# DAM EMERGENCY RESPONSE
# SUGGESTIONS FOR A DAM SAFETY ENGINEER'S TOOLKIT AND CHECKLIST

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## ABSTRACT

In October, 2005 and May, 2006 heavy rains caused distress at multiple dams across Massachusetts and New Hampshire. Numerous government and private dam safety professionals were called to respond to emergency situations at multiple locations throughout the state. In many cases, these professionals were called at home to respond to a situation at a dam they had never before seen. Alone, or in small teams, these engineers were asked to make rapid assessments of the situation, evaluating the potential risks to the dam, downstream property, and the public safety, and then make virtually instantaneous recommendations for action. Many of these evaluations and recommendations were developed based almost exclusively on the judgment and experience of the engineer on-site.

While at least one major dam failed and several others came close, the crises were successfully ended without any dambreak-related fatalities or major downstream property damage. However, these situations, along with last year's Hurricane Katrina experience, did point out the need for engineers and dam safety professionals to be ready to mobilize rapidly and on a large, state-wide scale to evaluate multiple situations and provide recommendations for actions which protect dams, property, and the public safety.

This paper proposes some suggestions for a "rapid-response" toolkit for dam safety engineers, and provides a list of readily and publicly-available information resources which could be utilized in the absence of site-specific information. The paper also proposes a generic "check list" of advisable actions which an engineer responding to a dam emergency may wish to accomplish in the first minutes and hours after arriving on-site. This paper does not suggest these recommendations to be comprehensive or complete, but rather presents them as a starting point to spur discussion and thought within the dam safety community as we plan for the next inevitable crisis.

## INTRODUCTION

In October of 2005, severe storms pummeled Massachusetts and New Hampshire over two consecutive weekends. The 10-day total rainfall equaled or exceeded the 100-year event in many areas of the state. These heavy rains imperiled a number of the thousands of dams in these states. Similarly, in May, 2006, areas of Northeastern Massachusetts and Southern New Hampshire received up to 15 inches of rainfall over a 3-day period. Appropriately enough, the authors had to stop work on this paper to respond to a number of dam safety emergencies throughout Massachusetts which resulted from this storm.

To cope with the widespread emergency situation developing at many dams, the Massachusetts Office of Dam Safety mobilized all of its forces and called on the services of private dam safety engineering consultants. In many cases, these inspectors and engineers were asked to travel on short notice to a dam they had never before seen, render an opinion regarding the seriousness of the situation, and offer recommendations for action.

Many dam owners and emergency services personnel were also faced with difficult decisions and sleepless nights during this crisis. Where is the closest supply of sandbags? Should an impoundment be drained? Should a downstream population be evacuated? Where, if anywhere, is the Emergency Action Plan (EAP) for the dam?

Undoubtedly, similar situations have been encountered before in other states and will occur again in the future. Such times are challenging and nerve-wracking for everyone involved with dam safety. Proper emergency planning and close coordination among engineers, inspectors, owners, and emergency managers can go far in helping to bring a crisis to a successful conclusion, but no amount of preparation can ready any dam safety professional for all of the possible circumstances which can occur during an emergency. In some cases, a dam safety engineer may be called upon to act without the benefit of pre-developed plans or even without basic knowledge of the structure he or she is standing upon. It is primarily these types of situations which this paper seeks to address.

The authors of this paper do not suppose this to be the final word on rapid response to a dam safety emergency. On the contrary, it is our intent to spur discussion and debate on the subject among the dam safety community. Out of these dialogues, we hope that many valuable ideas arise which will be helpful in future crises.

## RAPID RESPONSE TO DAM SAFETY EMERGENCIES

For the purposes of this paper, a rapid response situation is defined as the initial period of action at a developing or ongoing dam safety emergency. Such situations are often characterized by an initial lack of data regarding the dam, an incomplete understanding of the actual seriousness of the failure mode threatening the dam, and a lack of information regarding the potential consequences of a dam failure. The personnel responsible for rapid response to a potential dam safety emergency are typically an individual or small group sent to assess the situation and report back with observations and an opinion regarding the potential seriousness of the situation.

This paper will attempt to address actions to be taken by the individual or small team responsible for the initial rapid response to a possible dam safety emergency. This is typically a period of uncertainty and confusion, but often represents a critical junction during which key actions must be taken. Ideally, this period of rapid response should last only several hours and certainly no more than a day. After this time, the potential seriousness of the situation should have been assessed and understood, and either a full emergency management team called to the site or a more passive monitoring plan established. If a full emergency situation is declared then many of the recommendations in this paper may still apply, but a more formal chain of command will likely have been established with a more rigorous definition of the roles and responsibilities of each participant. Also, hopefully by such a time more information will have become available and a better understanding of the potential threat to the dam and risk posed to downstream areas will have been developed.

It is proposed that there are essentially five steps involved in rapid response to a potential dam safety emergency. These steps are as follows:

1. Preparation
2. Assessment
3. Monitoring
4. Response
5. Post-Action Documentation and Follow-up

These actions start before leaving for the dam site, either in response to a reported observed condition or out of general concern regarding potential risks to the integrity of a dam (flooding, earthquake, etc.). They continue and even repeat while on-site and conclude after returning home or to the office.

Prior to embarking on an in-depth discussion of the five proposed steps, it is important to note that there are likely to be significant differences from state to state in the particulars of some of the recommendations. Each state will have a different way of maintaining and distributing information. Each state or even each locality may have different regulations governing the chain-of-command in an emergency situation. Each dam safety professional will need to become acquainted with those particulars in his or her own state.

## PREPARATION

The purpose of preparation is to arrive at the dam site with the right information and the right equipment, or at least with as much of each as is possible on short notice. Upon receiving that "phone call in the middle of the night" about a possible dam failure, it is an understandable impulse to pull on one's boots and head for the site. However, fifteen minutes to half an hour of rapid preparation can often be far more beneficial than arriving early at a site with little to no knowledge regarding the dam, its setting, and current conditions.

### *Information*

Ideally, anyone responding to a potential dam safety emergency would have access to the files and information specific to that dam. Such information, typically kept by the Owner and/or the State Office of Dam Safety (or similar agency) would include the following:

- Summary Information
- Design / "As Built" Drawings
- Previous Inspection Reports
- Operations and Maintenance Manual
- Emergency Action Plan

Clearly, the Emergency Action Plan (EAP) would become the key document if failure is believed to be imminent or in progress. EAPs are often also filed with the state emergency management agency or local or state police / fire department.

Realistically however, in many rapid response situations, an engineer or inspector will not have quick access to these files. And in some cases, even when the files are available not all critical information may be included. For example, in many states EAPs are required for High Hazard dams but not for Significant or Low Hazard structures. When information from dam-specific files is unavailable or incomplete, there are other publicly available resources on the internet which can be utilized to retrieve basic useful data. In some states, Geographic Information System (GIS) databases are available over web-based viewers on the internet. In this paper, we have limited discussion to publicly available websites which can be accessed with a standard web browser. The following is a list of useful web sites where relevant information might be obtained:

- Dam-Specific Pertinent Data: Information from the U.S. Army Corps National Inventory of Dams is useful in assessing the physical characteristics of the dam.

  *National Inventory of Dams:* *http://crunch.tec.army.mil/nid/webpages/nid.cfm*

- Street Maps & Orthophotos: Aerial photos and particularly those services which allow active zooming and view manipulation are critical to rapidly assessing the types of property and size of population which may be at risk downstream.

  *Google Maps (Google Earth):* *http://maps.google.com/*
  *Live Local (Microsoft):* *http://local.live.com/*

- Topographic Maps: Topographic maps can help in understanding the size of the upstream watershed and the downstream channel configuration.

  *Topozone:* *http://www.topozone.com*

- Weather Forecasts & Radar: Weather sites offer an estimate of how much rain is expected to fall and also how much rain has been recorded in the recent past.

  *National Weather Service:* *http://www.weather.gov*

- Streamflow & River Forecasts: River forecast centers use computer models and weather forecasts to predict river response levels and expected flow rates. Together with real-time information from USGS streamflow gages, the engineer can form an understanding of watershed response to rainfall.

  *National Weather Service AHPS:* *http://www.weather.gov/ahps/*
  *U.S. Geologic Survey:* *http://waterdata.usgs.gov/nwis/rt*

- Flood Maps & Studies: Finally, FEMA maps show the extent of expected flooding in an area (without consideration for a possible dam break).

  *Federal Emergency Management Agency:* *http://msc.fema.gov*

### *Equipment*

It is also important to arrive on site with the right equipment. It should not be expected that the first engineer or inspector on site will come equipped to repair problems found at a dam, so it is not necessary to bring a backhoe or 100 square yards of geotextile (though such items may prove useful). The first engineer or inspector on site should, however, arrive with the proper equipment to assess and document the situation. The following is a list of equipment which might prove useful when responding to a dam safety emergency:

1. Field book & Pencils
2. Clip board
3. Digital camera (extra batteries)
4. Cell phone (with important numbers & battery charger)
5. Measuring tape and 6-ft ruler
6. Flashlight (extra batteries)
7. Rain gear and umbrella
8. Calculator
9. Laptop / PDA (with wireless internet connection)
10. Stake or ruler for staff gauge
11. Personal safety gear as appropriate
12. GPS Unit
13. Tracer Dye

Since the collection of such equipment takes time, it is generally a good idea to pre-assemble a “ready bag” or plastic tub with all necessary equipment so that it is ready to be loaded into a vehicle on short notice.

As dam safety emergencies often occur during periods of adverse weather and/or darkness, the engineer should be prepared to brave these conditions. Most electronic equipment, from cameras to cell phones, respond unfavorably to rain, so an umbrella and rain gear is required. The engineer’s vehicle can also make for a mobile office. A laptop or PDA is a suggested accessory, and one with a wireless internet connection may be particularly handy if the dam in question happens to be in one of the growing areas that have wireless internet connectivity.

Anyone at a dam in peril should always be aware of the inherent danger of the situation, and should be prepared to evacuate the site at a moment’s notice. Personal safety gear such as high-visibility clothing, flotation devices, and hard hats should be available.

### *Support Team*

It can be said that no engineer is an island. The responding engineer should be prepared to rely on the assistance of coworkers and other engineering / scientific professionals on-site, at the office, or in the employ of state and federal agencies to assess the situation and conduct on-the-fly geotechnical and hydrologic and hydraulic analyses.

## ASSESSMENT

Upon arrival at the dam site, the first order of business should be to assess the situation and the condition of the dam. The following is a suggested list of actions to be taken immediately after reaching the dam site.

- Assess potential threats to public safety: This is the primary purpose of any response to a dam safety emergency. The major potential threat is an imminent or on-going breach of the dam. In this case, immediate *response* is necessary, including evacuation of downstream flood wave impact areas. Other safety threats may include conditions which are potentially hazardous to workers or onlookers at the site (including the dam inspector or engineer). These situations should also be addressed immediately.

- Establish Chain-of-Command and Lines of Communication: The first question is “Who is in charge?” The answer for a dam safety inspector, engineer, or even dam owner is rarely, “I am.” In the case of a serious dam safety emergency, command of the situation generally falls to a professional emergency response commander. If an EAP exists, this information is typically contained therein. In many cases this will be the local fire chief. The chief will typically direct the operational response and report to elected officials such as the local mayor or governor. The role of the dam safety professional is to identify himself/herself to the local situation commander and provide expert advice on the severity of the situation and possible means of response. Due to the specialized and technical nature of dam safety work, a fire chief or other site commander will often look to the dam safety professional on-site in regards to how to handle a situation, but implementation remains in the hands of the emergency services personnel.

- Notifications: Who needs to know about the situation? Again, an EAP would contain a notification list. In its absence, below is a suggested partial list, not necessarily in order of priority:

    1. State Dam Safety Office
    2. Local Fire Department and Police Department
    3. Dam Owner
    4. State Emergency Management Office

  Downstream residents and property owners may also need to be notified depending on the severity of the situation. Notifications to persons and businesses downstream should alert them of the situation at the dam and warn them that additional flow may be released either in a controlled or uncontrolled manner. Downstream persons should be informed of available evacuation routes and where to tune in to receive additional information. Notification of downstream persons may be through phone call (automated or otherwise), television or radio broadcast, vehicle-mounted loudspeaker, or knocking on doors. If a large number of notifications must be made, then the aid of the police department, national guard, and/or local media may be necessary.

- Establish Baselines: In assessing the state of a dam, particularly one which is under stress from a potential failure-inducing condition, it is critically important to know how conditions are changing. Therefore, baseline conditions must be established quickly so that change can be identified and quantified.

    1. Mark and Record Water Level: Impoundment and tailwater water levels should be physically marked, with level and time recorded. Water levels can be marked either on a fixed structure such as a training wall or marked with a stake driven into the bank. In any event, the location

should be one that will remain accessible, undisturbed, and provide a means for ongoing measurement.

2. Measure Seepage: If seepage is of concern, then a means of measuring seepage flow must also be created. Ideally, seepage can be measured at an existing toe drain or weir, but in the absence of these kind of features, expedient measurement devices can be quickly fabricated and installed. A sheet of 4' x 8' plywood can be cut to create a V-notch weir and installed with shovels, sand bags, and plastic sheeting. The equation for computing flow rates over a 90-degree V-notch weir is as follows:

   $$Q\ (\text{cfs}) = 2.5 \times (\text{Head, ft})^{2.5}$$

3. Instrumentation Readings: If the dam has instrumentation such as observation wells, piezometers, etc., then these should be identified and initial readings taken.

- Documentation: Again, as a way of assessing changes in the situation at the dam, initial conditions should be documented to provide a point of reference. This may include noting the position of gates and valves, the location of observed seepage areas, the presence of erosion or subsidence, etc. Documentation may take one or (preferably) more of:

  1) Field Notes, 2) Sketches, 3) Photographs, 4) Video.

- Establish Limits of Potential Downstream Impacts: A vital part of assessing the seriousness of a dam safety emergency is determining the risk to downstream areas. If an Emergency Action Plan with an inundation map has already been prepared, then the job is simplified greatly.

  However, at dams where no inundation mapping is available, it is possible to estimate order-of-magnitude dam breach flows and inundation areas. An excellent reference for a preliminary dam breach simulation is the National Weather Service Simplified Dam Break "SMPDBK" computer program and manual. While it is probably infeasible to conduct a computer simulation in the field, the SMPDBK program calculates the peak dam breach flow based on the following equation, which is simple enough to be estimated in the field:

$$Q_p = 3.1\, b \left( \frac{C}{t + C/h_d^{1/2}} \right)^3 \qquad C = 23.4\, S_a / b$$

where: $Q_p$ = Peak flow (cfs)
b = Avg. breach width (~3 times height of dam)
$S_a$ = Reservoir surface area (acres)
t = Time to failure (hr); 0.5 for earth dams / 0.1 for gravity
$h_d$ = Dam height (ft)

The peak dam breach flow can be compared to historic USGS stream gage data, FEMA Flood Insurance Studies, or the always-reliable Manning's equation to broadly estimate downstream areas which may be in the inundation area. If time is too short to employ these methods, a general rule-of-thumb is that the dam breach flood wave is likely to be approximately one-half the observed head at the dam. Of course, the most conservative approach to estimating downstream impact areas is to project the height of the dam downstream along the stream channel topographic contours.

- Reconnoiter Downstream Areas: After determining what areas might be affected, it is important to visually assess the conditions in the downstream areas of potential impact. A "windshield survey" should be conducted to visually confirm which structures are likely within the limits of the flood wave area and to determine the condition of downstream flow conveyance structures (clogged culverts, overtopping bridge decks, etc.). It is particularly important to note roads and bridges which might be inundated by either a dam break flood wave or simply by large flows released in a controlled manner from the dam. These routes should be closed and posted.

- Estimating Watershed / Reservoir Response: Similar to conducting a dam break analysis, the development of rainfall-runoff models can be time consuming and infeasible during a dam safety emergency. However, often the initial response occurs during early stages of a flood event, with additional precipitation still in the forecast. Under these circumstances, it can be useful to develop an understanding of how far the reservoir will rise and/or how much additional flow the spillway will experience.

  Ideally, real-time information on riverine flows and even reservoir levels would be available from the dam owner (via installed instrumentation), USGS stream gages, or the NWS. Sometimes, the NWS, which is responsible for issuing flash flood warnings, can assist in predicting river crest times and flow rates.

  In the event that circumstances dictate a "do-it-yourself" approach, the engineer can utilize any number of hydrologic methods and mass-balance relationships to estimate watershed and reservoir response. For example, a basic understanding of the watershed can allow for a prediction of direct runoff using the NRCS method, as depicted in Figure 1. This method utilizes a "Curve Number," which describes the land use and soil type of the watershed to estimate direct runoff.

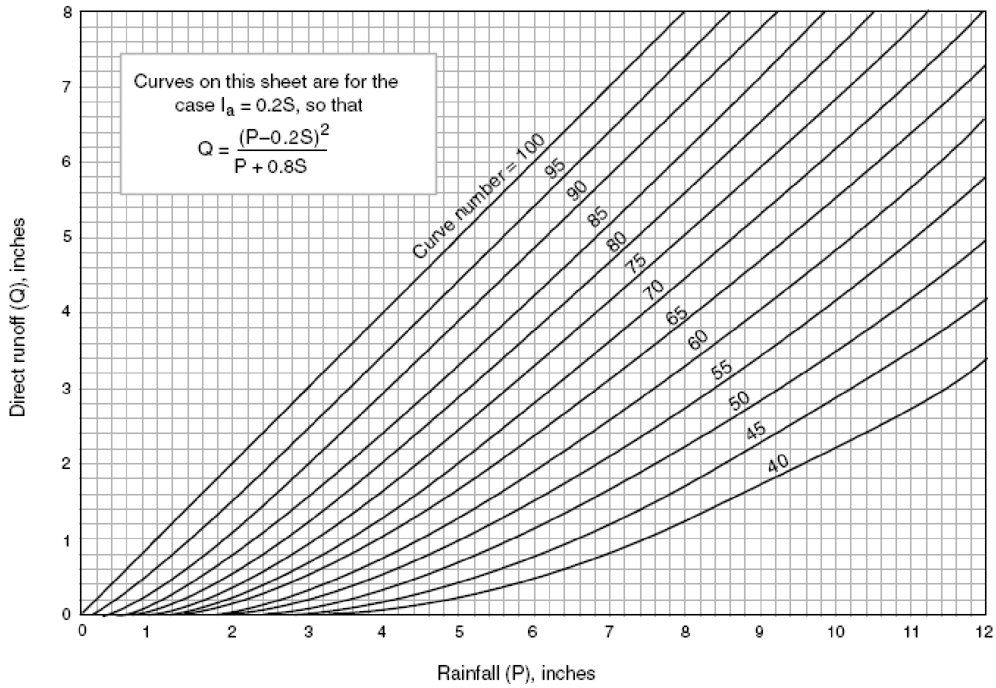



*Figure 1. Direct Runoff Analysis from the NRCS Handbook, Chapter 10*

Direct runoff can be translated into peak flow by considering the intensity / duration of rainfall and the approximate Time of Concentration of the watershed. The Time of Concentration is the amount of time required for water to travel from the furthest point of the watershed to the watershed outlet (i.e., the dam). The NRCS peak flow equation can be helpful to estimate the anticipated spillway adequacy (see Figure 2):

$$Q_{peak} = \frac{484 \text{ x (Watershed Area, mi}^2\text{) x Q (as derived above)}}{\text{Time to Peak (hrs)}}$$

The "Time to Peak" is the sum of the Time of Concentration plus one-half of the duration of excess rainfall. Time to Peak can be thought of as approximately the time from the onset of the flood to the time of the peak crest of the inflow stream.

If the Time to Peak is not known, and the engineer does not have an adequate "feel" for the watershed or the data from which to develop such feelings, a gross estimate of runoff volume can be made by simply multiplying the runoff depth obtained in Figure 1 by the watershed area.

Inflow Volume (acre-ft) = (Q inches / 12 in/ft ) x Watershed Area ($mi^2$) x 640

Spillway response can be estimated using the weir equation:

$Q = CLH^{1.5}$

where: Q = Flow rate; C = Weir Coefficient (2.7 to 3.6); H = Head

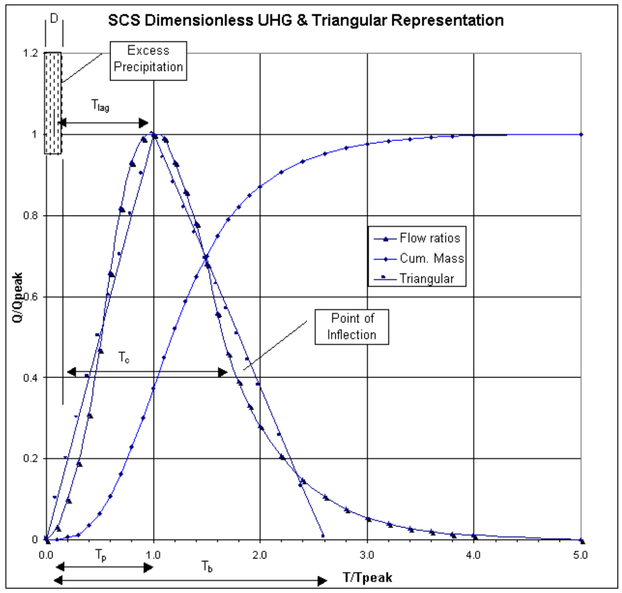



*Figure 2. Unit Hydrograph (UHG) Technical Manual, National Weather Service - Office of Hydrology, Hydrologic Research Laboratory and National Operational Hydrologic Remote Sensing Center*

Volumetric relationships based on simple mass balance relationships (i.e. water budget) can also assist the engineer in estimating reservoir response:

Inflow – Diversions = Outflow + Change in Reservoir Storage

Although this is a simple relationship, such calculations can become unwieldy quickly depending on the complexity of the reservoir / dam / watershed system and the introduction of time as a variable. Simplifying assumptions based on site characteristics and engineering judgment are required. An understanding of the reservoir normal and maximum volume is clearly important as well. An example of using a water budget to estimate watershed hydrologic response is as follows:

Known Information:

| | |
|---|---|
| Reservoir Surface Area, A: | 100 acres (estimated from topo map) |
| Spillway Length, L: | 25 ft. (visually estimated) |
| Reservoir Response, d: | 1 inch increase in water surface in one hour |
| Depth of Spillway Flow, H: | 2 feet over spillway crest (measured) |

Calculations:

Outflow from Spillway: $Q = CLH^{1.5}$ = 3.3 x 25' x $2^{1.5}$ = 233 cfs
Outflow Volume (per hr): $V_{out}$ = Q x t = 233 cfs x 3600 s / 43560 = 19.3 ac-ft
Change in Storage (per hr): ΔV = d x A = 1 in / 12 x 100 acres = 8.3 ac-ft
Inflow Volume (per hr): $V_{in} = V_{out}$ + ΔV = 19.3 ac-ft/hr + 8.3 ac-ft = 27.6 ac-ft
Average Inflow (per hr): $V_{in}$ / t = 27.6 ac-ft x 43560 / 3600 s = 334 cfs

Conclusion: Inflow exceeded outflow over past hour by over 40 percent.

## MONITORING

Once the baseline conditions are established, the next step is to begin a monitoring program. In many cases, this will be the most important activity performed by a dam safety professional. The best case scenario for any dam safety emergency is that conditions (impoundment levels, seepage, movement, etc.) are found to be stable or receding. In this case, the situation changes from one which requires emergency response to one which needs expedited repairs. While still serious, a situation where conditions are stable provides an opportunity to address the observed deficiencies with the benefit of more thorough thought and planning.

Monitoring typically involves frequent visual assessment of conditions at the dam and repeat collection of data to be compared against the baseline established during the initial assessment. The most important thing to look for during monitoring is change. The question which a dam safety professional should ask of himself/herself over and over is, “Are conditions changing, and if so, for the better or worse?” Detailed records should be kept during monitoring, including water level readings, seepage rates, additional photos, etc.

Monitoring frequency is an important consideration. If a situation is such that conditions appear to be worsening (impoundment levels continue to rise, etc.), then continuous monitoring is generally prudent. This may require multiple inspectors or engineers working in shifts to cover the site for long hours. In such a case, it is important that observations made and data collected by one person be available to and clearly understood by his or her relief. Again, understanding change is the key, so a new person on site must be thoroughly briefed on previous conditions.

Monitoring should be done in a manner which does not endanger the inspector or engineer. Do not attempt to make observations in locations where hazardous conditions (particularly swift currents) exist. If overnight monitoring is necessary, provisions for portable lighting must be made.

## RESPONSE

The response should focus on mitigating potential threats to public safety, downstream property, and the dam itself, in that order. In many cases, actions which serve to protect the dam will also protect downstream populations and property by reducing the possibility of an uncontrolled release of water from the impoundment. However, it should always be remembered that the foremost duty of a dam safety professional is the protection of human life and always takes precedent over preventing damage to the dam. Indeed, in some cases, a dam safety professional may recommend *causing* damage to a dam (controlled breach, etc.) in order to protect public safety.

### *Evacuation*

If, during the initial assessment or any time thereafter, an uncontrolled release of water from the impoundment (i.e. failure of the dam) is observed to be occurring or judged to be imminent, then the downstream population at risk should be evacuated immediately. If there is an existing EAP with inundation maps, then this may be used in determining the area to be evacuated. If no such map exists, then the techniques described above, along with a healthy dose of conservatism, can be used to quickly estimate the extent of downstream areas which should be evacuated. Typically, an evacuation order is given by the local mayor or his/her police or fire commander and then implemented by the local police department and fire department. The local media can also be enlisted to assist in warning downstream populations. A message similar to the following may be provided to television and radio stations for immediate broadcast via the Emergency Alert System:

> *The (Name) Dam in (Town or Other Location) has failed. A large flood wave released from the dam is now moving down the (River or Stream) at a high rate of speed. Persons near or along the (River or Stream) should move to high ground immediately.*
>
> *Water from the dam is expected to cause widespread flooding in the following locations: (Towns or Other Locations), and along the following roads: (Primary or Secondary Roads).*
>
> *Stay alert for further announcements. Updated information as to river levels, flood arrival times, and evacuation efforts will be broadcast as soon as they are available.*

Perhaps the most difficult decision for a dam safety professional to make during an emergency response is whether or not to recommend the evacuation of the population at risk from downstream areas when it is not yet certain that the dam will fail. There is no generic guidance which can be provided regarding such a situation, except to say that it is always preferable to err on the side of safety. Lost income can be replaced… lost life cannot. In some instances, downstream business owners may even be eligible for disaster assistance for disruptions caused by an evacuation order.

***Emergency Repair***

After determining the appropriate response regarding the downstream population, the next step is to decide upon the appropriate response regarding the situation at the dam itself. In many cases, the most appropriate response may be no immediate action at all beyond continued monitoring. If the emergency condition is judged to be stable or receding, then corrective actions may be more properly undertaken as part of a designed (and permitted) expedited repair program. If, however, the condition of the dam is judged to be deteriorating, then emergency actions may be justified.

There are a number of actions which may be useful in attempting to improve the survivability of a dam during an emergency situation. Some of the more typical have been described below, while others will need to be developed on the spur of the moment depending on particular circumstances. In any event, there are a number of items which have generally been found to be useful during emergency response situations. It may be useful to collect these items or at least identify a nearby source.

1. Shovels, picks, etc.
2. Sandbags
3. Plastic tarps or similar
4. Pole saw
5. Pole hook
6. Filter Fabric
7. Materials
   a. Sand
   b. Gravel
   c. Stone Riprap

***Additional Freeboard***

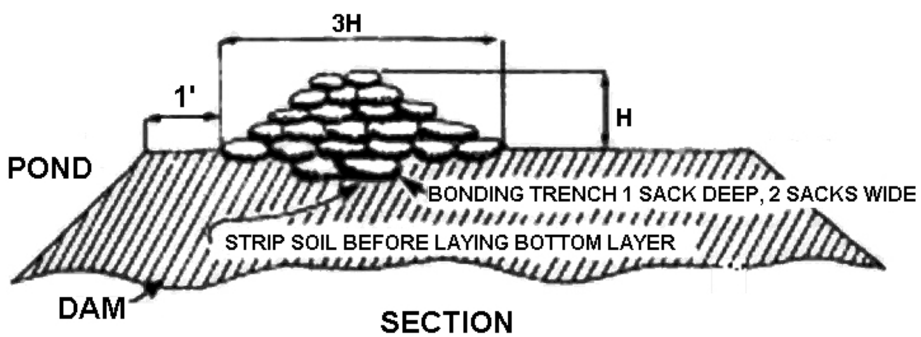
Increasing freeboard through the construction of temporary berms or parapet walls is one of the most basic responses to a potential overtopping event.

Sand Bags

Sand bag berms are one of the most common methods for temporarily increasing freeboard. Sand bag placement guidance is available from the USACE at the following website:

http://www.nww.usace.army.mil/html/offices/op/em/Library/Flood_Fighting_How_To_Use_Sandbags.pdf

The USACE recommends that the berm be formed with alternating header and stretcher courses and that joints be staggered. A basic construction diagram and material requirements table is presented below. Sandbag berm construction can be highly effective but requires appropriate material and is labor intensive. The maximum effective height should be limited to approximately three feet.




| Height above levee | Bags/100 feet |
|---|---|
| 1 foot | 800 |
| 2 feet | 2000 |
| 3 feet | 3400 |

(Source: US Army Corps of Engineers)

Earth Berms

Temporary earth berms may also be constructed on top of a dam or on an abutment. Side slopes should generally be 3:1 (H:V) or flatter and compaction should be at minimum through tracking with a construction vehicle. If granular material is used, then plastic sheeting is needed on the upstream face to provide a water-resistant barrier.

Parapets

Jersey barriers have also been used in conjunction with plastic sheeting.

These same techniques may also be used to direct flow in a certain direction, for instance away from a dam embankment and over a less-vulnerable abutment.

***Seepage Control***

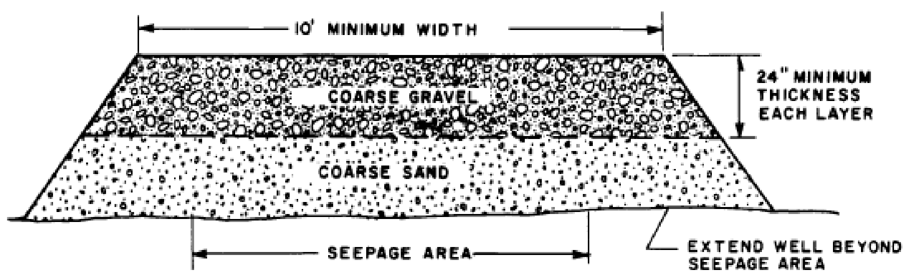
While all dams have some amount of seepage, uncontrolled excessive seepage can pose a threat to a dam (particularly earth fill dams) by initiating internal erosion or piping. There are a number of responses which can be attempted to mitigate damage potentially caused by uncontrolled seepage. In general, the purpose is to reduce the transport of soil material rather than reducing the seepage itself.

Filter Fabric

A woven or (preferably) non-woven geotextile fabric may be laid over an area where seepage is exiting an embankment or foundation to filter soil out of emerging seepage flow. Grass and irregularities should be cleared from the area of seepage (and at least five feet beyond in all directions), the filter fabric then laid flat and ballasted with a minimum of six inches of granular material (sand or gravel).

Granular Blanket Filter

A similar filter system can be constructed using just granular soil material of different particle sizes as shown below. Concrete sand is typically very effective as the material in direct contact with the embankment or foundation soils.




GRANULAR BLANKET

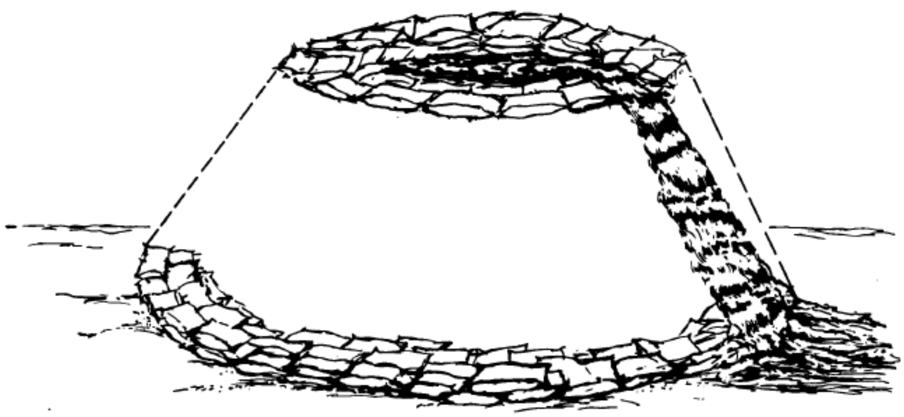
APPROXIMATE CONSTUCTION REQUIREMENTS

| BLANKET AREA (ft.$^2$) | 1,000 | 2,000 | 3,000 | 4,000 | 5,000 | 6,000 | 7,000 | 8,000 | 9,000 | 10,000 |
|---|---|---|---|---|---|---|---|---|---|---|
| MATERIAL REQUIRED PER LAYER (yd.$^3$) | 40 | 80 | 120 | 150 | 190 | 225 | 270 | 300 | 330 | 370 |
| NO. TRUCKS & DRIVERS | 3 | 3 | 6 | 6 | 6 | 8 | 10 | 10 | 12 | 12 |
| NO. GRADERS & OPERATORS | 5 | 5 | 10 | 10 | 15 | 15 | 15 | 20 | 20 | 20 |
| TOTAL TIME REQUIRED (hrs) | 4 | 8 | 6 | 8 | 8 | 8 | 8 | 8 | 9 | 10 |

(Source: US Army Corps of Engineers)

Boil Ring:

Another method of reducing internal erosion or piping is to increase the head over the exit point through the construction of a boil ring. The boil ring is intended to create a small pool over a discrete area of active seepage and thereby reduce the exit gradient. The boil should reduce but not stop seepage. Boil rings may be constructed as shown below. They are more difficult to construct on slopes.

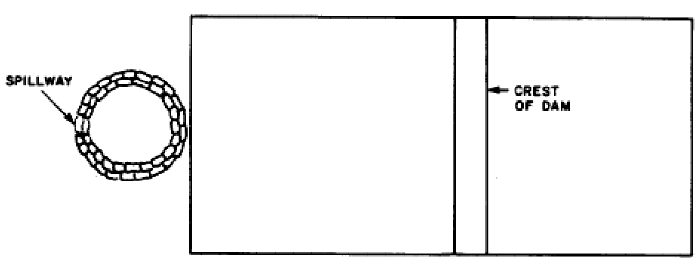


APPROXIMATE CONSTRUCTION REQUIREMENTS

| BOIL DIA. (ft) | 2 | | | 4 | | | 6 | | | 8 | | | 10 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RING HEIGHT (ft) | 2 | 4 | 6 | 2 | 4 | 6 | 2 | 4 | 6 | 2 | 4 | 6 | 2 | 4 | 6 |
| VOL. SAND REQ. (yd.$^3$) | 1 | 7 | 18 | 2 | 9 | 21 | 3 | 11 | 25 | 3 | 13 | 29 | 4 | 14 | 33 |
| SANDBAGS REQUIRED | 124 | 475 | 1150 | 160 | 600 | 1400 | 197 | 707 | 1600 | 233 | 824 | 1850 | 270 | 921 | 2100 |
| PERSONNEL REQUIRED | 5 | 5 | 5 | 10 | 10 | 10 | 20 | 20 | 20 | 25 | 25 | 25 | 30 | 30 | 30 |
| TIME TO COMPLETE (hrs.) | 1 | 3 | 7 | 1 | 3 | 5 | 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |


ELEVATION

WALL SHOULD BE BUILT ON FIRM FOUNDATION, WITH WIDTH OF BASE AT LEAST 1 1/2 TIMES THE HEIGHT. BE SURE TO PLACE SACKS ON GROUND CLEAR OF SAND DISCHARGE. TIE INTO DAM IF BOIL IS NEAR TOE.




PLAN

DO NOT SACK BOIL WHICH DOES NOT PUT OUT MATERIAL. HEIGHT OF SACK LOOP OR RING SHOULD BE ONLY SUFFCIENT TO CREATE ENOUGH HEAD TO SLOW DOWN FLOW THROUGH BOIL SO THAT NO MORE MATERIAL IS DISPLACED AND BOIL RUNS CLEAR. DO NOT TRY TO STOP FULLY, FLOW THROUGH BOIL.

SOURCE: NEW ENGLAND DIVISION ARMY CORPS OF ENGINEERS

(Source: US Army Corps of Engineers)

***Erosion Protection***

Overtopping of an embankment or other uncontrolled flows over an earthen surface can lead to erosions which could, in term, cause the failure of a dam. Even a gravity dam is susceptible if it has soil abutments which are vulnerable to erosion. The best approach is to prevent the flow or to divert it to a non-erodible flow path. Barring these, another approach is to protect areas where flow might occur by providing erosion-resistant cover:

Riprap

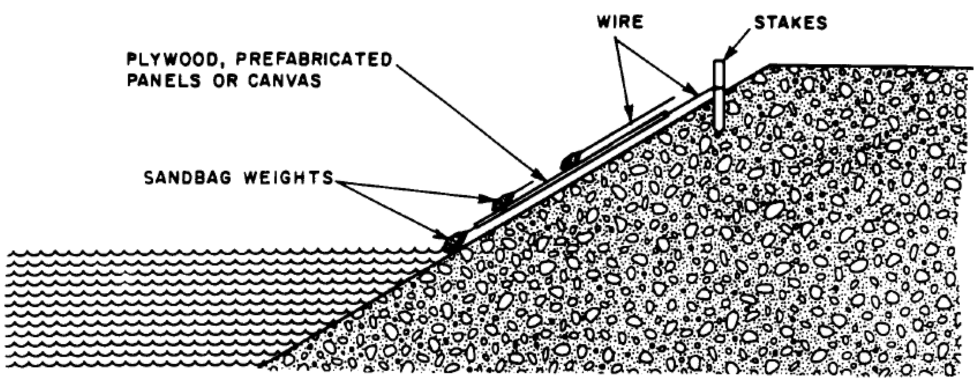
Stone riprap is an effective lining material, particularly when high velocity flow is anticipated. A bedding layer of granular material or filter fabric must be included.

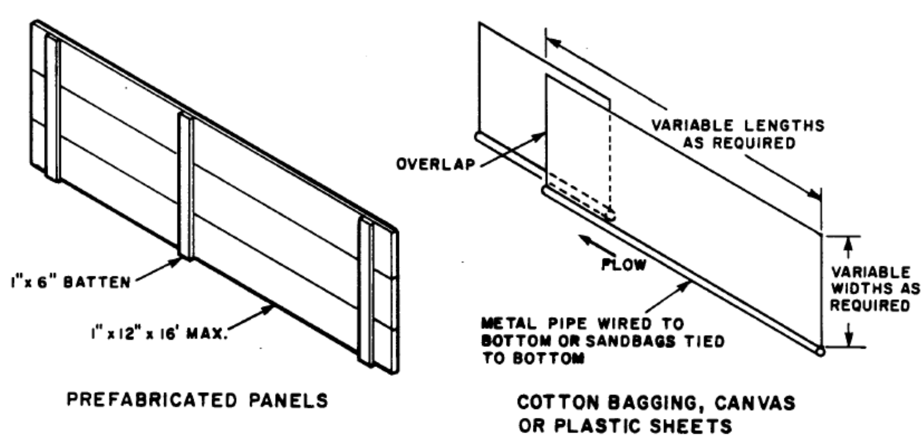
Sandbags

Filled sandbags can be laid flat as a liner in area where flow may occur.

Sheeting or Filter Fabric

A layer of plastic sheeting or filter fabric can also be useful in reducing erosion. Plywood or other wooden panels have also been suggested. The key to using sheeting is that it must be securely fastened in place using stakes, sandbags, stone, etc. It is also useful to key the upstream end into the ground so that flow is less likely to get under the sheeting.




(Source: US Army Corps of Engineers)

***Outflow Capacity Improvement***

In cases where high flows are threatening to overtop a dam, it may be useful to attempt to increase the outflow capacity of the spillway or other water control structures. If successful, this may slow or stop the rise of the impoundment behind the dam. Several potential responses may be considered in this regard:

Emergency Drawdown with Existing Outlets

The controlled drawdown of the impoundment through existing low level outlets is likely one of the first action items to attempt during a dam safety emergency. Make sure that all gates and valves are fully open and that no debris is clogging the inlets or trash racks. Unfortunately, low level outlets often do not have the ability to quickly drawdown an impoundment during flooding conditions.

Remove Stoplogs / Flashboards

Many dams, particularly smaller ones, rely on stoplogs or flashboards to provide increased water storage above the fixed spillway crest. Removal of these structures can significantly increase the outflow from a spillway by increasing the depth of flow over the weir. Stoplogs are typically designed to be removed in advance of a flood but often are not. Flashboards are designed to fail in a controlled manner during a flood but often do not. Prior to removing stoplogs or flashboards, there needs to be a thorough understanding of the consequences of the sudden increase of flow downstream of the dam. In some instances, removing stoplogs or flashboards could actually lead to increased downstream flooding, but this must be weighed against the risk of a dam failure. The safety of personnel who will attempt to remove the stoplogs/flashboards must also be considered.

Removal of stoplogs after flow has begun can be difficult. Some stoplogs are equipped with a special lifting bar. Others are simply boards. A fireman's pole hook has been seen to be effective in lifting stoplogs (usually with two people working in tandem with two hooks). Another approach is to use a pole saw (preferably powered) to cut the stoplog from the downstream face. Similar methods may be effective on flashboards, but these are sometimes fixed and must be knocked down with an excavator bucket or other similar means.

Emergency Channel Construction

One of the more potentially risky means of increasing outflow from an impoundment is to create an emergency channel. The risk is that the channel will be unstable and erode, leading to the very uncontrolled release of the impoundment that was trying to be prevented. If this action is judged necessary, then it is wise to either implement or be prepared to implement the evacuation of downstream areas.

Emergency channels should only, except under the most dire of circumstances, be constructed on natural soil or stone on the abutments of a dam. The size and extent of the channel should be developed and laid out on the ground after the area has been cleared. Construction should generally proceed from downstream end with an upstream lip or sill left in place initially. After the channel has been constructed, it should be lined with fabric, sandbags, stone, or other appropriate erosion-resistant material. Once preparations have been made downstream, the sill at the upstream end of the emergency channel may be slowly breached in a controlled manner until full flow is achieved. An additional supply of stone or sandbags should be kept ready nearby to close the inlet and slow flow if unexpected erosion is observed.

In most cases, normal environmental permitting procedures are waived during times of emergency. However, it is generally prudent to notify relevant governmental regulatory agencies either during or immediately after taking emergency actions at a dam. Many regulations and programmatic permits contain specific emergency clauses which discuss the appropriate procedures.

Following any response at a dam, the process of assessing and monitoring should be repeated in order to judge the success of the response and determine the need for additional actions.

## POST-ACTION DOCUMENTATION AND FOLLOW-UP

Once the immediate emergency situation is resolved, a dam safety inspector or engineer should prepare documentation of the situation as soon as possible. The documentation should include a written report which describes the conditions observed at the dam and any actions taken. Ideally, the report will also contain photographs and sketches of the dam. Any measurements taken at the dam, including impoundment levels, seepage rates, etc., should also be included. If additional actions, including follow-up inspections are judged necessary, these recommendations may be made in the report. Copies of the report should be provided to the appropriate dam safety regulatory agency and to the owner of the structure.

## REFERENCES

1. Wetmore, J.N. and Fread, D. L, *The NWS Simplified Dam-Break Flood Forecasting Model*, Revised 12/18/91 by Fread, D.L, Lewis, J.M., and Wiele, S.M., National Weather Service.
2. U.S. Department of Agriculture, Natural Resources Conservation Service, “Part 630 Hydrology, National Engineering Handbook,” September, 1997.
3. U.S. Department of Energy, Federal Energy Regulatory Commission, Office of Hydropower Licensing, “Engineering Guidelines for the Evaluation of Hydropower Projects,” April 1991.
4. U.S. Department of the Interior, Bureau of Reclamation, “Design of Small Dams”, A Water Resources Technical Publication, Third Edition, 1987.
5. U.S. Army Corps of Engineers, Hydrologic Engineering Center, "Example Emergency Plan for Blue Marsh Dam and Lake," Research Document No. 19, August 1983.
6. U.S. Army Corps of Engineers, Hydrologic Engineering Center, "Flood Emergency Plans, Guidelines for Corps Dams," Research Document No. 13, June 1980.
7. Federal Emergency Management Agency, Mitigation Directorate, National Dam Safety Program: “Federal Guidelines for Dam Safety: Emergency Action Guidelines for Dam Owners; FEMA 64”, October 1998.

# DAM EMERGENCY RESPONSE CHECKLIST[1]

## 1) PREPAREDNESS

### 1A) Information

- ☐ **Emergency Action Plan**
- ☐ Design / "As Built" Drawings
- ☐ Previous Inspection Reports
- ☐ Street Maps
- ☐ FEMA Flood Maps
- ☐ Rainfall Data / Forecasts
- ☐ Dam Summary Information
- ☐ Site Specific O&M Manual
- ☐ Topographic Maps
- ☐ Orthophotos
- ☐ Streamflow Data / Forecasts
- ☐ Relevant Phone Numbers

### 1B) Equipment

- ☐ Field book & Pencils
- ☐ Clip board
- ☐ Cell phone & battery charger
- ☐ Camera, film, memory, batteries
- ☐ Measuring tape and 6-ft ruler
- ☐ Flashlight & extra batteries
- ☐ Rain gear and umbrella
- ☐ Calculator
- ☐ Laptop / PDA
- ☐ Stake or Ruler for Staff Gage
- ☐ Personal Safety Equipment
- ☐ Tracer Dye
- ☐ GPS Unit
- ☐ ________________________

## 2) ASSESSMENT

- ☐ Assess Potential Threat to Public Safety
- ☐ Establish Chain of Command and Lines of Communications
- ☐ Notifications (if no EAP)
  - ☐ State Dam Safety Office
  - ☐ Local Fire & Police Department
  - ☐ Dam Owner
  - ☐ State Emergency Management Office
  - ☐ Downstream Population at Risk
- ☐ Establish Baselines
  - ☐ Mark and Record Water Levels
  - ☐ Measure Seepage
  - ☐ Take Instrumentation Readings (if any)
- ☐ Document Conditions
  - ☐ Field Notes
  - ☐ Sketches
  - ☐ Photos
  - ☐ Video

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[1] Suggested Checklist as per Cox & Leone, ASDSO 2006

- ☐ Establish Limits of Potential Downstream Inundation
  - ☐ EAP Inundation Maps (Preferred)
  - or ☐ FEMA Flood Maps
  - or ☐ Estimation Methods
- ☐ Reconnoiter Downstream Areas
- ☐ Estimate Watershed / Reservoir Response

**3) MONITORING**

- ☐ Establish Monitoring Program
- ☐ Establish Monitoring Frequency
- ☐ Identify Monitoring Personnel
- ☐ Develop Safety Guidelines
- ☐ Identify Location and Format for Collected Data
- ☐ Brief Relief Personnel
- ☐ Provide Temporary Lighting, Shelter, etc., as needed

**4) POTENTIAL RESPONSES**

If… Failure in Progress or Imminent

- ☐ Downstream Evacuation

If… Overtopping Possible

- ☐ Increase Freeboard and/or ☐ Increase Outflow

| | |
|---|---|
| ☐ Sand Bag Berm | ☐ Open Existing Outlets |
| or ☐ Earth Berm | or ☐ Remove Stop Logs/Flashboards |
| or ☐ Parapet | or ☐ Emergency Bypass Channel |

If… Uncontrolled Seepage

- ☐ Filter Fabric Cover or ☐ Granular Blanket Filter or ☐ Boil Ring

If… Erosion Occurring

- ☐ Riprap or ☐ Sandbags or ☐ Sheeting

Useful Tools and Materials

| | |
|---|---|
| ☐ Shovels, Picks, etc. | ☐ Filter Fabric |
| ☐ Fireman’s Pole Hook | ☐ Sand |
| ☐ Pole Saw | ☐ Gravel |
| ☐ Sandbags | ☐ Stone Riprap |
| ☐ Plastic tarps or similar | ☐ ____________________ |

**5) POST-ACTION DOCUMENTATION AND FOLLOW-UP**

- ☐ After-Action Report
- ☐ Short-Term Recommendations for Stabilizing Conditions, Managing Water Level, and Monitoring Conditions