SIMPLIFIED INUNDATION MAPS FOR EMERGENCY ACTION PLANS

National Dam Safety Review Board Emergency Action Plan Workgroup

EXECUTIVE SUMMARY

Development of Emergency Action Plans (EAPs) for all high and significant hazard potential dams in the United States is critical to reducing the risks of loss of life and property damage from dam failures. The high cost of detailed hydrology, dam breach and downstream routing engineering studies is consistently cited as the primary impediment to EAP development. Detailed studies may provide a more precise representation of potential flooding for a given set of assumptions, but not necessarily a more accurate representation of actual flooding should dam failure occur. For most small and intermediate size dams, simplified methods can provide useful inundation maps at a reduced cost. Simplified inundation maps (SIMS) are developed by either (1) employing simplified engineering assumptions and methods or (2) identifying potential at-risk residences on photo-based mapping without engineering analysis. SIMS can either form the permanent basis of emergency and evacuation planning or be used for the interim, until more detailed mapping can be obtained. Recommendations are presented to assist states and dam owners in developing (SIMS) for EAPs.

INTRODUCTION

The National Dam Safety Review Board (Board) monitors the safety of dams in the United States; advises the Administrator of the Federal Emergency Management Agency (FEMA) on national dam safety policy; consults with the Administrator of FEMA for the purpose of establishing and maintaining a coordinated National Dam Safety Program; determines with the Administrator of FEMA the amount of funds to be distributed to the states under the Dam Safety Act of 2006; and monitors state implementation of the dam safety assistance program.

The Board and the dam safety community recognize that development of Emergency Action Plans (EAPs) for all high and significant hazard potential dams in the United States is critical to reducing the risks of loss of life and property damage from dam failures. However, only about one-half of state regulated high hazard potential dams within the United States currently have an EAP.

At its January 2008 meeting, the Board voted to require states participating in the National Dam Safety Program to quickly address the high hazard potential dam safety issue. The Board voted to require that states increase by at least 10 percent each year the number of their state regulated high hazard potential dams with EAPs, with the goal of obtaining 100 percent EAP compliance of these dams by Fiscal Year (FY)2012. The Board also voted to require that states with less than a 75 percent EAP completion rate for state regulated high hazard potential dams reserve a portion of their grant funds from FEMA, beginning in FY 2008, for increasing their EAPs.

The Board formed the Work Group on Emergency Action Planning for Dams (Work Group) to evaluate, recommend, and monitor activities and initiatives to increase the number of EAPs at high and significant hazard potential dams and meet the goal for EAP compliance approved by the Board. An activity included in the Board approved plan of action for the Work Group is development of guidance documents to improve the EAP compliance rate.

The cost of detailed dam breach studies is consistently cited as the primary impediment to EAP development. Many states have accepted simplified and conservative inundation maps for use in EAPs. This guidance document is intended to assist states and dam owners in creation of simplified inundation maps (SIMS) for emergency and evacuation planning downstream of high and significant hazard potential dams. SIMS can either form the permanent basis of emergency and evacuation planning or be used for the interim, until more detailed mapping can be obtained.

SIMS are most applicable for small and intermediate sized dams with a limited number of homes downstream and where local emergency management agree that adequate evacuation procedures can be developed without more detailed inundation mapping. More detailed surveying or modeling may be warranted for large dams, those with a large population in the evacuation area or with significant downstream hydraulic complexities such as major diversion structures, split flows or potential for cascading dam failures.

Use of recommendations and methods presented in this guidance does not remove the need to comply with state or federal regulatory requirements, nor are they directed at inundation mapping for assessment of downstream hazard potential or for design or rehabilitation of dams. In all cases, EAP development should include close coordination with local emergency management to establish notification and evacuation procedures.

EMERGENCY ACTION PLANS FOR DAMS

An EAP is an essential document developed by the dam owner. The EAP is the primary safeguard in reducing loss of life from dam failure. The EAP identifies potential emergency conditions at the dam and specifies the pre-planned actions to be followed to minimize loss of life and property damage. The EAP contains procedures and information to assist the dam owner in issuing early warning and notification messages to emergency management authorities. The EAP also contains inundation maps to identify the areas subject to flooding in the unlikely event of dam failure.

In 1998, the Interagency Committee on Dam Safety prepared guidelines for emergency action planning for dam owners. This document, commonly known as FEMA 64 (reprinted 2004), describes the six basic elements of an EAP:

1. Notification flowchart
2. Emergency detection, evaluation, and classification
3. Responsibilities
4. Preparedness
5. Inundation Maps
6. Appendices

EAPs are critical in identifying areas downstream from dams requiring warning and evacuation in event of dam failure. Documented cases have demonstrated that warning and evacuation time can dramatically influence the loss of life. Loss of life can vary from 0.02 percent of the persons-at-risk when the warning time is 90 minutes to 50 percent when less than 15 minutes (Brown and Graham, 1988). Costa (1985) reported that the average number of fatalities per dam failure is 19 times greater when there is little to no warning.

DAM BREACH INUNDATION MAPS FOR EAPS

A dam breach flood inundation map is usually the most effective means of showing the timing and extent of expected flooding from dam failure. Dam breach inundation maps should be developed in coordination with the appropriate state and local emergency management agencies. The information presented in inundation maps varies in two major ways:

1. Assumed dam failure scenario
2. Flooding conditions at downstream locations

Assumed Dam Failure Scenario

Dam breach inundation studies usually assume one of two failure scenarios:

- Flows from a dam failure during "fair weather" or "sunny day" conditions with the reservoir at the normal pool level and receiving normal inflow (usually insignificant). A fair weather failure is generally considered to have the most potential for loss of human life, primarily due to the element of surprise.

- Flows from a dam failure during flood conditions or the inflow design flood. Failure during flood conditions is considered to show the upper limit of inundation and to have less potential for loss of human life because the downstream population is "on alert." The flood conditions scenario is more expensive to analyze due to the additional cost for the necessary watershed and spillway studies.

It is commonly believed that EAPs must include maps for both of these scenarios unless they are essentially the same when shown at the map scale. However, this is probably not required for most small and intermediate size dams where the communities needing notification are the same for either map. Often, in cases of actual emergencies, response agencies conservatively warn or evacuate an area larger than delineated on either map. Such conservatism is expected given the standard disclaimer included on most inundation maps:

"…the methods, procedures and assumptions used to develop the flooded areas, the limits of flooding shown and flood wave travel times are approximate and should only be used as a guideline for establishing evacuation zones. Actual areas inundated will depend on actual failure of flood conditions and may differ from areas shown on the maps..." (FERC 2007)

For most small and intermediate size dams, a single inundation map assuming dam failure during fair weather conditions with the reservoir level at the top of dam, neglecting reservoir inflows and spillway outflows, is an acceptable alternative to showing different inundation areas for fair weather and flood conditions. Use of a single "top of dam" inundation map eliminates the need for expensive watershed and spillway studies and provides a reasonable upper limit estimate for warning and evacuation. For large dams, or flood control structures with large amounts of freeboard, the difference in evacuation area between a top of dam breach and storm induced breach can be significant and using a top of dam breach may not be appropriate, nor is it appropriate to ignore spillway flows (Lemieux and Robinson, 2008).

<u>Flooding Conditions at Downstream Locations</u>

Inundation mapping shows a continuous "line of inundation" identifying the area potentially at-risk in event of dam failure. It starts at the dam and continues downstream to a point where the breach flood no longer poses a risk to life and property damage, such as large river or reservoir with the capacity of storing the flood waters. The need to consider the "domino effect" should be made on a case-by-case basis, if the assumed failure of a dam would cause the failure of any downstream dams.

Whenever possible, major streets, railroads, and other well known features should be depicted on the map. Maps should be prepared using terms accepted by local emergency agencies and residents who may prefer to use local flood crest levels, such as depth over a road, instead of water surface elevations to describe floods. Emergency management agencies may request that inundation maps highlight evacuation routes and emergency shelters. Local flood crest levels enable the National Weather Service (NWS) to issue immediate flash flood warnings, but timing of the incremental rise and water levels might assist in issuance of more specific river flood warnings.

Feedback from local emergency management agencies indicate the arrival time of the leading edge of the flood wave is more useful than the time of the peak because it indicates the time available prior to roads and other evacuation routes becoming inundated. Although important in delineating inundated areas, values of peak flow rate are not meaningful to emergency responders.

Information provided on flooding conditions at downstream locations might include:

- Distance downstream
- Arrival time of leading edge of flood wave
- Peak flow depth, incremental rise, or water surface elevation (as appropriate)
- Peak velocity

DAM BREACH OUTFLOWS FOR INUNDATION MAPS

Analyzing the failure of a dam for developing an inundation map can be viewed as a two-step process. First the estimation of the dam breach outflows, and second, routing the breach outflows downstream to determine the resulting flood inundation limits.

Reclamation (1988) grouped the methods of analysis for estimating dam breach outflows into four categories (Wahl, 1998):

1. Physically based methods – Estimate the development of a breach and the resulting breach outflows using an erosion model based on principals of hydraulics, sediment transport, and soil mechanics.

2. Parametric models – Use case study information to estimate time to failure and ultimate breach geometry (i.e. breach parameters), then simulate breach growth as a time-dependent linear process and compute breach outflows using principals of hydraulics.

3. Predictor equations – Estimate peak discharge from an empirical equation based on case study data and assume a reasonable outflow hydrograph shape.

4. Comparative analysis – If the dam under consideration is very similar in size and construction to a dam that failure, and the failure is well documented, appropriate breach parameters or peak outflows may be determined by comparison.

The NWS BREACH model is the best known physically based model but poorly simulates the mechanisms of breach development and the process of headcut erosion. Software for modeling headcut erosion of earth embankments is being released in WinDam-B, the second of three modules that will comprise the WinDAM system ("Windows Dam Analysis Modules"). The first module, comprised of WinDAM-A and WinDAM-A+, addresses flood routing through a reservoir, the potential of vegetation or riprap to delay or prevent failure of the embankment during overtopping, and the erosion technology in the SITES program. The WinDAM-B module incorporates computation of breach due to overtopping by applying technology developed in the Simplified Breach Analysis (SIMBA) computer model developed by the ARS Hydraulic Engineering Research Unit laboratory in Stillwater, Oklahoma. (NRCS, 2009)

The most commonly applied parametric breach methodology is the uniform breach formation rate routine found in NWS DAMBRK and other such models. The simplest parametric relations are those that estimate average breach width as a linear function of either the height of the dam or the depth of water stored behind the dam (e.g. maximum breach width equals three times dam height). More sophisticated regression relations use case study data to estimate breach width or time to failure as functions of one or more dam and reservoir properties such as storage volume, depth of water at failure, depth of breach, etc. As an alternative to determining breach parameters and then routing inflow and reservoir storage through the breach, the predictive method uses regression relations directly for peak breach outflow.

All four categories of methods for estimating breach outflows have shortcomings (Wahl, 1998):

1. Physically based models suffer from a poor understanding of the mechanisms of breach development, an inability to model these mechanisms and the high energy processes that dominate dam breach, and difficulty in measurements of representative material properties.

2. Parametric models use regression relations having high uncertainty. Additionally, the assumption of linear growth rate of breach dimensions is probably not realistic in most cases.

3. Predictor equations also use regression relations based on the available data and have high uncertainty.

4. Comparative analysis suffers from a lack of accurate and comprehensive case study data on a wide variety of dam types.

Wahl (1998) used many of the available relations to predict breach parameters for 108 documented case studies. Prediction errors of ± 75 percent were not uncommon for breach width, and prediction errors for failure times often exceeded one order of magnitude. Most relations used to estimate failure time are conservatively designed to underpredict the reported time more often than they overpredict, but overprediction errors of more than one-half order of magnitude did occur several times.

Wahl (2004) assessed uncertainty in predictions of embankment dam breach parameters and peak outflow using many of the available relations. The findings included:

1. Of four methods for estimating breach width, all of which had absolute mean prediction errors less than one-tenth of an order of magnitude.

2. Of five methods for estimating failure time, all underpredict the failure time on average, by amounts ranging from about one-fifth to two-thirds of an order of magnitude. The uncertainty bands on all of the failure time equations are very large, ranging from about ±0.6 to ±1 order of magnitude.

3. Of fourteen peak flow equations, all tend to overpredict observed peak flows, with most of the "envelope" equations overpredicting by about two-thirds to three-quarters of an order of magnitude. The uncertainty bands on the peak flow equations are about ±0.5 to ±1 order of magnitude.

Reclamation (1988) lists numerous sources of errors and uncertainties inherent in estimating dam breach flows at the dam and critical locations downstream:

- When will a dam fail?
- When and to what extent will a dam be overtopped?
- What are the size, shape, and time of formation of the breach?
- What are the storage volume and hydraulic resistance of the downstream channel valley?
- Will debris and sediment transported by the flood wave significantly affects its propagation?
- Can the flood wave be approximated adequately by the one-dimensional flow equations?

Estimates of breach outflow contain the greatest uncertainty of all aspects of dam failure flood forecasting. This uncertainty, when combined with the potential for debris bulking and other downstream obstructions, is generally larger than errors associated with the choice of routing methods or the source of topographic data. Results of watershed hydrology studies and detailed hydraulic modeling of downstream inundation limits may result in a more *precise* representation of potential flooding for a given set of assumptions, but not necessarily a more *accurate* representation of actual flooding should dam failure occur. Conservative estimates of inundation limits should be used for emergency and evacuation planning. Simplified methods can readily provide conservative inundation limits at a reduced cost.

SIMPLIFIED DAM BREACH INUNDATION MAPS FOR EAPS

Typically, flood inundation maps for EAPS have been developed from very detailed engineering studies. The high costs of detailed watershed hydrology analyses and field surveying of downstream cross sections are major impediments to EAP development. A number of states routinely accept simplified inundation maps (SIMS) for use in EAPs, but not for classifying hazard potential or establishing inflow design floods. Commonly used methods for SIMS fall into two categories:

1. Simplified Engineering Analyses

2. Photo-Based Mapping

Regardless of the methods used to create an inundation map, visual inspection of the potentially affected areas should be performed. Doing so allows for confirmation of the number and locations of residences, channel characteristics and the presence of alterations to the channel or floodplain.

Simplified Engineering Analyses

Several states including Washington and Texas have published simplified methods for predicting dam breach inundation maps for EAPs. For example, the State of Washington (2007) presents a simplified procedure for delineating inundation limits and estimating flow velocities for dam heights up to fifty feet and reservoir surface areas up to one hundred acres using tables of peak discharge values, generalized flood attenuation curves, and representative flow velocities. It is recommended to add between 0.5 and 2.0 feet to computed flood depths to account for debris bulking and other uncertainties.

At the 2008 ASDSO Annual Conference, Lemieux and Robinson recommended for small and intermediate sized dams using one simple, conservative evacuation map based on a top of dam breach flood instead of the detailed inundation maps that are commonly used. They suggest using hydrologic routing models (e.g. HEC-HMS) rather than more sophisticated hydraulic (i.e. dynamic-wave) models such as (e.g. HEC-RAS). They also suggest that use of U.S. Geological Survey (USGS) 7.5 minute quadrangle maps for creating cross sections used in flow routing, rather than collecting detailed survey mapping, is appropriate and cost effective in most cases.

In 1983 computer modeling of dam breach flood routing required much more extensive time and technical expertise than it does today. As such, the National Weather Service developed a simplified model for computing downstream flooding produced by a dam failure. The Simplified Dam Break Flood Forecasting Model (SMPDBK) quickly estimates peak flows, peak flood elevations and flood arrival times at selected downstream points using cross section data easily created from USGS 7.5 minute quadrangle maps. Although NWS no longer distributes

SMPDBK to the public, NWS still uses SMPDBK to help generate flood forecasts and warnings. SMPDBK remains commercially available with several hydrologic modeling software packages. The difference between the peak flow computed with SMPDBK versus more sophisticated unsteady flow models is often less than ten percent (NWS, undated).

Depending on the size of reservoir and channel conditions, after travelling ten miles downstream the routed flows is usually reduced only ten to forty percent from the peak outflow at the dam (State of Washington, 2007). In such cases, a constant or "steady state" discharge for the potentially affected areas downstream equal to the peak outflow at the dam may be assumed. The steady state peak discharge is conservatively estimated using predictive equations and applied at each of the downstream cross sections.

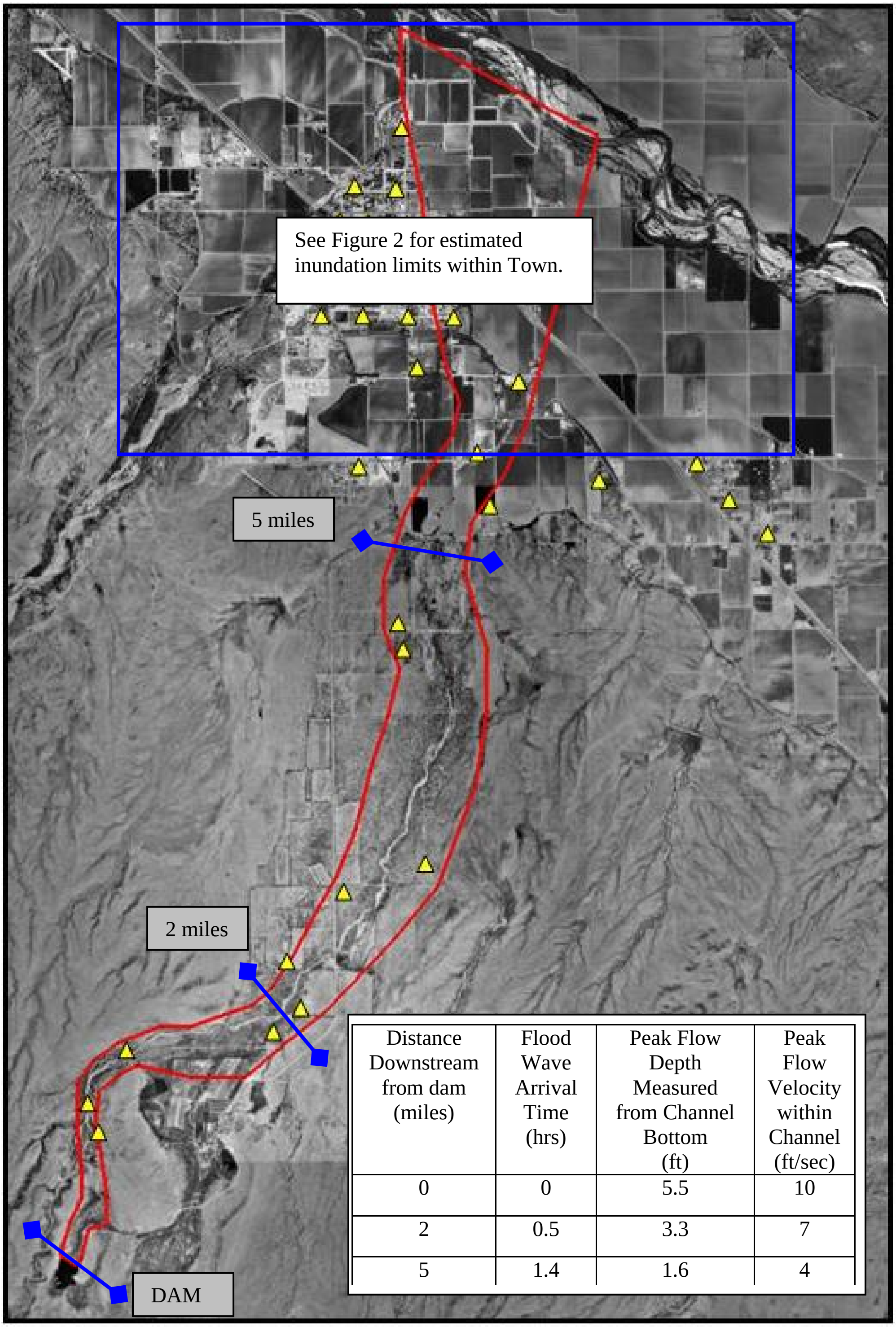
The best existing topographic data should be used to route dam breach outflows downstream. Nationwide, 30-meter digital elevation model (DEM) topographic data is available free of charge from the USGS (http://edc2.usgs.gov/geodata/index.php). Local municipalities with access to Geographic Information Systems (GIS) should make aerial photographs and digital topography available for use by dam owners. These systems typically have the best available topography and residence information for a region. If GIS cannot be used and no other site specific elevation data is available, there are several websites that provide topographic data based on USGS 7.5 minute quadrangles (see a list of common websites in the "Photo-Based Maps" section). Field surveying of downstream cross sections is usually not required unless little or no topographic data exists. An example of the need for more detailed mapping is modeling of a shallow channel and broad floodplain having only USGS 7.5 minute quadrangles with forty foot contour intervals.

DEM data can be used with a variety of (GIS)-based software packages to rapidly create cross sections at a fraction of the cost of field surveying. HEC-GeoRAS[1] is a free GIS extension that uses DEM data to prepare HEC-RAS cross sections and generates inundation GIS data from RAS output. The user must already have commercially available ArcGIS®, by ESRI. While the GeoRAS extension is designed for users with limited GIS experience, knowledge of GIS is advantageous. Commercially available stand-alone GIS-based modeling systems perform similar functions with several routing models including HEC-RAS, HEC-1, HEC-HMS, and SMPDBK. GIS-based data processing has made development of inundation mapping for EAPs easier than ever before.

Figures 1 and 2 are simplified inundation maps developed for a small dam about five miles upstream of a rural town with population of about two-thousand. Additional residences (marked by yellow triangles) are located along the channel between the dam and town. At its top, the dam is 38 feet high with a 210 acre-foot impoundment. The map was developed assuming failure during fair weather conditions with the reservoir level at the top of dam, neglecting reservoir inflows and spillway outflows. The inundation area terminates at a major river about eight miles from the dam. The map was developed using the HEC-1 computer model with conservative breach parameters and downstream cross sections prepared from 10-meter DEM data. HEC-1 uses the uniform breach formation rate routine for computing dam breach outflow

[1] A similar GIS extension HEC-GeoHMS uses DEM data for the upstream watershed to automate development of HEC-HMS input files and present results in a GIS format.

and hydrologic routing of downstream flows. The SIMS was developed in less than 16 hours of modeling and mapping time including locating and downloading the DEM and mapping files.



Distance Downstream from dam (miles)	Flood Wave Arrival Time (hrs)	Peak Flow Depth Measured from Channel Bottom (ft)	Peak Flow Velocity within Channel (ft/sec)
0	0	5.5	10
2	0.5	3.3	7
5	1.4	1.6	4

Figure 1

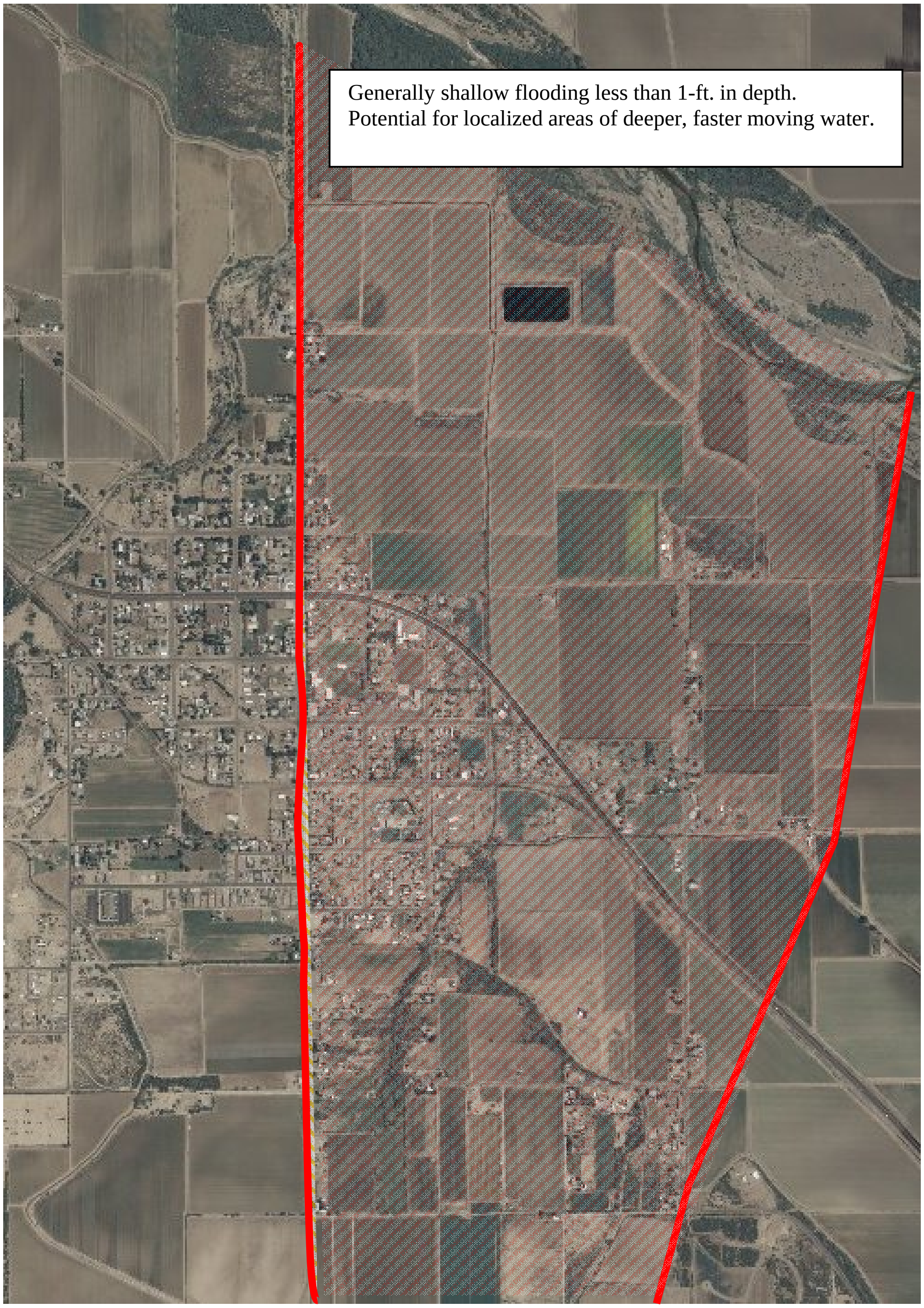

Generally shallow flooding less than 1-ft. in depth.
Potential for localized areas of deeper, faster moving water.

Figure 2

Photo-Based Maps

Photo-based SIMS are generally applicable for two cases:

1. A small or intermediate size dam with an easily-identified number of downstream structures for which local emergency management agree adequate evacuation procedures can be established.

2. A small or intermediate size dam for which funding is not immediately available for engineering studies and the photo-based mapping is to be used in the interim until such funding can be arranged and the mapping updated.

Photo-based SIMS are prepared by using aerial photography and/or topographic maps for identifying potential at-risk residences downstream of a dam with subsequent verification of the locations and numbers of residences through visual inspection of downstream areas. Potentially at-risk areas should be conservatively estimated. Caldwell and Phillips (2008) describe preparation of photo-based SIMS for 170 dams in Oklahoma. In Oklahoma, the maps were prepared by labeling potential at-risk residents on a photo-based map. Locations for most of the residents had been identified in hazard classification verification studies completed in previous years. Additional potential at-risk homes were verified by visual field review.

When developing photo-based SIMS for emergency and evacuation planning, the dam owner should coordinate with local municipalities and emergency management and agree upon potentially at-risk areas. Local floodplain administrators maintain copies of FEMA flood insurance rate maps (FIRMs) identifying showing the local floodprone areas. These maps are also available free online from the FEMA Mapping Service Center (http://msc.fema.gov). Many municipalities have access to a GIS that can show aerial photographs and topography of their jurisdiction. These systems typically have the best available topography and residence information for a region. If a municipality does not have GIS or current mapping, several websites with aerial photographs and topographic maps are available for no or little cost. Some publicly available mapping sites that may be useful are:

- USGS National Map Seamless Server (http://seamless.usgs.gov/index.php)
- FEMA Mapping Service Center (http://msc.fema.gov)
- Google Earth® (http://earth.google.com)
- Google Maps® (http://maps.google.com)
- Mapquest® (http://www.mapquest.com)
- Terraserver–USA® (http://www.terraserverusa.com)
- Topo!® State Series (http://www.natgeomaps.com)
- Trails.com® – former Topozone (http://www.trails.com)
- Yahoo Maps® (http://maps.yahoo.com)

The dam owner and local emergency management should review and update the inundation map annually to ensure new homes are identified and the residents contact information is current. The three primary steps in developing Photo-Based Inundation Maps are described below:

Step 1: Obtain an aerial photo of the area downstream of the dam and identify potential at-risk structures (see Figure 3).

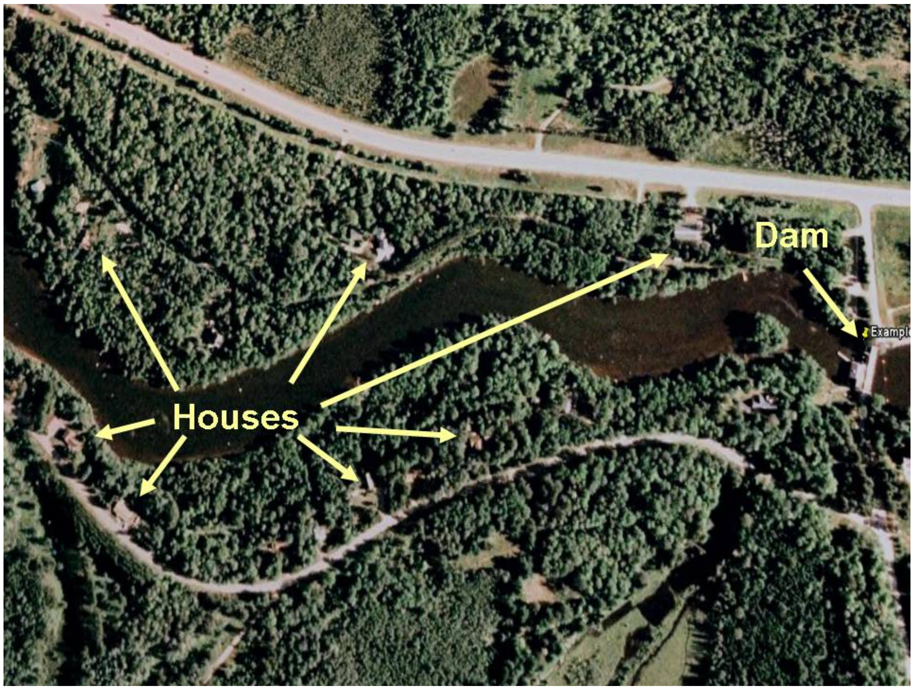


Figure 3

Step 2: Obtain a topographic map of the area downstream of the dam and conservatively delineate the inundation area by comparing the contour lines of the downstream area to the height of dam (see Figure 4).

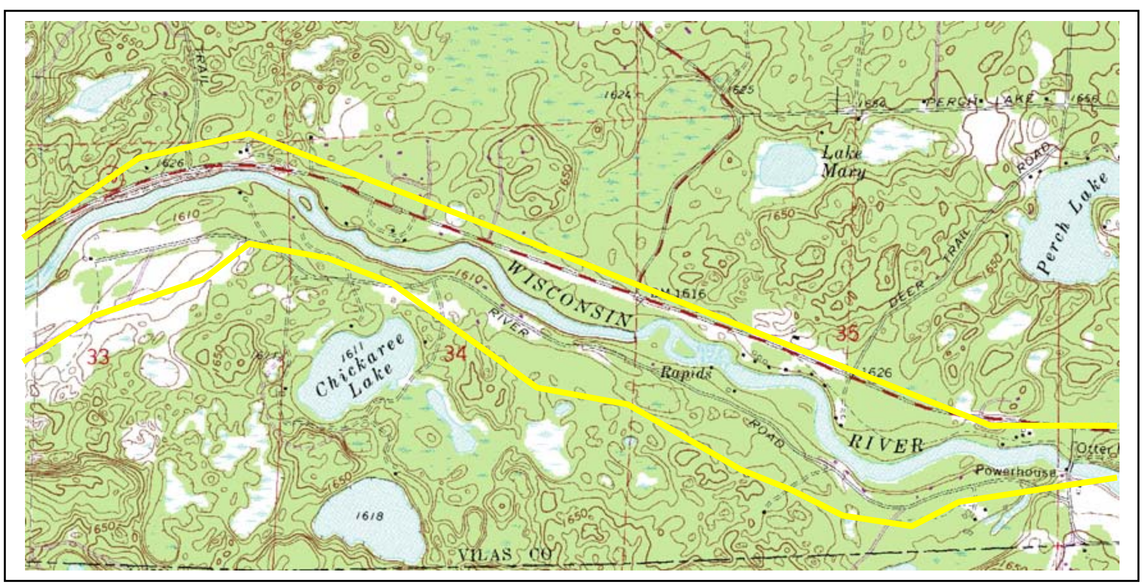


Figure 4

Step 3: Copy the inundation boundary from the topographic map to the aerial photo and identify any additional potential at-risk structures (see Figure 5).

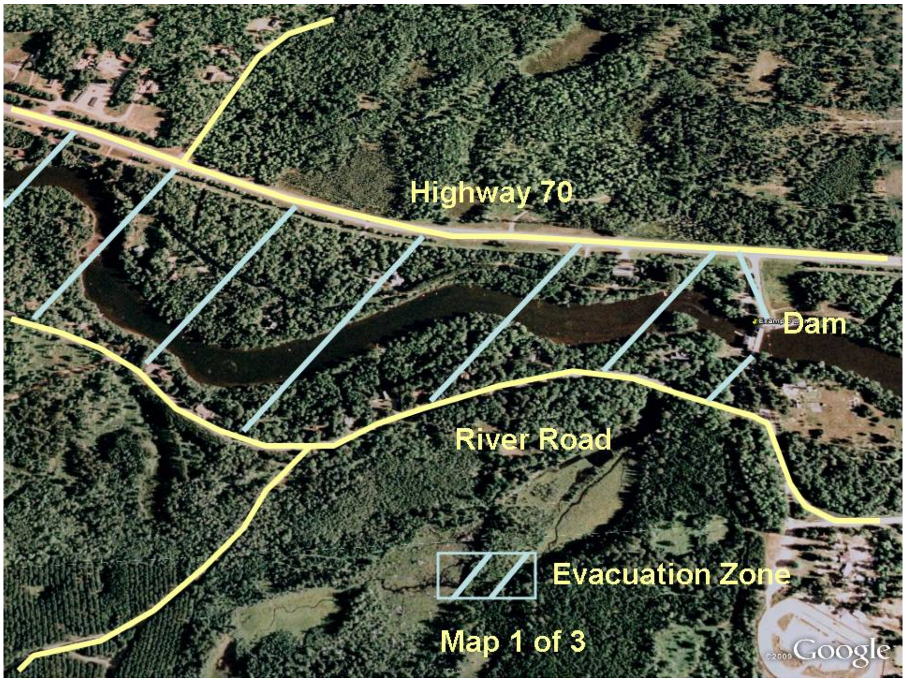


Figure 5

CONCLUSIONS AND RECOMMENDATIONS

The cost of dam breach inundation maps is a major impediment towards the goal of developing Emergency Action Plans for all high and significant hazard potential dams in the United States. Developing dam breach inundation maps is an inexact science dependent upon numerous assumptions and uncertainties. Conservative estimates of inundation limits should be used for emergency and evacuation planning purposes. Simplified inundation maps (SIMS) produce conservative inundation limits at a much lower cost than performing more detailed studies which may result in a more precise representation of potential flooding for a given set of assumptions, but not necessarily a more accurate representation of actual flooding should dam failure occur.

SIMS are most applicable for small and intermediate sized dams with a limited number of homes downstream and where local emergency management agree that adequate evacuation procedures can be developed without more detailed inundation mapping. More detailed surveying or modeling may be warranted for large dams, those with a large population in the evacuation area or with significant downstream hydraulic complexities such as major diversion structures, split flows or potential for cascading dam failures.

SIMS are developed by either (1) employing simplified engineering assumptions and methods or (2) identifying potential at-risk residences on photo-based mapping without engineering analysis. SIMS can either form the permanent basis of emergency and evacuation planning or be used for the interim, until more detailed mapping can be obtained. Many states have accepted SIMS for use in EAPs. EAP development must include close coordination with local emergency management to establish notification and evacuation procedures.

The following recommendations are provided to assist states and dam owners in developing reduced cost SIMS for EAPs. These recommendations are not a substitute for engineering judgment nor do they alleviate the need to comply with state or federal regulatory requirements.

Summary of Recommendations

1. A single inundation map assuming dam failure during fair weather conditions with the reservoir level at the top of dam, neglecting reservoir inflows and spillway outflows, is an acceptable alternative to showing different inundation areas for fair weather and flood conditions. Use of a single "top of dam" inundation map eliminates the need for expensive watershed and spillway studies and provides a reasonable upper limit estimate for warning and evacuation.

2. Whenever possible, major streets, railroads, and other well known features should be depicted on the maps. Maps should be prepared using terms accepted by local emergency agencies and residents who, for example, may prefer to use local flood crest levels, such as depth over a road, instead of water surface elevations to describe floods.

3. Information provided on flooding conditions at downstream locations might include:

   - Distance downstream
   - Arrival time of leading edge of flood wave
   - Peak flow depth, incremental rise, or water surface elevation (as appropriate)
   - Peak velocity

4. Flood wave arrival times may be estimated using the NWS "rule of thumb" of an average downstream speed of 3 to 4 miles per hour. In mountainous areas with steeper slopes and or little vegetation such as out west the speeds may be higher. The flood wave will attenuate in height and speed very quickly as it spreads across the floodplain.

5. Representative flow velocities may be estimated based on channel slope using values provided in the 2007 State of Washington guidance document.

6. In selecting conservative breach parameters the average breach width should be in the upper portion of the range of reasonable values; the time to failure should be in the lower portion of the range; and the Manning's n-value should be in the upper portion of the range. Chapter 2 of the FERC's Engineering Guidelines provides typical breach parameters for different dam types.

7. Depending on the size of reservoir and channel conditions, after travelling ten miles downstream the routed flows is usually reduced only ten to forty percent from the peak outflow at the dam (State of Washington, 2007). In such cases, a constant or "steady state" discharge for the potentially affected areas downstream equal to the peak outflow at the dam may be assumed. The steady state peak discharge is conservatively estimated using predictive equations and applied at each of the downstream cross sections.

8. The best existing topographic data should be used to route dam breach outflows downstream. Digital elevation model (DEM) topographic data is often available free of charge. DEM data can be used with a variety of (GIS)-based software packages to rapidly create downstream cross sections for flood routing. GIS-based data processing has made development of inundation mapping for EAPs easier than ever before. Field surveying of downstream cross sections is usually not required unless little or no topographic data exists.

9. Although unsteady routing models are becoming much more user-friendly, hydrologic routing models (HEC-HMS and HEC-1) and the NWS SMPDBK models provide useful results.

10. To account for debris bulking and other uncertainties, 0.5 to 2.0 feet should be added to computed flow depths at each cross section (with corresponding increases in width of inundation).

11. Photo-Based SIMS are generally applicable for two cases:

    a. A small or intermediate size dam with an easily-identified number of downstream structures for which local emergency management agree adequate evacuation procedures can be established.

    b. A small or intermediate size dam for which funding is not immediately available for engineering studies and the photo-based mapping is to be used in the interim until such funding can be arranged and the mapping updated.

12. Regardless of the SIMS method applied, a visual inspection of the potentially affected areas should also be performed to confirm the number and locations of residences, channel characteristics and the presence of alterations to the channel or floodplain.

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