Energy, Mineral and Land Resources
ENVIRONMENTAL QUALITY

North Carolina Simplified Inundation Maps (SIMs) for Emergency Action Plans (EAPs)

INTRODUCTION

Emergency Action Plans (EAPs) are critical to reducing the risks of loss of life and property damage from dam failures. It should be developed for all high and intermediate 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 dams[1], simplified methods can provide useful inundation maps at a reduced cost. Simplified Inundation Maps (SIMs) are developed by identifying potential at-risk residences or other structures on photo-based mapping rather than by performing more detailed engineering analysis and/or modeling (see note below). 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
2. Small or medium sized dams 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 appropriate mapping can be secured for long-term usage.

More detailed surveying or modeling may be warranted for:

1. Large sized dams
2. Dams with a large population in the evacuation area
3. Significant changes in local topography of upstream and downstream from the dam
4. Dams with potential for cascading dam failures or significant downstream Hydrologic & Hydraulic (H&H) complexities such as major diversion structures, split flows, etc.
5. Flood control structures with large amounts of freeboard
6. Publicly owned or important public utility dams i.e. water supply dams for communities

Use of recommendations and methods presented in this guidance does <u>not</u> remove the need to comply with state or federal regulatory requirements. SIMs shall 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.

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[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 piping failure is generally considered to simulate the potential for loss of human life, primarily due to the element of surprise.

- Flows from a dam failure during flood conditions or the Spillway Design Flood (SDF) event specific to the dam. Failure during "Rainy Day" conditions is considered to show the upper limit of inundation and to supposedly 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(s) and spillway studies.

Typical EAPs include maps for both scenarios unless they are essentially the same when shown at the map scale and present the "worst-case" simulation. However, this is probably not required for most small and medium sized dams in North Carolina, 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 highest point on the crest of dam to develop the 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; SIM should NOT be considered until a sound stage-storage analysis is conducted to demonstrate that the lower reservoir has enough impoundment capacity to hold the upper dam(s)' incoming breach flood. Moreover, SIMs should not be used for dams with significant downstream hydraulic complexities such as major diversion structures, split flows, etc.

SIMPLIFIED DAM BREACH INUNDATION MAPS ONLY 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. Whenever possible, major streets, railroads, and other well-known features should be depicted on the map as well.

PHOTO-BASED MAPS

Photo-based SIMs are prepared by using aerial photography and topographic contour maps for identifying potential at-risk infrastructure downstream of a dam with subsequent verification of the locations and numbers of structures through visual inspection of downstream areas. Potential 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 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) showing the local flood-prone 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:

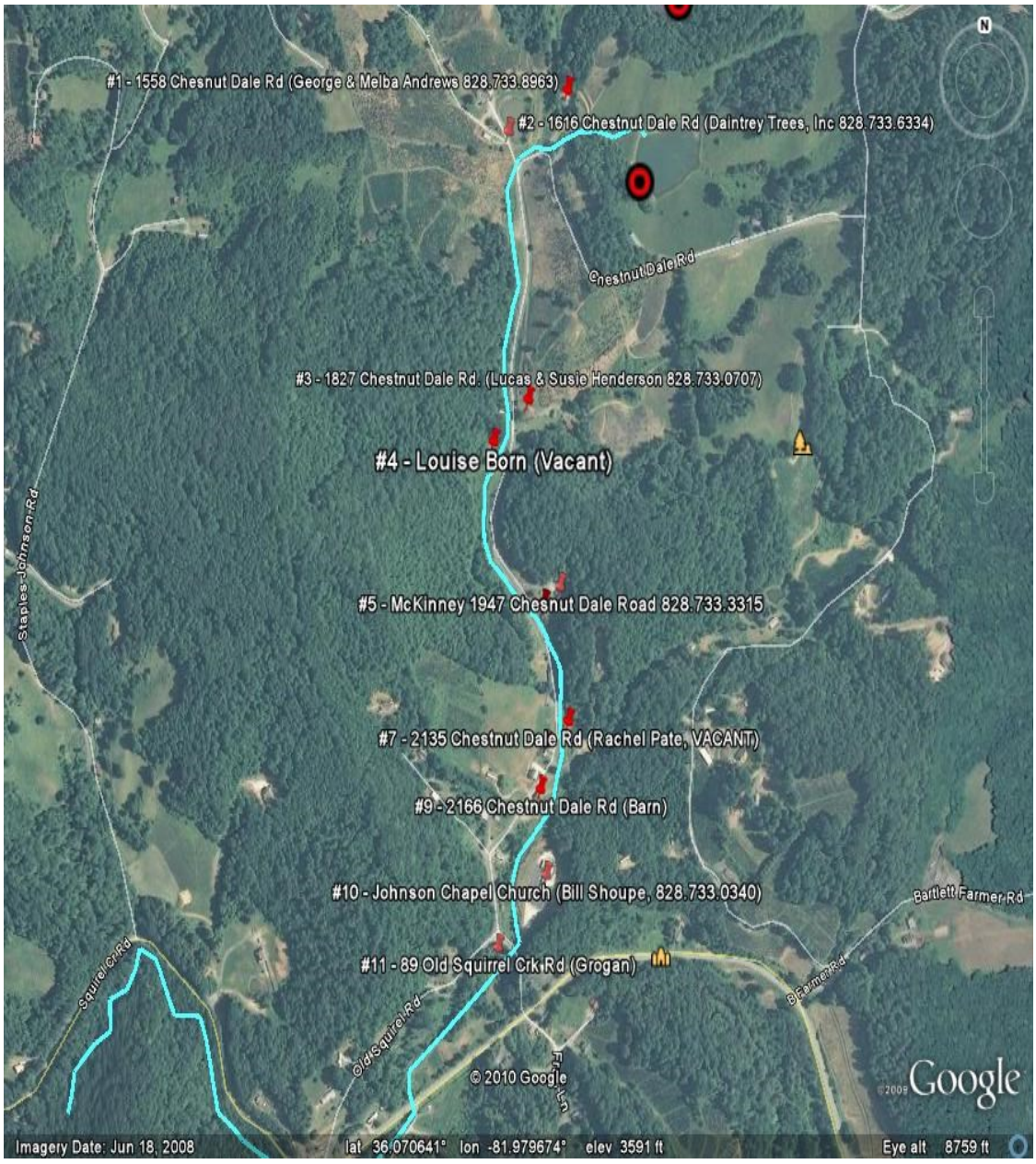
- Google Earth® (http://earth.google.com)
- USGS National Map Seamless Server (http://seamless.usgs.gov/index.php)
- FEMA Mapping Service Center (http://msc.fema.gov)
- Google Maps® (http://maps.google.com)
- Mapquest® (http://www.mapquest.com)
- Terraserver–USA® (http://www.terraserverusa.com)
- Topo!®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

PREPARING A SIM 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: Lay over topographic contour lines at a selected interval (2-ft recommended) of the area downstream of the dam.

Step 3: Assume the dam fails at a water surface elevation equal to half the structural height of the dam immediately at the downstream toe. For example, the dam breach flood wave height (DBFWH) just below a dam of 20 feet in height is expected to be about 10 feet.

Step 4: Then assume that the DBFWH would be halved every 10 miles downstream of the dam as followed, where H = structural height of dam:

Distance Downstream of Dam	Assumed Breach Flood Wave Height
Just below the dam	0.5H
0.5 mile	0.488H
1 mile	0.475H
1.5 miles	0.463H
2 miles	0.450H
2.5 miles	0.438H
3 miles	0.425H
3.5 miles	0.413H
4 miles	0.400H
4.5 miles	0.388H
5 miles	0.375H
5.5 miles	0.363H
6 miles	0.350H
6.5 miles	0.338H
7 miles	0.325H
7.5 miles	0.313H
8 miles	0.300H
8.5 miles	0.288H
9 miles	0.275H
9.5 miles	0.263H
10 miles	0.250H

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

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 you encounter additional homes, businesses, or roads near the streambed at the end of your recommended distance downstream, 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 on the topographic contour map, draw points on either side of the dam at the elevation of downstream toe. Move downstream at selected intervals where a contour line crosses the stream. Draw a line perpendicular to the stream (cross section lines) and mark the contour points that reflect the maximum breach height on either side of the streambed at least several hundred scaled feet in length to create an "inundation zone" for the recommended distance downstream of the dam, taking account of its local terrain.

Proceed until you are confident the breach flood wave may not further significantly impact any downstream structures (i.e. buildings, houses, roads, bridges, major utility lines, etc.) or until you encounter a major stream or river, where the water surface level confluences to FEMA's 100-yr floodplain water levels.

Step 6: Add the dam breach wave height to the bed elevation of the crossing contours at the streamline to determine the elevation of the breach wave on both sides of the stream at each cross-section. You may have to interpolate between contour crossing the line to establish these two points. Connect the points drawing two boundary lines from the dam down to the end of the inundation area. Copy the inundation boundary from the topographic map to the aerial photo and identify any additional potential at-risk structures.

Step 7: Field-verify all assumptions and hazards. A list of all downstream at-risk structures' locations should be listed within the EAP, <u>in order of their proximity to the dam</u> by referencing TABLE 5.1: Residents/Businesses/Roads/Infrastructure at Risk (Please reference below). The locations should be marked on the inundation map, using the "Entity No" to be easily referenced.

CONCLUSIONS

Developing dam breach inundation maps is an inexact science, depending 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, since it does not take account of any upstream or downstream H&H capacity for the dam as well as its downstream hazards'. Ultimately, the dam owner and emergency management personnel must agree to an EAP, utilizing the most representative inundation map available.

With that being said, a hired consultant engineer/firm is strongly advised to **<u>not</u>** utilize this methodology. The SIM is a generalized map that is only intended to be used in the interim for dam owners, who may not have sufficient engineering background or resources, until funding can be sought to generate a more scientifically assessed inundation map by a licensed Professional Engineer of NC. This is especially pertinent where the downstream hazards are not easily determinable and 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) 707-9220.*

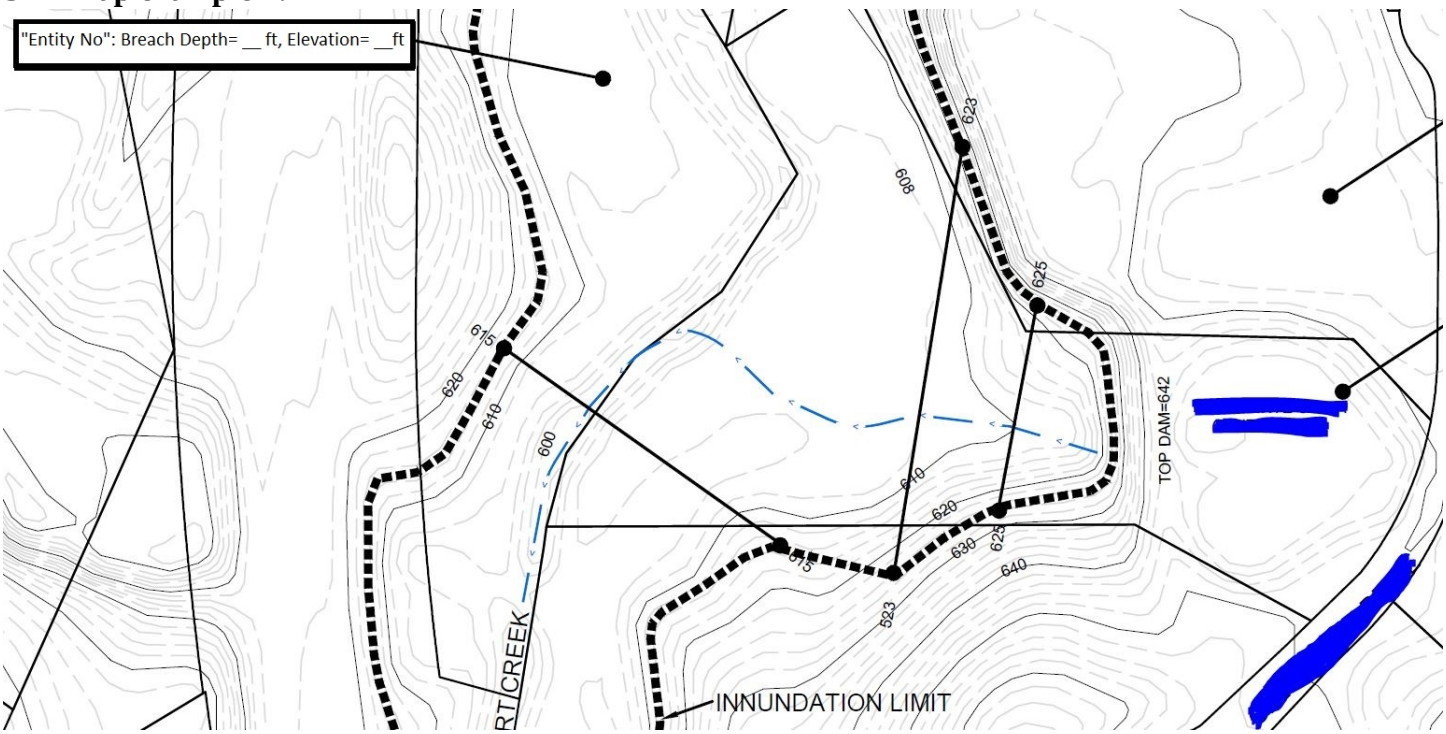
TABLE 5.1
Residents/Businesses/Roads/Infrastructure at Risk

Brief summary of number of entities within hazard zone. Whenever possible, major streets, railroads, and other well-known features should be depicted on the downstream inundation map or downstream hazards map.

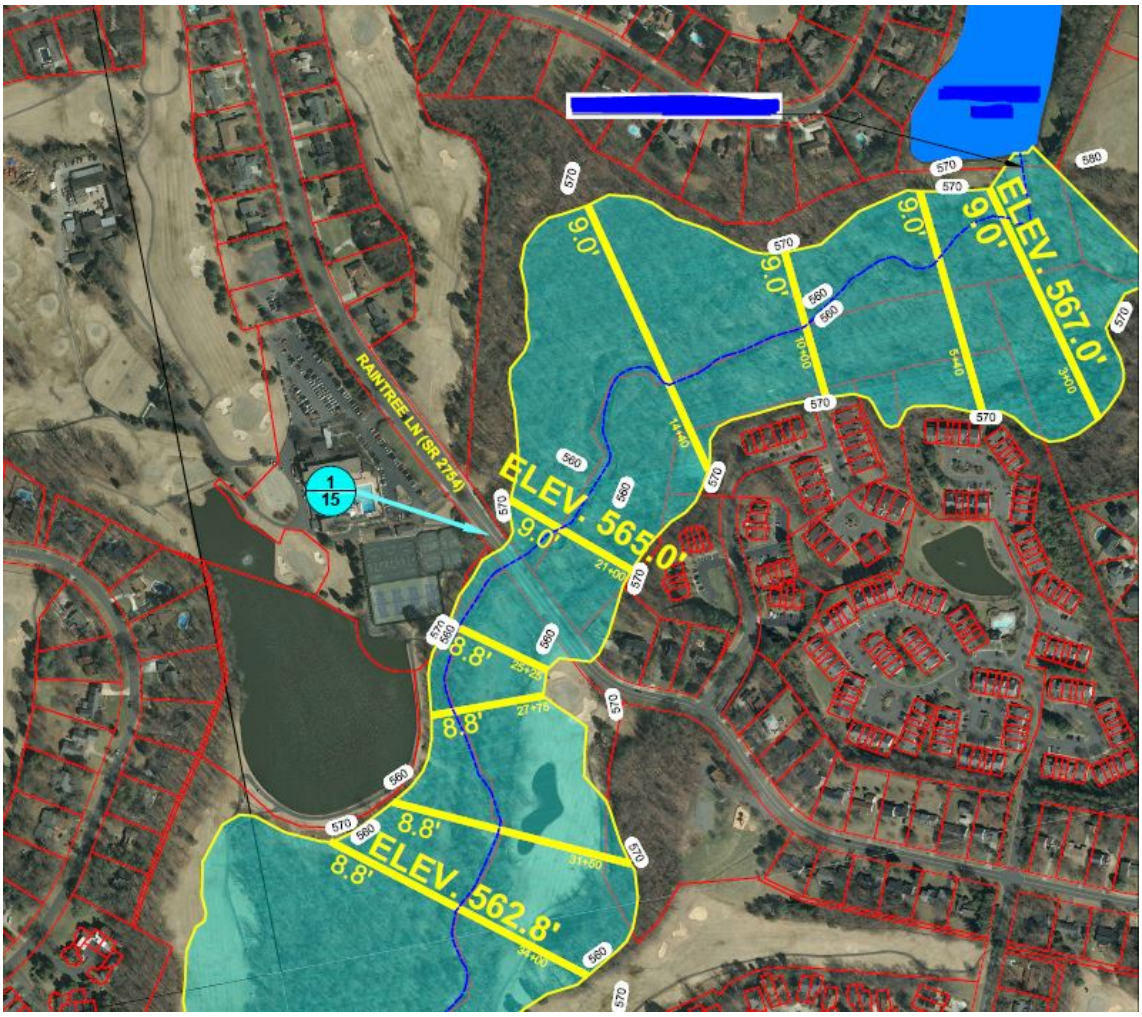
Entity No.	Resident/business/roads or other impacted entity	Property Address	Phone No. with area code	Distance downstream from dam (mi)
X	Name of entity	Address/location of entity	XXX-XXX-XXXX	Distance from dam
X	Name of entity	Address/location of entity	XXX	Distance from dam
X	Name of entity	Address/location of entity	XXX	Distance from dam
X	Name of entity	Address/location of entity	XXX	Distance from dam
X	Name of entity	Address/location of entity	XXX	Distance from dam
X	Name of entity	Address/location of entity	XXX	Distance from dam
X	Name of entity	Address/location of entity	XXX	Distance from dam
X	Name of entity	Address/location of entity	XXX	Distance from dam
X	Name of entity	Address/location of entity	XXX	Distance from dam
X	Name of entity	Address/location of entity	XXX	Distance from dam
X	Name of entity	Address/location of entity	XXX	Distance from dam
X	Name of entity	Address/location of entity	XXX	Distance from dam

(Use additional sheets if necessary)

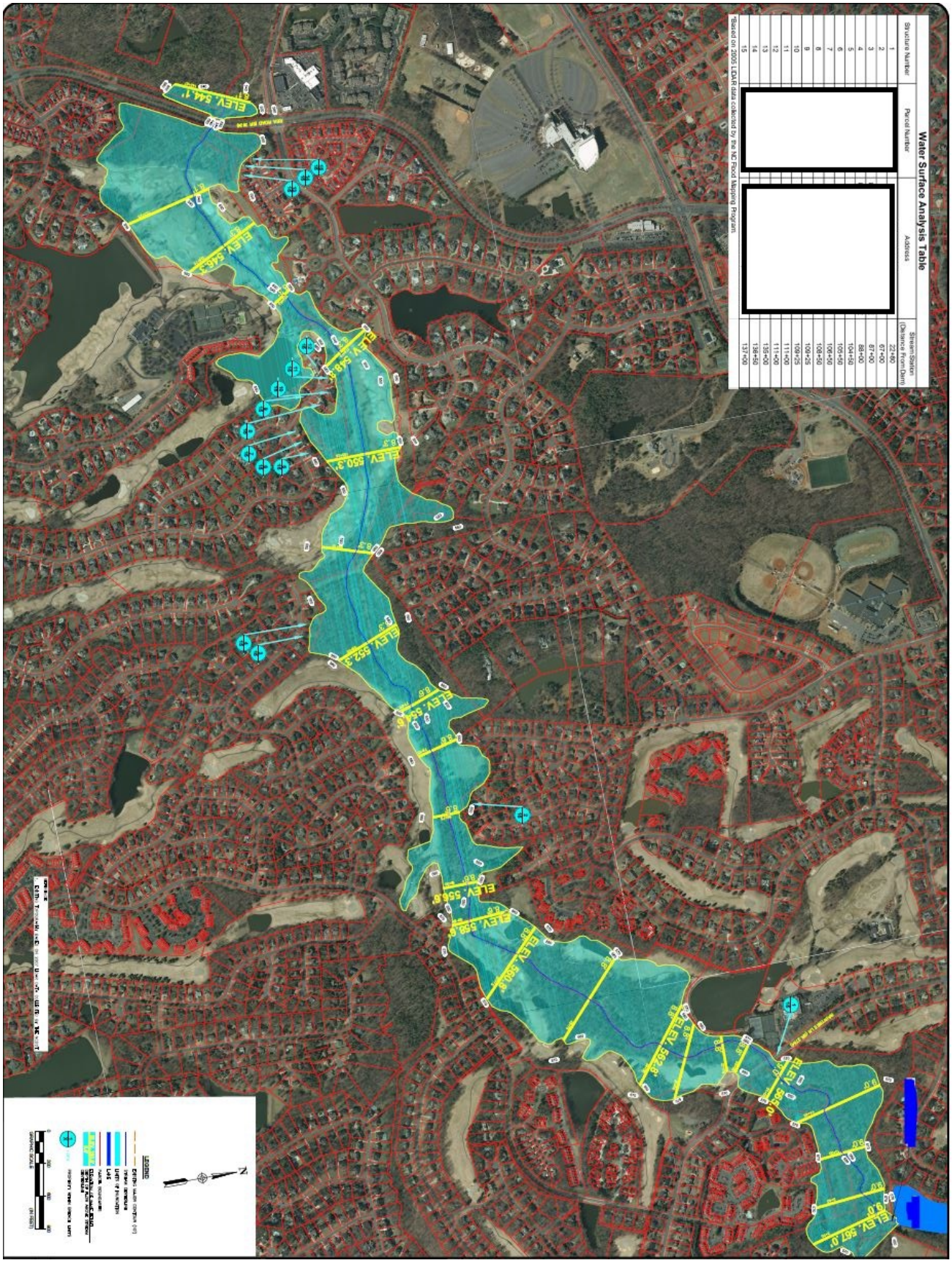
SIM map example 1:



SIM map example 2:



SIM map example 2 Full View:



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