Embankment Retrofit Design

April 2015

EMBANKMENT RETROFIT DESIGN

Many State, federal and local agencies have identified opportunities for retrofitting existing ponds and roadway culverts to provide additional stormwater quality management. While the Maryland Department of the Environment (MDE) recognizes the benefits and cost savings of such an approach, the designer must ensure the proposed retrofit does not impact the structural integrity of the existing embankment or put the safety of the public at risk.

MDE's Sediment, Stormwater, and Dam Safety (SSDS) Program has developed the following procedure to assist owners and designers to meet this objective. MDE discourages retrofit proposals involving an embankment that requires a permit from MDE's Dam Safety Division.

These include:

- All Hazard Class "B" and "C" structures;
- All embankments in Use III waters; and,
- All dam embankments with heights greater than 20 feet.

Under Maryland law (Annotated Code of Maryland, *Environment Article* §5-503) anyone who proposes to construct or alter a dam or pond must obtain a permit from MDE or the local approving authority having jurisdiction. A person is exempt from the requirement of obtaining a permit from MDE' s Dam Safety Division for small ponds if the structure meets minimum safety standards **and the work is approved by MDE or the local approving authority.**

Should a retrofit proposal involve such an embankment, the proposal will be referred to MDE's Dam Safety Division for review. This may require that the applicant submit a completed "Joint Federal/State Application for the Alteration of any Floodplain, Waterway, Tidal or Nontidal Wetland In Maryland" and payment of application fees for permit processing. The process is described here:

http://mde.maryland.gov/programs/Water/WetlandsandWaterways/PermitsandApplications/Pages/nontidal_permits.aspx

A designer must evaluate whether the Natural Resources Conservation Service Maryland (NRCS), Conservation Practice Standard, Pond Code 378 (Code 378) or the Special Embankment Design Category applies to either the existing facility or the proposed retrofit (See Figure 1). In addition, the designer must evaluate the existing condition of the embankment and correct any identified principal spillway, culvert, or embankment structural or maintenance issues.

I.   Evaluation Process for Proposed Retrofit Project

The following procedure describes the recommended process, as illustrated in Figure 2, for identifying and evaluating proposed retrofit projects.

Step 1. Determine the Embankment Design Category

Step 1 in the recommended retrofit design process, as shown in Figure 2, is to determine the embankment design category of the existing embankment. As previously mentioned, the designer must determine the Design Category (e.g. Code 378 or Special Embankment Design) of the embankment. The Design Category is used to determine the applicable design criteria. MDE has developed a flow chart to navigate the Code 378 requirements for all conduits penetrating embankments including stormwater management ponds (See Figure 1). Following the steps in this flow chart results in the determination of the Design Category of an existing or proposed embankment.

An embankment may be categorized under the following embankment Design Categories:

- Unclassified stormwater management pond, exempt from all Code 378 criteria but required to meet the 2000 Maryland Stormwater Management Design Manual, Volumes I and II, (Manual) Chapter 3 design criteria;
- Excavated pond required to meet minimum freeboard (Code 378, page 10);
- Special Embankment Design pond, required to meet special embankment design criteria;
- Code 378 small pond, required to meet all Code 378 criteria;
- Potential hazard class pond, required to be reviewed by MDE's Dam Safety Division.

For conduits penetrating a road embankment, please be aware if the answer is "yes" to any one of the following conditions, the road embankment shall meet Code 378 criteria or at a minimum the Special Embankment Design criteria:

1. HW-TW>10 and HW/D>2;
2. Permanent Pool Depth>3ft.; or
3. A riser is currently used or proposed as the control structure.

Existing Condition Breach Analysis

A dam breach analysis may be required to determine the hazard class of an embankment. The hazard class is used to determine whether a Dam Safety permit review will be required. The dam breach analysis should be performed following the criteria developed by MDE's Dam Safety Division. This information can be found in Appendix A.

For embankments less than 15 feet high, the brim-up storm (full to the top of the embankment elevation) may be used to determine the hazard classification. If the brim-up storm is larger than the probable maximum flood (PMF) storm, then the PMF may be used. Once the peak breach discharge is determined, HEC-RAS, Manning's equation, or a culvert analysis shall be used to calculate the flow depth in the area downstream of the embankment. For more information, refer to the guidance "Hazard Classifications for Smaller Ponds & Dams" located in Appendix A.

Step 2. Evaluate Whether Proposed Retrofit Changes the Design Category of the Existing Embankment

Step 2 in the recommended retrofit design process, as shown in Figure 2, is to evaluate whether a proposed retrofit will change the Design Category of the existing embankment. When proposing a retrofit, the impacts on the existing embankment and its associated Design Category must be evaluated. The goal shall be to minimize the impacts to the existing embankment thereby reducing or eliminating any requirements to upgrade its structural integrity to a higher standard of design.

Examples of proposed modifications that may change the Design Category of an embankment and therefore require a modification to the existing structure to meet the applicable design criteria for the new Design Category include, but are not limited to, the following:

- Addition of a riser or another flow reducing device to an existing roadway cross culvert or principal spillway pipe
- Modification to the openings of an existing control structure
- Reduction in the existing design storm storage volume
- Removal and replacement of an existing principal spillway pipe
- Physical modification to control structure
- Increase in design storm WSEL
- Reduction in freeboard
- Increase in storage below invert of principal spillway
- Increase in 10 year design storm WSEL above clay core elevation
- Increase in drainage area without additional storage
- Change in downstream characteristics resulting in change to hazard classification (i.e. hazard creep).

If, as a result of the proposed retrofit, the existing embankment falls under a new Design Category, the existing embankment will require an upgrade, and the proposed modifications will have to address the new applicable Design Category criteria.

Four scenarios will direct the path necessary to complete the retrofit design:

Scenario 1: The proposed retrofit changes the Design Category of the existing embankment and the existing embankment is NOT a roadway under the Special Embankment Design Category. The designer must choose one of two options to proceed with the retrofit design:

> **Option A:** Under Option A, the designer chooses to proceed to Step 3 and modify the scope of the proposed retrofit such that the Design Category of the existing embankment does not change. The designer then proceeds to Step 4.

> **Option B:** Under Option B, the designer chooses to proceed directly to Step 4 to evaluate the existing embankment under the new Design Category and make any modifications to the existing embankment as necessary to bring the embankment into compliance.

Scenario 2: The proposed retrofit changes the Design Category of the existing embankment and the existing embankment is a roadway under the Special Embankment Design Category. The designer must choose one of two options to proceed with the retrofit design:

>**Option B:** Under Option B, the designer chooses to proceed directly to Step 4 to evaluate the existing embankment under the new Design Category and make any modifications to the existing embankment as necessary to bring the embankment into compliance.

>**Option C:** Under Option C, the designer chooses to proceed to Step 3 and modify the scope of the proposed retrofit such that the Design Category of the existing embankment does not change. The designer then proceeds to Step 4.

Scenario 3: The proposed retrofit does NOT change the Design Category of the existing embankment and the existing embankment is a roadway under the Special Embankment Design Category. For existing roadway cross culverts under the Special Embankment Design Category where the proposed retrofit will not change this Design Category, the designer may proceed directly to Step 4. Under Step 4, the evaluation of the condition of the existing embankment will be limited to the evaluation of cross culvert and outfall structural integrity and stability.

Scenario 4: The proposed retrofit does NOT change the Design Category of the existing embankment and the existing embankment is NOT a roadway under the Special Embankment Design Category. The designer chooses to proceed directly to Step 4 to evaluate the existing embankment under its existing Design Category and make any modifications to the existing embankment as necessary to bring the embankment into compliance.

Step 3. Modify the Scope of the Proposed Retrofit to Eliminate Changes to the Embankment Design Category

Step 3 in the recommended retrofit design process, as shown in Figure 2, is to modify the scope of the proposed retrofit to eliminate any changes to the embankment Design Category. Options exist for retrofitting an existing pond structure without impacting the existing embankment or its Design Category. Three options are discussed below:

Excavate new wet pool. One possible option to achieve water quality management and avoid impacts to an existing embankment and/or control structure is to modify the pond area to create a wet pool, micro pool, forebay, filter, or infiltration facility within an existing pond. For minimal impacts it is necessary to keep the excavated storage area a minimum distance from the principal spillway and embankment. The following equation should be used to determine the minimum offset distance:

Minimum offset distance:
> $x \geq \max(10', 2D, 2H_{100})$, *where*:
> x = the distance from the outlet to the edge of the wet pool
> D = the depth of the wet pool
> H_{100} = the depth from the upstream toe of the embankment to the 100 yr WSEL.

Construction of interior embankment and weir: A weir wall and interior embankment may provide one alternative for achieving water quality within an existing pond. These structures shall be sufficiently offset from the embankment and principal spillway. The minimum offset distance can be determined using the equation above.

Extension of a roadway cross culvert or pipe conduit spillway and construction of interior embankment: It may be possible to retrofit an existing roadway cross culvert or pipe spillway with an interior embankment structure by extending the existing cross culvert or pipe spillway with a new manhole and pipe extension. The existing culvert or pipe spillway can be connected to the manhole which can then be connected to the extended spillway. The extended spillway and new interior embankment then act as a new embankment for the interior pond retrofit. The new interior embankment and pipe spillway must be designed and constructed to meet all requirements of Code 378, as applicable.

The design of an interior embankment and weir or principal spillway pipe shall not affect the hydraulic performance or reduce freeboard requirements of an existing facility under the original design criteria. Interior embankments must be designed and constructed with all applicable Design Category requirements. In many instances this will require the interior embankment and spillway to meet Code 378 design criteria.

Step 4. Evaluate Condition of Existing Embankment or Cross Culvert

Step 4 in the recommended retrofit design process, as shown in Figure 2, is to evaluate the condition of the existing embankment. Existing stormwater management ponds are required to be maintained by the owner/operator in good condition. In no instance should an existing embankment exhibiting potential failure be approved for retrofit. The designer of a retrofit proposal must perform a field inspection of the embankment and associated appurtenances and evaluate the condition of the existing structure with respect to the Design Category criteria. Table 1 provides the minimum required components of the existing condition evaluation for each embankment Design Category.

An existing condition evaluation must be performed to identify deficiencies in the structural integrity of the embankment. The existing conditions evaluation includes an inspection of the embankment using the checklist in Appendix A of Code 378. The inspection will identify areas of the embankment and principal spillway where physical embankment problems are impeding the ability of the embankment to function as intended or where maintenance or repairs are necessary. These problems may include the presence of woody vegetation on the embankment, seepage, leaking principal spillway pipe joints, a corroded principal spillway pipe, undermining of the embankment toe, or a clogged or failed control structure.

Table 1. Embankment Condition Evaluation

Embankment Design Category	Required Evaluation
Manual Chapter 3 Practice Excavated Pond	Determine condition of embankment. Determine condition of principal spillway. Determine available 10 year freeboard.
Special Embankment Design	Determine condition of cross culvert. Determine condition of the cross culvert outfall.
Code 378 Small Pond Embankment Requiring Dam Safety Review	Determine condition of embankment. Determine condition of principal spillway. Determine available 100 year freeboard. Determine danger reach impacts. Verify existence of clay core and cutoff trench. Verify existence of seepage control.

For existing embankments under the Special Embankment Design Category, the embankment conditions evaluation is limited to evaluation of the structural integrity and stability of the roadway cross culvert and outfall.

For all other Design Categories, the embankment shall also be evaluated to determine whether its construction meets the requirements of its original design criteria. Depending on the Design Category of the embankment (as determined using Figure 1), this evaluation may include confirming that seepage control, a clay core, adequate pipe material, and adequate embankment material and compaction were part of the original construction. Where design documents such as plans, computations, and approved as-builts are not available, determining the existence of a clay core, cut off trench, or seepage control may require a geotechnical analysis including soil borings.

Step 5. Bring Existing Embankment Design Into Compliance

Step 5 in the recommended retrofit design process, as shown in Figure 2, is to bring the existing embankment into compliance with the Design Category. Depending on the results of Step 4, further action may be required to bring the existing embankment into compliance with its existing and/or proposed Design Category. There will be situations where the existing embankment was not constructed to current design criteria and, therefore, upgrades to the embankment and/or principal spillway will be necessary. The following are two situations where this may be an issue:

- Existing Code 378 small ponds not constructed in accordance with Code 378;
- Existing embankments of Manual Chapter 3 structural practices not constructed in accordance with Manual Chapter 3 requirements.

Common issues that may arise during the evaluation of an existing embankment structure are discussed below. These issues will require correction as part of any proposed retrofit design,

with the exception of existing embankments under the Special Embankment Design category where the proposed retrofit will not change the Design Category.

Embankment Condition: Embankment seepage, presence of woody vegetation, slumping, sliding of slopes, animal burrows, piping along principle spillway, and erosion of the embankment or emergency spillway are all examples of conditions that must be corrected for any existing facility being considered for retrofitting. Correction of these items is part of the regular maintenance for any embankment. Any proposed retrofit utilizing an existing embankment with these conditions present will require correction as part of the design approval.

Spillway Condition: Pipe corrosion, pipe leakage (infiltration/exfiltration), outfall erosion, concrete spalling, inoperable pond drains, and principal spillway structure blockages are all examples of conditions that must be corrected for any existing facility under consideration for retrofitting. Correction of these items is part of the regular maintenance for any structure. Any proposed retrofit utilizing an existing embankment with these conditions present will require correction as part of the design approval.

Control Structure Condition: Blocked openings, missing or broken trash rack(s), missing anti-vortex device(s), malfunctioning low flow valve(s) or drain(s), concrete spalling or cracking, corrosion, and evidence of leakage are all examples of conditions that must be corrected for any existing facility under consideration for retrofitting. Correction of these items is part of any regular embankment maintenance. Any proposed retrofit utilizing an existing embankment with these conditions present will require correction as part of the design approval.

Embankment Material: For all Code 378 and special embankment design ponds, seepage control, a clay cutoff trench, and compacted embankment material are minimum specifications to ensure structural integrity. For special embankment design ponds, the clay cutoff trench and core may be absent with the approval of a geotechnical engineer. For Code 378 embankments, a clay core must be present in the embankment. These criteria must be met as a condition of a proposed retrofit approval.

It may be possible to correct a lack of an internal embankment core and cutoff trench by providing an impermeable liner on the upstream slope of the embankment.

Pipe Material: Ponds with principal spillway barrel pipes must meet the construction and material specifications found in Code 378 including water tight joints. This applies to all special embankment designs, Manual Chapter 3 embankments, and Code 378 facilities. Precast box culverts are not an acceptable spillway as they do not have water tight joints. Manholes and inlet structures shall not be located in dam embankments unless they have been carefully constructed to be water tight. Utilities in embankments and along the axis of the dam must not have gravel bedding. These utilities must be constructed to meet the requirements for pipe spillways.

For Code 378 ponds, special embankment design ponds, and Manual Chapter 3 embankments, the pipe spillway must be founded on a concrete cradle. With the exception of special embankment design ponds, any deviations from these design requirements will require correction. Slip lining may be an option for correcting pipe leakage or misaligned joints.
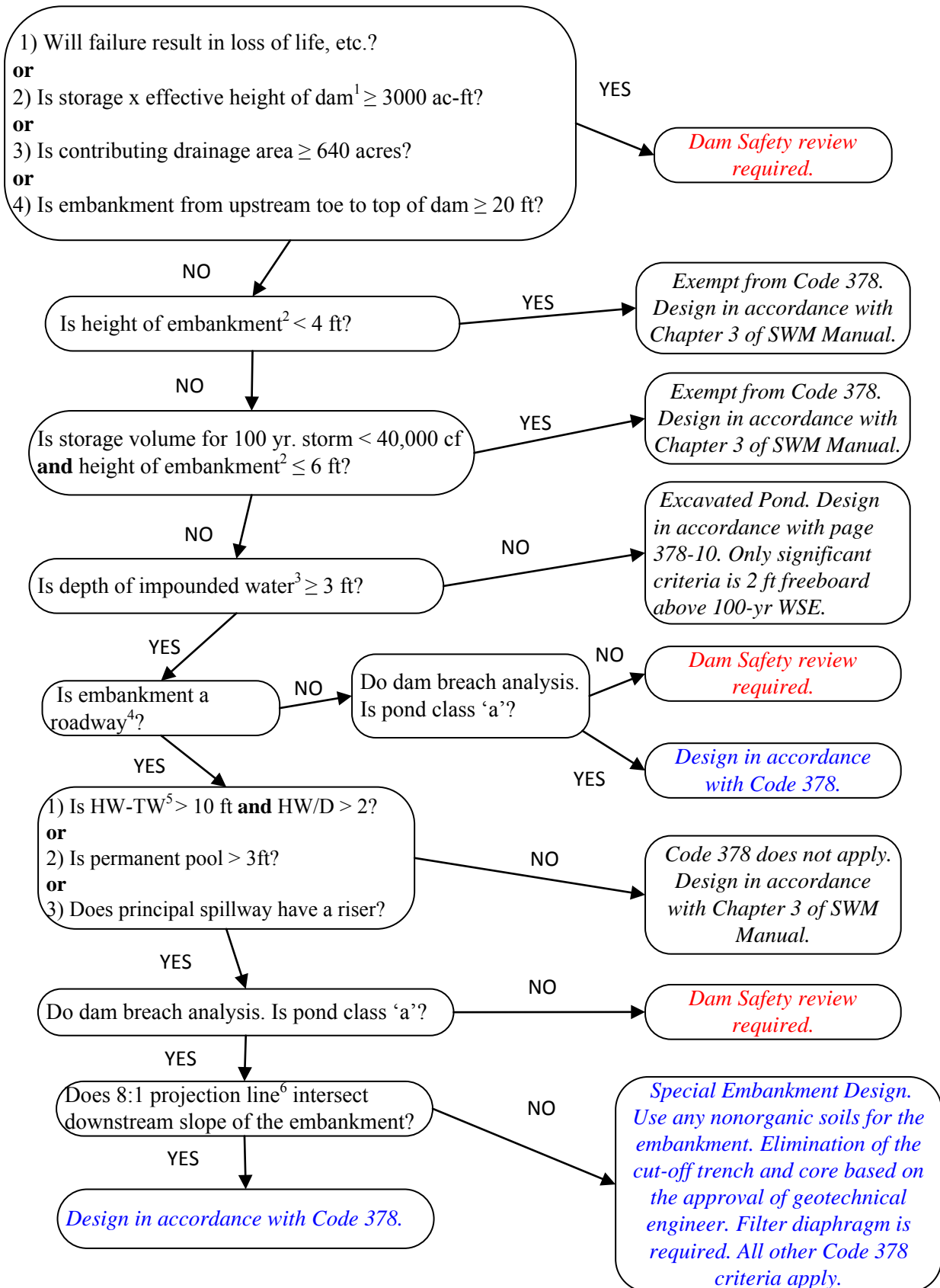
Step 6. Proceed with Retrofit Design

Step 6 in the recommended retrofit design process, as shown in Figure 2, is to proceed with submittal of the retrofit design. All proposed retrofit designs shall be submitted to the appropriate authority having jurisdiction for review and approval. For State and federal applicants, including the State Highway Administration, plans shall be submitted to MDE's Sediment, Stormwater, and Dam Safety Program, Plan Review Division for review and approval. All submission requirements including minimum plan content shall be included in the plan submission.

II.   Other Considerations

Please note that all pond retrofit designs shall, at a minimum, maintain the existing 1 year, 2 year, 10 year and 100 year frequency design storm water surface elevations and discharge rates, as required by the authority having jurisdiction. In addition, existing ponds providing 2 year quantity management may be required to be redesigned to provide CPv management in place of the 2 year quantity management. Any water quality or channel protection volume management provided by the existing facility shall not be affected by the retrofit design.

Figure 1. Determine Design Category of Pond Embankment

1) Will failure result in loss of life, etc.?
or
2) Is storage x effective height of dam[1] $\geq$ 3000 ac-ft?
or
3) Is contributing drainage area $\geq$ 640 acres?
or
4) Is embankment from upstream toe to top of dam $\geq$ 20 ft?

YES → *Dam Safety review required.*

NO ↓

Is height of embankment[2] < 4 ft?

YES → *Exempt from Code 378. Design in accordance with Chapter 3 of SWM Manual.*

NO ↓

Is storage volume for 100 yr. storm < 40,000 cf **and** height of embankment[2] $\leq$ 6 ft?

YES → *Exempt from Code 378. Design in accordance with Chapter 3 of SWM Manual.*

NO ↓

Is depth of impounded water[3] $\geq$ 3 ft?

NO → *Excavated Pond. Design in accordance with page 378-10. Only significant criteria is 2 ft freeboard above 100-yr WSE.*

YES ↓

Is embankment a roadway[4]?

NO → Do dam breach analysis. Is pond class 'a'?

    NO → *Dam Safety review required.*

    YES → *Design in accordance with Code 378.*

YES ↓

1) Is HW-TW[5] > 10 ft **and** HW/D > 2?
or
2) Is permanent pool > 3ft?
or
3) Does principal spillway have a riser?

NO → *Code 378 does not apply. Design in accordance with Chapter 3 of SWM Manual.*

YES ↓

Do dam breach analysis. Is pond class 'a'?

NO → *Dam Safety review required.*

YES ↓

Does 8:1 projection line[6] intersect downstream slope of the embankment?

NO → *Special Embankment Design. Use any nonorganic soils for the embankment. Elimination of the cut-off trench and core based on the approval of geotechnical engineer. Filter diaphragm is required. All other Code 378 criteria apply.*

YES ↓

Design in accordance with Code 378.

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Figure 1. (continued)

Definitions Referenced:

[1] Effective Height of Dam: Difference in elevation, in feet, between the emergency spillway crest and the lowest point on a profile taken along the centerline of the dam, excluding the cutoff trench. If there is no emergency spillway, use the principal spillway.

[2] Height of Embankment: Top of the dam to the lowest point of excavation, excluding the cutoff trench, along the center line of the dam (NRCS definition).

[3] Depth of Impounded Water: The depth of water impounded against the embankment at the 100-year storm high water elevation. Measure from the low point on the upstream toe of the embankment to the 100-year storm water surface elevation.

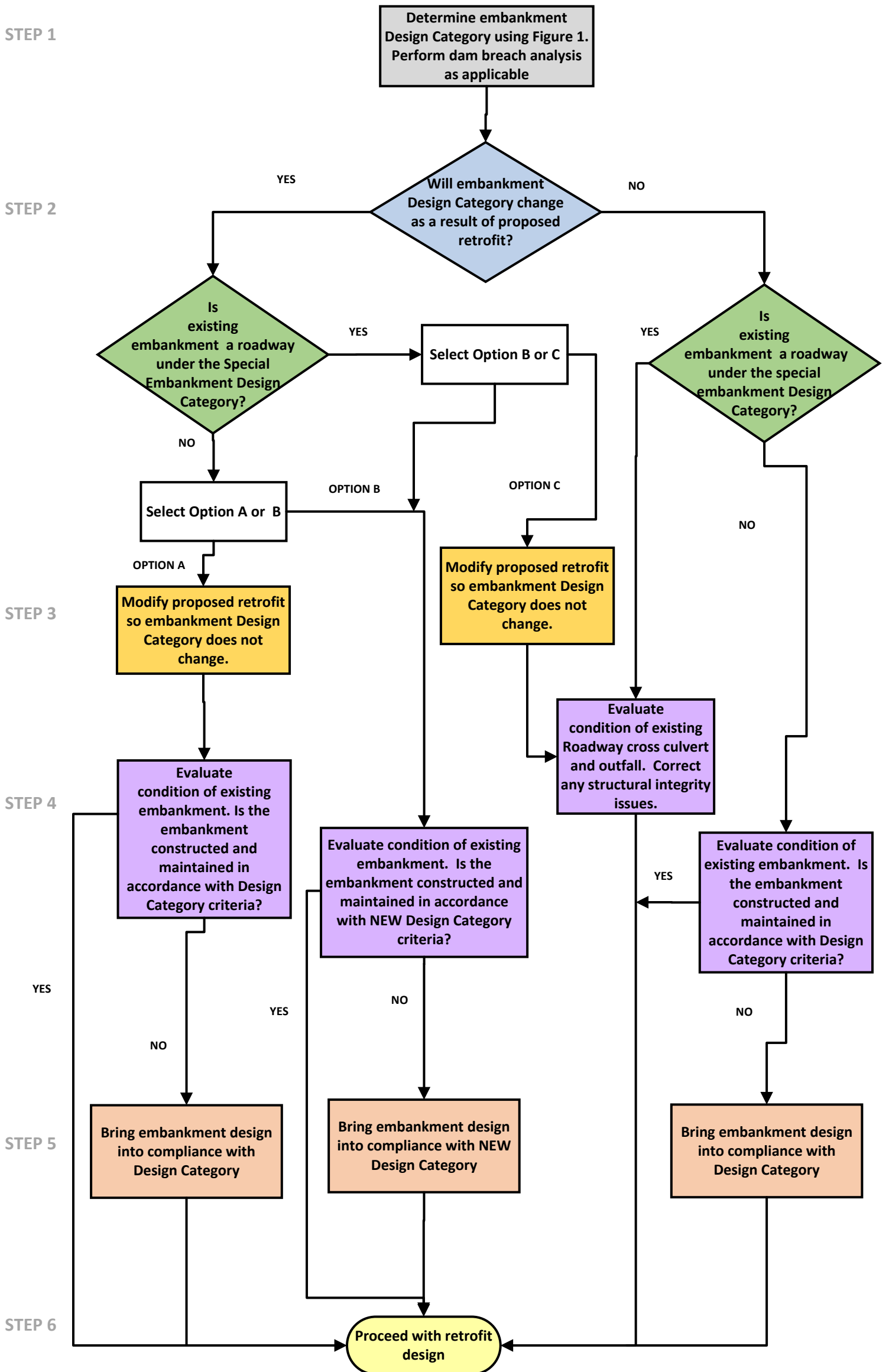[4] Roadway Embankment: The top of the roadway embankment must have a minimum top width of 50 feet.

[5] Use HW (head water) when TW (tail water) is below inlet invert elevation.

[6] 8:1 projection line is drawn at a 8:1 slope starting at the point where the 100 year water surface elevation meets the inside slope of the embankment.
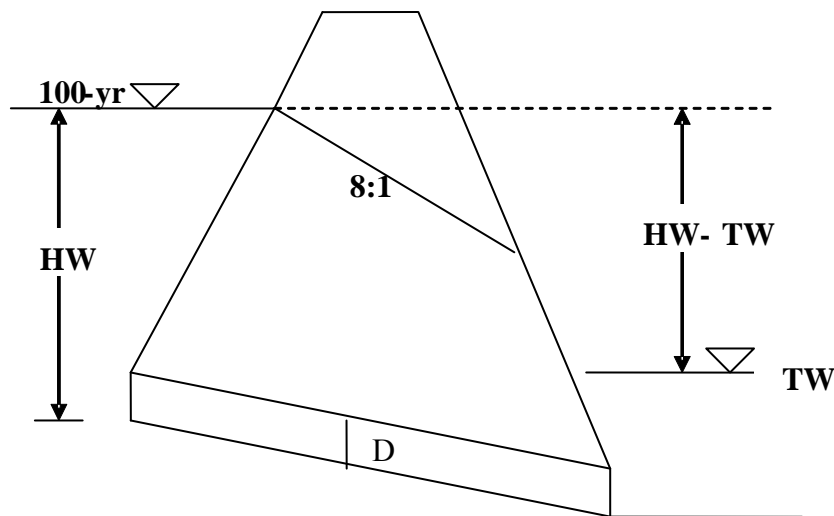
*   Use HW when TW is below the inlet invert
        elevation

Figure 2. Retrofit Proposal Analysis Flow Chart

STEP 1 — Determine embankment Design Category using Figure 1. Perform dam breach analysis as applicable

STEP 2 — Will embankment Design Category change as a result of proposed retrofit?

YES — Is existing embankment a roadway under the Special Embankment Design Category?

NO — Is existing embankment a roadway under the special embankment Design Category?

YES — Select Option B or C

Select Option A or B

OPTION A — Modify proposed retrofit so embankment Design Category does not change.

OPTION B

OPTION C — Modify proposed retrofit so embankment Design Category does not change.

STEP 3

Evaluate condition of existing Roadway cross culvert and outfall. Correct any structural integrity issues.

STEP 4 — Evaluate condition of existing embankment. Is the embankment constructed and maintained in accordance with Design Category criteria?

Evaluate condition of existing embankment. Is the embankment constructed and maintained in accordance with NEW Design Category criteria?

Evaluate condition of existing embankment. Is the embankment constructed and maintained in accordance with Design Category criteria?

STEP 5 — Bring embankment design into compliance with Design Category

Bring embankment design into compliance with NEW Design Category

Bring embankment design into compliance with Design Category

STEP 6 — Proceed with retrofit design

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APPENDIX A. HAZARD CLASSIFICATION AND DANGER REACH STUDIES FOR DAMS

HAZARD CLASSIFICATIONS
FOR SMALLER PONDS & DAMS

By

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September 2010

For small ponds & dams[1] no more than *15 feet* in height, storage volumes *less than 20 acre-feet*, and watershed areas less than 640 acres, only a brim-up storm may be necessary to determine the hazard classification. The brim-up storm is the 24-hour rainfall loading condition that fills up the reservoir to the lowest point on top of the dam.

The breach flows may be determined by the National Weather Service (NWS) Simple Dambreak Equation if flow attenuation is not significant. The NRCS Breach Equation for small ponds is usually not recommended as it does not account for pond storage volumes. A spreadsheet (smpdbk.xls) of the NWS equation is available at the web link listed below. Otherwise the HEC-1, HMS, or Hydrocad Hydrology Models can be used to determine breach flows and floodplain flow attenuation. Breach flow attenuation may be insignificant for short danger reaches less than 1000 feet in length. It is also possible to load a triangular breach hydrograph into the TR-20 Hydrology Model to determine flow attenuation as well.

http://mde.maryland.gov/programs/Water/DamSafety/Pages/dambreakguidelines.aspx

The brim-up breach flow is used to evaluate flood impacts to any downstream structures in harms way. If there are no flood impacts, the analysis can stop at this point and the structure would be classified as low hazard. If the structure is low hazard, small pond approval can be obtained from the local soil conservation district and county government.

If flood risk occurs downstream from a brim-up failure to homes, buildings, or roads, it is necessary to perform an incremental flood evaluation during several storm loading conditions. These loading conditions include several storm events that will or could occur during the lifespan of the dam. The storms to be examined include the following loading conditions: 1) normal pool, 2) 100-year flood, 3) brim-up flood, 4) 50% probable maximum flood (PMF) and 5) PMF. Refer to the report "Hazard Classifications and Danger Reach Studies for Dams" at the website listed above for the procedure to perform an incremental flood evaluation.

HAZARD CLASSIFICATIONS
&
DANGER REACH STUDIES FOR DAMS

By

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To determine the hazard classification of a proposed dam[1] or reevaluate the hazard classification of an existing dam, an *incremental flood analysis* is required. The first step in an incremental flood analysis is to determine downstream flood depths and velocities without the dam failing to establish baseline flooding conditions. The second step is to determine the increased flood depths and velocities associated with dam failures during the same storm loading conditions. These loading conditions include several storm events that will or could occur during the lifespan of the dam. The storms to be examined include the following loading conditions: *1) normal pool, 2) 100-year flood, 3) brim-up flood, 4) 50% probable maximum flood (PMF) and 5) PMF*.

The normal pool or sunny day loading condition is the breach flow released from the dam during a normal pool failure. If there is no permanent pool, a sunny day failure would be assumed to occur at the first large opening in the principal spillway above the low flow outlet. The storm event that fills the reservoir up to the top of dam is the brim-up storm event. This storm event can be determined very quickly by selecting a few rainfall events larger than the design storm and routing them through the spillways. The PMF is the largest flood that is expected to occur on a watershed. The PMF is based on the most severe combination of meteorological and hydrological conditions that are reasonably possible.

In Maryland, ***all significant and high hazard dams require an emergency action plan*** to safeguard lives and reduce property damage in the event of a dam failure. In order develop an emergency action plan for an existing or proposed dam, a danger reach map must be completed. *If the hazard classification of an existing dam is well known, only a danger reach study is needed to define the downstream reach that would receive increased flooding if the dam were to fail.*

The hazard classification of the dam is usually based on the increased flood depths and velocities against or over downstream structures. These structures include houses, buildings, important utilities, roads and railroads. The U.S. Bureau of Reclamation Flood Danger Graphs[2] shown on pages 5, 6, and 7 of this document are used to determine if increased flood dangers will exists with a dam failure. If the depths and velocities with a dam failure increase from low to high danger as shown on the graphs, the dam would be classified as significant or a high hazard structure depending on the type of structure flooded and the probable loss of life. The definitions of low, significant & high hazard classifications for dams are defined on page 3.

After the hazard classification of the dam has been defined, the danger reach is typically determined by failing the dam during the normal pool and design storm loading conditions, and routing the dam failures downstream to a point where the increased flood depths are less than one foot. A low, significant, or high hazard dam is usually designed to safely pass the 100-year storm, 50% PMF, or PMF, respectively. The minimum freeboard above the design storm to the top of the dam is one foot but may be increased if there is no emergency spillway or if wave run-up is significant.

Dam Failure

A dam failure hydrograph may be computed by the HEC-1, HMS, Hydrocad, or National Weather Service (NWS) Dam-Break Models. For dams equal to or greater than 75 feet in height, the HECRAS or NWS Dam-Break Models are recommended for dam failure. For dams smaller than 75 feet high, the HEC-1, or NWS Dam-Break Models may be used to determine the breach hydrograph. Although the NWS Dam-Break Model is considered to be the most accurate model to determine dam failures, it is also very complex and temperamental, and requires considerable engineering expertise.

To determine the dam failure hydrograph, four parameters are needed to define the breach formation through the dam. These parameters include the breach bottom width, side slopes, time of failure, and the selected failure and breach bottom elevations. For earth embankment dams, the average breach width ranges from 1 to 5 times the height of water against the dam at failure; the breach side slopes range between 0 to 1 foot horizontal to 1 foot vertical; and the time of failure ranges from about 10 minutes for small dams to approximately 4 hours for very large dams. In 1987, Froelich developed breach predictor equations that estimate the average breach width and time of failure based on the height of water above the breach bottom and the corresponding storage volume. These equations, which were revised by Froelich in 1995, are included on page 12 of this document. Examples of input data for the HEC-1 and NWS Dam-Break Models can be obtained by contacting the Maryland Dam Safety Division.

Hydrology

To determine the storms used for hazard classifications or danger reach delineations, the HEC-1, HMS, Hydrocad, or TR-20 Computer Models are required for drainage areas less than or equal to 10 square miles. For dams less than 10 square miles of drainage area, use a 24-hour duration rainfall for the 100-year and brim-up storm events; and a 6-hour duration rainfall for the 50% PMF and PMF. For drainage areas larger than 10 square miles, the HMR-52 Model is recommended to determine the rainfall amount and distribution. The rainfall hyetograph data from the HMR-52 Model is inputted into the HEC-1 or HMS Models for flow computations. The HMR-52 Model maximizes rainfall by generating elliptical rainfall bands over the watershed of the dam and the danger reach area. The HMR-52 model is free to download on our MDE Technical References Website. Go to http://mde.maryland.gov and search for technical references.

It is recommended that the watershed hydrology parameters (drainage area, curve numbers, times of concentration) be determined using the GISHydro2000 Model developed by the University of Maryland. This GIS Model is free on the internet at the following website: www.gishydro.umd.edu/ . The model will load electronic soil maps, digital elevation and landuse data for Maryland, as well as

many other GIS datasets & shape files. It will compute watershed areas, hydrologic soil groups, landuse curve numbers, times of concentration, and generate a TR-20 Hydrology Model. It will also determine USGS Regression flow rates up to the 500-year storm. The times of concentration should be verified using the standard velocity segment method outlined in TR-55 Publication.

I.   Compute Storm Events and Breach Flows in the Danger Reach Area below the Dam

      A. Calculate runoff, flows, and hydrographs (hydrology) on the watershed above the dam and the danger reach area below the dam for the 100-year, brim-up, 50% PMF, and 100% PMF storm events. (**GISHydro2000**, **HEC-1, HMS, Hydrocad, TR-20, & HMR-52 Models**).

      B. Route storms as well as sunny day failure through dam and downstream floodplain with & without dam failure. *If the hazard classification of the dam is known, only the sunny day and design storm (PMF for High Hazard Dams) are necessary to define the danger reach limits*. **The danger reach must extend downstream to a point where the increased flood levels are less than one foot.**

Hydraulics

Compute the existing and proposed water surface elevations for the selected storm events. The HEC-1, HMS, and Hydrocad Hydrology Models can provide approximate flood depths based on the Manning's Formula. If there are more than a few houses or building in jeopardy, the HECRAS or National Weather Service Dam-Break Hydraulic Models should be used to determine the flood depths. The HECRAS Models is recommended because it is easy to learn and apply, and will result in reasonably accurate water surface elevations.   In special cases where there are flat floodplain areas with many impacted structures, a two or three dimensional model may be needed to determine more accurate flood conditions especially

For danger reaches that impact only downstream roads and a few buildings, the HEC-1 Model may be used for both hydrology and hydraulic calculations. The HEC-1 Model is not as accurate in calculating the depth of flooding because the floodplain cross sections are not detailed and the water surface slopes are approximated. To use only the HEC-1 Model for hydrologic and hydraulic computations, discuss the dam failure study with the Dam Safety Division for approval.

I.   Calculate the Water Surface Profiles both With and Without Dam Failure in The Danger Reach
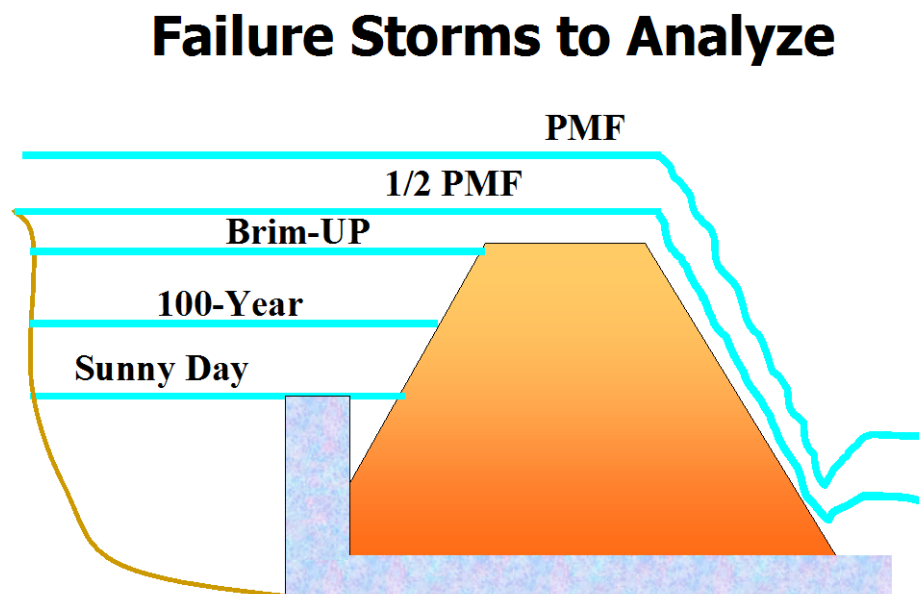
      A.   Input flow values, stream cross-sections, Manning's roughness values, and dam & road structure data into the water surface profile models.

      B.   Determine increased flood risks to houses, buildings, and roads by using the enclosed USBR Hazard Graphs.

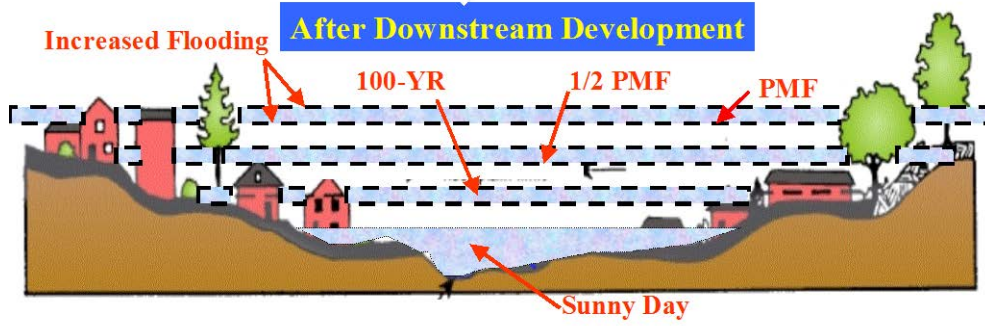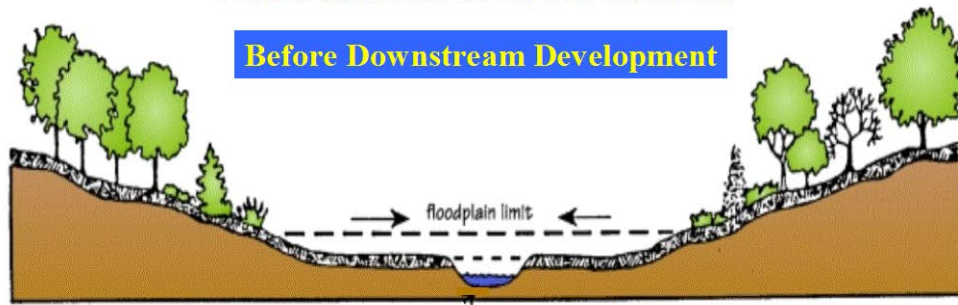## II.   Determine Hazard Classification of Dam

A.   Classify or reclassify dam as a low, significant, or high hazard structure.

    1. Low Hazard -   Unlikely loss of life; minor increases to existing flood levels at roads and buildings.

    2. Significant Hazard -   Possible loss of life, significant increased flood risks to roads and buildings with no more than 2 houses or 6 lives in jeopardy.

    3. High Hazard -   Probable loss of life; major increases to existing flood levels at houses, buildings, major interstates and state roads with more than 6 lives in jeopardy.

III.   Develop Danger Reach Maps

A   Plot the flood boundaries for the sunny day and design storm dam failures on topographic maps. The map must clearly show downstream roads, buildings, and houses within the danger reach, and the recommended evacuations routes. The danger reach maps are to be included in the Emergency Action Plan for the dam and should be no larger than 11" x 17" per panel.

Failure Storms to Analyze

Increased Flood Risks

Before Downstream Development

floodplain limit

After Downstream Development

Increased Flooding
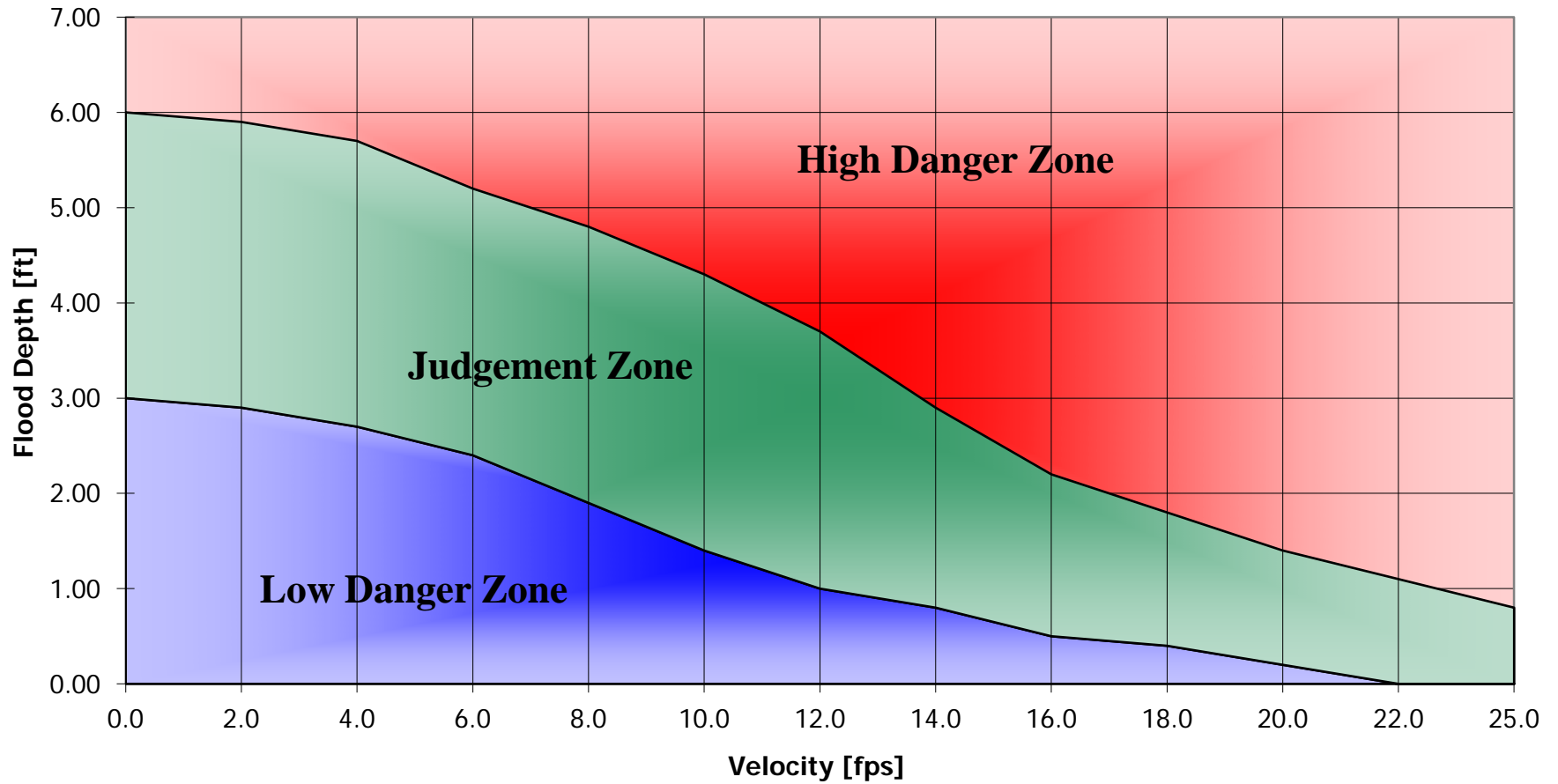
100-YR   1/2 PMF   PMF

Sunny Day

Flood Danger for Cars

Source: ACER Technical Memorandum No. 11, "Downstream Hazard Classification Guidelines", USBR, 1988

Flood Danger for Houses
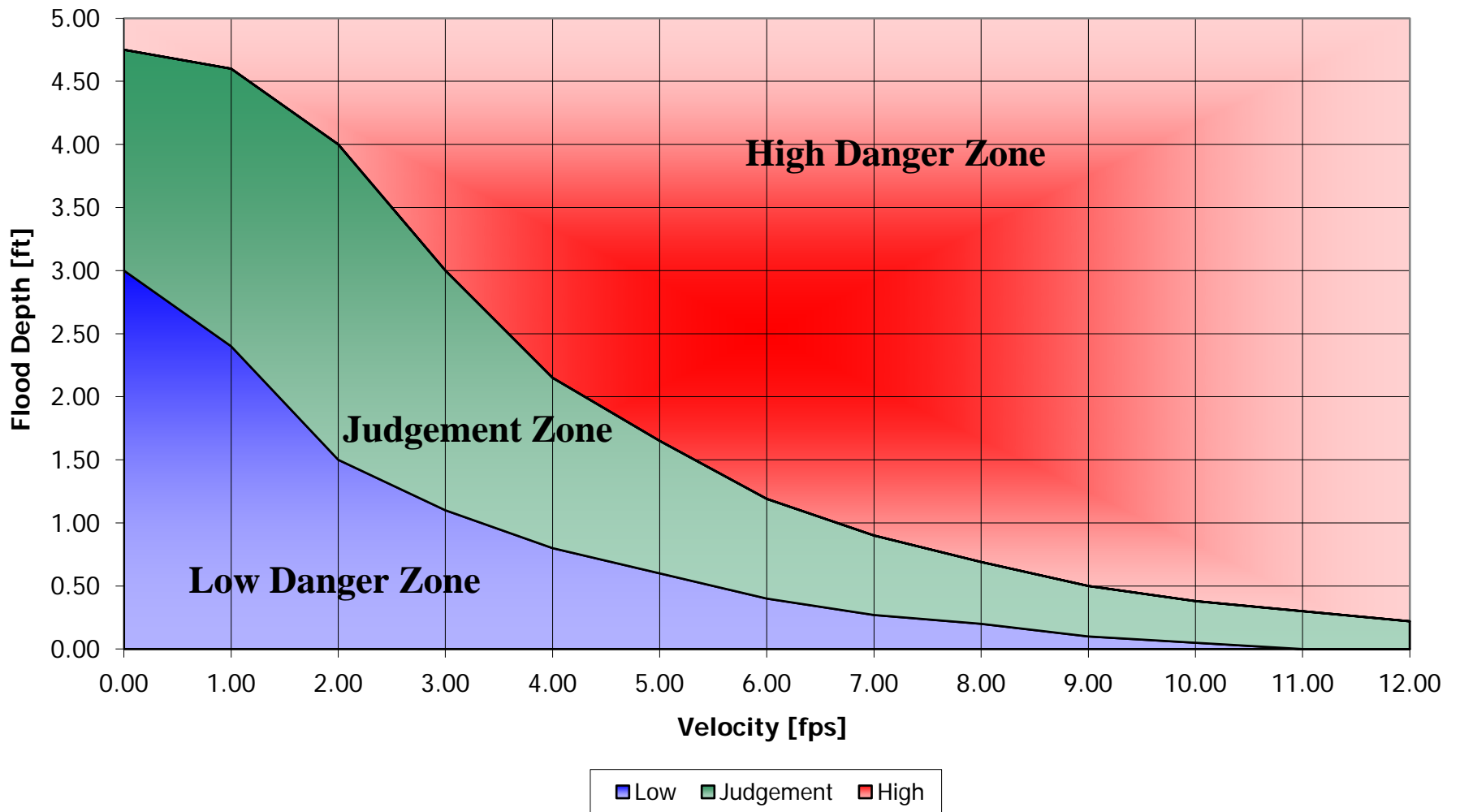

Source: ACER Technical Memorandum No. 11, "Downstream Hazard Classification Guidelines", USBR, 1988

Flood Danger for Adults

High Danger Zone

Judgement Zone

Low Danger Zone

Flood Depth [ft]

Velocity [fps]

Low   Judgement   High

Source: ACER Technical Memorandum No. 11, "Downstream Hazard Classification Guidelines", USBR, 1988

WORLD RECORD RAINFALL AMOUNTS

SOURCE: JENNINGS, A. H. WORLD'S GREATEST OBSERVED POINT RAINFALL.
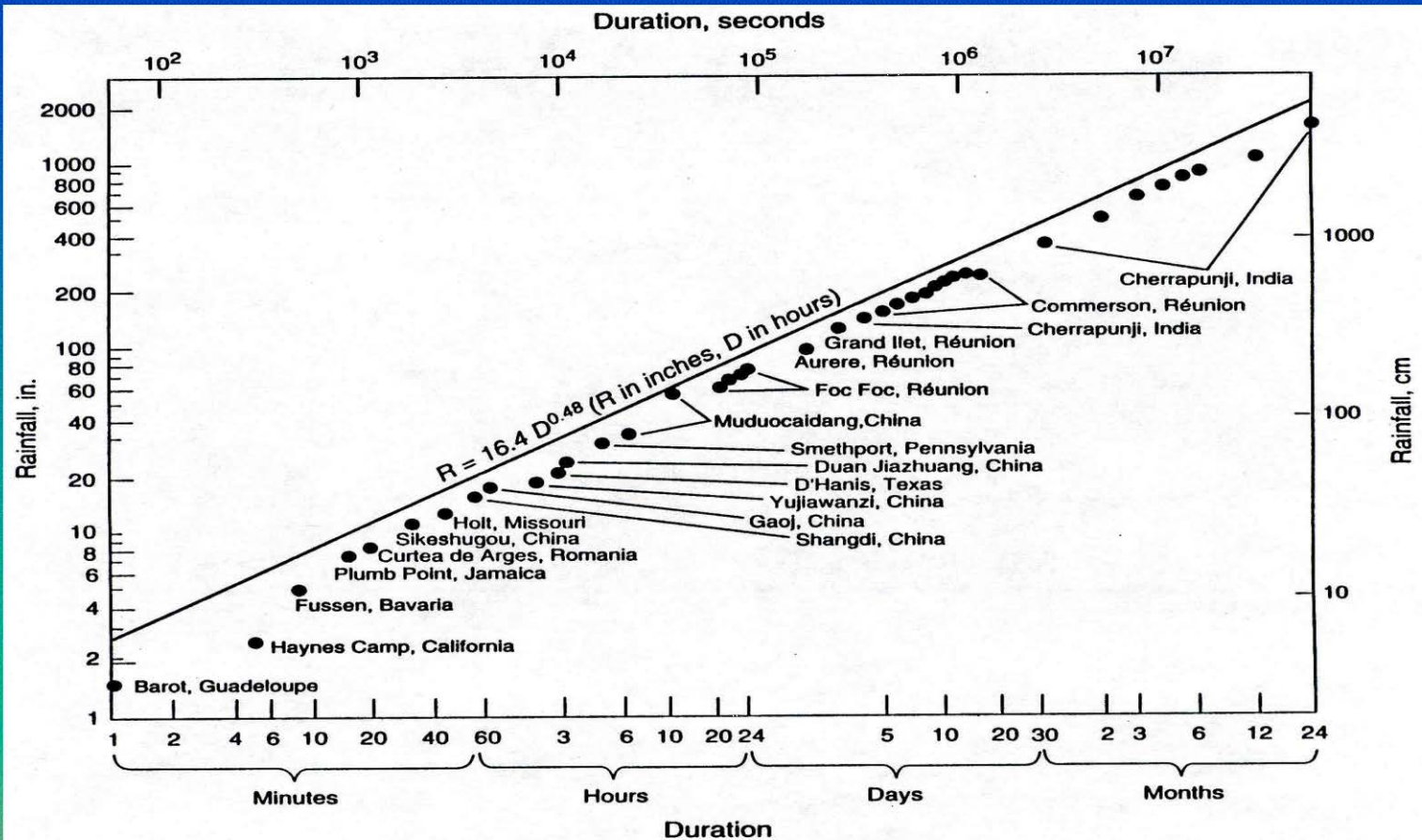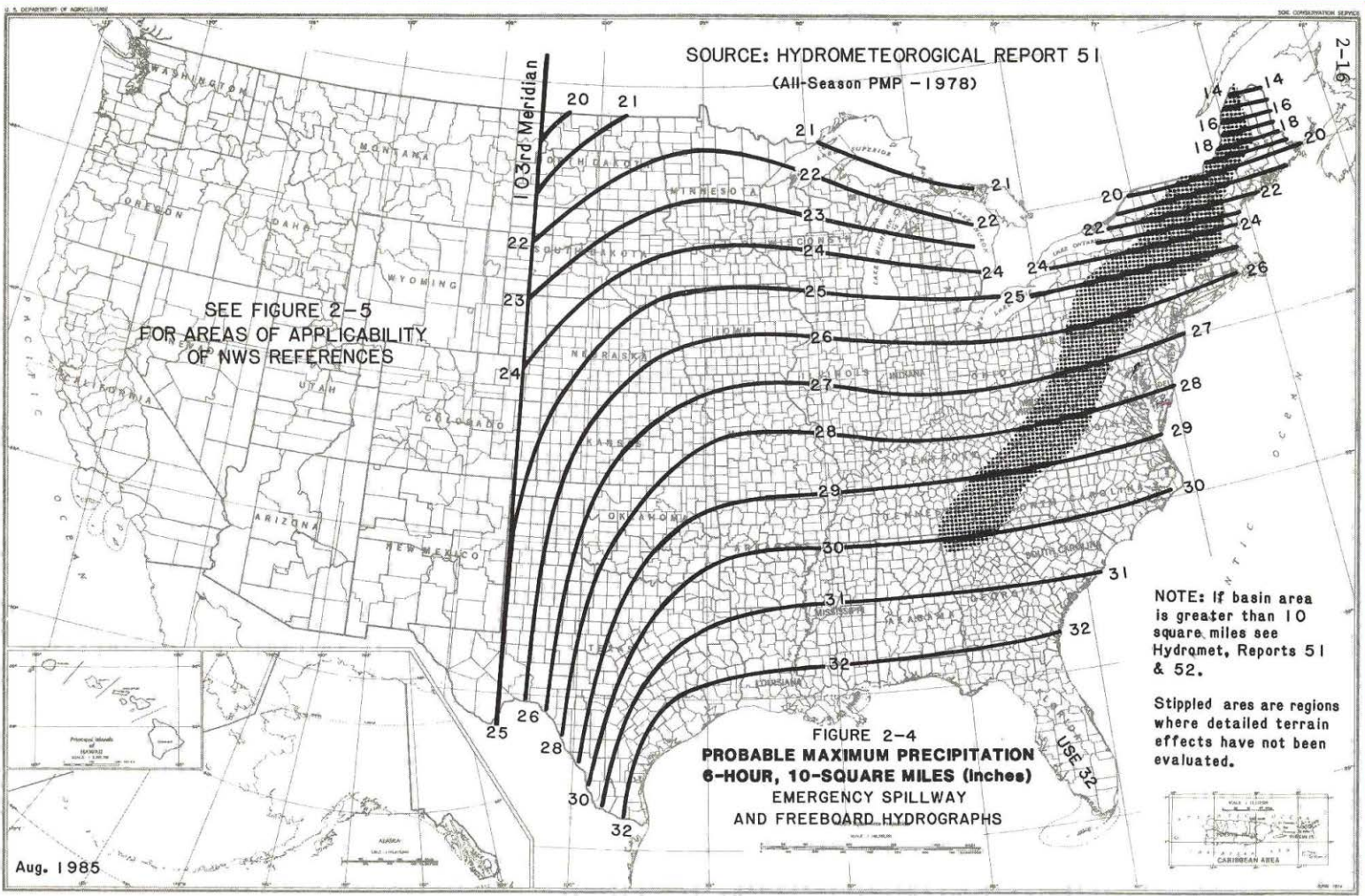MONTHLY WEATHER REV., VOL 78, 1950
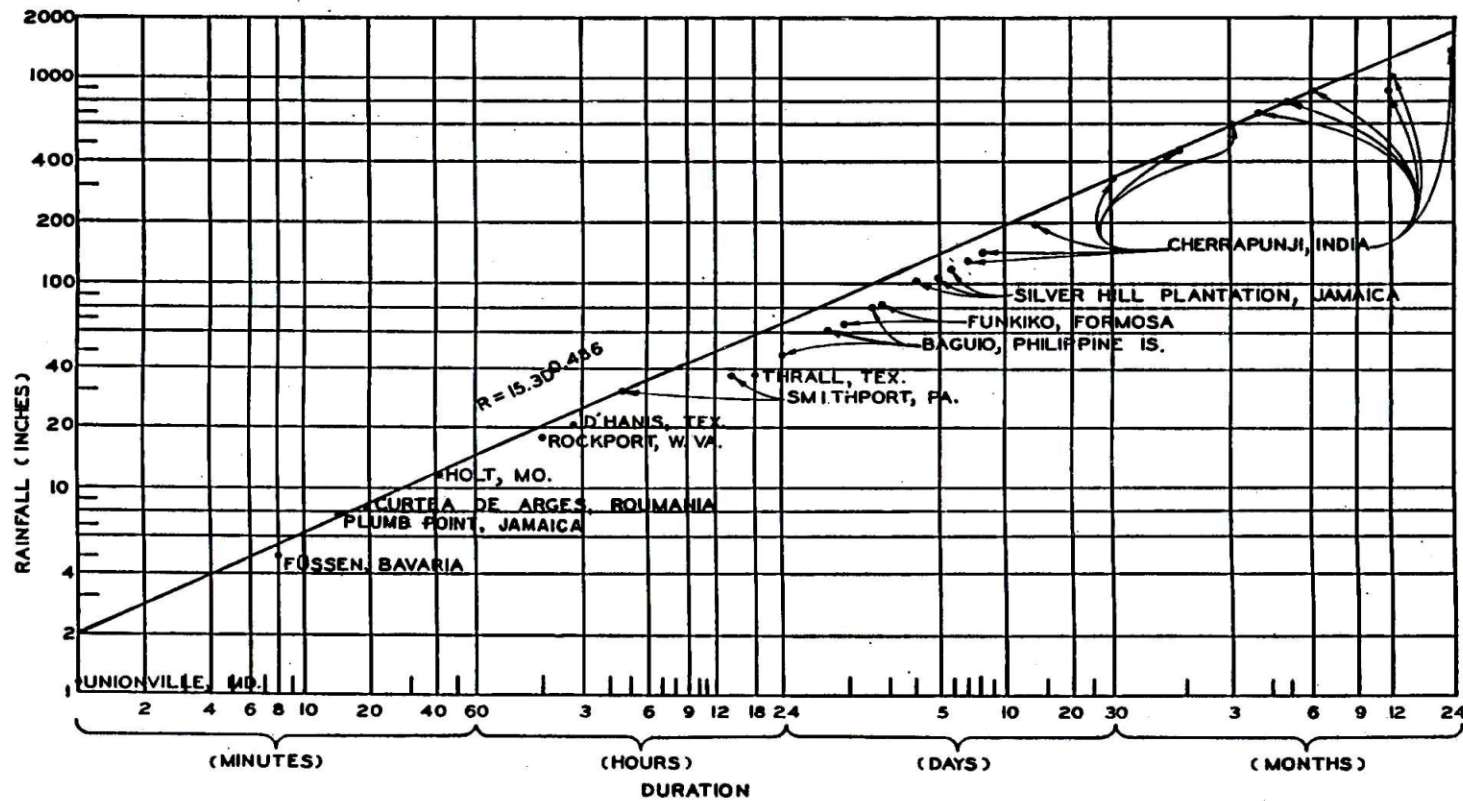
FIGURE 1 Maximum observed point rainfalls as a function of duration. (Courtesy of John Vogel, National Weather Service.), 1986.

SOURCE: HYDROMETEOROLOGICAL REPORT 51
(All-Season PMP — 1978)

SEE FIGURE 2-5
FOR AREAS OF APPLICABILITY
OF NWS REFERENCES

NOTE: If basin area is greater than 10 square miles see Hydromet. Reports 51 & 52.

Stippled ares are regions where detailed terrain effects have not been evaluated.

FIGURE 2-4
PROBABLE MAXIMUM PRECIPITATION
6-HOUR, 10-SQUARE MILES (Inches)
EMERGENCY SPILLWAY
AND FREEBOARD HYDROGRAPHS

Aug. 1985

(210-VI-TR60, OCT. 1985)

2-16

Suggested Breach Parameters for Earth Dams

Source	Average Breach Width (ft)	Breach Side Slope (1V:ZH)	Breach Failure Time (hrs)
NWS (1988)	1H to 5H	Z = 0 to 1	0.1 to 2.0
COE (1980)	0.5H to 4H	Z = 0 to 1	0.5 to 4
FERC (1991)	1H to 5H	Z = 0 to 1	0.1 to 1.0
USBR (1982)	3H	N/A	0.00333b
Boss Dambrk (1988)	0.5 to 4H	Z= 0 to 1	0.5 to 4
Harrington (1999)	1H to 8H	Z= 0 to 1	H/120 to H/180

Note: H = Height of water against dam above breach bottom elevation in feet.

Froelich Breach Predictor Equations

$$b = 9.5 K_0 (V_s H)^{0.25}$$

$$\tau = 0.59 \, (V_s^{0.47}) / H^{0.91}$$

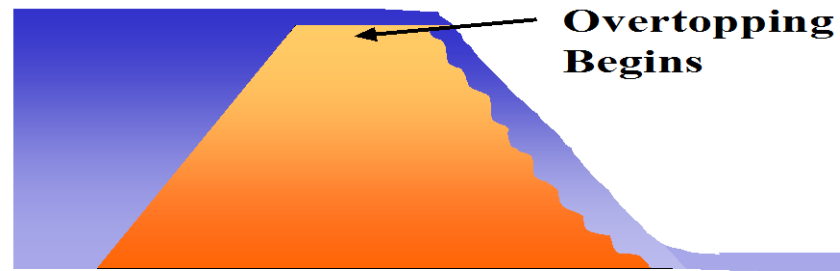**b** = Average Breach Width (ft),

= Time of Failure (hrs)

K_0 = 0.7 for Piping & 1.0 for Overtopping Failure

Vs = Storage Volume (ac-ft)
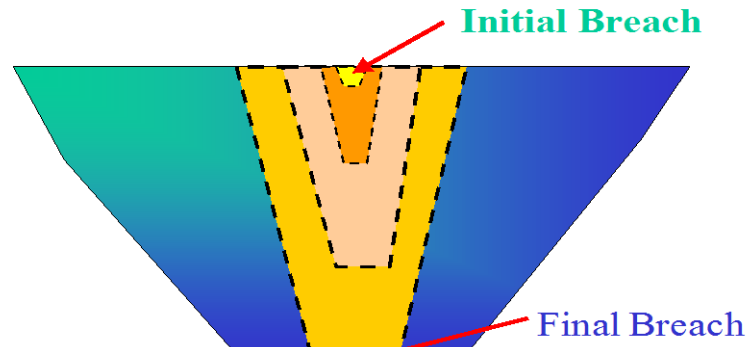
H = Selected Failure Depth (ft) above Breach Bottom

τ = Time of Failure (hrs)

Overtopping Failure

Overtopping Begins

Profile View

Overtopping Breach of Earth Dam

Initial Breach

Final Breach

Cross Section View

Breach Photo

Breach Shape

Breach Parameters

Trigger Elevation for Failure

H, Breach Height

1

Z = 0 to 1

Breach Bottom Elevation

Bottom Width, b