



North Carolina Simplified Inundation Maps For Emergency Action Plans

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INTRODUCTION

Emergency Action Plans (EAPs) are critical to reducing the risks of loss of life and property damage from dam failures, and should be developed for all high hazard potential dams in North Carolina. Inundation maps, or maps depicting the downstream hazards most likely to be affected in the event of a dam failure, are essential to the dam owner and emergency personnel when developing evacuation plans. For most small and medium sized dams¹, simplified methods can provide useful inundation maps at a reduced cost. Simplified inundation maps (SIMS) are developed by identifying potential at risk residences on photo-based mapping without a detailed engineering analysis and/or modeling. North Carolina has adopted a simplified inundation map methodology based in part on recommendations by the Association of State Dam Safety Officials (refer to ASDSO website, www.damsafety.org, for additional resources)

SIMS are most applicable for:

1. Small and medium sized dams with an easily-identified number of downstream structures for which local emergency management agree adequate evacuation procedures can be established, and
2. A small or medium sized 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.

More detailed surveying or modeling may be warranted for

1. Large dams,
2. Dams with a large population in the evacuation area,
3. Dams with significant downstream hydraulic complexities such as major diversion structures, split flows or potential for cascading dam failures,
4. Flood control structures with large amounts of freeboard, and
5. Publicly owned or important public utility dams.

Use of recommendations and methods presented in this guidance does not remove the need to comply with state or federal regulatory requirements. SIMS may not replace 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.

¹ Small dams have less than 750 acre-feet impoundment capacity and are less than 35 feet in height. Medium dams have 750 to less than 7,500 acre-feet impoundment capacity and are 35 to less than 50 feet in height. [15A NCAC 2K.0205(e)]

EMERGENCY ACTION PLANS FOR DAMS

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 maps to identify the downstream hazards subject to flooding in the unlikely event of dam failure. The North Carolina EAP Template describes the basic elements of an EAP:

1. Event detection and level determination
2. Notification flowcharts and communications
3. Expected actions
4. Termination and follow-up
5. Responsibilities
6. Maps
7. Supporting information

EAPs are critical in identifying areas downstream from dams requiring warning and evacuation in the 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.

SIMPLIFIED INUNDATION MAPS (SIMS) FOR EAPS

Inundation maps are usually the most effective means of showing the extent of expected flooding from dam failure. Ideally, inundation maps should be developed in coordination with the appropriate state and local emergency management agencies.

Traditionally, dam breach inundation studies usually assumed one of two failure scenarios:

- Flows from a dam failure during “sunny day” conditions with the reservoir at the normal pool level and receiving normal inflow (usually insignificant). A sunny day 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 design flood specific to the dam. 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 requires more detailed engineering analysis and modeling for the necessary watershed and spillway studies.

Traditionally prepared EAPs 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 medium sized 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 ... 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 medium sized dams, a single inundation map assuming dam failure during sunny day 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 sunny day and flood conditions. When appropriate, use of a single “top of dam” inundation map 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).

Flooding Conditions at Downstream Locations

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 a 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 could cause the failure of any downstream dams. SIMS should not be used for dams with significant downstream hydraulic complexities such as major diversion structures, split flows or potential for cascading dam failures. Whenever possible, major streets, railroads, and other well-known features should be depicted on the map.

SIMPLIFIED DAM BREACH INUNDATION MAPS FOR EAPS

North Carolina accepts SIMS for use in EAPs, but not for classifying hazard potential or establishing design storms. 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.

Photo-Based Maps

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 and labeled on a photo-based map. Locations for most of the hazards may have been identified in hazard classification verification studies completed in previous years. Additional potential at-risk structures should be 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 North Carolina Floodplain Mapping Program (www.ncfloodmaps.com). 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:

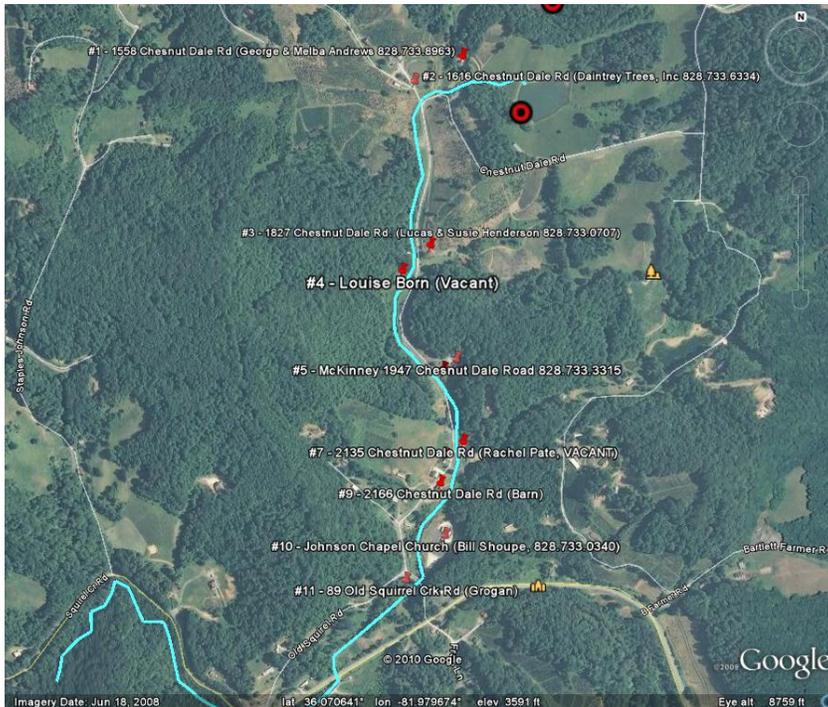
- Google Earth® (<http://earth.google.com>)
- USGS National Map Seamless Server (<http://seamless.usgs.gov/index.php>)
- FEMA Mapping Service Center (<http://msc.fema.gov>)
- Google Maps® (<http://maps.google.com>)
- Mapquest® (<http://www.mapquest.com>)
- Terraserver–USA® (<http://www.terraserverusa.com>)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

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.

PREPARING A SIMS UTILIZING A PHOTO-BASED HAZARD MAP

The recommended procedure for developing photo-based inundation maps is described below:

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



Step 2: Obtain a topographic map or contour map of the area downstream of the dam.

Step 3: Assume the dam fails at a water elevation equal to half the height of the dam just below the dam. For example, the dam breach height just below a dam 20 feet in height is expected to be about 10 feet.

Step 4: Assume that the breach flood wave height would be halved every 10 miles downstream of the dam. In other words, the breach flood wave height is assumed to be approximately $0.5H$ immediately downstream of the dam, where H =height of dam, $0.4H$ approximately 4 miles downstream of the dam, and $0.25H$ approximately 10 miles downstream,

Table 1

Distance Downstream of Dam	Assumed Breach Flood Wave Height, where H=height of dam
Just below the dam	0.5H
0.5 mile	0.488H
1 mile	0.475H
1.5 miles	0.463H
2 miles	0.45H
3 miles	0.425H
4 miles	0.4H
5 miles	0.375H
10 miles	0.25 H

The distance to measure downstream varies with the dam surface area. In general, the following distances are recommended:

Table 2

Surface Area of Dam Pond, at Normal Pool	Recommended Distance Downstream of Dam
Less than 25 acres	2 miles
25 to less than 100 acres	5 miles
100 acres or more	10 miles

If, at the end of your distance downstream, you encounter homes, businesses, or roads near the streambed, you should extend the distance to include the additional structures or roads. The goal is to define a distance at which the breach flood is generally contained within channel limits and/or to the point where no other downstream structures will be significantly impacted.

Step 5: Starting immediately below the dam, select points downstream where contours cross the stream and/or where intermediate contour crossings of the stream can be easily determined (such as half the distance between two contours crossing the stream). At these points draw a line perpendicular to the stream at least several hundred scaled feet in length. At each line, measure the distance to the dam and calculate the breach wave height from Table 1.

Step 6: Add the breach wave height to the elevation of the crossing contour at the streamline to determine the elevation of the breach wave on both sides of the stream at each line. Using valley contours which cross the line, identify the points on each side of the stream along the line which represent the elevation of the breach wave. You may have to interpolate between contours crossing the line to establish these two points. Perform this task for each for each line drawn downstream from the dam.



Contour interval = 5 feet
This dam is 27 feet tall

- Step 7:** When you have plotted all points, connect the point sets on each side of the stream to establish the breach wave corridor. Copy the inundation boundary from the topographic map to the aerial photo and identify any additional potential at-risk structures.
- Step 8:** The following procedure can be used to transfer the point sets to another map base not containing contour data. On the contour map used above, measure the scaled horizontal distance between the stream and the breach wave elevation point for each of the two points on each of the lines. This distances will be termed the point offset distance. Establish as best possible the location of each line and the stream on the second map base. Re-establish the point sets on each side of the stream by plotting the scaled offset distances on each line. Connect the point sets in the same manner as stated above.
- Step 9:** Field-verify all assumptions and hazards. Prepare a list of downstream residences, businesses, and road locations, in order of their proximity to the dam, to be included within the EAP. If possible, the locations should be marked on the inundation map. This may be done by number labels on the map corresponding to numbered addresses on the hazards list.

CONCLUSIONS

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. Ultimately, the dam owner and emergency management personnel must agree to an emergency action plan, utilizing the most representative inundation map available. If the downstream hazards are not easily determinable, further engineering analysis is necessary.

These recommendations are not a substitute for engineering judgment nor do they alleviate the need to comply with state or federal regulatory requirements. If you have any questions, please contact the North Carolina Dam Safety Staff at (919) 733-4574.

REFERENCES

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