptions behind the inundation mapping is not necessary. As discussed below, this sole evacuation line will be based on a conservative maximum pool breach inundation area.

For larger dams with significant population at risk, collecting detailed survey data and running more complex models to develop detailed inundation boundaries may be warranted. This can help with evacuation planning. Frank (2008) discusses how detailed inundation mapping would have helped with the return of evacuees following the emergency at Lake Needwood Dam. However, for most small and medium sized dams, having a single evacuation line is adequate.

Lesson 2: Emergency planners prefer to have all of the information they need to complete an evacuation included on the maps. This includes showing residences that are cut off but not inundated, and bridges that likely pass the flood but should be closed because of the potential for clogging by debris. Don't assume that fine print in the EAP detailing the assumptions behind the map will be read in an emergency.

Sometimes access to houses is cut off but the houses themselves are not inundated. Sometimes a road or culvert passes the flood wave, but most certainly would need to be closed. However, engineers are not in a position to make these decisions – this must be done by the local emergency managers.

Montana is starting a procedure where a "base" single line inundation map is taken to a meeting with local officials to discuss other areas of evacuation. The map is then marked with dotted lines as "areas to be evacuated but not may not be inundated". The map is further refined during a tabletop exercise. The evacuation map and plan is a collaborative effort with the engineer, dam owner, and emergency planners.

Figure 1 shows the evacuation map of a medium sized mountain dam in western Montana. Following a tabletop exercise, a number of areas were identified as needing evacuation, but would likely not be inundated.

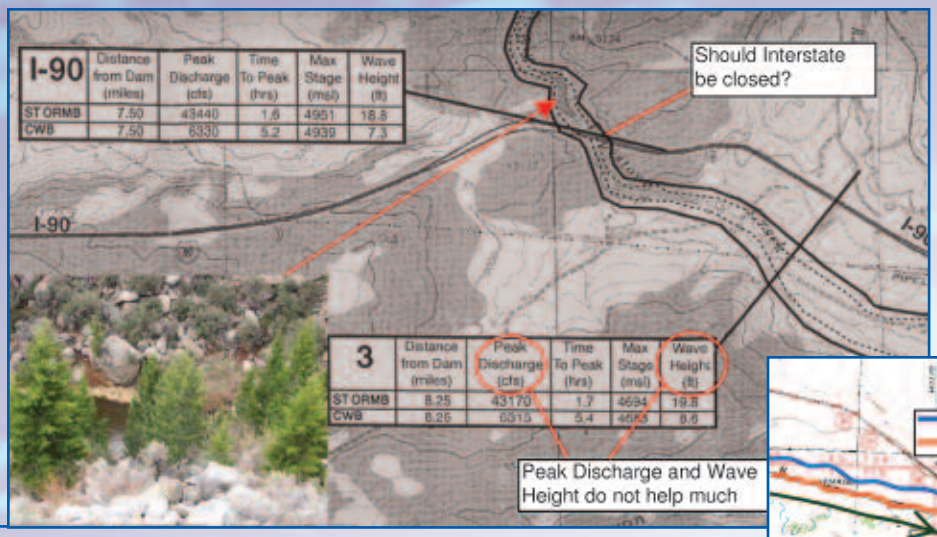

FIGURE 2: Information on an evacuation map must be useful to emergency managers.

FIGURE 3: Debris may force the breach flow outside of the clear weather breach boundary.

Lesson 3: Only include information on maps that is usable to emergency managers and make sure that information is consistently defined.

Often times, the information shown on the map downstream of the dam (time, peak flow, wave height, velocity) is misunderstood. Different agencies have different interpretations for data. For example, wave height is sometimes measured with respect to channel bottom, and sometimes with respect to the channel over bank. Actual wave height is dependent on the amount of debris and other factors. Although wave height seems like a valuable piece of information, its usefulness is limited. 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.

Time to flood wave arrival can also be misleading. Sometimes it is peak flood wave arrival and sometimes it is first flood wave arrival. Is the time for the dam to breach included in this measurement? Sometimes it is; other times not. Peak flow and velocity are also commonly included on the maps, but we have found this information has little value to emergency managers. The evacuation maps can be simplified by showing only the time when the breach flood wave first arrives at certain locations downstream—in other words, the time emergency managers have to evacuate people before the water arrives. This is measured from the start of the breach flow at the dam to the time when the flood wave first arrives downstream at a particular cross-section.

When reviewing an evacuation map, one must ask the question, "Is there too much information or not enough information available?" The map in Figure 2 contains wave height, peak flow, and time to peak, all of which have limited value for guiding an evacuation. A more important piece of information (Should the Interstate be closed?) is omitted. The photo insert showing the canyon upstream of the dam indicates that debris will certainly play a role. These are all decisions that should be discussed as the dam owner, engineer and emergency planner develop the map.

Lesson 4. Clear weather breach maps can underestimate evacuation area, and should not be used for evacuation planning.

Debris and other factors can increase the flood wave height above the clear weather breach line, which is based on normal reservoir elevation instead of top of dam. The engineering models used to develop the inundation maps do not take debris jams into account. In addition, the elevation information used in the engineering models is often taken from USGS topographic maps with 40-feet contours. The results can be in error by several feet. Montana is opting to no longer base evacuation maps on the clear weather breach.

Figure 3 illustrates some of the problems with use of clear weather breach maps for the inundation area below another western Montana dam. The modeled flood wave goes through a trailer park before going through the City of Whitehall. Debris will undoubtedly raise the water level. During the tabletop exercise, it was noted that Highway 287 could also direct water into downtown Whitehall, which is outside of the clear weather breach area. If you are an emergency manager, what line do you use to evacuate? If you choose the clear weather breach line, you might miss some folks. Use of the probable maximum flood (PMF) breach may result in an evacuation area that is too large. As described below, use of an evacuation area with a top-of-dam breach may be just the right balance of conservatism.

CIRCLE 3 ON READER INFORMATION CARD

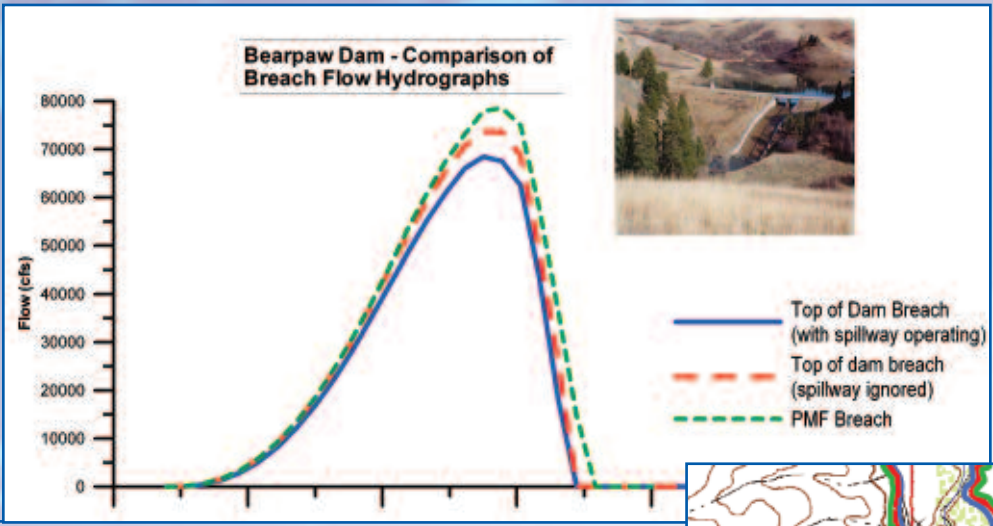

FIGURE 4A: Neglecting the spillway or routing the PMF does not significantly change peak breach flow for Bearpaw dam

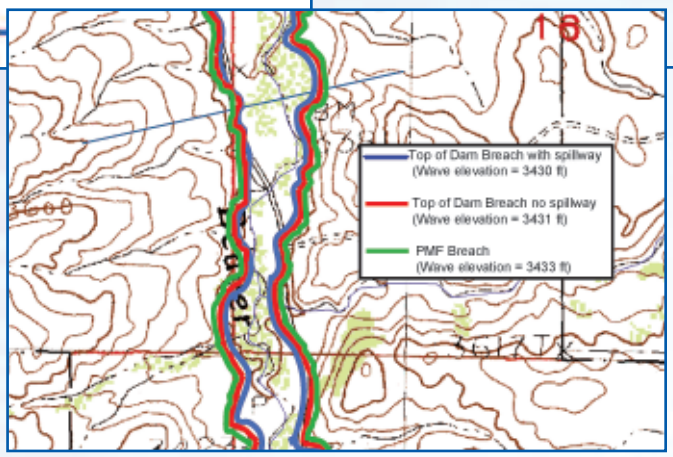

FIGURE 4B: Varying the dam breach scenario has little impact on the Bearpaw dam evacuation boundary

Lesson 5. The cost of developing a new EAP map must be reasonable. Using a "hydrology free" top of dam breach flood wave as a basis for the evacuation map is appropriate for most small and medium sized dams and provides significant cost savings.

Developing inundation areas for inflow design storm induced breaches can be expensive, and in some cases cost prohibitive for dam owners required to develop an EAP. A recent survey of states by the National Dam Safety Review Board showed that one of the main problems with EAP compliance is the high cost of developing an EAP map. Calculation of the inflow design flood in itself can require several days of analysis. Montana is recommending that a top of dam breach, ignoring spillway or outlet flows, be used as a basis for the evacuation maps contained in an EAP. This eliminates the need for hydrology or development of a spillway/outlet rating curve, and provides a big cost savings. The resulting area is generally conservative, and eliminates any guesswork about the effects of debris on wave height. Use of a top of dam breach can be looked at as a "safety factor" to account for uncertainties.

Choosing cross-sections from USGS topographic maps as opposed to collecting detailed survey data is also appropriate and cost effective when the end result is an evacuation map. This approach may not be adequate for the other types of inundation mapping such as for a hazard evaluation. However, for EAP mapping, it is an appropriate cost savings measure for small to medium sized dams.

Figure 4a compares breach flow hydrographs for Bearpaw Dam, a 616 acre foot dam, near Havre Montana. A top of dam breach that ignores spillway flow results in only a 7% larger peak flow than a top of dam breach where spillways are assumed to be operating. For comparison purposes, the Probable Maximum Flood (PMF) breach flow is also shown. Ignoring spillway flows reduces the complexity of the dam breach model which results in a cost savings.

Figure 4b compares inundation areas 2.6 miles downstream of Bearpaw dam for the three breach flow hydrographs shown in Figure 4a. In developing an evacuation map for this dam, the effort (and cost) to include spillway flows, collect detailed survey data or calculate and route an extreme storm event is clearly not warranted.

For large dams, or flood control structures with large amounts of freeboard, the difference in evacuation area between a top of dam breach and a storm induced breach can be significant. For these situations, using a top of dam breach or ignoring spillway flows may not be appropriate. However, for the majority of small to medium sized high and significant hazard dams, using a top of dam breach with no spillway flow as a basis for the evacuation map is adequate.

Lesson 6. All EAP maps must have documentation in a standard format. EAP documentation must record all engineering assumptions, modifications made by emergency planners, source of original data, and level of accuracy.

Often it is necessary for map users to be able to reference assumptions and engineering methods that were used to develop the maps. In addition, maps get gradually modified over time (converting to a GIS, reproduction, changes in initial engineering assumptions or dam configuration and changes made to evacuation boundary by local emergency managers). A standard and consistent format of EAP map documentation is needed to address these issues.

The Federal Geographic Data Committee (FGDC) has developed a standard format of map documentation that is used widely in Geographic Information System applications, called METADATA.

All maps developed by state and federal agencies are required to have associated METADATA. METADATA defines data source, where original data is stored, the creator of the original data, the datum, accuracy, assumptions, and provides a long term record of changes. Montana used FGDC standards to develop a METADATA template which is included as an appendix in each EAP.

Although Montana's EAP METADATA template has been simplified when compared to standard METADATA, it is compliant with federal standards. It would be helpful if a standard user-friendly EAP METADATA template was developed for use nationwide.

SUMMARY

In an effort to provide conservative, simple, well documented, cost effective and useful emergency action plan evacuation maps, Montana is working towards adopting the following procedures:

1. EAP maps will contain a single evacuation line, based on a top of dam breach inundation area, ignoring spillway or outlet flows. Dams with large amounts of freeboard may need to consider spillway flows.

2. EAP maps must be reviewed by local emergency managers. Additional evacuation areas will be determined by local county officials and marked on map using a dotted line. Other critical evacuation information will also be marked on the map.

3. At selected distances downstream of the dam, the time of first flood wave arrival will be shown. If wave height is also shown on the map, a reference as to where it is measured from will be clearly spelled out.

4. All EAP's will contain FGDC compliant, easy to understand METADATA in the appendix which documents the origin of the maps, initial assumptions, the level of accuracy and all subsequent modifications.

5. For dams with a significant population in the evacuation area, more accurate surveying and modeling may be warranted. The simplified approach described in this paper may be acceptable as an interim measure.

REFERENCES

Bearpaw Lake Dam Emergency Action Plan

Delmoe Lake Dam Emergency Action Plan

Federal Guidelines for Dam Safety, Emergency Action Planning for Dam Owners FEMA 64, April 2005 http://www.fema.gov/plan/prevent/damfailure/fema64.shtm

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