Dam Owner Emergency Intervention Toolbox

July 2016

Gannett Fleming

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Dam Owner Emergency Intervention Toolbox

July 2016

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How to Use this Document

This Dam Emergency Intervention Toolbox is designed to be an educational, interactive tool to assist dam owners and operators in preparing for, identifying, and responding to emergency conditions at their dams. Informative text, tables, and figures as well as forms, where dam owner/operator input or site-specific information is necessary, comprise the main body of the document. In addition to these in-text contents, the outer margin of each page is reserved for owner or operator notes and also contains calculators, resources, and advisory symbols where applicable. The interactive features and symbols used in this toolbox are as follows:

Form A: *Sample*

Dam Name:

Forms: Pertinent forms within this document are intended to be useful in responding to an emergency condition that arises at a dam, and should be completed in advance of an emergency situation.

Sample Calculator	
A = B + C	
Input	
Variable 1 (B):	______ ft
Variable 2 (C):	______ ft
Output	
Answer (A):	______ ft

Calculators: Located in the sidebar, calculators provide a simplified way to estimate quantities of materials and other useful information necessary to intervene during an emergency condition at a dam.

Caution

Caution: This symbol alerts the reader to important information in the text on ensuring personal safety or avoiding errors that may potentially damage the dam.

Preventive Measure

Preventive Measure: This symbol alerts the reader of maintenance or preparatory actions described within the text that could prevent or decrease the effects of an emergency condition at the dam.

Resource Title

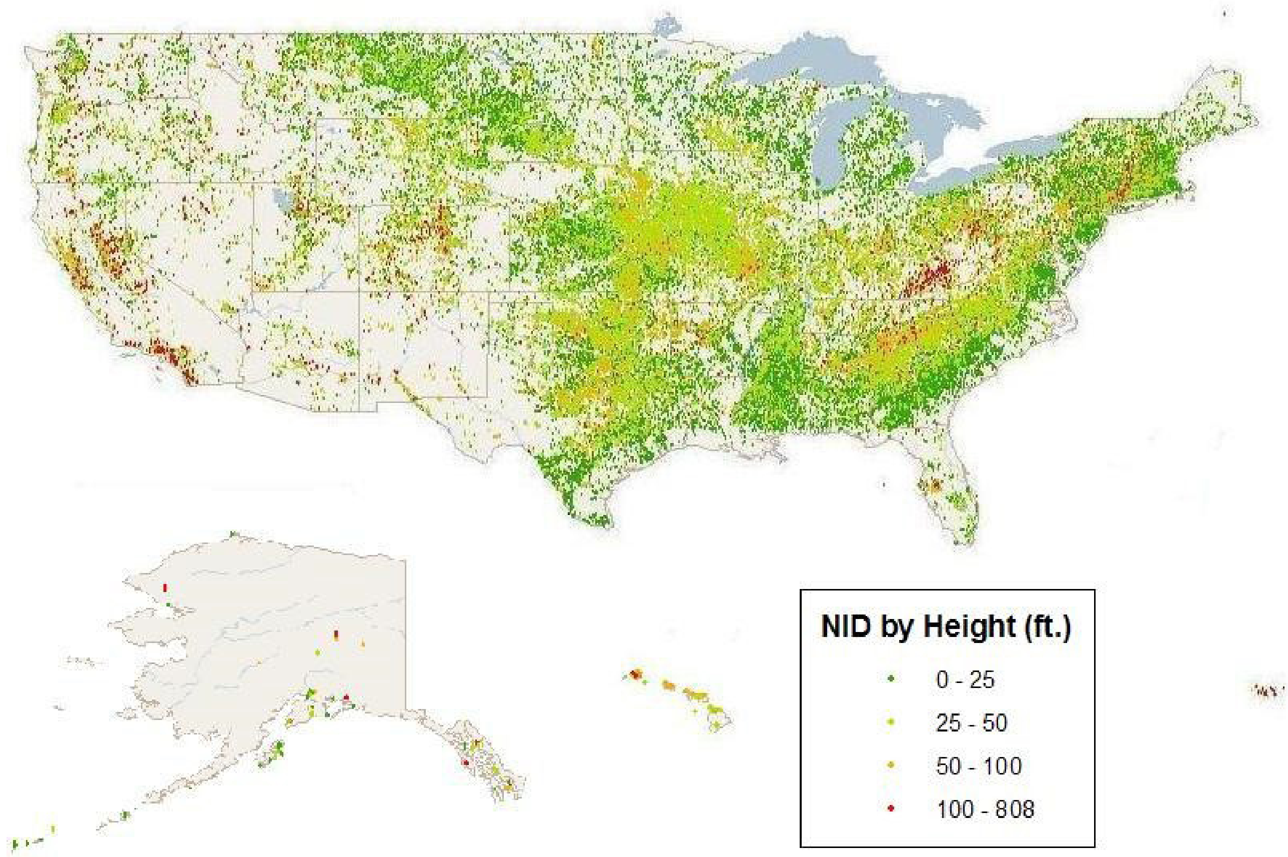
Resources: This symbol indicates that supplemental information on a particular topic is available online in document, presentation, or video format. Additional publication details pertaining to each resource are included at the end of the document.

1.0 Introduction

1.1 Purpose

The Unites States has more than 85,000 dams within its borders (**Figure 1**). Most of these structures are earthen embankment dams built between 1930 and 1980. According to the United States Army Corps of Engineers (USACE) National Inventory of Dams (NID), approximately 15,000 of these dams are characterized as high-hazard due to the expected loss of life associated with a potential failure of the structure. However, the vast majority of the dams in the country are smaller, unregulated, and privately-owned. Although the downstream hazards associated with these dams are often less severe due to their remote locations and small storage capacity compared to those recognized as high-hazard, it is important that all dam owners properly operate, maintain, and inspect their dams.

Figure 1: *Map of Dams across the United States*



Source: National Inventory of Dams

The National Dam Inspection Act, Public Law 92-367 (Act) enacted in 1972 first assigned liability to the dam owner and encouraged owners to properly operate, maintain, and inspect their dams in order to reduce the risks associated with incidents and failures to an acceptable level with an appropriate standard of care.

This Dam Emergency Intervention Toolbox was developed to provide owners of dams throughout the United States with the necessary information and tools to identify and remedy unsafe conditions which may develop. In addition to presenting identification techniques and intervention actions that may be performed to prevent or delay an incident resulting from an observed unusual dam condition, the toolbox includes background information on embankment dams, inspection guidelines, and recordation practices for monitoring procedures. User-input sections of the toolbox support the text and allow for site-specific recommendations.

For all dams with an Emergency Action Plan (EAP), this Dam Emergency Intervention Toolbox and the EAP should be considered companion documents for responding to emergency events. While this document contains general guidance responding to emergency conditions at dams, EAPs contain information for coordination with local emergency responders during emergency circumstances.

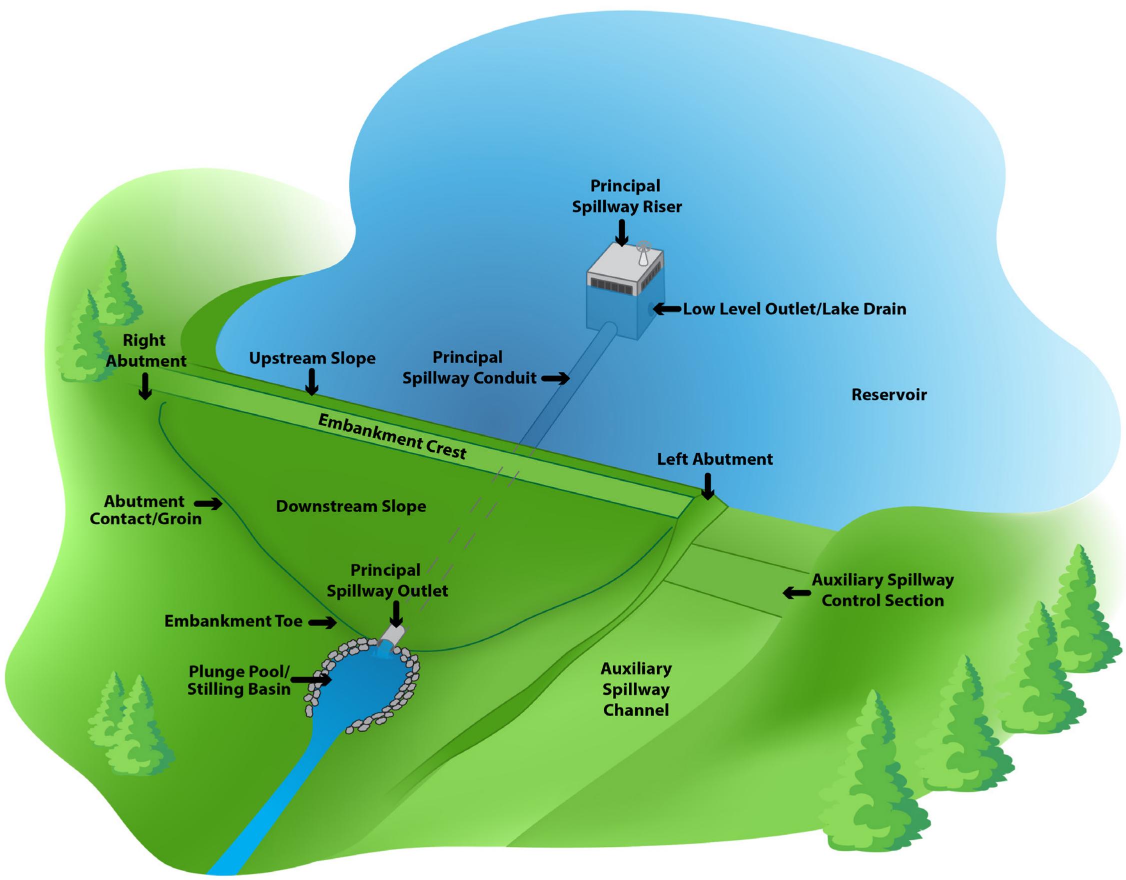
The Dam Emergency Intervention Toolbox is available in two formats: (1) a hard copy version which includes all text, pertinent descriptions, emergency response guidance, and user-input sections; and (2) an interactive electronic version which includes all of the aforementioned materials with interactive content. The supplemental and interactive content available within the electronic version include automated population and calculation of user-input sections when applicable as well as additional resources. Content for this manual was obtained from various state dam safety reference documents and regulations, federal best practice documentation, and industry practices developed and/or proven successful at other dam facilities.

1.2 Typical Embankment Dam Features

A dam is an artificial barrier constructed on natural terrain in order to control, store, or divert water. Dams are classified according to their size, type of construction materials used, structure, function, ownership, and the consequences of their failure (**Figure 1**). The most common types of dams in the U.S. are low-hazard, privately owned, earth embankment dams.

The basic features common to most embankment dams are illustrated in **Figure 2**, and include the dam structure, service or principal spillway(s), auxiliary or secondary spillway, and outlet works. A glossary of common terms used to describe dam features is provided in Appendix A. A brief discussion of basic embankment dam features is provided in the following paragraphs.

Figure 2: *Typical Features of an Embankment Dam*



See: Glossary in Appendix A for term definitions

Dam Embankment

The upstream and downstream slopes of embankment dams are typically 2.5H:1V (horizontal to vertical) or flatter. Their capacity for water retention is due to the low permeability of the entire mass (in the case of a homogeneous embankment) or a zone of low-permeability material (in the case of a zoned embankment dam).

Materials used to construct embankment dams include natural soil or rock obtained from onsite borrow areas or nearby quarries. If the natural material has a high permeability, then a zone of very low permeability or impervious material is normally included in the dam to provide resistance to flow and dissipate the hydrostatic pressure caused by the reservoir over a short distance. Some embankment dams use a masonry or concrete corewall to create the impervious barrier within the embankment. The ability of an embankment dam to resist the hydrostatic pressure caused by reservoir water is primarily the result of the mass or weight of the structure and the internal strength of the soil materials.

Many small dams and older dams consist of a homogeneous earth embankment where the dam is constructed of similar material throughout. Modern embankment dams are normally constructed with a zoned embankment and are composed of zones of selected materials having different degrees of porosity, permeability and density. Most modern zoned embankments include a chimney drain and toe drain to collect and filter seepage through the embankment and increase the stability and long-term performance of the structure. The chimney and toe drain consist of coarse-grained material (sand and gravel) which has little resistance to the flow of water and is not prone to shrinking or cracking. Seepage entering the drains flows freely through it and exits safely beyond the dam without saturating the material in the downstream zone. In general, embankment dams are designed to control seepage and prevent seepage from exiting the downstream slope.

Service/Principal Spillways

The service spillway, also referred to as the principal or primary spillway, is the main structure over or through which flow is discharged from the reservoir and the primary means used to control the reservoir level. If the rate of flow is controlled by mechanical means such as gates or stoplogs, it is considered a controlled spillway. If the elevation of the spillway crest is fixed, it is considered an uncontrolled spillway. Common types of service spillways include stoplog- or gate-controlled concrete drop structures and concrete or corrugated metal conduit riser structures. Some dams use steel sheet pile instead of concrete to create the spillway control structure. Many spillways are constructed using both steel sheet pile and reinforced concrete. Because service spillways are the primary means of controlling reservoir flows, they are generally designed to a high standard of performance so that they perform satisfactorily under all flow conditions without sustaining damage during reservoir level fluctuation over time.

Auxiliary/Secondary Spillways

Auxiliary spillways, also referred to as secondary spillways, are designed to operate only during exceptionally large floods and their purpose is to pass major flood flows around the structure and prevent dam overtopping and failure. Most auxiliary spillways consist of an open trapezoidal channel excavated through natural materials having an approach channel, a level crest or control section, and an outlet channel. Because auxiliary spillways are intended for infrequent activation, many are designed to allow erosion damage to occur during the passage of the design flood provided the crest of the spillway is not breached and the safety of the embankment is not compromised.

Auxiliary spillways excavated into overburden are normally covered with a layer of topsoil and vegetated with grasses adapted to the local environment. The grass cover in the spillway is often an important erosion control feature needed for successful performance of the spillway. Where a grass cover cannot provide reliable erosion protection or spillway flow velocities are excessive, some auxiliary spillways are equipped with concrete control structures or are armored with articulating concrete blocks or other erosion resistant materials to prevent breaching or failure of the spillway.

Low-Level Outlets/Lake Drains

Low-level outlets provide a means for lowering or draining the reservoir and normally consist of a conduit through the embankment equipped with one or more control valves. Low-level outlets are sometimes incorporated as a feature within a concrete spillway structure such as a stoplog bay extending to the bottom of the structure or a gated opening at the base of the structure. The low-level outlet must be able to evacuate the major portion of the reservoir storage volume by gravity flow. At low hazard dams where the reservoir is very small, low-level outlets are occasionally omitted and lowering or draining of the reservoir is achieved using portable pumps or by installing a temporary siphon.

1.3 Common Causes of Embankment Dam Incidents and Failures

Natural hazards such as floods, earthquakes, and landslides are important contributors to dam incidents. The most important natural hazards threatening dams are floods. In addition to natural hazards, human behavior is another element of dam failure risk. Simple mistakes, misoperation, negligence, oversights, or destructive intent can interact with other hazards to compound the possibility of failure. As a result, failures can be a result of human factors including poor design, improper construction, improper operation, inadequate maintenance, or a combination of these factors.

The fundamental causes of dam incidents at embankment dams and their approximate percentage of occurrence is summarized in **Table 1.**

Table 1: *Causes of Dam Incidents*

Cause	Percentage (%)
Earthquake Instability	1
Faulty Construction	2
Gate Failure	2
Slope Failure	5
Spillway Erosion	31
Overtopping	23
Seepage/Piping	36

Comprehending potential failure modes for a dam is an important first step to improve dam safety, prevent a dam failure, or minimize the effects of failure. Equally important is understanding the warning signs for particular failure modes and how to effectively respond to them. Performing regular dam inspections is critical for early problem identification and intervention. All personnel responsible for the operation of the dam should be aware of the common failure modes and be able to identify early warning signs for each failure mode. If a problem is detected early, the state dam safety agency can be contacted to recommend and help implement corrective measures. Acting promptly may avoid a possible dam failure.

Experience has shown that in an emergency, advance preparedness is key. Questions to ask yourself include:

- Do you have your engineer's personal cell phone number in case you need to call in the middle of the night?
- What about an alternate engineer if your primary is unavailable?
- Can you contact your local contractor at 2:00 am if you need to get an excavator to the dam as soon as possible?
- If you need to call a pump supplier, there is some fundamental information about your dam that you need to provide them. Do you have this information readily available?

In an emergency situation, various individuals may be involved in the decision-making process and the manner in which an embankment dam fails and the particular causes of failure are usually varied, multiple, complex, and interrelated. Therefore, all dam safety personnel should also be knowledgeable of the potential problems which can lead to dam failure as well as the appropriate measures to take when mitigating them. The following sections of the Dam Emergency Intervention Toolbox provide information useful for preparing for a dam emergency, identifying the symptoms of the most common failure modes for embankment dams, and responding to emergency conditions.

2.0 Preparing for a Dam Emergency

Although each dam failure mode is unique, there are many common elements from one incident to the next. As a result, plans and preparations, even when generalized and limited in detail, will improve intervention response time and success. Compiling and maintaining site-specific information about the dam as well as an inventory of stockpiled materials and locally available materials, equipment, labor, and expertise can increase efficiency and effectiveness when responding to emergency conditions.

2.1 Baseline Dam Information

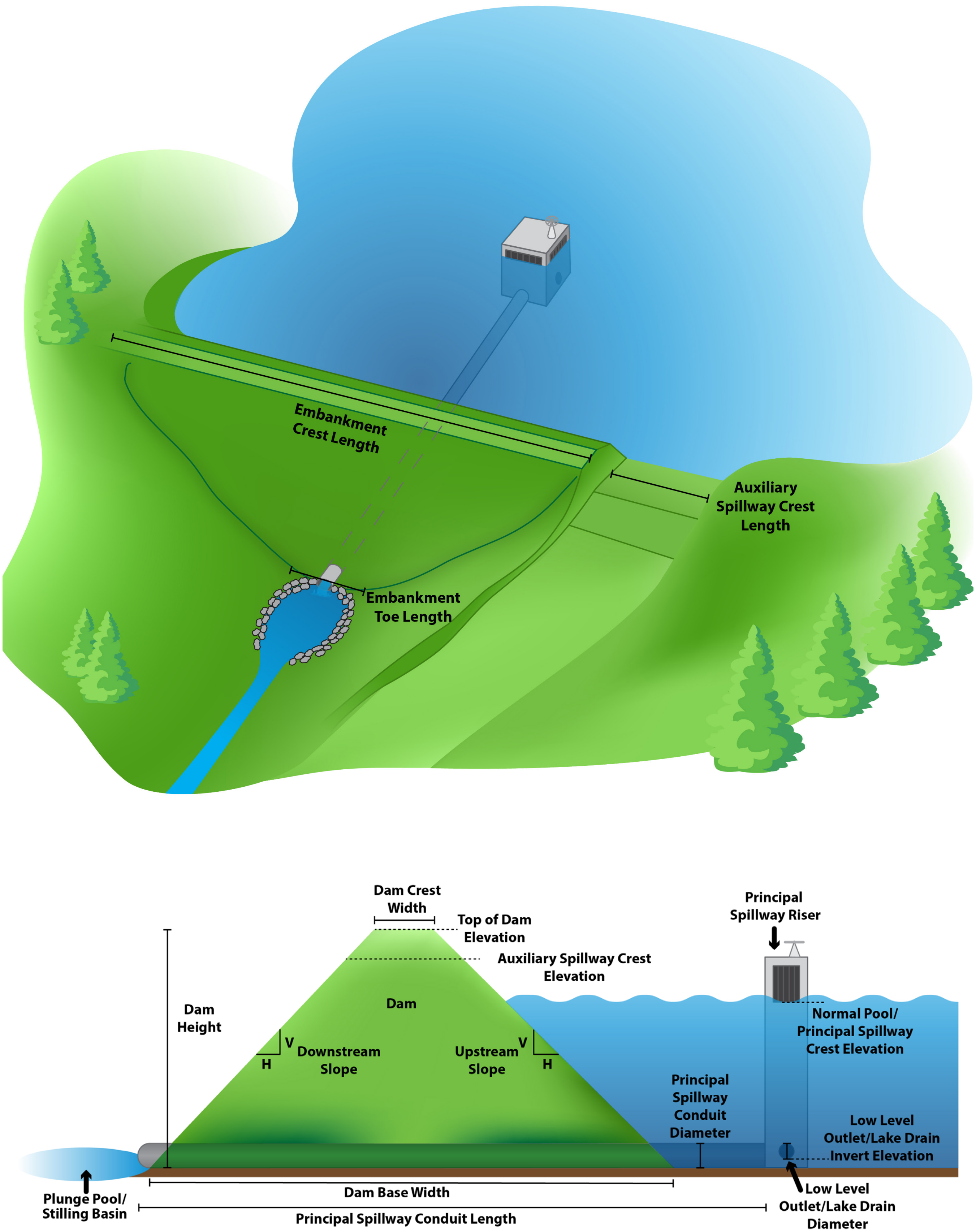
Possessing a basic knowledge of a dam and its appurtenant features can be helpful when responding to an emergency. Supplying baseline dam information to state dam safety personnel, engineers, contractors, and equipment or material providers who are not familiar with the dam site may be necessary when intervening during an emergency situation. For example, a pump or siphon supplier will need to know some baseline information in order to bring the correct equipment and materials to the site.

Important dam dimensions that may be helpful when responding to a dam emergency are shown in **Figure 3**. **Form 1** is provided to help collect and record this and other helpful information. Common unit conversions and formulas are provided in **Appendix B**, if needed, to convert dimensions into the units shown in **Form 1**.

Documenting access (i.e. locations of access roads, gate and lock combinations, etc...) to the dam is equally as important as compiling baseline dam characteristics. **Form 2** is provided to record and store information related to gaining access to the dam that may need to be shared with emergency personnel, large-equipment contractors, or others not familiar with the entry procedures.

Basic information about the history of the dam may also be helpful during an emergency. **Form 3** is provided to help summarize information about the dams history related to dam construction, operation and maintenance.

Figure 3: *Important Dimensions of a Dam*



Form 1: *Summary of Key Dam Characteristics*

Dam Name:	NID ID:
Dam Owner:	Dam Operator:
County:	
Latitude:	Longitude:
Contributing Stream:	
Reservoir Drainage Area:	mi^2
Normal Pool Elevation:	ft
Normal Pool Volume:	acre-ft
Top of Dam Elevation:	ft
Dam Height:	ft
Embankment Crest Length:	ft
Embankment Toe Length:	ft
Dam Crest Width:	ft
Dam Base Width:	ft
Upstream Slope: ______ ft H: ______ ft V = ______	ft H: 1ft V
Upstream Slope Length:	ft
Downstream Slope: ______ ft H: ______ ft V = ______	ft H: 1ft V
Downstream Slope Length:	ft
Principal Spillway Type:	
Principal Spillway Crest Elevation:	ft
Principal Spillway Capacity:	cfs
Auxiliary Spillway Type:	
Auxiliary Spillway Crest Elevation:	ft
Auxiliary Spillway Crest Length:	ft
Auxiliary Spillway Capacity:	cfs
Low-Level Outlet Conduit Type:	
Low-Level Outlet Invert Elevation:	ft
Low-Level Outlet Diameter:	ft
Low-Level Outlet Capacity:	cfs

Slope Length Calculator

$$L = \left(H^2 + \left(\frac{H}{\left(\frac{1}{S}\right)}\right)^2\right)^{0.5}$$

Upstream Slope Input	
Horizontal Component of Upstream Slope (S):	______ ft H:1ft V
Dam Height (H):	______ ft
Output	
Length (L):	______ ft
Downstream Slope Input	
Horizontal Component of Downstream Slope (S):	______ ft H:1ft V
Dam Height (H):	______ ft
Output	
Length (L):	______ ft

Assume: Embankment slope is constant throughout length.

Note: Output is calculated from the Pythagorean Theorem [$c^2 = a^2 + b^2$] in conjunction with the slope equation [$m = y/x$].

Form 2: *Dam Access Details*

Latitude:	
Longitude:	
Access Road Culmination (i.e. Embankment Toe, Dam Crest, etc...):	
Directions to Access Road (from nearest major roadway):	
Access Road Condition:	
Number of Access Gates/Locks:	
Lock Location	**Lock Combination or Key Location/Contact**

**** Complete form for each access road or entryway***

Form 3: *Basic Historical Dam Construction, Operation, and Maintenance*

Year Designed:	Year Constructed:
Primary Purpose:	Secondary Purpose(s):
Original Hazard Classification:	
Current Hazard Classification:	
Frequency of Inspection:	Emergency Action Plan Available (Y/N):
Summary of Rehabilitation:	Year: _________
Summary of Engineering Study Performed:	Year: _________

Note: Form can be extended as necessary to provide more dam history information.

Notes:

Preventive Measure

2.2 Identification of Materials, Equipment, Labor, and Expertise

Because of the likely limitation on time when performing emergency interventions, it is helpful to identify available resources quickly. Any emergency repair will require equipment, materials, labor, and expertise.

Materials such as clay fill, sand, gravel, stone, riprap, sandbags, cement, plastic sheeting, geotextile, etc., and equipment for handling these materials, should ideally be kept at the site. If this is not possible, prior identification and arrangements with local contractors or other sources for the use of available off-site materials and equipment should be identified. Using the following forms, dam owners can create an inventory of both in-house resources and local resources, including contact information so that this information is available during an emergency.

Forms 4 and **5** should be completed for identifying common emergency supplies and equipment, respectively. If items are available nearby, detail locations and any necessary contact information. If items are not available nearby, identify local suppliers that could provide corresponding resources.

Form 6 should be completed for identifying expertise and labor that can be called upon during an emergency situation. The expertise/engineering related section is intended for the dam owner to list entities such as engineers, contractors, and others than can lend knowledgeable assistance. The labor/construction related section is intended for the dam owner to list those that would be able to mobilize labor and construction related services.

All forms are also included in **Appendix C**.

Form 4: *Emergency Intervention Materials and Providers*

Supplies*	Location	Contact	Comments
Fire Extinguishers			Safety precaution
Flashlights			Recommend to be stored on-site for immediate response
Sandbags			Recommend an adequate supply be stored nearby and identify outside contacts
Sand			Consider stockpiling nearby; used to create sandbags and construct filters
Gravel			Used to construct filtered drainage berms and maintain access roads
Clay/Soil Fill			Identify possible clay and soil borrow areas that can be safely accessed
Riprap/Rock Fill			Consider stockpiling nearby due to broad usage; identify outside contacts
Concrete/Grout			Concrete structure repair; identify outside contacts
Plastic Sheeting			6 mil polyethylene sheeting recommended for flood fighting applications
Geotextile			Preferably non-clogging and woven
Caulk			Recommend flexible sealant be stored nearby for concrete structure repair
Shovels			Recommend to be stored nearby for immediate response
Buckets			Recommend to be stored nearby for immediate response
Rope			Broad usage
Extension Cords			Power to equipment

* *When filling out information for the material providers, it is important to consult the 'Cautions, Consideration, and Initiation of Intervention' section of the following chapter as not all types of material used for emergency dam intervention are eligible for grant or loan reimbursement.*

Form 5: *Emergency Intervention Equipment and Providers*

Supplies	Location	Contact	Comments
Communication System			Two-way radios are preferred due to reliability and multiple users
Heavy Equipment (dump truck, backhoe, excavator, front-end loader, bulldozer, etc)			Identify several sources which could provide equipment
Pumps			Identify suppliers which could provide pumps
Siphon Materials			Identify material providers that could supply siphon construction/installation materials
Generators			Power source; note that large flood events often result in power outage
Floodlights			Identify adequate lighting source for night/low visibility consideration
Sand Bags and Filling Equipment			Identify for the event in which a large scale sandbagging job is deemed necessary

Form 6: *Emergency Intervention Expertise and Labor Assistance*

Expertise/Engineering Related			
Agency/Organization	**Principal Contact**	**Work/Office Phone**	**24-Hour Phone**

Labor/Construction Related			
Organization	**Principal Contact**	**Work/Office Phone**	**24-Hour Phone**

3.0 Identifying Emergency Conditions at Dams

Effective operation, maintenance, and inspection programs are important to early identification of issues at the dam site. A good maintenance program will increase the safety of the dam, and ensure it will perform as intended, including during times of unusual events such as earthquakes or flooding. When routine inspections are completed and documented, baseline dam conditions are established and unusual or changing conditions are easily detected. Changing conditions should be evaluated upon observation as they can indicate that an embankment dam is experiencing an unusual or emergency event that must be addressed.

Resources provided by each state's dam safety program should contain guidelines for developing and implementing successful operation, maintenance, and inspection programs for its dams.

3.1 Event Level Determination

An *unusual event* is an event which takes place, or a condition which develops, that is not normally encountered in the routine operation of the dam and reservoir, or necessitates a variation from the standard operation and maintenance procedures for the dam. An *emergency event* is an *unusual event* of a serious nature that may endanger the dam, or endanger persons or property, and demands immediate attention.

Possible unusual or emergency events at embankment dams are included in **Table 2** for guidance in identifying and distinguishing them.

Events included in **Table 2** that most commonly lead to embankment dam failures are described in greater detail below. Additional resources including reference books, articles, presentations, and videos related to each topic and available online are listed alongside each description**.**

3.2 Embankment Overtopping

When the continual increase of reservoir elevation occurs as the result of a large storm event, inoperable outlet works, obstruction of the spillway, insufficient spillway capacity, or overtopping of the dam crest becomes a concern (**Figure 4**). Failures attributed to overtopping result from the erosive action of uncontrolled flow over, around, and adjacent to the embankment. Earth embankments are generally not designed to be overtopped and therefore are particularly susceptible to erosion. Once erosion has begun during overtopping, it is almost impossible to stop. For this reason, detection and monitoring of reservoir pool levels as well as emergency intervention is important. Prior to initiating emergency actions, it is important to verify whether or not the spillways are obstructed with debris and functioning as efficiently as possible.

Notes:

Preventive Measure

Animation of an Overtopping Failure (Online Video)

Dam Checklist: Overtopping (Online Video)

Caution

Table 2: *Event Level Determination Guide*

Event	Observation	Event Level
Flooding or Overtopping	Reservoir water surface elevation greater than highest spillway elevation and increasing.	1
	Reservoir water surface elevation increase so that the spillway is opened to full design discharge for any reason, or any other cause of flow over the dam embankment.	2
Earthquake	An earthquake has been felt or is reported to have occurred in the area with Richter Magnitude (M) of 4.0M or greater within a 30-mile distance of the dam, 5.0M or greater within 60 miles, or 6.0M within a 120 mile radius of the dam.	1
	Earthquake resulting in visible damage to the dam or appurtenances.	1, 2
	Earthquake resulting in uncontrolled release of water from the dam.	2
Seepage and Piping	Observation of new seepage in the dam or appurtenant structures with no measurable flow.	1
	Observation of seepage with cloudy discharge.	1, 2
	Observation of new seepage with measurable flow.	1, 2
	Uncontrolled seepage with cloudy discharge.	2
	Uncontrolled seepage and flow rate increasing.	2
Cracking	New cracks in the embankment greater than 1-inch wide without seepage.	1
	New cracks observed in concrete appurtenant structures greater than 1/4-inch wide.	1
	New cracks in the embankment, or appurtenant structures with seepage flowing through the crack (reference seepage, above).	2
Movement	Movement/settlement/slide of the embankment greater than 10 cubic feet of material.	2
Instruments	Abnormal reading.	1
Sabotage	Sabotage, vandalism, or destruction at the dam that is not likely to lead to dam failure.	1
	Sabotage, bomb threat, or destruction that may result in dam failure.	2
	Sabotage that has caused imminent dam failure.	2

Note: 1 = Unusual, 2 = Emergency

Figure 4: *Examples of Dam Overtopping During a Flood*

Source: Association of State Dam Safety Officials

If debris is the issue, removal may be difficult due to pressure from the high velocity flow and should be accomplished by using long poles or hooks on ropes. Personnel should not be allowed close to spillway inlets.

If there is no debris within the spillway(s) or overtopping is imminent, intervention actions are focused on preventing overtopping of the dam crest and can include the following:

» Lowering the Reservoir
» Raising the Embankment
» Protecting the Embankment and Auxiliary Spillway from Erosion
» Constructing a Bypass Channel

In addition to the intervention techniques listed above, a well vegetated earth embankment may withstand limited overtopping if its top is level and water flows over the top and down the face as an evenly distributed sheet without becoming concentrated.

3.3 Uncontrolled Seepage

Active Boils

A boil is an artesian condition that occurs near the toe or exit channel of a dam where seepage flow is actively upwelling sandy or muddy water. Boils usually occur within 10 to 300 feet from the downstream toe of the dam and, in some instances, have occurred up to 1,000 feet away. A photograph showing a boil at the downstream toe of an embankment dam is presented in **Figure 5**.

Notes:

Flood Overtopping Failure of Dams and Levees

Dam Safety Factsheet: Dam Failure Modes

Overtopping Protection for Dams (P-1014)

Preventive Measure

Dam Safety Factsheet: Earthen Dam Seepage

Figure 5: *Boil at the Toe of an Embankment Dam*

Dam Safety Factsheet: Dam Failure Modes

Caution

Animation of a Piping Failure (Online Video)

Training Aids for Dam Safety: Evaluation of Seepage Conditions

Research Needs Workshop: Seepage Through Embankment Dams

Dam Checklist: Seepage (Online Video)

Boils will often have an obvious exit, such as a rodent hole, which may be small. When material is carried upward through a boil, it is deposited in a circular pattern around the exit location, and appears comparable to an ant hill or volcano. Alternately, boils may exit into standing water. In this case, they may be difficult to identify. What appears to be standing water on the landward side of the structure may be the exit point for a boil. When investigating suspected boils in standing water, care should be taken in approaching and investigating the site. The water should be disturbed as little as possible and allowed to settle prior to identifying the exit point.

Boils of any size should be clearly marked and named so that they can be easily located and monitored for changes in conditions. It is advisable to construct a weir that is able to measure the outflow, allowing inspectors to monitor whether the condition is worsening or improving.

Water that flows from a boil can transport material from the dam and may lead to a piping condition and failure of the dam. A boil that discharges clear water with a constant discharge may not be an immediate threat to the safety of the dam. Continuous observation of the boil is recommended until it is determined that the condition is stable and safe. If the flow from the boil is increasing and is muddy or is transporting sand, corrective action should be taken immediately. If the boil is determined to be a threat to safety, the following intervention methods may be employed to decrease risk to the structure and the downstream community:

» Lowering the Reservoir
» Constructing Ring Dikes
» Installing a Filter Blanket

Seepage along an Embankment Penetration or Defect

Because compaction of the embankment material is more difficult around conduits and along other penetrations that extend from the reservoir to the downstream slope of earthen dams, such features can result in differential settlement and cracks or low strength zones within an embankment. The interface between the embankment soil and such structures can become a location for a preferential flow path for seeping water. Cloudy or muddy seepage emerging from around the headwall or cradle of a conduit or tunnel can be a sign of uncontrolled seepage. In extreme conditions, excessive seepage and erosion of the embankment soil along an embankment penetration can form a clearly defined pipe or tube that continues to progress into the embankment (**Figure 6**). If seepage along the embankment is suspected, the following methods can be employed to reduce the risk of an incident or failure occurring.

» Lowering the Reservoir
» Installing a Filter Blanket

Figure 6: *Photo of Internal Erosion Failure along an Outlet Conduit*

Sinkholes and Whirlpools in the Reservoir

Sinkholes on the embankment and whirlpools in the reservoir, while serious conditions of their own, pose the most danger to a dam when they are the result of or accompanied by uncontrolled seepage and piping. Caused by the collapse of embankment materials, sinkholes are cavernous depressions that range in size and location at embankment dams. If sinkholes are noticed on the embankment or downstream of the dam, the entire area should be inspected and monitored for any signs of seepage or additional sinkholes. Sinkholes that appear in the reservoir floor or rim upstream of the dam represent seepage entrance locations. Unless the reservoir is drawn down periodically, these may not be detected.

A whirlpool is a body of swirling water in the reservoir that may be caused by flow through a channel in or under the dam. **Figure 7** is a photograph of a whirlpool in the reservoir along the upstream slope of an embankment dam. Whirlpools in reservoirs may form when mechanical or hydraulic components, such as drains or intakes located beneath the reservoir surface are operated. They can also be the result uncontrolled seepage through the embankment. If the latter is present and left alone, the seepage can increase and enlarge until the dam is breached. Monitoring for signs of uncontrolled seepage from the embankment should be initiated following the detection of a whirlpool in the reservoir.

Internal Erosion Risks for Embankments and Foundations

Evaluation and Monitoring of Seepage and Internal Erosion (P-1032)

National Dam Safety: Seepage and Piping, Parts 1 and 2 (Online Videos)

Figure 7: *Photo of a Whirlpool at the Upstream Slope of an Embankment Dam*

Source: U.S. Forest Service

The following remedial actions should be taken if a sinkhole or whirlpool associated with uncontrolled seepage is observed:

» Lowering the Reservoir

» Plugging Sinkholes

Internal Erosion Risks for Embankments and Foundations

If sinkholes are observed at the embankment or downstream of the toe or whirlpools noted within the reservoir with no indication of seepage flow, the area should be continuously monitored until detailed investigation and analyses can be performed and the cause determined.

3.4 Slope Failure

Animation of a Slide Failure (Online Video)

Wherever the ground surface of a dam embankment is not horizontal, a component of gravity will work to move the sloping soil mass downwards. Slope instability occurs when the shear stress developed along a potential rupture surface within a dam embankment exceeds the resisting shear strength of the soil. Slope failures occur when high water pressures exist within the embankment soil pores or the slope becomes saturated; often during prolonged periods of high water or heavy rainfall. Under these conditions, the soil in an embankment structure can become unstable and cause sloughing, shearing, and collapse of the dam embankment. Failures can also occur due to seismic shaking (dynamic shear forces) and/or liquefaction of the embankment or foundation soils. Sudden drawdown of the reservoir causes a reversal in the direction of flow along the embankment, potentially resulting in a failure of the upstream slope if already in a saturated state.

Embankment Dam Slope Stability

Classic symptoms of slope stability problems are listed below:

» Wide deep cracks that parallel the dam crest. These cracks may also extend down the slope (**Figure 8**).

» Vertical movement of the material along the crack. This movement may be very obvious or very subtle if the stability problem is just starting to develop.

» If the slope has slumped or is starting to slump, examine the area along the toe of the embankment. In many cases there will be a noticeable bulge in the slope.

If signs of a developing slope stability problem are noted at the dam, the following corrective actions may be taken:

» Lowering the Reservoir

» See "Uncontrolled Seepage" if it becomes a symptom

Deep seated sliding often requires the removal and replacement of that section of the dam, and the stabilization of the area with a soil or rock berm. If signs of such slope failure are observed, a professional engineer should be called to the site to assess the situation and evaluate remediation options.

Dam Checklist: Cracking (Online Video)

Training Aids for Dam Safety: Evaluation of Embankment Dam Stability and Deformation

Slope Stability (EM 1110-2-1903)

Figure 8: *Slides on the Downstream Slope of an Embankment Dam*

Spillways: Spilling the Right Way

Dam Safety Fact Sheet: Earthen Spillways

Earthen Spillways Design and Analysis State of Practice

Dam Safety Fact Sheet: Groundcover

3.5 Auxiliary Spillway Erosion

Because auxiliary spillways are not designed to convey flow regularly and are typically constructed in natural soils, they often exhibit some level of erosion when activated. Major erosion and headcutting of the auxiliary spillway can result in breaching the spillway crest and result in an uncontrolled release of the reservoir storage. Lateral erosion can damage the embankment.

If this erosion is minor, or minor enough that it does not compromise the integrity of the dam embankment or result in breaching the crest of the spillway, it can be repaired as soon as the flood event is over. However, even a small amount of irregularity on the auxiliary spillway slope may be enough to concentrate flow and can create substantial erosion (**Figure 9**). If not repaired and maintained properly, this erosion can grow until it is large enough to compromise the stability of the dam and require one of the following emergency remediation techniques to be enacted:

» Lowering the Reservoir
» Protecting the Embankment and Auxiliary Spillway from Erosion
» Diverting, Preventing, or Limiting Damaging Flow within the Auxiliary Spillway

Figure 9: *Severe Auxiliary Spillway Erosion*

Source: North Dakota State Water Commission

4.0 Responding to Emergency Conditions at Dams

Flood fighting is an art, and can be extremely difficult to execute. There is no absolute method that one can apply to guarantee success. However, failure to react in a timely manner and apply proven flood fighting techniques greatly increases the risk of failure.

The action to be taken upon the discovery of a potentially unsafe condition will depend on the nature of the problem and the time estimated to be available for remedial or mitigation measures. As time permits, one or more of the following actions will be required:

1. Monitoring the Progression of the Condition.
2. Notification of the state dam safety office or regulatory agency.
3. Initiation of Emergency Action Plan (if applicable).
4. Initiation of Intervention Action.

4.1 Monitoring the Progression of the Condition

Preventive Measure

Just as routine operation, maintenance, and inspection are essential to the observation of potentially dangerous situations at dams, establishing an effective monitoring program that accurately tracks the dam's condition during an unusual event is one of the most important parts of any dam emergency intervention action. Monitoring typically involves visiting the dam site frequently, recording reservoir pool elevation and any existing instrumentation measurements, and documenting the progress of the newly developed, potentially hazardous condition. These conditions should then be compared with baseline conditions and analyzed to determine if any trends are developing and if notification of dam safety personnel, initiation of the emergency action plan, and/or intervention action becomes necessary.

Special attention should be given to any data from the dam that is changing. The dam safety professional inspecting the site should continually ask themselves, "Are conditions of the dam changing, and if so, for better or for worse?" If conditions appear to be worsening, it is best practice to initiate continuous monitoring. Continuous monitoring generally requires several inspectors taking shifts. It is imperative that any conditions, observations, or recordings made by one individual are explained and understood by the person replacing them. This ensures the accuracy of data and observations collected. In the event that overnight monitoring is necessary, portable lighting will often need to be used to keep workers safe. While observing the dam, the inspector should never place themselves in a situation where they may be exposed to hazardous conditions such as swift currents or unstable slopes.

Caution

If conditions continue to worsen and the observed unusual event progresses to an emergency event, state dam safety personnel should be notified of the developing condition, activation of the EAP should be considered, and the embankment failure mode and appropriate intervention method should be identified.

Notes:

4.2 Notification of the State Dam Safety Office or Regulatory Agency

Notification of the state dam safety office or regulatory agency is essential to any intervention effort since development of failure could vary in some or many respects from previous forecasts or assumptions, and advice may be needed. Additionally, it is good practice to notify required agencies either during or directly after performing the emergency actions, so that the necessary regulatory procedures can be completed.

When reporting a dam incident to dam safety personnel, remember that when locating problem areas, all directions, e.g., "left of," or "right from," are taken while facing downstream. Items that should be reported include:

Form 7: *State Dam Safety Office or Regulatory Agency Notification Form*

Name of Person Reporting:	
24-Hour Phone Number of Person Reporting:	
Name of Dam:	Dam Operator (if known):
Latitude of Dam:	Longitude of Dam:
Nature of the Problem (e.g., potential overtopping, excessive seepage, boils, etc...):	
Location of Problem in Terms of Embankment Height:	
Location of Problem along Dam's Crest (e.g., 100 feet to the right of the outlet or abutment):	
Location of Problem in Terms of Slope (e.g., upstream, downstream, or crest):	
Extent of Problem Area (can often be established by pacing):	
Estimated Quantity of Seepage:	
Quality of the Seepage (clear, cloudy, muddy, etc...):	
Current Reservoir Pool Elevation:	
Is the Reservoir Pool Rising or Falling?	
Readings Taken from Existing Instrumentation (if applicable) and How They Compare to Baseline Condition Readings:	
Current Weather Conditions at the Site:	
Was the Situation Worsening while being Observed?	
Other Information:	

4.3 Initiation of Emergency Action Plan

If downstream populations are judged to be in possible danger as a result of the emergency condition at the dam site, notification of additional authorities and agencies is necessary. The EAP for the dam, if available and up to date, should be consulted and initiated. For those significant- or low-hazard structures without EAPs, an emergency call list prepared prior to an emergency is crucial to a successful intervention.

4.4 Cautions, Considerations, and Initiation of Intervention

After making notifications to the State dam safety office or regulatory agency, local authorities, and emergency personnel as well as appropriate organizations and government agencies about the changing dam conditions, the dam owner should initiate efforts to prevent or delay failure of the dam. Public safety should be the number one concern in selecting emergency response measures, followed by downstream property and lastly, the dam itself. While techniques for emergency intervention will depend on the nature of the problem, anticipated time for action, and availability of resources, the following sections provide descriptions of possible actions to take to avoid or delay failure of the dam. Failure modes and intervention actions are site-specific, and a method of intervention proven successful at one location may not be ideal for another. It is important to ensure that intervention actions will "do no harm", as some actions incorrectly applied could accelerate failure of the dam. As a result, a familiarity with the soils, geology, and other conditions specific to the dam site as well as the downstream inundation area and people at risk is necessary to deciding if and how to intervene.

Caution

In some instances, a condition will have progressed too far to realistically expect an emergency intervention to be successful in preventing the complete failure of the dam. Cases such as this warrant that actions be taken to delay a breach as long as possible, in order to provide as much time as possible for emergency procedures and evacuation to be enacted downstream. In others, the safest dam emergency response is to perform a controlled breach of the structure.

Regardless of the approach taken to intervene in a dam emergency, it is highly recommended that at least one technically qualified individual, previously trained in problem detection, evaluation, and remedial action, be at the project or on call at all times. Any intervention effort to protect the lives of people downstream or prevent the dam from failure should be undertaken only if working conditions are safe. Caution must be exercised by all those monitoring and/or working around the dam during the implementation of any emergency measure.

After the emergency situation has been resolved, documentation of the situation and actions taken should be developed as soon as possible. This should contain the conditions observed and any responses made throughout the entire emergency timeline. It should also be as descriptive as possible, and contain pictures, sketches, and any relevant measurements or data taken. The report should also recommend any further actions, if deemed necessary. These could include inspections or further repair of the structure. Copies of this report should be provided to the dam owner as well as all relevant dam safety agency personnel.

In addition to other documentation purposes, recording all intervention activities may be beneficial when applying for grants, loans, or other sources of funding assistance for the costs incurred during emergency action. Although local, state, and federal options for financial reprieve are made available for emergency construction or rehabilitation projects, most have specific eligibility requirements. Such requirements may include specifications on the materials used during the intervention. For example, in order for the Federal Emergency Management Agency (FEMA) to provide an entity with financial assistance following an emergency, the materials used during the emergency must be on a list of those certified by the agency. Consideration should be given to sources of funding and compliance with dam safety agency requirements prior to identifying material providers.

4.5 Lowering the Reservoir

Guidelines for Use of Pumps and Siphons for Emergency Reservoir Drawdown

One of the first considerations in an emergency situation is to lower the reservoir to mitigate adverse conditions such as overtopping, seepage, slope failure, and erosion. Lowering the reservoir allows for additional storage capacity and reduces the hydraulic head fostering seepage potential. For this reason, outlet works and other control structures should always operate properly. Current practice is to consider the need for emergency drawdown in sizing the capacity of outlet work facilities. For existing dams, the drawdown capability and downstream consequences of large releases should be considered.

Caution

When deciding whether to lower the reservoir, consider these factors:

1. Anticipated time for drawdown,
2. The effects on the purpose(s) of the reservoir/dam,
3. The potential for instability of the upstream slope of the existing embankment from rapid drawdown, and
4. The potential damage downstream because of higher-than-normal discharges.

These four factors may be secondary, however, when a dam failure is imminent.

Dam Safety: Lake Drains

In some cases, pumps or siphons can be used to lower the reservoir. The following flow chart in conjunction with the Maximum Siphon Lift Equation may be useful in determining whether a pump or siphon is the more appropriate means of lowering the reservoir if low-level drawdown is not possible or additional capacity is needed (**Figure 10**).

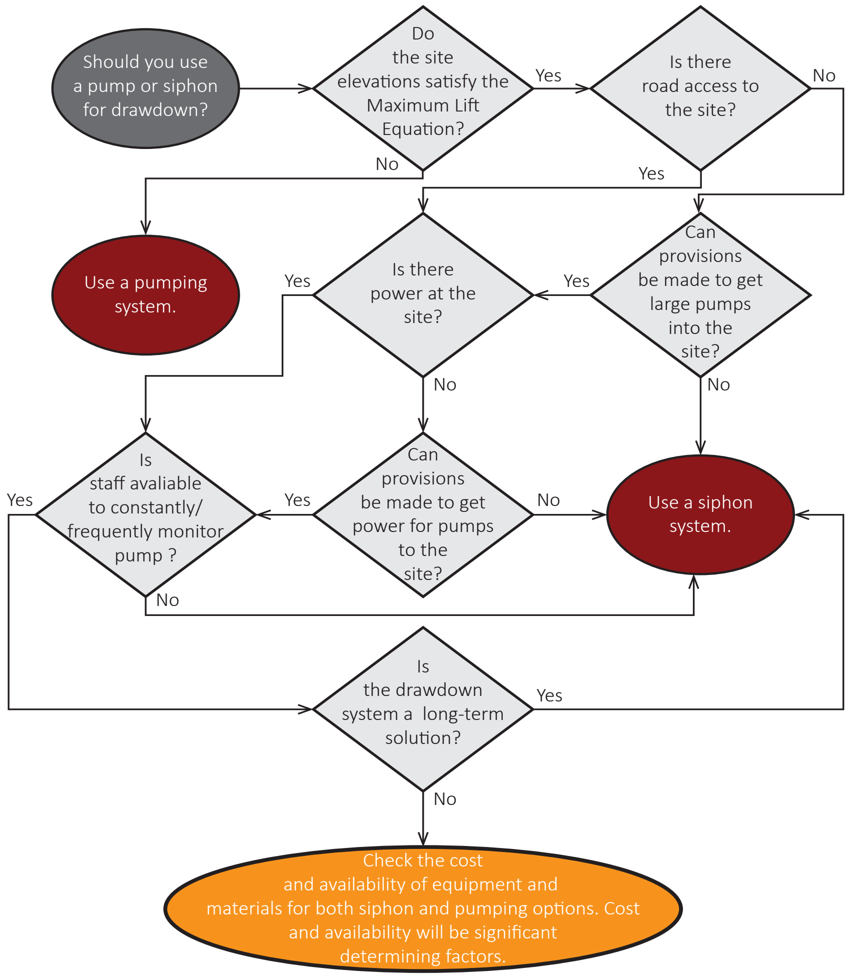
Drawdown Time Calculator		
t = 0.504 x (V/Q) x (% to be drained/100)		
Input		
Total Volume (V):	______	acre-ft
% of Volume to be Drained:	______	%
Discharge Capacity (Q):	______	cfs
Output		
Drawdown Time (t):	______	days

Assume: No inflow to reservoir and discharge capacity does not change as the reservoir pool level lowers.

Note: See Appendix B for any unit conversion calculations.

If pumps are the desired means for drawing down the reservoir, the pump supplier identified in **Form 4** should be contacted for assistance in determining the appropriate type, size, and number of pump system components for dispatch to and implementation at the dam site. A pump system like those shown in **Figure 11** used to prevent a potential overtopping failure is comprised of an inlet pipe, pump and associated power source, outlet pipe, and air valves. It is beneficial to relay dimensions delineated in **Figure 12** to the pump supplier so they are able to refine their solution for pump capacity as well as piping diameter and length. Although the pump supplier will offer site-specific guidance, general guidelines for the relationship between maximum flow and pump pipe diameter are listed in **Table 3.**

Figure 10: *Drawdown System Selection Flow Chart*



Source: Morrison Maierle, Inc., *Guidelines for Use of Pumps and Siphons for Emergency Reservoir Drawdown* (2012)

Maximum Siphon Lift Calculator

$TOD - TWS \le 20 - (TWS/1000)$

Input

Top of Dam Elevation (TOD): ______ ft

Target Water Surface Elevation (TWS): ______ ft

Output

______ ft ≤ ______ ft

Results

- If the output statement is true, then a siphon may be feasible. Proceed to the **Predicted Siphon Flowrate Calculator** for additional calculations.
- If the output statement is false, then a siphon is not feasible.

Assume: Top of Dam Elevation and Target Water Surface Elevation are of consistent datum; and atmospheric pressure at sea level.

Source: Morrison Maierle, Inc., *Guidelines for Use of Pumps and Siphons for Emergency Reservoir Drawdown* (2012)

National Dam Safety: Rapid Drawdown Stability

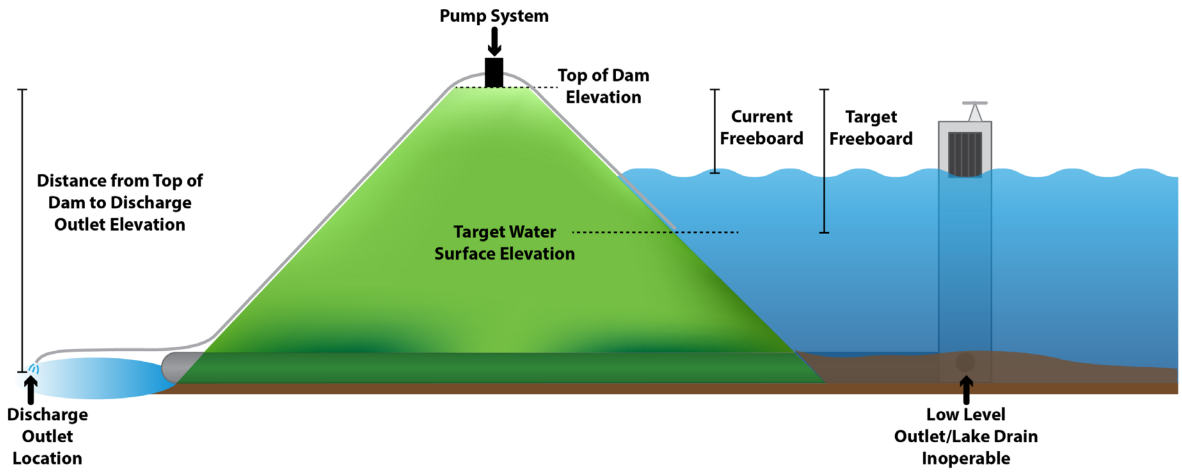
How Low Can you Go? The Needs and Considerations for Outlets

Simple Steps to Siphoning

Figure 11: *Pump Outlet Piping Along the Downstream Slope of Dam and Discharge Location*

Source: Morrison Maierle, Inc., *Guidelines for Use of Pumps and Siphons for Emergency Reservoir Drawdown* (2012)

Figure 12: *Useful Dimensions for Determining Pump System Capacity and Size*



Pipe Length Calculator

Input for Upstream Slope

Target Freeboard: ______ ft

Horizontal Component of Upstream Slope: _____ft H:1ft V

Output

Length of Pipe Needed (L_u): ______ ft

Input for Dam Crest

Dam Crest Width: ______ ft

Output

Length of Pipe Needed (L_c): ______ ft

Input for Downstream Slope

Dam Height: ______ ft

Horizontal Component of Downstream Slope: _____ft H:1ft V

Output

Length of Pipe Needed (L_d): ______ ft

Additional Pipe Required to Reach Downstream Discharge Location

Length of Pipe Needed (L_a): ______ ft

Total Pipe Required

Total Length of Pipe: ______ ft

Assume: Embankment slopes are constant throughout length.

Note: Approximate pipe length on the upstream and downstream slopes are calculated using the same equation used in the Upstream and Downstream Slope Calculators on page 9.

Table 3: *General Relationship between Maximum Flow and Pump Pipe Diameter*

Maximum Flow	Pump Pipe Diameter
300 gpm	4 in
600 gpm	6 in
1100 gpm	8 in
1700 gpm	10 in
2500 gpm	12 in

Source: Morrison Maierle, Inc., *Guidelines for Use of Pumps and Siphons for Emergency Reservoir Drawdown (2012)*

When determining the total length of pipe necessary to construct either a pump or siphon drawdown system, the following variables should be identified, calculated, and summed:

» Length of piping material required on upstream slope, L_u

» Length of piping material required on dam crest (equal to the dam crest width), L_c

» Length of piping material required on downstream slope, L_d and

» Length of additional piping material required to reach desired discharge location downstream, L_a

Siphon flowrate capacity should be determined using the Predicted Siphon Flowrate Calculator and dam characteristic variables represented in **Figure 12.**

During dam emergency situations that require the use of a siphon, the following materials should be collected to construct the inlet, piping, priming appurtenances, outlet, and air vacuum breaker valves for a PVC siphon as shown in **Figures 13 and 14**:

» PVC pipe

» Rubber sleeve connectors

» Flat band clamps

- Two 22.5 degree elbows
- One 90 degree elbow
- Two valves
- 3-inch tee tap with air tight plug
- Pump and hose to fill pipe with water

If the reservoir cannot be lowered fast enough through outlet works, pumps, siphons, or other control structures, a “controlled” breach of an earthen dam can be performed to speed the process. The controlled breach should be at a location that would produce the least damage downstream from the released reservoir water. It is important to remember that a controlled breach is a dangerous operation that can quickly become out of control and should only be undertaken as a last resort, and then after proper planning and consultation.

Figure 13: *Example of Siphon System Installed on Embankment Dam*

Predicted Siphon Flowrate Calculator

$$Q = 0.0438D^{2.5}H^{0.5}(12fL + (KD) + D)^{-0.5}$$
$$f = 425(n^2/D^{0.33})$$

Input

Siphon Pipe Diameter (D): ______ in

Elevation Difference between TWS and Siphon Pipe Outlet (H): ______ ft

Manning's "n" Value for the Siphon Pipe (typical plastic pipe values range from 0.007-0.012) (n): ______

Total Length of Siphon Pipe (L): ______ ft

Sum of Hydraulic Losses Associated with Siphon Components (table below) (K): ______

Output

Flow (Q) = ______ ft³/s

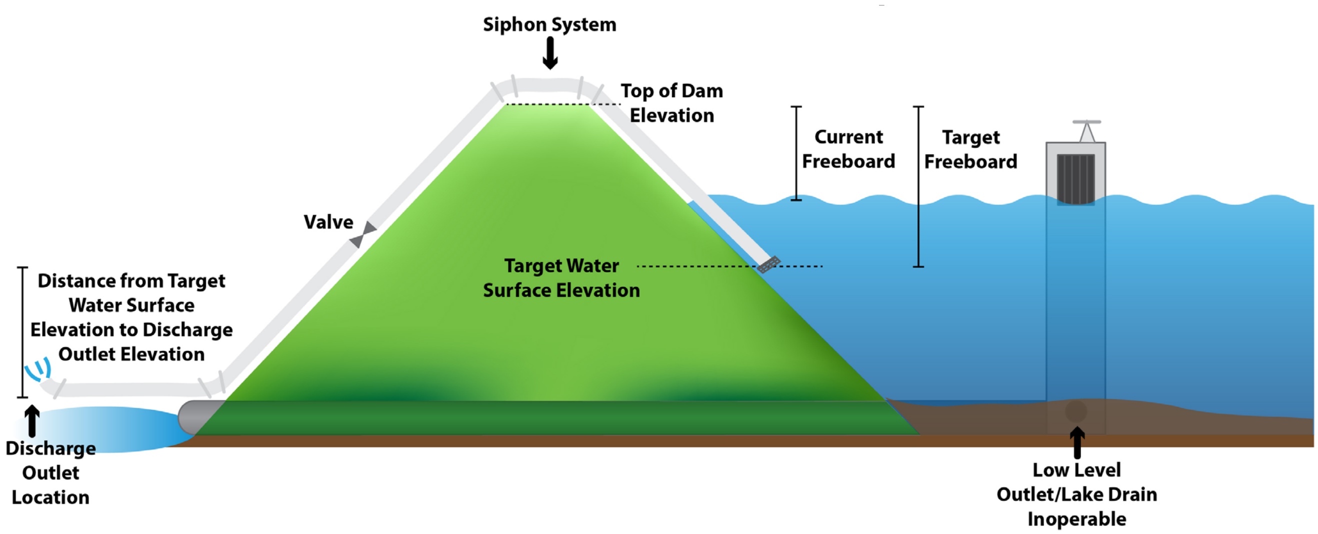
Note: Equation is only valid for the following dam sites:
1) Maximum Siphon Lift Equation is satisfied.
2) A vacuum breaker valve does not hinder the siphon effect between the inlet and outlet.

Source: Morrison Maierle, Inc., *Guidelines for Use of Pumps and Siphons for Emergency Reservoir Drawdown* (2012).

Table 1: K Values for Select Components

Component	K Value
Entrance Loss	0.8
45˚ Bend	0.3
Gate Valve (fully open)	0.2
Ball Valve (fully open)	10.0
Butterfly Valve (fully open)	0.2
Check Valve	10.0
Exit Loss	1.0

Figure 14: *Useful Dimensions for Determining Siphon System Capacity and Size*



Sandbag Pyramid Stacking Calculator		
X = 6 x L		
Input for 1 ft High Sandbag Wall		
Sandbag Length Required (L):	______	ft
Output		
Approx. # of Sandbags (X):	______	bags
Approx. Sand Volume:	______	yd^3
X = 21 x L		
Input for 2 ft High Sandbag Wall		
Sandbag Length Required (L):	______	ft
Output		
Approx. # of Sandbags (X):	______	bags
Approx. Sand Volume:	______	yd^3
X = 45 x L		
Input for 3 ft High Sandbag Wall		
Sandbag Length Required (L):	______	ft
Output		
Approx. # of Sandbags (X):	______	bags
Approx. Sand Volume:	______	yd^3
X = 78 x L		
Input for 4 ft High Sandbag Wall		
Sandbag Length Required (L):	______	ft
Output		
Approx. # of Sandbags (X):	______	bags
Approx. Sand Volume:	______	yd^3

Assume: Length per sandbag = 1 ft

4.6 Raising the Embankment to Prevent Overtopping

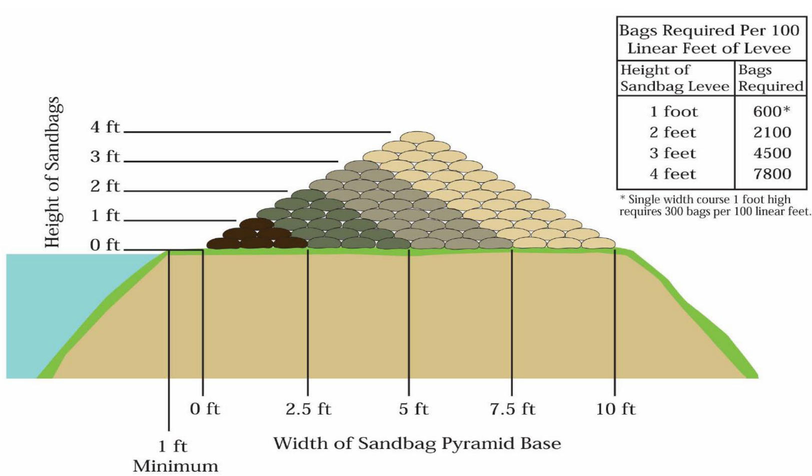
Raising the embankment is an emergency intervention technique used to prevent dam failure from imminent overtopping. For the past century, sandbags have been and still remain the primary tool for flood fighting. Both the proper filling and placement of sandbags is important to successfully increasing freeboard at dams. The U.S. Army Corps of Engineers' *Sandbagging Techniques* brochure provides a description of proper sandbag construction materials, correct filling procedures, and several sandbag placement methods.

Filling sandbags is a two-person job. One should hold the bag open, while the other scoops sand into the bag. Although it may not be feasible during emergency conditions, for large-scale filling jobs, special power loading equipment can be used to fill bags. Regardless of the technique used, sandbags should be filled approximately 1/3 to 1/2 of their total capacity. Sandbags are most effective at this fill:volume ratio as it prevents the bags from getting too heavy and allows them to be stacked with a good seal. Prior to placement, the open portion of the bag should be folded to form a triangle, and tucked under the bag.

Sandbags should be stacked to form a pyramid by alternating bags placed crosswise with bags placed lengthwise. Bags in successive levels should be offset by one-half the length of a bag. Every level should be stamped down to eliminate voids and create a tight seal. The schematic in **Figure 15,** in conjunction with the Sandbag Pyramid Stacking and Single-Width Sandbag Stacking Calculators, provides guidance on the number of sandbags necessary to achieve a desired height.

In addition to stacking sandbags, Jersey barriers, or K-rails as they are also known, can provide a means of increasing freeboard in an emergency situation. If time is not of immediate concern to the intervention effort, more sophisticated means of construction and technology may be used to provide temporary overtopping protection. Flood fighting professionals may be contacted to install Portadams, Rapid Deployment Flood Walls, or Hesco Barriers, if time allows.

Figure 15: *Sandbag Placement Schematic*



Source: *USACE, Sandbagging Techniques (2004)*

Regardless of the material or product used, great care should be taken when attempting to temporarily raise the top of a dam embankment to prevent overtopping during a severe storm as the flood inflow may continue to increase and result in the overtopping of the raised dam. If the temporarily raised dam fails, the flow could concentrate at the failure point and prematurely erode the embankment and release an even greater volume and depth of water than would have otherwise occurred. Ideally, the crest of the dam should be completely level so that if it was overtopped, there would be a shallow uniform flow over the embankment crest and downstream slope, rather than concentrated flows. Caution and consideration should also be given to raising the dam with respect to the implications that increasing the storage volume at the site may have on hydraulic loading and embankment stability. As a result, an engineer should be contacted prior to any intervention involving the use of sandbags to temporarily increase the freeboard at a dam during a severe storm.

4.7 Protecting the Embankment and Auxiliary Spillway from Erosion

During floods, wave action against the upstream slope of the dam embankment can erode wide terraces along the length of the dam if it is unprotected. If the auxiliary spillway is activated, there is the potential for unforeseen erosion of the exit channel and headcutting to occur. Similarly, if the dam is overtopped, the flows over the crest of the dam and the downstream slope can erode and breach the dam. Riprap, sandbags, or another protective material can be used in an emergency to protect the structure from further damage. It is important that the armoring material be heavy enough that it remains in place and is not affected and displaced by any wave action or overtopping. The amount of material needed for protecting an area of the embankment or auxiliary spillway can be determined using the Material for Protection Calculator. Actions taken to protect the embankment or auxiliary spillway may slow down the progression of the failure long enough to withstand a hazardous situation.

Effective protection from erosion and overtopping is most commonly provided using riprap placed over the affected area(s). If rock riprap is used, it should consist of a heterogeneous mixture of irregular shaped stone placed over gravel bedding. The biggest rock must be large and heavy enough to break up the energy of the maximum expected flow conditions and hold smaller stones in place. The smaller rocks help to fill the spaces between the larger pieces and to form a stable mass. The gravel bedding material prevents soil particles on the embankment surface from being washed out through the spaces between the rocks in the riprap. If the bedding material can be washed out through the voids in the riprap, graded layers of bedding material may be required to transition from the finer material to the coarser riprap material.

If riprap is not readily available, experience has shown that a combination of polyethylene sheeting and sandbags can be an expedient, effective, and economical method of temporarily armoring an embankment. Other materials such as snow fence, or burlap have successfully been used in place of the

Single-Width Sandbag Stacking Calculator	
X = 3 x L	
Input for 1 ft High Sandbag Wall	
Sandbag Length Required (L):	______ ft
Output	
Approx. # of Sandbags (X):	______ bags
Approx. Sand Volume*:	______ yd^3
X = 6 x L	
Input for 2 ft High Sandbag Wall	
Sandbag Length Required (L):	______ ft
Output	
Approx. # of Sandbags (X):	______ bags
Approx. Sand Volume*:	______ yd^3

** Assume width of sandbag = 10 in.*

Caution

Material for Protection Calculator	
M = L x W	
Input	
Length of Area to be Protected (L):	_____ ft
Width of Area to be Protected (W):	_____ ft
Output	
Amount of Material (M) =	_____ ft^2

Overtopping Protection for Dams (P-1014)

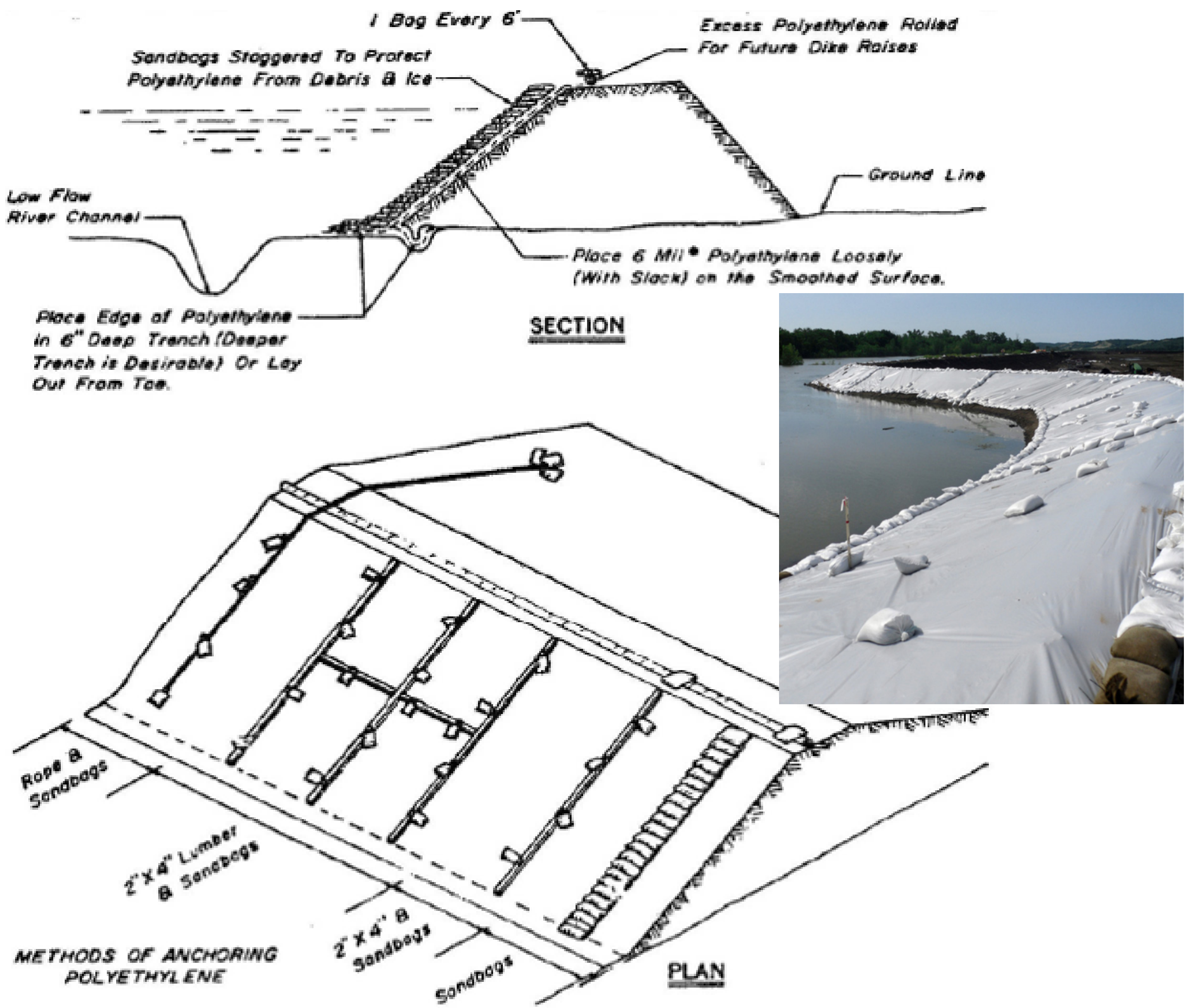
Caution

Sandbagging Techniques

Approval Standard for Flood Abatement Equipment, FM Standard 2510

polyethylene sheeting. Polyethylene sheeting and sandbags can be used in a variety of combinations, and time becomes the factor that may determine which combination to use. Ideally, polyethylene sheeting and sandbag protection should be placed in the dry. However, many cases of unexpected slope attack occur during high water, and a method for placement in the wet is therefore described below. **Figures 16** and **17** provide diagrams showing recommended methods of laying polyethylene sheeting and sandbags in both wet and dry conditions. The Polyethylene Sheeting Material Calculator can be used to determine the amount of sheeting necessary to protect the embankment slope.

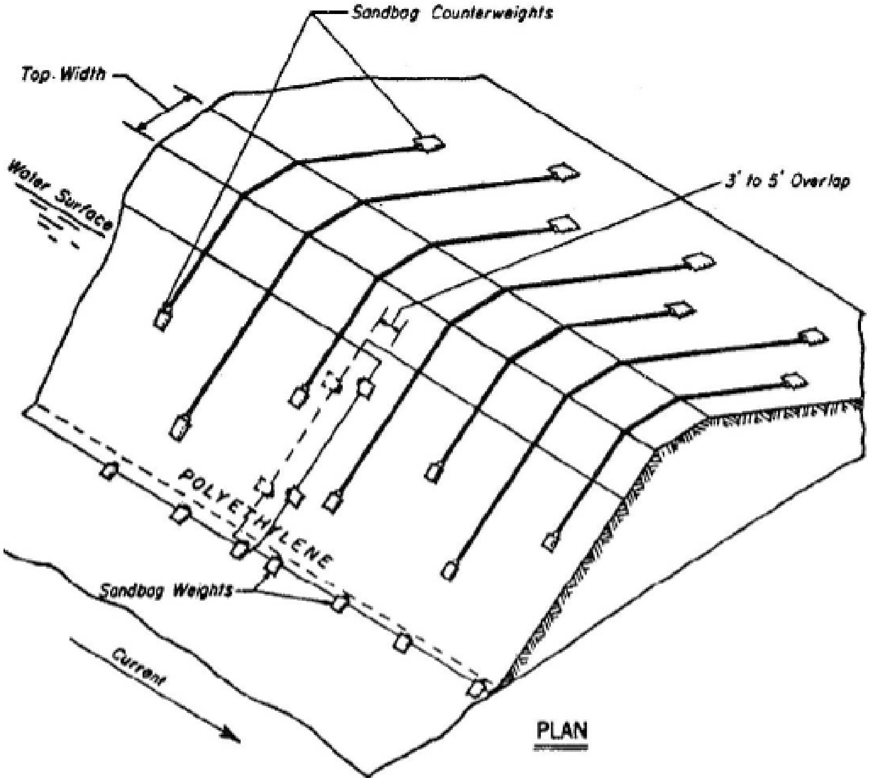
Figure 16: *Placement of Polyethylene Sheeting Slope Protection in the Dry*



* 6 Mil Black Polyethylene is the most Desirable, 6 Mil Clear Second, 4 Mil Black Third, 4 Mil Clear Fourth & 2 Mil Polyethylene Should Only Be Used As A Last Resort.

Source: USACE. *Levee Owner's Manual for Non-Federal Flood Control Works* (2006).
Photo Source: USACE

Figure 17: *Placement of Polyethylene Sheeting Slope Protection in the Wet*



Source: USACE. *Levee Owner's Manual for Non-Federal Flood Control Works* (2006).
Photo Source: U.S. Air Force

Anchoring the polyethylene sheeting is important for a successful job. It may be done in two different ways:

1. A trench is excavated along the upstream side, polyethylene sheeting is placed in the trench, and the trench is backfilled; and

2. Polyethylene sheeting placed flat-out from the toe and one or more rows of sandbags placed over the flap.

The polyethylene sheeting should then be unrolled up the slope and over the top enough to allow for anchoring with sandbags. Polyethylene sheeting should be placed from downstream to upstream along the slopes and overlapped at least two feet.

Polyethylene Sheeting Material Calculator

Embankment Area (A_E)	
$A_E = \left(\frac{L_C + L_T}{2}\right) \times L_s$	
Embankment Input	
Embankment Crest Length (L_C):	______ ft
Embankment Toe Length (L_T):	______ ft
Slope Length (L_s):	______ ft
Output	
Embankment Area (A_E):	______ ft²
Crest Area (A_C)	
$A_C = L \times W$	
Input	
Embankment Crest Length (L):	______ ft
Embankment Crest Width (W):	______ ft
Output	
Crest Area (A_C):	______ ft²
Material Total	
$T = A_E + A_C$	
Total Amount of Material (T):	______ ft²

Note: Slope Length from Length of Upstream or Downstream Slope Calculator on page 9.

Sandbag Techniques (Online Video)

Flood Fighting: How to Use Sandbags

It is important that polyethylene sheeting placed on dam slopes be held down along the slopes as well. An effective method of anchoring polyethylene sheeting is a grid system of sandbags using two bags tied with rope and the rope saddled over the dam crown with a bag on each slope.

In many situations during high water, polyethylene sheeting and sandbags placed in the wet must provide the emergency protection. Wet placement may also be required to replace or maintain damaged polyethylene sheeting or polyethylene sheeting displaced by current action. Sandbag anchors are formed at the bottom edge and ends of the polyethylene sheeting by bunching the polyethylene sheeting around a fistful of sand or rock, and tying the sandbags to this fist-sized ball. Counterweights consisting of two or more sandbags connected by a length of ¼-inch rope are used to hold the center portion of the polyethylene sheeting down. The number of counterweights will depend on the uniformity of the dam slope and current velocity. Placement of the polyethylene sheeting consists of first casting out the polyethylene sheeting with the bottom weights and then adding counterweights to slowly sink the polyethylene sheeting into place. The polyethylene sheeting, in most cases, will continue to move down slope until the bottom edge reaches the toe of the slope. Sufficient counterweights should be added to ensure that no air voids exist between the polyethylene sheeting and the dam face and to keep the polyethylene sheeting from flapping or being carried away in the current. For this reason, it is important to have enough counterweights prepared prior to the placement of the sheet.

4.8 Constructing a Bypass Channel

Caution

Digging a bypass channel around the dam through an abutment can both relieve the hydrostatic pressure building up behind the dam and prevent overtopping of the structure. The location for a bypass channel should be chosen with extreme caution so that the embankment will not be affected by rapid erosion of the channel. Excavation of natural soil or stone, rather than part of the structure itself, is ideal. Construction of the bypass channel should begin from the downstream end, leaving an obstruction on the upstream end. Prior to activation of the channel, the entire channel should be cleared of any large vegetation or obstructions. Anything that could cause an irregularity in the flow offers the potential for destructive erosion of the embankment. After being cleared, the channel should be uniformly lined with fabric, sandbags, stone, or another erosion resistant material. Once it is fully constructed, the upstream end of the channel should gradually be breached, releasing water from the reservoir (**Figure 18**). Supplies of stone, sandbags, and other materials should be stockpiled at the site in order to slow the flow if potentially hazardous erosion is noticed.

Caution

Because of the volatility of this action, precautions for a variety of scenarios should be taken beforehand. Emergency intervention by this action should not be undertaken without approval from state dam safety personnel. In addition, the work should be performed under the supervision of an experienced professional engineer. If applicable, downstream areas should be prepared for evacuation.

Figure 18: *Bypass Channel Constructed around Cofferdam to Prevent Overtopping of Erodible Structure*

Source: John Foster, Texas State Soil and Water Conservation Board

4.9 Constructing Ring Dikes

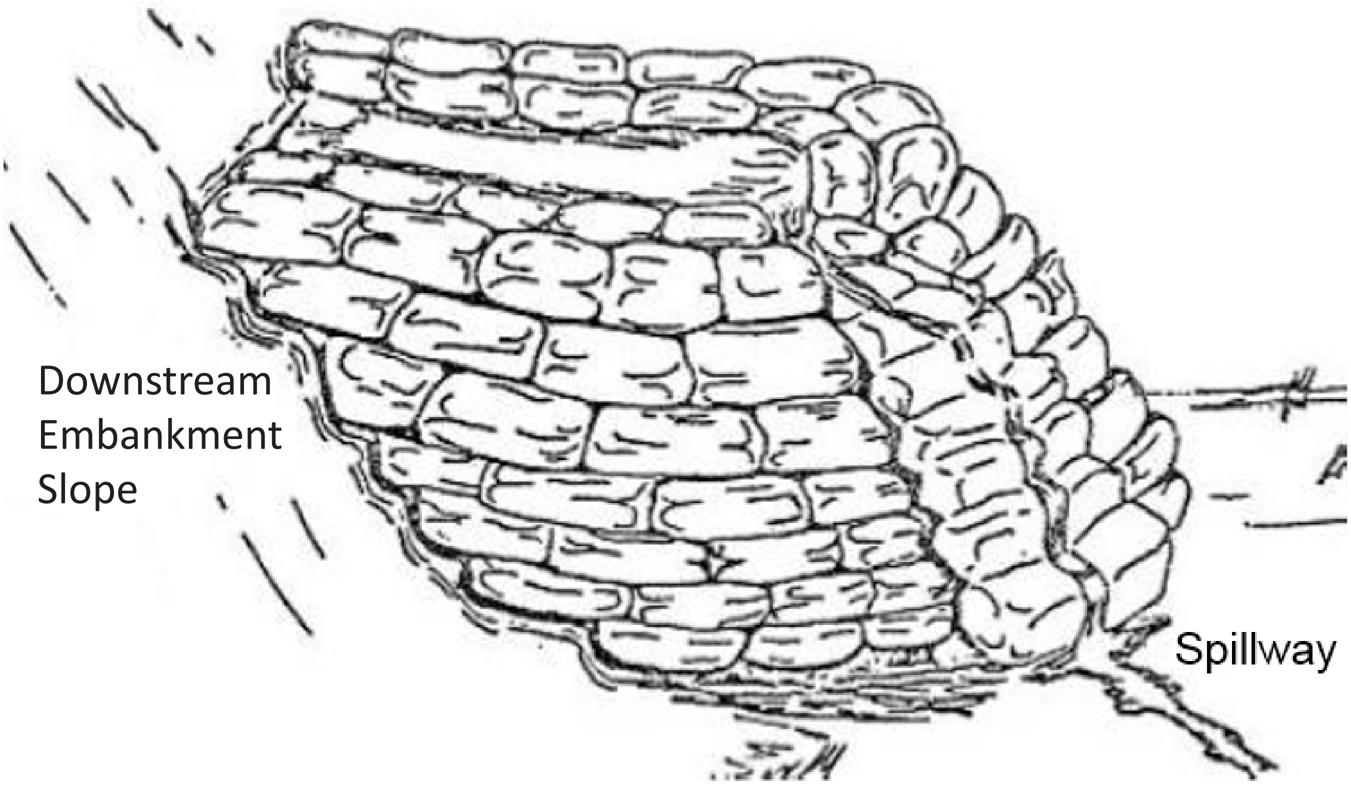
Ring levees are useful in creating a hydraulic back pressure to resist seepage flow, especially where the seepage is concentrated at a boil. Ring levees are most often constructed with sandbags (see Sandbag filling techniques in Section 4.6). However, concrete well rings, short pieces of large diameter pipe, earth berms, and sheet piling can also be used to encircle a boil. Regardless of construction material, a ring dike should not be built too high or it can develop new boils outside of the affected area. The primary objective is to prevent the loss of embankment material with the seepage. The purpose of the ring dike is to raise a head of water over the boil to counterbalance the upward pressure of the seepage flow. The height of the water column is adjusted so that the water exiting the boil runs clear and no longer removes soil from the dam foundation. It is important that the flow of water is not stopped completely, as this may cause additional boils to break out nearby. Treated areas should be kept under constant surveillance until the water recedes.

Caution

The diameter and height of a ring dike will depend on the actual conditions at each boil. The base width should be at least 1½ times the contemplated height, and the inner ring of sandbags should begin between one and three feet from the outer edge of the boil. "Weak" or "quick" ground near a boil should be included within the sack ring to prevent these areas from developing into new boils when the active boil is treated. Where several boils develop in a localized area, a ring dam of sandbags should be constructed around the entire area. The ring should ideally be of sufficient diameter to permit sacking operations to keep ahead of the flow of water. When a boil is located near the toe of a dam, the sandbag ring should be tied into the downstream slope of the dam, as shown in **Figures 19** and **20**.

Approval Standard for Flood Abatement Equipment, FM Standard 2510.

Figure 19: *Sketch of Sandbag Ring Levee Tied to the Downstream Slope of the Dam*



Source: USACE. *Levee Owner's Manual for Non-Federal Flood Control Works* (2006).

Figure 20: *Sandbag Ring Levee around a Boil at the Downstream Toe of an Embankment Dam*

The base or foundation for the sandbag ring should be cleared of debris and scarified to provide a reasonably watertight bond between the ground surface and the sandbags. The ring should be constructed with sacks filled approximately two-thirds (2/3) full of sand, and tamped firmly into place. Do not tie the ends of the sacks. When adding subsequent layers, the joints should be staggered for stability and water tightness. Each successive level should bring the outer layer in, while keeping the interior face straight. The untied ends of sandbags should be laid towards the inside of the ring and folded under.

A spillway or exit channel should be constructed on the top of the sack ring so that the level of the water in the ring dam can be adjusted, and the overflow water can be carried a safe distance from the boil, away from the direction of the dam. Because the height of the water is the critical factor in adjusting the rate of flow through the boil, the spillway will require constant monitoring and adjustment once the sandbag ring dam is filled with water. This spillway is normally constructed of sandbags, but alternately, a V-shaped drain can be constructed of two boards (**Figures 21** and **22**); or PVC pipe, plastic sheeting, or other materials may be helpful in building the spillway.

An alternate method of ringing boils is by use of corrugated sheet-steel piling, as shown in **Figure 23**. The area is cleared of debris, and the piling is driven about 1½ feet into the ground around the boil. This method accomplishes the same task faster than sandbagging, but is limited in use by the availability of material, equipment, and the location and foundation condition of boils. Expedient methods can be improvised in other ways, to include using sections of corrugated metal piping. Special care must be taken with the design of these structures to make sure there is a reliable means for adjusting the water level, so the water column doesn't completely stop the flow of water through the boil.

Sandbag Techniques (Online Video)

Sandbagging Techniques (Document and Presentation)

Flood Fighting: How to Use Sandbags

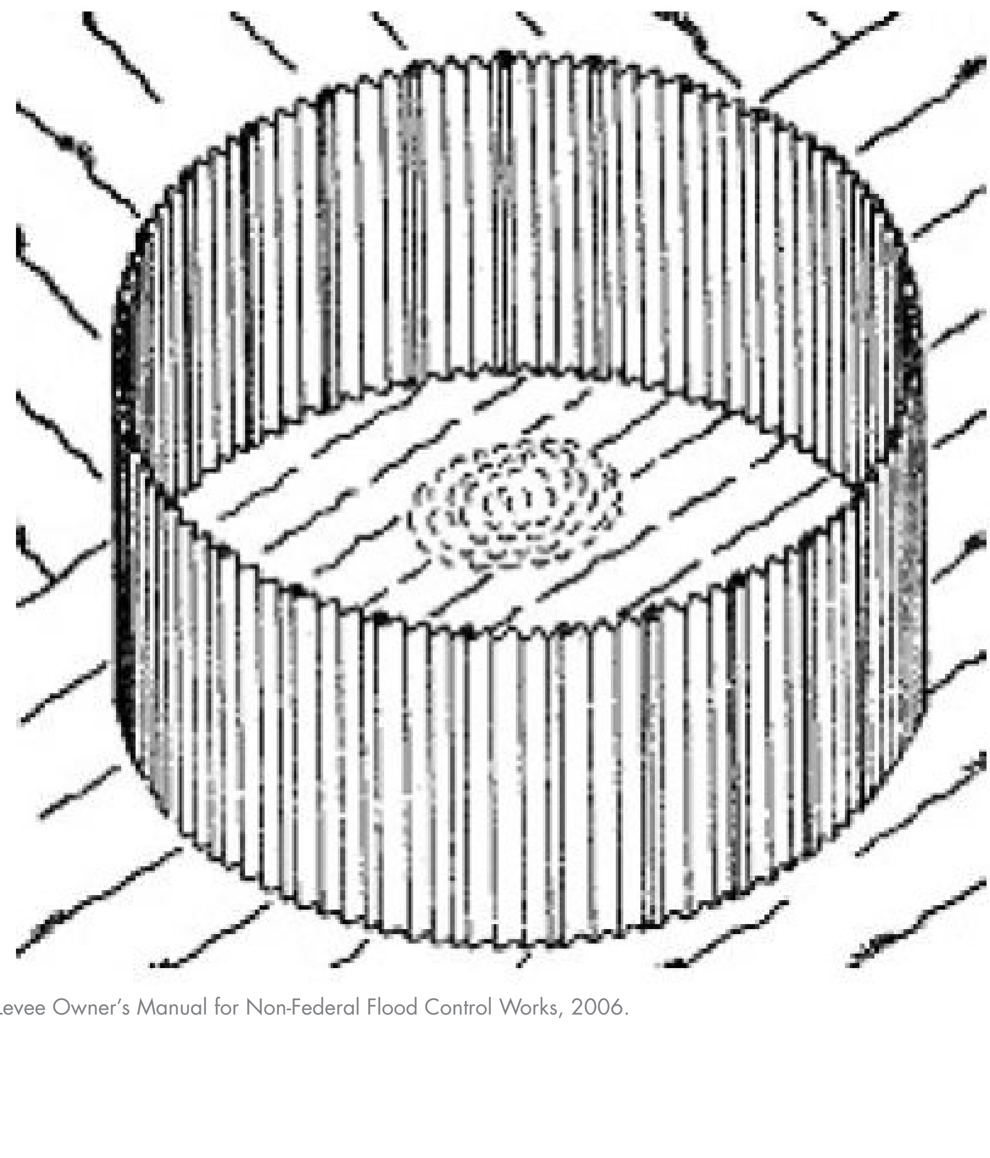
Caution

Figure 21: *Sketch of a Typical Sandbag Ring Levee with Spillway*

Source: USACE, Levee Owner's Manual for Non-Federal Flood Control Works (2006).

Figure 22: *Photo of Sandbag Levee with V-notch Weir Outlet to Monitor Changes in Seepage*

Figure 23: *Illustration of a Ring of Corrugated Sheet Steel Piling to Encircle a Boil*



Source: USACE, Levee Owner's Manual for Non-Federal Flood Control Works, 2006.

4.10 Installing a Filter Blanket

The purpose of a filter is to arrest the dam material being carried away from the embankment by seepage and prevent a piping failure. A filter blanket should only be constructed if the site is safe and accessible.

A filter blanket is traditionally constructed by placing a layer of fine filter material (concrete sand) over a seepage exit and overlaying that with a coarse drainage material. Coarse fill materials such as riprap or sandbags are most often used to construct the filter blanket. It is important to note that if the rate of flow through the exit is too high or concentrated, fine filter material may be swept away with the seepage. In this case, it may be beneficial to construct an inverted filter blanket in which coarse drainage material is placed over the exit prior to the placement of fine filter material in order to reduce high uplift pressures in the compromised section of the embankment. Similarly, a geotextile can be substituted as the filter material, however, they are less desirable as they may clog over time. Additional information on filters for embankment dams is included in FEMA's best practices for design and construction manual, Filters for Embankment Dams. Examples of a filter blanket constructed on the downstream slope of a dam are presented in **Figure 24**. A photograph of the construction of a filtered drainage berm constructed at the toe of an embankment dam is presented in **Figure 25**.

Caution

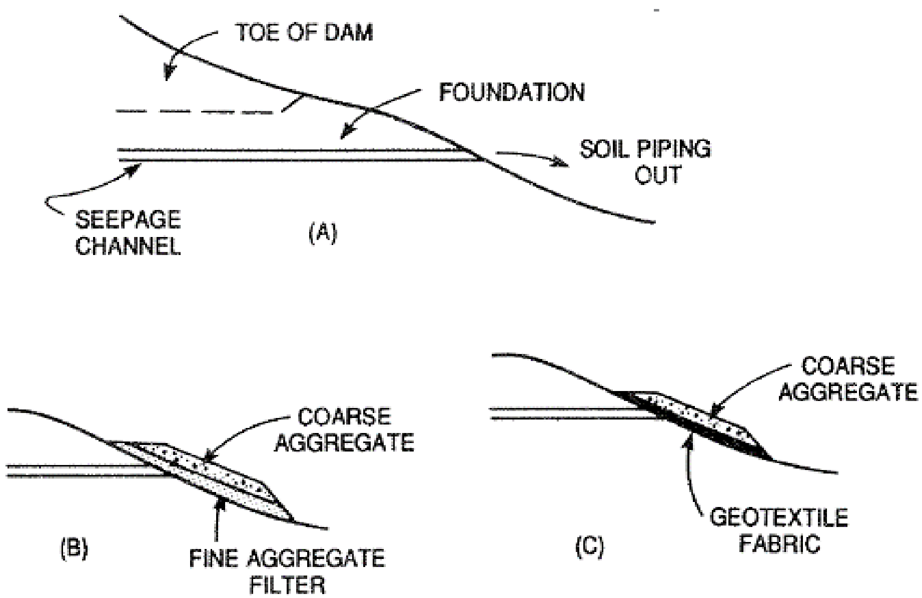
Filters for Embankment Dams: Best Practices for Design and Construction

National Engineering Handbook, Gradation Design of Sand and Gravel Filters

National Engineering Handbook, Filter Diaphragms

Filter Design and Construction Considerations

Figure 24: *Emergency Filter Installation to Temporarily Control Seepage on the Downstream Slope of an Embankment Dam*



KEY

(A) Conditions requiring remedial measures (example)

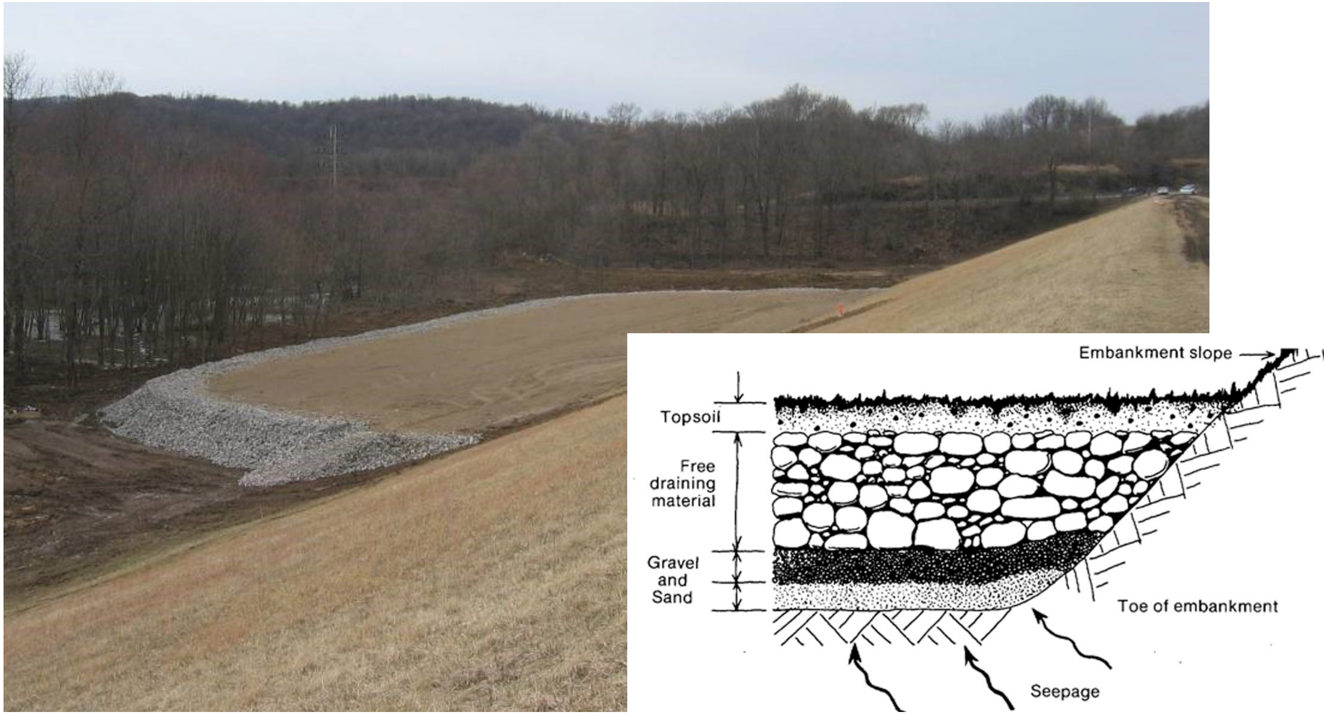
(B) Use of fine filter aggregate and coarse aggregate to control low flow seepage.

(C) Use of geotextile and coarse aggregate.

Source: USBR, Training Aids for Dam Safety: Evaluation of Seepage Conditions (1990).

Note: The document has been superceded, however, the diagram is still accurate.

Figure 25: *Example of a Filtered Drainage Berm Constructed at Toe of an Embankment Dam During Emergency*



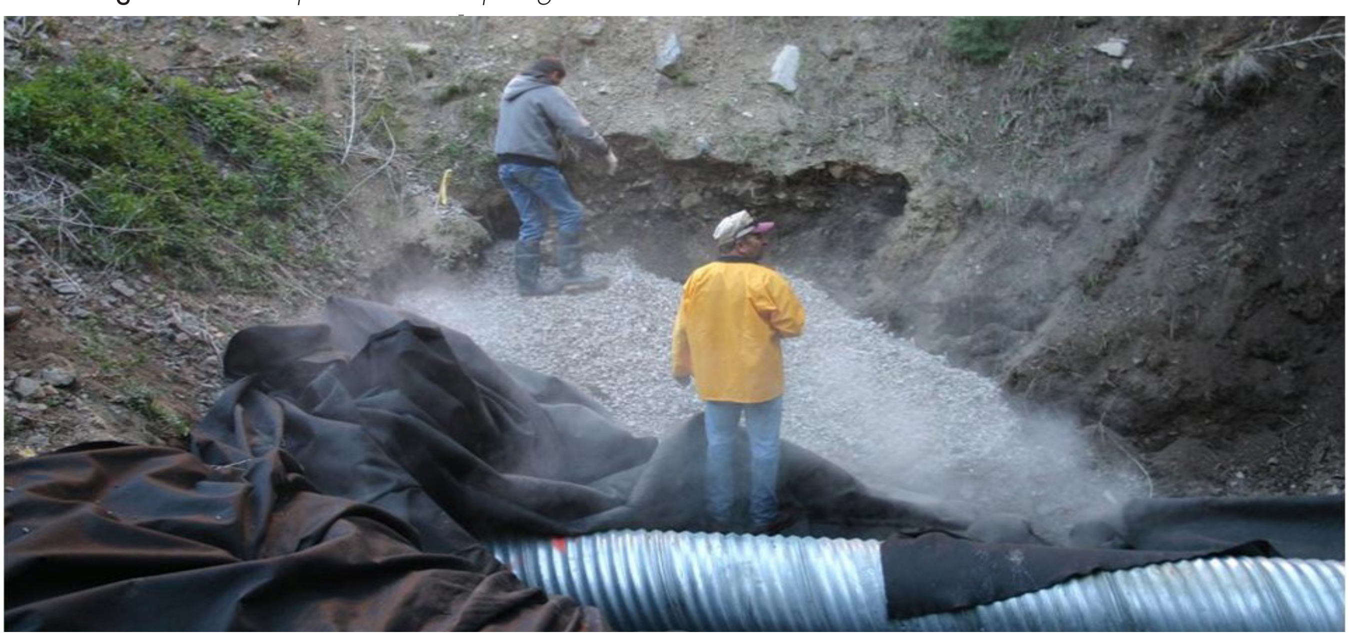
Source: Mia Kannick, Ohio Department of Natural Resources and Dam Safety

Geotextiles in Embankment Dams: Status Report on the Use of Geotextiles in Embankment Dam Construction and Rehabilitation

Technical Manual: Conduits through Embankment Dams

When signs of seepage and piping along the conduit are observed, a filter blanket should be installed around the conduit after it is extended. When a filter blanket is constructed around a conduit, it is known as a filter diaphragm. Filter diaphragms are constructed using the same process described above. An example of a filter diaphragm being constructed around a conduit using commonly available quarry and concrete plant aggregate materials is illustrated in **Figure 26**.

Figure 26: *Example of Filter Diaphragm Construction around a Conduit in an Embankment Dam*



Source: Dr. Debora Miller, Senior Geotechnical Engineer

4.11 Plugging Sinkholes

If a sinkhole is observed in the upstream slope of the dam embankment that includes seepage flow, an attempt can be made to stop or control the seepage by plugging the entrance with riprap, sandbags, plastic sheeting, or other available coarse fill materials. Based on the dimensions of the affected area, the Fill Volume Calculator will estimate the approximate amount of material needed to intervene. If the plug attempt decreases the flow, progressively smaller material such as gravel, sand, etc. can be added. If the sinkhole is narrow and due to a defect like an animal burrow, it may be possible to plug the hole by gradually placing a mixture of soil and straw or dry hay into the water at the entrance. An example of a sinkhole along the upstream slope of an embankment dam before and after emergency intervention is presented in the photographs in **Figure 27**. Efforts should be made to locate the exit point downstream and attempt to construct a ring dike or filter berm to retard the removal of material.

Fill Volume Calculator	
V = L x W x H	
Input	
Length (L):	______ ft
Width (W):	______ ft
Height (H):	______ ft
Output	
Volume (V) =	______ ft^3

Figure 27: *Sinkhole in Upstream Slope of Dam at Waterline (left); Temporary Repaired Sinkhole with Gravel, Geotextile and Sandbags (right)*

4.12 Diverting, Preventing, or Limiting Damaging Flow within the Auxiliary Spillway

In the event that a portion of the auxiliary spillway is determined to be susceptible to erosion during flow conveyance, diverting the damaging flow around the area of interest within the spillway may be attempted. If only one section of the spillway is in danger of eroding and the remainder of the spillway area is more capable of safely passing storm flow, sandbags or plastic sheeting may be strategically placed to prevent activation and subsequent erosion of weaker section (**See Section 4.7**). Sandbags, riprap, rock-filled gabions and other methods can be used to divert the damaging flow to more erosion resistant areas of the spillway. The Fill Volume Calculator can be used to determine the volume of material necessary for protection based on the desired dimensions of the berm, fuse plug, or blockade. When attempting to divert flows within a spillway exit channel, caution is required to make sure that the diversion works do not restrict the flow in the spillway to the point

Flood Fighting: How to Use Sandbags

Sandbag Techniques (Online Video)

Approval Standard for Flood Abatement Equipment, FM Standard 2510.

Sandbagging Techniques (Document and Presentation)

Caution

of causing the embankment to overtop. Examples of the use of sandbags, rock filled gabions, and geotextiles to divert flows in eroding auxiliary spillways are presented in **Figure 28**.

If the entirety of the auxiliary spillway is constructed of erodible materials, techniques outlined in **Sections 4.6** and **4.7** can be implemented. In addition to raising the crest of the spillway using sandbags or armoring the spillway with riprap or polyethylene sheeting, spillway activation can be delayed or prevented by installing a fuse plug across the entire width of the approach. A fuse plug is comprised of a low embankment or natural saddle designed to provide additional temporary storage during a large storm (**Figure 29**). Constructed most commonly from homogeneous or zoned material, fuse plugs are susceptible to erosion and breaching. Therefore, it is advised that fuse plug construction be considered a technique for delaying imminent failure and the evacuation of downstream communities be performed simultaneously.

Figure 28: *Photographs showing examples of the use of sandbags and rock filled gabions to divert flows in eroding auxiliary spillways.*

Source: North Dakota State Water Commission

Figure 29: *Construction of Temporary Fuse Plug across the Auxiliary Spillway Crest of Renwick Dam*

Source: Dennis Reep, Water Resources Engineer

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Appendix A

Glossary of Terms

Glossary of Terms

Adapted from FEMA's Federal Guidelines for Dam Safety: Glossary of Terms

Abutment. The undisturbed natural material of the valley side against which the dam is constructed. The left and right abutments are defined as being on the left and right side of an observer looking downstream.

Acre-Foot. A term used in measuring the volume of water that would cover one acre to a depth of one foot. It is equal to 43,560 cubic feet.

Air-Vent Pipe. A pipe designed to provide air to the outlet conduit to reduce turbulence during release of water. Extra air is usually necessary downstream on constrictions.

Appurtenant Structure. A structure necessary for the operation of a dam such as outlets, trashracks, valves, spillways, power plants, tunnels, etc.

Auxiliary Spillway. See Spillway

Base Width (Base Thickness). The maximum width or thickness of a dam measured horizontally between upstream and downstream faces and normal (perpendicular) to the axis of the dam but excluding projections for outlets, etc.

Berm. A horizontal step or bench in the sloping profile of an embankment dam.

Breach. An eroded opening through a dam that drains the reservoir. A controlled breach is a constructed opening. An uncontrolled breach is an unintentional opening that allows uncontrolled discharge from the reservoir.

Buttress Dam. A dam consisting of a watertight upstream face supported at intervals on the downstream side by a series of buttresses.

Channel. A general term for any natural or artificial watercourse.

Conduit. A closed channel to convey water through, around, or under a dam.

Construction Joint. The interface between two successive placings or pours of concrete where a bond, not permanent separation, is intended.

Core Wall. A wall built of impervious material, usually concrete or asphaltic concrete, in the body of an embankment dam to prevent leakage.

Crest of Dam. See top of dam.

Crest Length. The length of the top of a dam, including the length of the spillway, powerhouse, navigation lock, fish pass, etc., where these structures form part of the length of the dam. If detached from a dam, these structures should not be included.

Cross-section. A sectional view of a dam formed by passing a plane through the dam perpendicular to the axis.

Cutoff Wall. A wall of impervious material (e.g., concrete, asphaltic concrete, steel-sheet piling) built into the foundation to reduce seepage under the dam

Dam. A barrier constructed across a watercourse for the purpose of impounding or diverting water.

a. **Embankment Dam.** Any dam constructed of excavated natural materials or of industrial waste materials.

Dam Failure. The uncontrolled release of reservoir contents.

Design Flood. See Spillway Design Flood.

Diversion Channel, Canal, or Tunnel. A waterway used to divert water from its natural course. These terms are generally applied to temporary structures such as those designed to bypass water around a dam site during construction. "Channel" is normally used instead of "canal" when the waterway is short. Occasionally these terms are applied to permanent structures.

Drain, toe. A system of pipe and/or pervious material along the downstream toe of a dam used to collect seepage from the foundation and embankment and convey it to a free outlet.

Drainage Area. The area that drains to a particular point on a river or stream.

Drawdown. The difference between a water level and a lower water level in a reservoir within a particular time. Used as a verb, it is the lowering of the water surface due to release of water from the reservoir.

EAP Operations. All actions taken by the state dam safety programs and other involved agencies to address an unusual or emergency event.

Earthen Dam or Earthfill Dam. See Dam, Embankment.

Earthquake. A sudden motion or trembling in the earth caused by the abrupt release of accumulated stress along a fault.

Emergency Action Plan (EAP). A comprehensive, single-source document providing accurate and current instructions intended to help dam owners/operators save lives, minimize property damage, and minimize environmental impacts caused by large releases from a dam, dam failure, or other events that present hazardous conditions.

Emergency Event. An event which takes place or a condition which develops that is of a serious nature that may endanger the dam, or endanger persons or property, and demands immediate attention.

Emergency Spillway. See Spillway.

Face. The external surface of a structure, e.g., the surface of a wall of a dam.

Filter (filter zone). A band of granular material graded (either naturally or by selection) so as to allow seepage through or within the layers while preventing the migration of material from adjacent zones.

Flashboards. A length of timber, concrete, or steel placed on the crest of a spillway to raise the retention water level but that may be quickly removed in the event of a flood, either by a tripping device or by deliberately designed failure of the flashboard or its supports.

Flood. A temporary rise in water levels resulting in inundation of areas not normally covered by water. May be expressed in terms of probability of exceedance per year such as one percent chance flood or expressed as a fraction of the probable maximum flood of other reference flood. Some related terms are:

a. **Flood, Inflow Design (IDF).** That flood used in the design of a safe dam and its appurtenant works particularly for sizing the spillway and outlet works, and for determining maximum temporary storage and height of dam requirements.

b. **Flood, Probable Maximum (PMF).** The largest flood reasonably expected at a point on a stream because of a probable maximum storm and favorable runoff conditions.

Floodplain. An area adjoining a body of water or natural stream that has been, or may be, covered by flood water.

Flood Routing. The determination of the attenuating effect of storage on a flood passing through a valley, channel, or reservoir.

Foundation of Dam. The natural material on which the dam structure is placed.

Freeboard. Vertical distance between a stated water level and the top of dam.

Gallery. A passageway within the body of a dam or abutment.

Gate. A device in which a leaf or member is moved across the waterway from an external position to control or stop the flow.

a. **Bulkhead Gate.** A gate used either for temporary closure of a channel or conduit to empty it for inspection or maintenance or for closure against flowing water when the head difference is small, e.g., for diversion tunnel closure.

b. **Crest Gate (Spillway Gate).** A gate on the crest of a spillway to control overflow or reservoir water level.

c. **Emergency Gate.** A standby or reserve gate used only when the normal means of water control is not available.

d. **Flap Gate.** A gate hinged along one edge, usually either the top or bottom edge.

e. **Flood Gate.** A gate to control flood release from a reservoir

f. **Outlet Gate.** A gate controlling the flow of water through a reservoir outlet.

g. **Regulating Gate (Regulating Valve).** A gate or valve that operates under full pressure and flow to throttle and vary the rate of discharge.

h. **Slide Gate (Sluice Gate).** A gate that can be opened or closed by sliding in supporting guides.

Gravity Dam. A dam constructed of concrete, masonry, or both that relies on its weight for stability.

Groin. The contact at the surface between the dam and adjacent natural ground.

Height, Hydraulic. The vertical difference between the maximum flood control pool (no surcharge) and the lowest point along the downstream toe.

Height, Structural. The vertical difference between the top of the dam and the lowest point of contact with the foundation.

Hydrograph, Breach or Dam Failure. A flood hydrograph resulting from a dam breach.

Hydrograph, Flood. A graphical representation of the flood discharge with respect to time for a particular point on a stream or river.

Hydrograph, Unit. A hydrograph with a volume of one inch of runoff resulting from a storm of a specified duration and areal distribution. Hydrographs from other storms of the same duration and distribution are assumed to have the same time base but with ordinates of flow in proportion to the runoff volumes.

Inclinometer. An instrument, usually consisting of a metal or plastic tube inserted in a drill hole and a sensitized monitor either lowered into the tube or fixed within it. The monitor measures at different points the tube's inclination to the vertical. By integration, the lateral position at different levels of the tube may be found relative to a point, usually the top or bottom of the tube, assumed to be fixed. The system may be used to measure settlement.

Instrumentation. An arrangement of devices installed into or near dams (i.e., piezometer, inclinometer, strain gage, survey points, etc.) that provide measurements that can be used to evaluate performance parameters of a structure.

Intake. Any structure in a reservoir, dam or river for the purpose of directing water into a conduit, tunnel, canal or pipeline.

Inundation Map. A map delineating the area that would be submerged by a particular flood event.

Leakage. Uncontrolled loss of water by flow through a hole or crack.

Length of Dam. The length along the top of the dam between contact abutments. This also includes the spillway, power plants, navigation lock, fish pass, etc., where these form part of the length of the dam. If detached from the dam, these structures should not be included.

Masonry Dam. A dam constructed mainly of stone, brick, or concrete blocks that may or may not be joined with mortar. A dam having only a masonry facing should not be referred to as masonry dam.

Outlet. An opening through which water can be discharged.

Parapet Wall. A wall built along the top of a dam (upstream or downstream edge) used for safety of vehicles and pedestrians, to prevent overtopping caused by wave runup, or ornamentation.

Peak Flow. The maximum instantaneous discharge that occurs during a flood. It coincides with the peak of a flood hydrograph.

Pervious Zone. A part of the cross-section of an embankment dam comprising material of high permeability.

Phreatic Surface. The free surface of water seeping at atmospheric pressure through soil or rock.

Piezometer. An instrument for measuring pore water pressure within soil, rock, or concrete.

Piping. The progressive development of internal erosion by seepage appearing downstream as a hole or seam discharging water containing soil particles.

Probability. The likelihood of an event occurring within a given period of time.

Probable Maximum Precipitation (PMP). Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location.

Relief Wells. A line of vertical wells or boreholes to facilitate drainage of the foundation and abutments and to reduce water pressure.

Reservoir. A body of water impounded by a dam and in which water can be stored.

Reservoir Surface Area. The area covered by a reservoir when filled to a specified level.

Riprap. A layer of stone, precast blocks, bags of cement or other suitable material, generally placed on the upstream slopes of an embankment or along a watercourse as protection against wave action, erosion, or scour. It consists of pieces of relatively large size as distinguished from a gravel blanket.

Seepage. Flow or movement of water through a dam, its foundation, or its abutments.

Slope. Inclination from the horizontal, measured as the ratio of horizontal units to corresponding vertical units.

Slope Protection. The protection of a slope against wave action or erosion.

Spillway. A structure over or through which flow is discharged from a reservoir. If the rate of flow is controlled by mechanical means such as gates, it is considered a controlled spillway. If the elevation of the spillway crest is the only control, it is considered an uncontrolled spillway.

a. **Auxiliary Spillway (Emergency Spillway).** A secondary spillway designed to operate only during exceptionally large floods.

b. **Fuse Plug Spillway.** An auxiliary or emergency spillway comprising a low embankment or natural saddle designed to be overtopped and eroded away during a very rare and exceptionally large flood.

c. **Service Spillway (Principal Spillway).** The principal or first-used spillway during flood flows.

Spillway Channel. An open channel or closed conduit conveying water from the spillway inlet downstream.

Spillway Crest. The lowest level at which water can flow over or through the spillway.

Spillway, Chute. An inclined channel, usually separate from the dam, to convey reservoir overflow into the natural channel below the dam or into an adjacent natural drainage channel.

Stilling Basin. A basin constructed to dissipate the energy of fast-flowing water, e.g., from a spillway or bottom outlet, and to protect the riverbed from erosion.

Stoplogs. Timbers or steel beams placed on top of each other with their ends held in guides on each side of a channel or conduit so as to provide a cheaper or more easily handled means of temporary closure than a bulkhead gate.

Storage. The retention of water or delay of runoff either by planned operation, as in a reservoir, or by temporary filling of overflow areas, as in the progression of a flood wave through a natural stream channel. Definitions of specific types of storage in reservoirs are:

a. **Dead Storage.** The reservoir volume between the invert of the lowest intake and the reservoir bottom.

b. **Active Storage.** The reservoir volume between the normal reservoir water surface elevation and the invert of the lowest intake.

c. **Flood Storage.** The reservoir volume between the crest of the dam and the normal reservoir water surface elevation.

Toe of Dam. The junction of the downstream face of a dam with the ground surface, referred to as the downstream toe. For an embankment dam the junction of upstream face with ground surface is called the upstream toe.

Top of Dam. The elevation of the uppermost surface of a dam, usually a road or walkway, excluding any parapet wall, railings, etc.

Trashrack. A screen located at an intake to prevent the ingress of debris.

Unusual Event. An event which takes place, or a condition which develops, that is not normally encountered in the routine operation of the dam and reservoir, or necessitates a variation from the operating procedures.

Uplift. The upward pressure in the pores of a material (interstitial pressure) or on the base of a structure.

Valve. A device fitted to a pipeline or orifice in which the closure member is either rotated or moved transversely or longitudinally in the waterway so as to control or stop the flow

Appendix B

Measurement Unit Conversions

Units and Conversions Calculator

A) Length Measurement Conversions

Conversion	Input	Output	Formula
inches (in) to feet (ft)	________ in	= ________ ft	1 in = (1/12) ft
ft to in	________ ft	= ________ in	1 ft = 12 in
ft to yards (yd)	________ ft	= ________ yd	1 ft = (1/3) yd
yd to ft	________ yd	= ________ ft	1 yd = 3 ft
yd to mile (mi)	________ yd	= ________ mi	1 yd = (1/1,760) mi
mi to yd	________ mi	= ________ yd	1 mi = 1,760 yd

B) Area Measurement Conversions

Conversion	Input	Output	Formula
ft^2 to yd^2	________ ft^2	= ________ yd^2	1 ft^2 = (1/9) yd^2
yd^2 to ft^2	________ yd^2	= ________ ft^2	1 yd^2 = 9 ft^2
yd^2 to acre	________ yd^2	= ________ acre	1 yd^2 = (1/4840) acre
acre to yd^2	________ acre	= ________ yd^2	1 acre = 4840 yd^2
acre to mi^2	________ acre	= ________ mi^2	1 acre = (1/640) mi^2
mi^2 to acre	________ mi^2	= ________ acre	1 mi^2 = 640 acre

C) Volume Measurement Conversions

Conversion	Input	Output	Formula
gallon (gal) to ft^3	________ gal	= ________ ft^3	1 gal = (1/7.48) ft^3
ft^3 to gal	________ ft^3	= ________ gal	1 ft^3 = 7.48 gal
ft^3 to yd^3	________ ft^3	= ________ yd^3	1 ft^3 = (1/27) yd^3
yd^3 to ft^3	________ yd^3	= ________ ft^3	1 yd^3 = 27 ft^3
yd^3 to acre-ft	________ yd^3	= ________ acre-ft	1 yd^3 = (1/1,613.33) acre-ft
acre-ft to yd^3	________ acre-ft	= ________ yd^3	1 acre-ft = 1,613.33 yd^3

Units and Conversions Calculator (Continued)

D) Discharge Rate Conversions

Conversion	Input	Output	Formula
ft^3/s to ft^3/min	_________ ft^3/s	= _________ ft^3/min	1 ft^3/s = (1/60) ft^3/min
ft^3/min to ft^3/s	_________ ft^3/min	= _________ ft^3/s	1 ft^3/min = 60 ft^3/s
ft^3/min to ft^3/hr	_________ ft^3/min	= _________ ft^3/hr	1 ft^3/min = (1/60) ft^3/hr
ft^3/hr to ft^3/min	_________ ft^3/hr	= _________ ft^3/min	1 ft^3/hr = 60 ft^3/min
ft^3/hr to ft^3/day	_________ ft^3/hr	= _________ ft^3/day	1 ft^3/hr = (1/24) ft^3/day
ft^3/day to ft^3/hr	_________ ft^3/day	= _________ ft^3/hr	1 ft^3/day = 24 ft^3/hr
gal/min to ft^3/s	_________ gal/min	= _________ ft^3/s	1 gal/min = (1/448.83) ft^3/s
ft^3/s to gal/min	_________ ft^3/min	= _________ gal/min	1 ft^3/s = 448.83 gal/min
gal/s to gal/min	_________ gal/s	= _________ gal/min	1 gal/s = (1/60) gal/min
gal/min to gal/s	_________ gal/min	= _________ gal/s	1 gal/min = 60 gal/s
gal/min to gal/hr	_________ gal/min	= _________ gal/hr	1 gal/min = (1/60) gal/hr
gal/hr to gal/min	_________ gal/hr	= _________ gal/min	1 gal/hr = 60 gal/min
gal/hr to gal/day	_________ gal/hr	= _________ gal/day	1 gal/hr = (1/24) gal/day
gal/day to gal/hr	_________ gal/day	= _________ gal/hr	1 gal/day = 24 gal/hr
gal/day to million (mil) gal/day	_________ gal/day	= _________ mil gal/day	1 gal/day = (1/1,000,000) mil gal/day
mil gal/day to gal/day	_________ mil gal/day	= _________ gal/day	1 mil gal/day = 1,000,000 gal/day

Appendix C

Forms

Form 1: *Summary of Key Dam Characteristics*

Dam Name:	NID ID:
Dam Owner:	Dam Operator:
County:	
Latitude:	Longitude:
Contributing Stream:	
Reservoir Drainage Area:	mi²
Normal Pool Elevation:	ft
Normal Pool Volume:	acre-ft
Top of Dam Elevation:	ft
Dam Height:	ft
Embankment Crest Length:	ft
Embankment Toe Length:	ft
Dam Crest Width:	ft
Dam Base Width:	ft
Upstream Slope: ______ ft H: ______ ft V = ______ ft H: 1ft V	
Upstream Slope Length:	ft
Downstream Slope: ______ ft H: ______ ft V = ______ ft H: 1ft V	
Downstream Slope Length:	ft
Principal Spillway Type:	
Principal Spillway Crest Elevation:	ft
Principal Spillway Capacity:	cfs
Auxiliary Spillway Type:	
Auxiliary Spillway Crest Elevation:	ft
Auxiliary Spillway Crest Length:	ft
Auxiliary Spillway Capacity:	cfs
Low-Level Outlet Conduit Type:	
Low-Level Outlet Invert Elevation:	ft
Low-Level Outlet Diameter:	ft
Low-Level Outlet Capacity:	cfs

Slope Length Calculator

$$L = \left(H^2 + \left(\frac{H}{\left(\frac{1}{S}\right)}\right)^2\right)^{0.5}$$

Upstream Slope Input

Horizontal Component of Upstream Slope (S_u):	______ ft H:1ft V
Dam Height (H):	______ ft

Output

Length (L_u):	______ ft

Downstream Slope Input

Horizontal Component of Downstream Slope (S_d):	______ ft H:1ft V
Dam Height (H):	______ ft

Output

Length (L_d):	______ ft

Assume: Embankment slope is constant throughout length.

Note: Output is calculated from the Pythagorean Theorem [$c^2 = a^2 + b^2$] in conjunction with the slope equation [$m = y/x$].

Form 2: *Dam Access Details*

Latitude:	
Longitude:	
Access Road Culmination (i.e. Embankment Toe, Dam Crest, etc…):	
Directions to Access Road (from nearest major roadway):	
Access Road Condition:	
Number of Access Gates/Locks:	
Lock Location	**Lock Combination or Key Location/Contact**

** Complete form for each access road or entryway*

Form 3: *Basic Historical Dam Construction, Operation, and Maintenance*

Year Designed:	Year Constructed:
Primary Purpose:	Secondary Purpose(s):
Original Hazard Classification:	
Current Hazard Classification:	
Frequency of Inspection:	Emergency Action Plan Available (Y/N):
Summary of Rehabilitation:	Year: _________
Summary of Engineering Study Performed:	Year: _________

Note: Form can be extended as necessary to provide more dam history information.

Form 4: *Emergency Intervention Materials and Providers*

Supplies*	Location	Contact	Comments
Fire Extinguishers			Safety precaution
Flashlights			Recommend to be stored on-site for immediate response
Sandbags			Recommend an adequate supply be stored nearby and identify outside contacts
Sand			Consider stockpiling nearby; used to create sandbags and construct filters
Gravel			Used to construct filtered drainage berms and maintain access roads
Clay/Soil Fill			Identify possible clay and soil borrow areas that can be safely accessed
Riprap/Rock Fill			Consider stockpiling nearby due to broad usage; identify outside contacts
Concrete/Grout			Concrete structure repair; identify outside contacts
Plastic Sheeting			6 mil polyethylene sheeting recommended for flood fighting applications
Geotextile			Preferably non-clogging and woven
Caulk			Recommend flexible sealant be stored nearby for concrete structure repair
Shovels			Recommend to be stored nearby for immediate response
Buckets			Recommend to be stored nearby for immediate response
Rope			Broad usage
Extension Cords			Power to equipment

* ***When filling out information for the material providers, it is important to consult the 'Cautions, Consideration, and Initiation of Intervention' section of the following chapter as not all types of material used for emergency dam intervention are eligible for grant or loan reimbursement.***

Form 5: *Emergency Intervention Equipment and Providers*

Supplies	Location	Contact	Comments
Communication System			Two-way radios are preferred due to reliability and multiple users
Heavy Equipment (dump truck, backhoe, excavator, front-end loader, bulldozer, etc)			Identify several sources which could provide equipment
Pumps			Identify suppliers which could provide pumps
Siphon Materials			Identify material providers that could supply siphon construction/installation materials
Generators			Power source; note that large flood events often result in power outage
Floodlights			Identify adequate lighting source for night/low visibility consideration
Sand Bags and Filling Equipment			Identify for the event in which a large scale sandbagging job is deemed necessary

Form 6: *Emergency Intervention Expertise and Labor Assistance*

Expertise/Engineering Related			
Agency/Organization	Principal Contact	Work/Office Phone	24-Hour Phone

Labor/Construction Related			
Organization	Principal Contact	Work/Office Phone	24-Hour Phone

Form 7: *State Dam Safety Office or Regulatory Agency Notification Form*

Name of Person Reporting:	
24-Hour Phone Number of Person Reporting:	
Name of Dam:	Dam Operator (if known):
Latitude of Dam:	Longitude of Dam:
Nature of the Problem (e.g., potential overtopping, excessive seepage, boils, etc...):	
Location of Problem in Terms of Embankment Height:	
Location of Problem along Dam's Crest (e.g., 100 feet to the right of the outlet or abutment):	
Location of Problem in Terms of Slope (e.g., upstream, downstream, or crest):	
Extent of Problem Area (can often be established by pacing):	
Estimated Quantity of Seepage:	
Quality of the Seepage (clear, cloudy, muddy, etc...):	
Current Reservoir Pool Elevation:	
Is the Reservoir Pool Rising or Falling?:	
Readings Taken from Existing Instrumentation (if applicable) and How They Compare to Baseline Condition Readings:	
Current Weather Conditions at the Site:	
Was the Situation Worsening while being Observed?:	
Other Information:	