



# VIRGINIA SOIL AND WATER CONSERVATION BOARD GUIDANCE DOCUMENT ON DAM BREAK INUNDATION ZONE AND INCREMENTAL DAMAGE ANALYSIS AND MAPPING PROCEDURES

(Approved XXXXXX, 2010)  
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## **Summary:**

This guidance document specifies the procedures to be utilized by the Virginia Soil and Water Conservation Board in determining the adequacy of a dam break inundation zone analysis and map prepared in accordance with 4VAC50-20-54 and the adequacy of an incremental damage analysis conducted in accordance with 4VAC50-20-52.

## **Electronic Copy:**

An electronic copy of this guidance in PDF format is available on the Regulatory TownHall under the Virginia Soil and Water Conservation Board at <http://townhall.virginia.gov/L/GDocs.cfm>.

## **Contact Information:**

Please contact the Department of Conservation and Recreation's Division of Dam Safety and Floodplain Management at [dam@dcr.virginia.gov](mailto:dam@dcr.virginia.gov) or by calling 804-371-6095 with any questions regarding the application of this guidance.

## **Disclaimer:**

This document is provided as guidance and, as such, sets forth standard operating procedures for the Virginia Soil and Water Conservation Board and the Department of Conservation and Recreation that administers the program on behalf of the Board. This guidance provides a general interpretation of the applicable Code and Regulations but is not meant to be exhaustive in nature. Each situation may differ and may require additional interpretation of the Dam Safety Act and attendant regulations.

## **Dam Break Inundation Zone and Incremental Damage Analysis and Mapping Procedures**

### **I. Background:**

The Impounding Structure Regulations require an owner of a regulated dam to conduct a dam break analysis to support the appropriate hazard classification of the impounding structure in accordance with 4VAC50-20-40 (Hazard Potential Classification of Impounding Structures). Additionally, in accordance with Section 4VAC50-20-54 of the Impounding Structure Regulations, a dam break inundation zone map shall be developed that meets the requirements of the Dam Safety Act and the Impounding Structure Regulations for regulated dams with a High, Significant or Low Hazard Potential. The spillway design flood requirement of dams may also be reduced if it can be demonstrated through an incremental damage analysis in accordance with

4VAC50-20-52 that such a determination will not reduce the protection of public safety that would be afforded by using the spillway design flood that would otherwise be specified by Table 1. This guidance outlines the procedures that dam owners and their engineers should utilize to conduct dam break and incremental damage assessment analyses as well as to produce the associated maps.

**II. Definitions (pursuant to § 10.1-604 and 4VAC50-20-30):**

"Dam break inundation zone" means the area downstream of a dam that would be inundated or otherwise directly affected by the failure of a dam.

**III. Authority:**

The Dam Safety Act in the Code of Virginia contains the following authorities applicable to this guidance:

**§ 10.1-605. Promulgation of regulations by the Board.**

The Board shall promulgate regulations to ensure that impounding structures in the Commonwealth are properly and safely constructed, maintained and operated.

The Impounding Structure Regulations contain the following authorities applicable to this guidance:

**4VAC50-20-54. Dam break inundation zone mapping.**

A. Dam break inundation zone maps shall be provided to the department to meet the requirements set out in Hazard Potential Classifications of Impounding Structures (4VAC50-20-40), Emergency Action Plan for High and Significant Potential Hazard Impounding Structures (4VAC50-20-175), and Emergency Preparedness for Low Hazard Potential Impounding Structures (4VAC50-20-177), as applicable.

B. The location of the end of the inundation mapping should be indicated where the water surface elevation of the dam break inundation zone and the water surface elevation of the spillway design flood during an impounding structure nonfailure event converge to within one foot of each other. The inundation maps shall be supplemented with water surface profiles showing the peak water surface elevation prior to failure and the peak water surface elevation after failure.

C. All inundation zone map(s), except those utilized in meeting the requirements of Emergency Preparedness for Low Hazard Potential Impounding Structures (4VAC50-20-177), shall be signed and sealed by a licensed professional engineer.

D. For determining the hazard potential classification, a minimum of the following shall be provided to the department:

1. A sunny day dam break analysis utilizing the volume retained at the normal or typical water surface elevation of the impounding structure;
2. A dam break analysis utilizing the spillway design flood with a dam failure;
3. An analysis utilizing the spillway design flood without a dam failure; and
4. For the purposes of future growth planning, a dam break analysis utilizing the probable maximum flood with a dam failure.

E. To meet the requirements of Emergency Preparedness set out in 4VAC50-20-177, all Low Hazard Potential impounding structures shall provide a simple map, acceptable to the department, demonstrating the general inundation that would result

from a dam failure. Such maps do not require preparation by a professional licensed engineer, however, it is preferred that the maps be prepared by a licensed professional engineer.

F. To meet the Emergency Action Plan requirements set out in 4VAC50-20-175, all owners of High and Significant Hazard Potential impounding structures shall provide dam break inundation map(s) representing the impacts that would occur with both a sunny day dam failure and a spillway design flood dam failure.

1. The map(s) shall be developed at a scale sufficient to graphically display downstream inhabited areas and structures, roads, public utilities that may be affected, and other pertinent structures within the identified inundation area. In coordination with the local organization for emergency management, a list of downstream inundation zone property owners and occupants, including telephone numbers may be plotted on the map or may be provided with the map for reference during an emergency.

2. Each map shall include the following statement: "The information contained in this map is prepared for use in notification of downstream property owners by emergency management personnel."

#### **4VAC50-20-40. Hazard potential classifications of impounding structures.**

A. Impounding structures shall be classified in one of three hazard classifications as defined in subsection B of this section and Table 1.

B. For the purpose of this chapter, hazards pertain to potential loss of human life or damage to the property of others downstream from the impounding structure in event of failure or faulty operation of the impounding structure or appurtenant facilities. Hazard potential classifications of impounding structures are as follows:

1. High Hazard Potential is defined where an impounding structure failure will cause probable loss of life or serious economic damage. "Probable loss of life" means that impacts will occur that are likely to cause a loss of human life, including but not limited to impacts to residences, businesses, other occupied structures, or major roadways. Economic damage may occur to, but not be limited to, building(s), industrial or commercial facilities, public utilities, major roadways, railroads, personal property, and agricultural interests. "Major roadways" include, but are not limited to, interstates, primary highways, high-volume urban streets, or other high-volume roadways.

2. Significant Hazard Potential is defined where an impounding structure failure may cause the loss of life or appreciable economic damage. "May cause loss of life" means that impacts will occur that could cause a loss of human life, including but not limited to impacts to facilities that are frequently utilized by humans other than residences, businesses, or other occupied structures, or to secondary roadways. Economic damage may occur to, but not be limited to, building(s), industrial or commercial facilities, public utilities, secondary roadways, railroads, personal property, and agricultural interests. "Secondary roadways" include, but are not limited to, secondary highways, low-volume urban streets, service roads, or other low-volume roadways.

3. Low Hazard Potential is defined where an impounding structure failure would result in no expected loss of life and would cause no more than minimal economic damage. "No expected loss of life" means no loss of human life is anticipated.

C. The hazard potential classification shall be proposed by the owner and shall be subject to approval by the board. To support the appropriate hazard classification, dam break analysis shall be conducted by the owner's engineer. Present and planned land-use for which a development plan has been officially approved by the locality in the dam break inundation zones downstream from the impounding structure shall be considered in determining the classification.

D. Impounding structures shall be subject to reclassification by the board as necessary.

**4VAC50-20-52. Incremental damage analysis.**

A. When appropriate, the spillway design flood requirement may be reduced by the board in accordance with this section.

B. The owner's engineer may proceed with an incremental damage analysis. Once the owner's engineer has determined the required spillway design flood through application of Table 1, further analysis may be performed to evaluate the limiting flood condition for incremental damages. Site-specific conditions should be recognized and considered. This analysis may be used to lower the spillway design flood. In no situation shall the allowable reduced level be less than the level at which the incremental increase in water surface elevation downstream due to failure of an impounding structure is no longer considered to present an additional downstream threat. This engineering analysis will need to present water surface elevations at each structure that may be impacted downstream of the dam. An additional downstream threat to persons or property is presumed to exist when water depths exceed two feet or when the product of water depth (in feet) and flow velocity (in feet per second) is greater than seven.

C. The spillway design flood shall not be reduced below the minimum threshold values as determined by Table 1.

D. The required spillway design flood shall be subject to reclassification by the board as necessary to reflect changed conditions at the impounding structure and in the dam break inundation zone.

**IV. Discussion and Interpretation:**

**Dam Break Analysis and Inundation Zone Mapping**

The Impounding Structure Regulations require an owner of a regulated dam to conduct a dam break analysis to support the appropriate hazard classification of the impounding structure in accordance with 4VAC50-20-40 (Hazard Potential Classification of Impounding Structures). Additionally, in accordance with Section 4VAC50-20-54 of the Impounding Structure Regulations, a dam break inundation zone map shall be developed that meets the requirements of the Dam Safety Act and the Impounding Structure Regulations for regulated dams with a High, Significant or Low Hazard Potential. This section requires that dam break inundation zone maps shall be provided to the department to meet the requirements set out in Hazard Potential Classifications of Impounding Structures (4VAC50-20-40), Emergency Action Plan for High and Significant Potential Hazard Impounding Structures (4VAC50-20-175), and Emergency Preparedness for Low Hazard Potential Impounding Structures (4VAC50-20-177), as applicable. All dam break inundation zone maps shall be signed and sealed by a professional engineer licensed in the Commonwealth of Virginia (unless solely developed to satisfy the requirements

of 4VAC50-20-177 which allows the owner to develop a simple dam break inundation map acceptable to the director, demonstrating the general inundation that would result from an impounding structure failure. Such maps required pursuant to this section do not require preparation by a professional licensed engineer; however, maps prepared by a licensed professional engineer are preferred and are additionally required to satisfy §§ 4VAC50-20-40 and 4VAC50-20-54.)

A dam break analysis using an approved hydrologic/hydraulic computer model shall be conducted by the dam owner's professional engineer. The modeling effort must conform to the intended use of the chosen computer model. Mixing the criteria of one procedure, listed in 4VAC50-20-320 (Acceptable design procedures and references) with criteria from another procedure, unless otherwise mentioned, is prohibited. Compute modeling must generate appropriate inflow hydrographs which are routed through the dam and downstream of the dam. Some computer models that are acceptable include HEC-1, HEC-HMS, HEC-RAS and the NRCS computer models TR-60 with TR-66. Other computer models may be used if approved by the DCR Regional Engineer prior to submitting the results to the Division of Dam Safety and Floodplain Management. Present and planned land-use for which a development plan has been officially approved by the locality in the dam break inundation zones downstream from the impounding structure shall be considered when conducting the dam break analysis.

For the validation of the hazard potential of a dam and the development of an Emergency Action Plan, at a minimum, the following shall be reflected on each map using an approved hydrologic/hydraulic computer model and shown on one map (numerous sheets are allowed to accommodate scale):

1. Sunny day dam break with the starting water surface elevation at the normal or typical water surface elevation of the impounding structure. If the impounding structure was designed and built for flood control, the starting water surface elevation shall be at the crest of the auxiliary or emergency spillway.
2. Dam failure during the required spillway design flood. An overtopping failure shall be modeled if the emergency spillway is unable to pass the spillway design flood without overtopping the crest of the dam. A piping failure shall be modeled if the emergency spillway has enough capacity to pass the required spillway design flood without overtopping the crest of the dam.
3. Routing the spillway design flood through the dam without any failure.
4. Dam failure during the Probable Maximum Flood.

Topographic information, including TINS, that show at a minimum ten-foot contour elevations shall be used to develop the hydrologic/hydraulic computer model downstream of the dam, including cross sections at potential damage locations (homes, businesses, roads, utilities, etc.) downstream of the dam. The dam owner's engineer must develop reliable cross sections to input into the computer model. If adequate topographic information is not available, the dam owner must provide an alternative method for identifying potential damage locations that must be approved by the DCR Regional Engineer, prior to initiating the evaluation. Topography may be a component of the submitted inundation map; however, map clutter must be avoided. If the topography is not submitted on the inundation map, a copy of the topographical information or

TINS used shall be submitted with the engineering analysis. Paper copies of all hydrologic and hydraulic computer model runs shall be provided to the Regional Engineer.

The owner's engineer shall use sanctioned engineering criteria and sound professional judgment for the worst case storm conditions in the selection of:

- a. Dam failure parameters
- b. Rainfall distributions
- c. Flood routing procedures and coefficients
- d. Use of available topography and supporting field surveys
- e. Development of SCS Curve Numbers
- f. Development of spillway rating curves and area-capacity curves
- g. Determination of the Time of Concentration and/or lag time
- h. Other steps used during the modeling and analysis of flood conditions in the watershed and downstream of the impounding structure.

The judgments and the engineering criteria used by the dam owner's engineer shall be reviewed and approved by the DCR Regional Engineer for appropriateness. The DCR Regional Engineer will provide specific guidance via written correspondence to the dam owner should the judgments or the use of the engineering criteria be determined to be inappropriate. If the map is acceptable, a statement of confirmation that the map appears to be in conformance with the regulations will also be provided to the owner.

The computer model shall be extended to a point downstream of the impounding structure where the water surface elevations of the spillway design flood with and without dam failure converge to within one foot of each other or to the last impacted structure caused by a sunny-day dam failure, whichever is farthest downstream.

The following shall be clearly marked at each potential damage location on each map:

- a. Cross Section number and distance downstream from the dam to the nearest tenth of a mile
- b. Relative time of travel, in minutes, of the first flood waters associated with a dam failure to reach the impact location
- c. Relative time of travel, in minutes, of the peak flood level associated with a dam failure to reach the impact location
- d. Maximum depth of water with a dam failure at each impact location in feet (depth of water on the structure)

The map lines delineating the inundation areas shall be drawn in such thickness (solid, dashed or dotted lines in black) to identify the inundation limits as the main feature of the map. The lines shall not obliterate the location of structures, or features which are shown as being inundated. The map shall also identify the scale and show the north arrow on each map sheet.

Inundation maps may have color in the background and shall be at a scale where impacted structures downstream may be clearly seen. The maps should not utilize color-coding of the inundation lines since the maps will often be copied on black and white reproduction equipment. If the inundation area is too large to be shown on one map, an index map shall be included which

shows the full extent of the inundation area and the outline of the detailed maps with an identifier for each map sheet. Impacted structures (homes, businesses, roads, utilities, etc) shall be clearly shown and if cross-hatching is used it must not obscure the structures. The physical addresses and contact persons may be located on a separate attachment to avoid clutter. This information will be used to aid emergency responders in quickly locating impacted structures and conducting evacuations. Inundation maps shall not be produced in a size larger than 11" by 17" and the final size must be folded to a size of 8 1/2" by 11". The inundation maps shall be submitted to the DCR Regional Engineer electronically in a Windows compatible image format and as a set of paper maps. Acceptable digital image formats consist of JPEG, TIF, BMP, GIF, PNG, or EMF files. Adobe software constructed PDFs are also acceptable. Image resolution should be sufficient to view and read the necessary information noted above.

A narrative describing the accuracy and limitation of the information supplied on the inundation maps, including reference to the datum used, shall be provided to the DCR Regional Engineer. Since local officials are likely to use the maps for evacuation purposes, the following note shall be attached to each map: "Mapping of flooded areas and flood wave travel times are approximate. Timing and extent of actual inundation may differ from the information presented on this map."

The hazard potential classification shall be proposed by the dam owner and shall be subject to reclassification by the Virginia Soil and Water Conservation Board, upon review of the information submitted by the dam owner and the owner's engineer and any pertinent information regarding potential impacts downstream of the dam caused by a failure of the dam.

### **Incremental Damage Assessment**

Once a dam owner has had the consulting engineer complete the Dam Break Inundation Zone Analysis and Map (Map) and concluded a determination of the hazard classification and, once the hazard classification has been reviewed and accepted by the appropriate Regional Engineer; the Spillway Design Flood (SDF) would then be identified in Table 1 of the Impounding Structure Regulations (4VAC50-20-50). Should the dam owner wish to consider lowering the SDF through an Incremental Damage Analysis (IDA), the consulting engineer must then perform the following procedures. However, as noted in Table 1 of the Impounding Structure Regulations an SDF less than the Minimum Threshold will not be accepted.

#### **1. Identify the Required SDF**

Once the hazard classification is determined, Table 1 will identify the required SDF. If the dam owner decides to have the consulting engineer perform an incremental damage analysis, the computer models previously used to determine the inundation and subsequent hazard classification must be used to identify the flood event at which no significant increase in damage will occur due to a dam failure. This process may start with the required SDF or with the Minimum Threshold for IDA (Minimum Threshold), see Table 1.

#### **2. Have Models Showing all Requirements with Backup Calculations**

The consulting engineer must have at a minimum, hydrologic computer models for the Sunny-Day Dam Failure, Spillway Design Flood With a Dam Failure, Spillway Design Flood Without a

Dam Failure and the Probable Maximum Flood With a Dam Failure. These models must be routed downstream of the dam to a point in which the maximum water surface elevations during the SDF with a Dam Failure and the SDF without a Dam Failure converge to within one foot of each other or to the last impacted structure cause by a sunny-day dam failure, whichever is farthest downstream.

### 3. Prepare the Map

The results of the models are plotted onto the Map to demonstrate inundation expected by each event. All homes, buildings, roads and other impacted facilities shall be shown on the map.

### 4. Use IDA to Determine if the SDF can be Reduced

If it can be shown that the aforementioned list of potentially impacted facilities would, at some lesser flood compared to the SDF, be severely damaged due to floods associated storm flows without a dam failure then the owner can have the consulting engineer adjust the input storm in the computer models in an attempt to identify at what storm event that a dam failure would not significantly add to damaged facilities or threats to life downstream.

When structures, such as homes, businesses, and utilities buildings are identified in the inundation zone, the consulting engineer can determine significant impact to that structure if, during a dam failure, the water depth will equal or exceed two feet above the ground/building connection. If the product of the depth of water on a structure in feet and the velocity of water flowing at that location in feet per second equals seven (7) or more, then the structure is considered significantly impacted and projects the probable loss of life. If the depth of water is less than two feet on the structure and the product of the total water depth and the velocity of water at the structure is less than seven (7) during any dam failure, the structure would not be considered threatened nor would result in probable loss of life.

### 5. Determination of the Adjusted SDF

An IDA should always result in the same answer no matter whether you start at the SDF or at the Minimum Threshold working toward the Adjusted SDF. The Adjusted SDF should represent the maximum flood at which the dam will provide maximum flood protection downstream and no further damages would be expected with larger flood events with a dam failure.

The dam owner may choose to have the engineer design the emergency spillway to the Adjusted SDF or some flood event larger than the adjusted SDF that would consider potential increases in hazard classification due to future development downstream of the dam.

The dam owner's consulting engineer will need to provide one set of paper copies of the computer model results and an electronic copy on diskette. Profiles, calculations and other supporting information used to determine an adjusted SDF shall be submitted to the Dam Safety Regional Engineer for review and acceptance.

Dam Safety's acceptance of an adjusted SDF does not guarantee that any future development will not place new increased spillway capacity requirements on the dam owner.

For a Secondary roadway (secondary highway, low-volume urban street, service road and other low-volume roadway) located below a dam the hazard classification may be significant requiring a SDF of ½ PMF (see roadways guidance for additional information on how roadways may impact hazard classification). If the dam owner desires, an IDA may be performed that would identify at what flood event (between the ½ PMF and the 100-Year Flood) the computed water surface elevation for the flood event without a dam failure would result in a water level at or just below the roadway surface edge without a dam failure. With this storm event, if a dam failure would overtop the roadway by four (4) inches or more, it could lead to possible loss of life of persons in vehicles on the roadway or loss of the roadway itself. If the dam failure does not overtop the roadway for the Sunny-Day Failure and storm events up to the PMF with a dam failure, then the dam should be classified as Low Hazard, if there are no other impacted structures or facilities, should the dam fail. If the roadway is a major roadway (interstate, primary highway, high-volume urban street or other high-volume roadway) then the incremental damage analysis would start at PMF and could result in a SDF no less than the ½ PMF.

If there are several roadways below a dam, then the roadway that results in the largest spillway design flood applies.

If a secondary or low volume roadway crosses the dam then the SDF would usually be at a minimum the ½ PMF (see roadways guidance for additional information on how roadways may impact hazard classification) and no IDA would be permitted for a dam with a significant hazard classification. If a major roadway crosses the dam then the SDF would be the PMF and no IDA would be permitted.

In cases where there are other facilities below the dam along with roadways, the impact that creates the highest hazard classification shall dictate. If permitted, the owner may choose to have the consulting engineer perform an IDA in the hopes of lowering the SDF.

#### **V Adoption, Amendments, and Repeal:**

This document was adopted by the Board on XXXX, 2010 and may be amended or repealed as necessary by the Board.