



Association of State
Dam Safety Officials

Dam Failure and Incident Investigation Guide

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A product of the ASDSO Dam Failure & Incidents Committee



ASDSO
DamSafety.org

This guide shares lessons from previous dam incident and failure experiences and is designed to assist State dam safety agencies and dam owners in making good decisions during the chaotic and high stress period during and following a dam failure or major incident.

As with any guide, it is expected that some refinements may be identified as more investigations are completed. As such, this guide is being issued as a “living document”, with the expectation that applicable revisions or updates will be made as necessary. The initial version was published in December 2011. This current version 2.0, dated March 2021, features revisions from lessons learned during the past ten years. Please check the ASDSO website to ensure you are using the latest version.

Association of State Dam Safety Officials
Dam Failure and Incidents Committee
Dam Failure and Incident Investigation Guideline

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PURPOSE

Dam failures and incidents are usually high-stress events and often occur without much warning. Furthermore, these events are somewhat rare and dam owners and regulators likely have little experience in investigating these events. Therefore, this guideline is intended to assist organizations and individuals involved in dam safety with preparing for, responding to and investigating dam failures and incidents.

Competent and independent investigations serve the following purposes:

- To determine the physical causes of failure.
- To understand contributing human factors, including organizational and cultural factors.
- To better support communication with the public and the press.
- To increase the public's knowledge of dam safety and reestablish trust.
- To improve understanding of warning signs of dam distress.
- To improve dam safety engineering and regulation and reduce the potential for future failures.
- To learn what went right and recognize efforts and successes.

BACKGROUND

This guideline was created by the Association of State Dam Safety Officials (ASDSO) Dam Failure and Incidents Committee (DFIC) (see the committee roster in Appendix A). The committee includes members with direct experience in many of the major dam failures and incidents of the past 15 years including Silver Lake Dam (Michigan), Big Bay Dam (Mississippi), Taum Sauk Dam (Missouri), Hadlock Pond Dam (New York), Lake Delhi Dam (Iowa), Hope Mills Dam (North Carolina), Oroville Dam (California), Spencer Dam (2019), and the Edenville/Sanford Dams (2020). The committee members have also researched, developed case studies, and made presentations on over 70 additional dam failures and incidents.

Research has shown that there has been great variability in how dam failures and incidents were investigated in the past [1]. For example, some previous investigations have suffered from a lack of independence, whereas other investigations have aided in initial response, recovery from the failure, and sharing of the lessons learned throughout the dam safety profession. Historically, few investigations considered factors beyond physical influences, like human factor inputs. This guideline is intended to promote best practices for investigations of dam failures and incidents.

Note: In the remainder of this document, the term dam "failure" is generally inclusive of both dam failures and incidents.

AUTHORITY

This guideline was created under the authority of the Association of State Dam Safety Officials (ASDSO). The DFIC charter includes development of this guideline.

This guideline is not law or policy and, therefore, is not binding on the States or any other party. However, individual States and other parties may choose to use this guideline to adopt such policies for conducting investigations of dam failures.

AUDIENCE

This guideline is written based on the assumption that the State Dam Safety Official (SDSO) initiates and conducts a failure investigation. However, the target audience for this guideline also includes others who may initiate or participate in investigations, include dam owners, federal agencies, and engineers, geologists, and other technical specialists.

INTRODUCTION

The SDSO should consider consequences of a failure and other factors in determining whether an investigation is needed. The Committee recommends that failures that result in loss of life, high economic losses, large evacuations, and/or other major impacts should be investigated, and major dam incidents (without dam breach) and failure of low-hazard potential dams that could produce valuable lessons learned should also be considered for investigation. The scale of the investigation is usually in proportion to the magnitude of the loss of life and other adverse impacts.

Minor failures and incidents can be investigated by the dam owner or SDSO; however, major failures and incidents should be independently investigated. Experience clearly shows a need to establish and maintain independence of the investigation team members since, in the past, some investigations have suffered due to public concerns that the investigation members (or their home organizations) had a stake in the outcome of the investigation.

The table in Appendix B provides information on many of the major dam failures and their investigations in the past 40 years.

PLANNING FOR POTENTIAL DAM FAILURES AND INCIDENTS

There have been dam failures in every state. Despite best efforts, dam failures can be expected to occur again.

Complicating the response to dam failures is the fact that multiple dam failures can occur in a single large event like a hurricane or earthquake - [See swarming dam failures](#).

Given the time pressure and stress associated with significant dam failures and incidents, investigations will be much more efficient and effective if basic planning for investigations is performed in advance.

In general, the SDSO should brief their field staff on procedures for responding to incidents that could lead to dam failures, including intervention techniques, and the need for collecting information during a failure, and carrying out a successful investigation. They should also brief senior staff on likely actions needed during and following a dam failure (including the likely need for an investigation).

More specific recommendations include the following:

- ✓ Review relevant case studies of past failures, and the response to such failures, to extract applicable lessons learned
- ✓ Review the State’s Dam Safety Laws and Regulations to determine whether the State has the authority to investigate dam failures and incidents and if that authority and funding could be extended to an external investigation team
- ✓ Train and communicate with field staff about dam safety incident response and failure investigation procedures (such as video, safety, documentation, timeline, etc.)
- ✓ Thoroughly document any known problems with dams (particularly problem dams) and keep good records
- ✓ Incorporate this failure investigation guideline into State program emergency action plans, policies, and procedures
- ✓ Explore ways of funding and rapidly mobilizing resources (e.g. equipment and materials) for responding to a dam incident
- ✓ Get Incident Command System training so that staff can communicate and coordinate with the emergency management community (this is especially important for large-scale events)
- ✓ Plan to set up a dam safety Emergency Operations Center.
- ✓ Develop a relationship with state and local emergency management officials
- ✓ Be knowledgeable about the ability to get neighbor State, and Federal assistance as needed during an emergency
- ✓ Digitize records so they are available at all times in all locations
- ✓ Prepare a “Go-Bag” with equipment and clothing for an inclement weather or an overnight stay (see Appendix C)
- ✓ Develop an internal and external communication protocol, including communication methods (e.g. radio, cell, email, satellite phone, etc.)
- ✓ Make sure dam Emergency Action Plans are available to staff at all times.
- ✓ Recognize that dams can fail individually or groups of dams can fail during a large loading event – such as a hurricane. These large events can cause issues with access, communications, operations and resources to respond to and monitor multiple dams at once.

DURING THE DAM FAILURE OR INCIDENT

What should be done immediately after learning about a dam incident or failure?

- ✓ Confirm the event is taking place – is it really a dam safety concern?
- ✓ Follow established procedures for emergency events (e.g. the dam’s Emergency Action Plan), such as notifying law enforcement, emergency management, senior State staff, and dam safety staff. Conference calls with follow-up email notes are a good way to coordinate and create a record of response.
- ✓ Learn whether the dam is State-regulated or regulated by others (e.g. Federal Energy Regulatory Commission, US Bureau of Reclamation, or other Federal agency). The State needs to be aware of and help ensure the warning and evacuation response of any dam, including those regulated/owned by the Federal agencies.
- ✓ Consider contacting nearby state dam safety officers or FERC, Bureau of Reclamation, or the US Army Corps of Engineers for assistance.
- ✓ Collect information about the dam from State dam safety files and the Internet (e.g. Google Earth). Of prime importance are the Emergency Action Plan (EAP), the inundation map, warning/evacuation plans, design/construction documents, past inspection reports, and past investigations.
- ✓ Promptly send State dam safety staff to the site with gear (see Appendix C for a recommended list of equipment). Make sure that they know their role and the activities they should perform in the field:
 - Meet with the dam owner/operator. Share and collect information. Make sure they have and are following the Emergency Action Plan.
 - Coordinate with the owner to identify and mitigate safety hazards. Dam failure sites can be inherently dangerous (e.g. sinkholes open up, slopes fail, or flows cause rapid erosion). Do not put staff at unacceptable risk
 - Support efforts in the field with technical expertise, equipment, and materials to prevent failure, if possible. Decisions may need to be made rapidly, so it is important to have experienced senior personnel at the site.
 - Support the dam owner in the use of the Emergency Action Plan and the local emergency management agency in the warning and evacuation of people downstream. Verify areas that would be inundated by reviewing the inundation map (if available) and/or Internet (e.g. Google Earth/MapQuest/Bing).
 - Keep a log of events describing actions and observations with date/times.
 - Take video/pictures with date/time stamps. It is helpful to take several photos from the same position during the event to show change over time.
 - Develop a communication plan to ensure communication with the public and others. Periodic press releases are a good way of sharing the facts of the event and tamping down rumors.

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- Collect names, phone numbers, and emails of staff and witnesses (people taking photos/video of the event).
 - Assign a staff member to monitor social media and take screen shots of relevant material.
 - Record reservoir and tailwater elevations, gate positions, flow readings, and other instrumentation readings with time/date.

What if the dam incident is during a Federally declared disaster declaration?

If the dam incident is part of a Federally declared disaster or emergency, FEMA may have the ability to use its authorities to conduct or assist with dam failure investigations. Federal agencies, such as the Bureau of Reclamation (Reclamation), the US Army Corps of Engineers (USACE), and the Federal Energy Regulatory Commission (FERC) may be able to assist.

What should be done immediately following the failure?

- ✓ Coordinate with the dam owner and appropriate authorities to:
 - Make the site safe. Areas of interest to the investigators and areas (such as scarps) that present a hazard to the public should be signed and fenced off.
 - Coordinate the security of the site and physically protect areas important to the investigation against tampering and/or degradation.
 - Document the site with video and photography of all areas.
- ✓ Coordinate with the owner and consider contacting ASDSO or another qualified entity to discuss whether an investigation is needed and how to conduct an investigation.
- ✓ Alert appropriate State officials that a failure investigation will likely be needed (when appropriate). Point out the benefits of an independent investigation and the pitfalls if not performed or not performed properly [see Baker 2008].
- ✓ Develop an initial press release stating the main points that the public needs to know and work with public affairs staff to post on Internet and distribute to the public and news entities. Media interest can be intense. Include an appropriate concern for people or their families who have been impacted by the failure (loss of life, injuries, damaged homes, etc.).
- ✓ Establish a public website and post all available information.
- ✓ Perform photo and video documentation of the site. Document inundated areas downstream. Disaster response agencies may perform aerial photographic survey mapping to determine the extent of the damages.

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- ✓ Send a formal communication to the dam owner that an investigation will likely be conducted and that they are prohibited from making physical changes to the site (except as necessary to make the site safe). This communication should also state that all information regarding the dam must be retained and not destroyed.

How should a Communication Plan be prepared?

- ✓ Work with your public affairs office to determine a media point of contact.
- ✓ Determine the main information points to communicate to the public, such as:
 - Concern for people and their families that were impacted.
 - The State is committed to finding out what happened at the dam and why it failed. (Avoid speculating on cause.)
 - This dam failure is a serious issue that needs to be addressed.
 - The State's dam safety office is the appropriate entity to address this problem because of their mission to protect the public.
 - The State dam safety office has a reasonable and responsible approach to handle this issue.
 - The State is committed to full transparency and sharing of all information.
 - The State dam safety office is listening, cares, and will address issues as they arise.
 - The state has set up an email/hotline for the public for share photos/videos/concerns or other information about the failure.
- ✓ Prepare to provide background on the dam of concern, dam safety generally, and the State's dam safety program:
 - Find the number of dams in your state, their hazard class, and ownership.
 - Collect information on the number of dams with dam safety concerns or issues (especially issues similar to the current incident)
 - Get program component background – authority, inspections, and design criteria.
- ✓ Prepare for questions, such as:
 - When was this dam last inspected?
 - Who owns or is responsible for the dam?
 - What caused the dam to fail?
 - Will there be an investigation?
 - What is the State doing for the victims?
 - Where can people go for help?

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- Questions about rumors.
 - Are there other dams like this one that may fail?
 - Is the event over, or are there more dams that may fail in the immediate future?
 - How many State dam safety staff are there? How many for each dam?
- ✓ Determine methods of communication
- Press releases
 - Formal letters
 - Data (drawings, reports, photos)
 - Social media
 - Website
 - Interviews
 - Press briefings

SETTING UP THE INVESTIGATION

When should an SDSO set up an investigation?

The following should be considered in determining whether an investigation is necessary:

- ✓ Did the failure cause loss of life or injuries?
- ✓ Was there a large evacuation?
- ✓ Did the failure cause significant economic, cultural, or environmental impact beyond that of the dam owner? Are there likely to be lawsuits to recover damages?
- ✓ Is the dam regulated by the State?
- ✓ Are there likely technical lessons to be learned?
- ✓ If the event was an incident, but not a failure, would an investigation be beneficial to resolving the event and for lessons learned for the dam safety industry?
- ✓ Was there a federally declared disaster or emergency?
- ✓ Was there high press coverage?

Note that the State may choose to perform an investigation of a failed dam regulated by others.

How is an investigation initiated?

- ✓ Contact ASDSO and discuss the need for an investigation
- ✓ Create a document describing the dam failure and the reasons for the investigation (see objectives below).
- ✓ Consider routing the draft document for review (such as to ASDSO or other SDSOs).
- ✓ Brief or transmit the document to State officials who would authorize and fund the investigation.

What are the objectives of the investigation?

- ✓ Uncover and document the facts
- ✓ Restore/maintain public confidence
- ✓ Coordinate/manage the failure aftermath
- ✓ To determine the mechanical failure processes and the human/organizational causes of the failure so failures can be prevented in the future
- ✓ Prevent/reduce rumors and cause speculation by others

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- ✓ To learn about the emergency response, warning and evacuation
 - ✓ Serves as an authoritative factual basis for any future judicial proceedings

How quickly should the investigation be established?

In general, the sooner the investigation is established, the better. Evidence can change or degrade. People's memories fade or become inaccurate. Investigations can take weeks to authorize, fund and staff. That is why it is important to collect perishable information (e.g. witness statements, photos, documents) during and immediately following an incident/failure. If the investigation cannot be quickly established (within a few days), consideration should be made to having State dam safety staff or others collect information in the field and provide the information to the team once it is formed.

Once approval is received for an investigation, what is the next step?

The SDSO should draft an investigation charter which describes the investigation objectives, scope, timeframe, funding authority, resources to be provided to the team, limitations, needed disciplines, etc. The document should have signature blanks for the investigation team leader and the State. A press release should be issued.

What should be the scope and scale of the investigation?

The investigation scope must be broad enough to encompass all contributing causes (physical/human/organizational) which contributed to the causes of failure. The investigation could include investigation of upstream and downstream impacts. It could also include the emergency management responses to the failure, including warning and evacuation. Review of the regulator, designer, construction firm, dam owner/operator should all be included in the investigation.

The team may need to include in their scope of work answers to questions by the public or media. For instance, how the dam failure contributed to a natural flood and whether alternate operations would have affected the outcome.

For small, low hazard, non-complicated failures, a single, well-qualified individual may be able to conduct the investigation. Conversely, a high hazard or large failure could involve a large team and even sub-teams to cover many technical issues and disciplines. All investigations should have the expertise and resources needed to competently perform the investigative work required.

If there are multiple teams, an overall management structure should be put in place to protect evidence, share data, prevent overlap/confusion, and to coherently communicate with the public.

How much will the investigation cost and who will fund it?

A simple low hazard dam failure with limited consequences may be able to be investigated by a single competent engineer for less than \$10,000. The 3-member Lake Delhi investigation team cost roughly \$110,000. The investigation following the New Orleans levee failures cost many millions of dollars. The Spencer Dam Failure investigation cost several hundred thousand dollars. The cost will depend on the number of members, complexity, number of team members, and scope of the review.

There are multiple potential options for funding an investigation. Some of the possible options are as follows:

- Investigators and other resources could be provided by others at little to no cost to the states. As an example, following the Lake Delhi failure, three Federal agencies provided team members at no cost to the State.
- If a federal disaster or emergency is declared, FEMA may be able to fund or conduct the investigation.
- The dam owner could fund the investigation (although it needs to be carefully established so that it isn't perceived by others as not being independent).
- Some states may be able to fund all or part of the investigation. The State could then attempt to recoup costs from the dam owner, if they desired.
- Some engineers may be willing to volunteer their time because of their high interest in learning the lessons from dam failures and the importance they place on contributing to the improvement of their dam safety industry.
- The SDSO can contact ASDSO to discuss funding strategies.

What issues arise if the State sets up an investigation but may not have adequately inspected or regulated the failed dam?

There may be a reluctance of a State to set up an investigation if the State may not have fully fulfilled its policies/guidelines for properly regulating a dam that has failed. However, this information will likely come into the public at some point even if an investigation is not performed. The authors of this document believe that it is better for the State to initiate and conduct a fully open and comprehensive investigation at the beginning. This helps to restore the public trust and prevent intrigue/speculations/inefficiency later. Failure to include the State's activities in the investigation could threaten the independence and credibility of the investigation.

How can I assure the independence of the investigation team and its members?

The members should be chosen by an independent body (Such as ASDSO) and assigned from organizations that have no actual or perceived interest in the outcome of the investigation. Team members may be asked to sign a “no conflict of interest statement.” The perceived independence can be affected by who sets up the investigation, who selects team members, who pays, etc. Team members or the organizations they work for should not have been involved in the dam’s planning, design, construction, ongoing inspection/evaluation or repairs.

In general, what are some steps to initiating an investigation? ?

Here are some steps:

- ✓ Brief senior State officials (e.g., the natural resources director and attorney general) on the failure and next steps. Cite previous dam failure experiences (good and bad) and the benefits of conducting a thorough and independent technical investigation.
- ✓ Coordinate with ASDSO/other qualified entities, and the dam owner about the possibility of an investigation. Discuss the following:
 - Scope of the investigation: should it review only the failure at the dam site or should it also include a review of the emergency response?
 - Scale of the event and consequences of failure.
 - It is preferable to ensure independence that a separate entity choose the investigation team members. This entity will consider the likely failure modes involved, the disciplines needed. The team members will need to be senior level, respected people within their discipline and the dam safety community. In general, these team members should have a strong command of dam design, construction, monitoring, instrumentation, failure modes and maintenance. Experience in dam incidents and failures investigations is desirable. Team members need to be experts in non-technical aspects of the failure such as dam safety programs and human factors.
 - Identify the team member that will lead the investigation
 - Technical Advisors can be assigned on a part time basis to the team to cover specific technical disciplines that are not a main focus of the investigation.
 - Team members need to be vetted, in writing, of any potential conflict of interest that they or the organizations they work for may have.
 - The need to quickly set up the team and perform a site visit. Some site data and people’s memories will degrade with time.
 - Note that large/complex failures may need task groups (e.g., for modeling) to support the investigation team. Large/complex failures may also warrant the creation of a separate peer review team to review the work of the investigation team.

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- Develop a formal memorandum or letter and establish the investigation emphasizing the team's independence. Identify team members and their credentials. State the scope and objectives that the team be open, thorough and transparent. This helps to establish team credibility and trust. Send this memorandum/letter to the team and other interested parties (e.g., the media).

What are some examples of how investigations were established?

*The **2010 Lake Delhi Dam Failure**. The SDSO contacted the Bureau of Reclamation about performing an independent investigation. The Bureau of Reclamation, FERC and the USACE each provided one team member at no cost to the dam owner.*

2015 Failure of 49 Jurisdictional South Carolina Dams. FEMA's mitigation group deployed a team to assess the failed dams and provide expertise and insights. [FEMA South Carolina Report](#).

*The **2017 Oroville Spillway incident investigation**: The dam owner requested that ASDSO and USSD select the investigation team. ASDSO and USSD established a joint team. This team selected the investigation team members without input from the dam owner or regulator. The contracts to pay the investigators were negotiated with the dam owner.*

*The **2019 Spencer Dam Failure Investigation**: The SDSO recommended that the dam owner (a utility) have an independent dam failure investigation performed. The dam owner contacted ASDSO. ASDSO set up a Spencer Dam Oversight Group. They surveyed ASDSO membership for interest and selected the Spencer Dam Failure Investigation team. The team members negotiated contracts with the dam owner.*

Are there times when it may be appropriate that more than one team be established?

Yes. For both the Taum Sauk and Silver Lake dam failures, the Federal Energy Regulatory Commission (FERC) established data collection teams and independent investigation teams. The data collection teams were sent to the site quickly and performed analyses. Later, the independent investigation teams were established.

How should the project be managed?

There can be a lot of logistical, coordination, and management tasks involved in conducting an investigation. For larger investigations, it may be desirable to identify a project manager for the team. This project manager will free the technical investigation members and the leader to focus on the technical aspects of the investigation. On some teams, the team leader can fulfill the project manager role.

Will there be other investigations?

Early establishment of a robust failure investigation team will lessen the likelihood that other investigations will arise. However, there may be other investigations. The following examples of entities may proceed with their own investigations:

- The dam owner
- The dam designer or construction firm
- Law enforcement
- Insurance company
- State Legislature
- Office of State Inspector General
- Congress (usually for failures of Federally regulated dams)
- General Accounting Office (usually for failures of Federally regulated dams)
- Federal agencies (usually for failures of Federally regulated dams), federal agencies may also conduct investigations of non-federal dams to more fully develop their dam technical practices or emergency management practices

Any site investigations (e.g. drilling) by multiple investigation teams must be coordinated. Multiple, uncoordinated site investigations will likely lead to confusion and loss of evidence. Coordination should be initiated as soon as possible by a conference call or meeting with all investigative parties. Consider the need for only one on-site field program that collects the needed information for all parties. Periodic coordination meetings/updates should be held.

How is the potential liability of team members addressed?

Liability could include the following:

- Needing to appear as an expert or fact witness
- Being sued
- Being subpoenaed for documents

The report should contain a signature page with a narrative of professional statement and limitations (there may be several standard disclaimer examples available). If the investigation team members are State and Federal employees, their liability is limited because the State and Federal government will represent them if they were acting within the scope of the job. Any liability concerns should be identified and addressed early by legal counsel.

Once team members are identified, what are the next steps?

- ✓ Provide a letter of authority to the investigation team leader to conduct the investigation.
- ✓ Ensure that the investigation team has appropriate authority to access the site – in some cases provide a letter to the dam owner authorizing the investigation team.
- ✓ Identify a State person and a dam owner representative to liaison with the team.
- ✓ Review the communication plan for ways to announce the investigation, its independence, membership, and objectives. Emphasize transparency and welcome input from the public.
- ✓ Negotiate contracts with non-volunteer investigation team members.

How long will the investigation take?

A relatively straightforward investigation can be completed in 2 to 3 months. It is more typical for an investigation to take about 6 months. Investigation of a major dam failure (such as Teton or the New Orleans Levees) may take years.

CONDUCTING THE INVESTIGATION

What, in general, are the steps in conducting an investigation?

- ✓ The team collects and reviews dam and event information, records, and files.
- ✓ The team visits the site and collects site information, conducts interviews, and reviews local records.
- ✓ The team performs additional site forensic investigations, modeling and analyses.
- ✓ The investigation report is developed, reviewed, signed, and transmitted.

How should the investigation team's work begin?

The team should have a kickoff meeting (conference call) to plan and begin the investigation. Some of the topics discussed should include:

- ✓ Development of a project plan
- ✓ Discussion of the authority documents
- ✓ Designation of team leader
- ✓ Planning for communication with media and others (key messages/what to say/not to say)
- ✓ Data sharing and intra-team communication methods (FTP, SharePoint, email groups, etc.)
- ✓ Reviewing data collected and asking what additional data is needed

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- ✓ Consider what geotechnical (or other) field data collection program is needed
 - ✓ Hydrologic and seismic data of the event and the record of reservoir elevations (as appropriate)
 - ✓ Plan for the site visit (when, safety, equipment needed, agenda, objectives)

What philosophy and approach should the team have?

Each failure investigation should be conducted to address the specific circumstances of each particular failure. However, the following are some general considerations which will apply to most failure investigations:

- ✓ The investigation is not just about the discovery of the actual physical processes which led to failure. Beyond the physical dimension, the investigation should also address the human contributors to failure such as poor design, poor construction, lack of inspection, poor maintenance, inadequate training, incorrect operations, lack of staff, ineffective organizational culture, misadjusted instruments, poor regulation, etc. These human factors can generally be divided into three categories: (a) lack of information (e.g., due to limited materials sampling and testing), (b) lack of understanding (e.g., due to inaccurate analytical models), and (c) errors, heuristics, and biases in human reasoning, judgment, and decision making at both individual and group/organizational levels.
- ✓ Each team member should have an open mind and not prematurely lock in on favored hypotheses regarding causes and failure modes until all data is available, analyzed, and reviewed. However, it may be helpful to develop multiple *candidate* hypotheses early in the investigation through dialogue among team members, with hypotheses then being modified, rejected, and added as the investigation progresses, and with the ultimate goal being to identify a single leading hypothesis at the conclusion of the investigation. While the investigation is under way, these tentative working hypotheses generally should not be shared with the public, since doing so can create a bias to resist changing the hypotheses.
- ✓ Scientific hypotheses can usually be extensively tested, with the hypotheses considered to be increasingly corroborated as they pass more tests over time. In contrast, dam failures involve a single event which has already occurred, and thus cannot be replicated even once for testing, much less multiple times. As a result, the plausibility of failure hypotheses should be judged based on how well each hypothesis fits the available evidence, both in absolute terms and relative to competing hypotheses.
- ✓ All information about the dam should be thoroughly researched, collected, scanned (with good file names), and placed in electronic folders. Records may be in multiple locations in various formats. It is essential that records are located early. Records that are found later in the investigation have the potential to cause disruption to efficiency and workflow.
- ✓ The team should carefully consider the report drafting, review and finalization steps using current file sharing technology.
- ✓ Consider all possible failure modes and their causal interactions in space and time:

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- Instead of there being a single primary/root cause, there may be multiple causes of comparable importance.
 - Causes may act in parallel such that they counter each other, add to each other, and/or amplify each other (e.g., interaction of seepage and erosion involved in piping). The history of repairs, even minor, may shed light on the causes of the ultimate failure/incident.
 - Causes may follow each sequentially, so that if A causes B, B in turn causes C, with B thus serving as both cause and effect.
 - Flow charts or branching failure mode event trees may aid in graphically displaying processes.
 - One cause can contribute to different effects in varying degrees, and a given effect may have several causes which contribute in varying degrees. In other words, a “cause/effect matrix” may be involved, as developed by one of the Committee members (Alvi) for investigation of partial failure of Prettyboy Dam.
 - In short, failure can be due to an elaborate set of non-linear events, and so a goal of failure investigation is to develop a narrative “story” which explains the failure. This is analogous to the approach taken in historical sciences such as cosmology, geology, evolutionary biology, and archeology (and perhaps history itself).

What information should be provided to the team?

Provide contact information for state staff, dam owner, dam operators, eyewitnesses, and law enforcement.

Provide all dam information, including dam design drawings/specifications, dam modification design drawings/specifications, construction reports/photos, performance/monitoring information, inspection reports, EAP, inundation map, and correspondence.

Also, provide event information including: press releases, eyewitness accounts, log of operations, event timeline, photographs, video, surveys, news reports, emails, and websites.

The team may need to request/search for information not provided by state and owner. Sources may include museums, libraries, etc. The team may request information directly from the public.

How should information be provided to the team?

Because team members will likely be located in different areas of the country, electronic sharing of information is preferred. However, some file sizes can be very large. Because of the large volume of files, mailing hard drives via trackable mail may be preferable to using a file share website. Effort spent to name files correctly and placing them into descriptive folders will prevent a lot of inefficiency and confusion.

What will the team do during the site visit?

- ✓ The team will normally attend an entrance meeting with State representatives at an office near the dam site.
- ✓ The team should complete a written job hazard analysis specific to places to be visited (e.g. the dam site).
- ✓ The team should review additional local and State office records.
- ✓ The team will go to the dam site. Often, they will take measurements, perform limited surveys, collect material samples, take photos, and plan further site investigation.
- ✓ The team should conduct pre-arranged individual interviews in-person with the following: eyewitnesses, dam operation staff, maintenance staff, bystanders, inspectors, dam designer, contractors, and others. It is important to document what people were thinking or doing and what they saw, heard or felt. Tie people's recollections to the time line of events. Prepare a list of questions in advance of the interviews. The process of interviews can range from casual to sworn/recorded testimony. If there are many witnesses, it may make sense to request them to document their experiences through a written, open-ended questionnaire with a follow-up in person interview.
 - In general, focus on open ended, non-leading questions which allow the person to fill in all necessary details. Direct yes/no questions should only be used for verification or clarification purposes. The investigation team should be able to answer the who, what, when, where, why and how related to each line of questioning.
 - Use a logical questioning pattern while obtaining information, e.g., go from the general to the specific or use a time sequence past to present.
 - The team should identify what they did to verify the truth or accuracy of the statements made by a person.
- ✓ In accordance with the communication plan, the State should consider setting up a public meeting so people can meet with the team, learn about the investigation, and provide information.
- ✓ Develop a timeline of events.
- ✓ Conduct multiple site visits if necessary.

What types of forensic data collection and analyses may need be performed?

The types of forensic studies and related data collection efforts depend on the dam type, the failure modes, and the extent of the data available. For example, if the failure involved the foundation and there is little information about the foundation, it may be necessary to conduct a drilling/sampling exploration program.

A site survey (topographic) should be performed soon after failure. A survey will provide needed information for most subsequent analyses.

Studies could include:

- Geophysical
- Geotechnical
- Hydrologic/Hydraulic
- Surveys
- Structural
- Mechanical/electrical
- Organizational influences

The team should also visit upstream and downstream areas affected by the failure. If the investigation includes emergency management, warning and evacuation, the team should interview local public officials with these responsibilities.

How should information collected be documented and organized for records management?

Through the process of collecting and recording information, proper documentation is essential. The team should ensure all information is complete and technically accurate.

- ✓ Use field notes, photographs and checklists as the primary method of documenting investigation activities.
- ✓ Observations, calculations and measurement entries should be clearly and permanently recorded at the time they are made.
- ✓ Records must be legible and recorded in permanent ink. Error corrections should not be obliterated or erased. Error corrections should be single lined out, dated and initialed or signed.
- ✓ Consider scanning all collected information and posting the data in a well-organized, but protected, file-share site.

What other work might the team perform?

- ✓ Conducting briefings
- ✓ Developing the outline of the investigation report
- ✓ Developing graphics to visualize processes and the failure sequence
- ✓ Coordinating with any other ongoing investigations
- ✓ Serving as fact witnesses for subsequent court proceedings

INVESTIGATION REPORT

Who is the intended audience for the report?

The report will be read by the State, the dam owner, relatives of those who have died or been injured (if any), people or entities who have experienced losses, the press (and therefore the larger public), the justice system (plaintiffs, defendants, attorneys, judges), and engineers wishing to improve the practice of designing, constructing/operating dams. The communication plan should be consulted for how the report should be drafted and organized.

It is important to be in control of the message that goes out. The report should be organized and written to allow for understanding by all of the above (this could be accomplished by including an executive summary). This may mean explaining the failure cause(s) in layman's terms for the public, as well as in highly technical terms for the engineering audience. When in-depth technical work needs to be included in the report, consider putting it in as an appendix. Actual photos or created visualizations of the failure sequences can serve both audiences.

What should the tone of the report be?

The report should focus on presenting the facts in an understandable manner. While the report should document all potential failure causes, it should focus on those causes which contributed to failure.

The report should not be blaming – it should be constructive and make positive, actionable recommendations for improvement.

What should the report contain?

The report should contain all important material relevant to the investigation. To avoid making the report too large, use appendixes.

How should the report be organized?

Here is a sample table of contents:

Title page

Signature page

Executive Summary (include consequences)

Table of Contents

Authority (scope and Purpose)

Methodology (how the team performed its work and limitations)

Project Description

Dam description, history, safety regulation, hazard classification

Design (as applicable to the failure modes)

Construction (as applicable to the failure modes)

Operations and Maintenance (as applicable to the failure modes)

Instrumentation and Monitoring (as applicable to the failure modes)

About the Failure Event

General description

Detailed chronology (incorporating history, witness accounts, operation records, efforts to save the dam, photo/video evidence, instrumentation records)

Emergency response

Failure modes considered (include flood and earthquake loadings, if applicable)

Summary of field data

Analyses

Likely Causes of Failure (contributing causes of failure could include organizational and human factors, as well as poor maintenance, operational errors, instrumentation problems, poor design/construction, lack of monitoring, and anything else that created the situation which put the dam at risk, regulation)

Acknowledgement of other investigation reports (if any)

Conclusions

Safety Recommendations (Identify the audience of each recommendation)

Other Recommendations (additional investigations and other recommendations. Identify the audience of each recommendation.)

Acknowledgements

List of references

Glossary (if appropriate)

Dissenting opinions of team members (if any)

Resumes of investigation team members

Appendices:

- Historical chronology of the dam
- Timeline of failure events

-
- Pre and Post-Failure photographs
 - Drawings
 - State regulatory program
 - Operational logs
 - History of dam inspections and findings/recommendations
 - Hydrologic modeling and flood routings
 - Geotechnical analysis
 - Hydraulic structures analysis
 - Instrumentation/monitoring data
 - Causes considered but deemed not relevant

Who should review the draft report?

Develop a plan for review of the report; normally the report is not sent to the public in draft. The report may need to be reviewed by the following:

1. Team members
2. Entities who authorized the investigation
3. Technical peer reviewer (depending on the scope/scale of the investigation)
4. It may be acceptable to have the dam owner and regulator to review the report to ensure facts are correct, but they should be told in writing that review and comment on the conclusions and recommendations of the team will not be considered. The report methodology should acknowledge the limited review of the owner and regulator if they comment.

How is the report finalized and who should receive the final report?

Develop a plan for reviewing, signing, finalizing, and distributing the final report. Each member should sign the final report. The signed report should be sent under letter of the investigation team to the entity that established the team. Copies of the letter (with report attached) should be sent to other interested parties.

The state and dam owner should be made aware when the report will be issued.

The State can issue a press release indicating that the investigation is complete and including a link to the report itself. Public meetings can be held to share the results with the public. The report should be posted on the Web site. It may be beneficial to post a large amount of data on the failure to show openness and enhance public trust.

SHARING LESSONS FOR THE FUTURE

A primary objective of the investigation is to identify specific safety recommendations with a target audience. The tone of the recommendations should be on what can be done to improve dam safety – not on assigning blame, fault or responsibility.

Lessons for the future can be in the areas of dam design, operations, monitoring, inspection, construction, operations, maintenance, standards, emergency management, warning, evacuation, guidelines, policies, risk, research, regulation, or ownership.

The investigation team should develop and deliver papers/presentations to dam safety conferences/literature. An engineering case study should be developed so that engineers can learn from the failure in a facilitated session. Consider disseminating lessons learned through ASDSO or similar organizations.

Lessons about particular failure modes should be shared with organizations that represent engineers in that area. For example, if the failure mode involved a specific type of gate, the report should be sent to entities that design, construct, or operate dams with that particular type of gate.

CONCLUSIONS

- > Dam owners and regulators should prepare themselves and their management for the potential for a dam failure and the need for an investigation.
- > Dam failure investigations are important to learn from the failures, prevent failures in the future and restore public trust that may have been lost because of the failure.
- > It is essential that the selection of investigation team members and the investigation be independent from the dam owner or regulator. Team members must be free from any conflict of interest. Any

perceptions of conflict of interest have the potential to cause a media controversy and undermine or kill an investigation.

- > The owner or regulator should collect information about the failure as it is happening and in the following days.
- > Recent examples have shown that it can take weeks or months to get the investigation teams established and under contract. The dam safety industry should establish quicker means to performing prompt investigations.

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Lee Wooten, PE - GEI Consultants

REFERENCES

[1] Dam Failure Investigation Approaches, Baker, Mark and Graham, Wayne, ASDSO, 2008

[Independent Forensic Team Report Oroville Dam Spillway Incident](#)

[Spencer Dam Failure Investigation Report](#)

APPENDIX A

Table 1
Summary of Selected Dam Failures and Investigations

Year	Dam Name, State	Dam Height (ft)	Water Released (ac-ft)	Owner/Regulator	Loss of Life	Damages	Brief Summary of Investigation Process
1972	Buffalo Creek, WV	44	982	Private Coal Company/ None?	131	\$19 million (1972 dollars)	<p>Governor appointed an "ad hoc" commission. There were public concerns about perceived lack of independence of commission members. The final commission report is at: http://www.wvculture.org/history/disasters/buffcreekgovreport.html</p> <p>U.S. Department of the Interior established a Federal commission. The U.S. Senate requested the USACE to investigate other coal waste dams in the region.</p>
1976	Teton, ID	305	251,000	Bur Rec/Bur Rec	11	\$300 million (1976 dollars) 3000 homes were destroyed.	<p>3 days post failure, the US Department of the Interior established the Interior Teton Dam Failure Review Group (IRG). They had three different subgroups: geology, grouting, and embankment construction.</p> <p>The State of Idaho also established the "Independent Panel to Review Cause of the Teton Dam Failure." The final report is at: http://www.archive.org/stream/reporttousdepart00inde/reporttousdepart00inde_djvu.txt</p> <p>The General Accounting Office also reviewed the dam design/construction practices of Reclamation and the USACE.</p>

2003	Silver Lake Fuse Plug Spillway, MI	33*	25,000	Electric Utility/ FERC	0	\$100 million. Damaged homes, roads/ bridges, and flooded a large coal powerplant.	Staff engineers were immediately dispatched to site. The FERC formed an investigative team. A separate "Independent Review Board" was also established. The utility also hired a consultant to review the failure. The final report is at: http://www.ferc.gov/industries/hydro/power/safety/projects/silver-lake.asp
2004	Big Bay, MS	51	14,200	Private land owner/ State of Mississippi	0	\$8.5 million. More than 100 homes were destroyed.	The dam owner employed a consulting engineer to investigate the cause of failure.
2005	New Orleans Levees, LA	Approx . 15	250,000	Various/ USACE	Approx. 1200	\$20 - \$28 billion. 100,000 homes damaged or destroyed.	The USACE formed the Interagency Performance Evaluation Task Force (IPET) consisting of 23 members from Federal, water districts, a consultant and academia. Their work was peer reviewed by the National Research Council. The final IPET report is at: http://www.usace.army.mil/CEC/W/Pages/ipetrep_final.aspx An independent investigation was also performed by a team led by the University of California at Berkeley and sponsored by the National Science Foundation - here is their report: http://www.ce.berkeley.edu/projects/neworleans/

2005	Taum Sauk Upper Reservoir, MO	84	4350	Private utility/ FERC	0 deaths, 4 injuries	Fines totalled \$195 million. The dam replacement was very expensive.	Within 2 days, the FERC published an Action Plan. There were two investigative teams: one team of FERC dam safety engineers and an independent panel. Final report: http://ferc.gov/industries/hydro-power/safety/projects/taum-sauk.asp
2006	KaLoko, HI	50	1140	Private owner/ State of Hawaii	7	Several homes and roads were destroyed. Damages totaled about \$9 million	The State attorney general began an investigation. A citizen's group calling itself "Dam Mad" launched a petition drive for an independent investigation believing that the attorney general had a conflict of interest. The State legislature established a "Hawaii Special Deputy Attorney General" (also an engineer) to investigate. A criminal case was filed against the dam owner and has taken many years to resolve. Investigation report: http://pinetreewatchdog.org/wp-content/uploads/2011/08/Kaloko-Report.pdf
2010	Lake Delhi	38	9920	Recreation association/ State of Iowa	0	16 residences destroyed/70 damaged. 180,000 cubic yards of sediment released downstream.	The Iowa governor sent a letter to FEMA requesting an investigation team. FEMA worked with the National Dam Safety Review Board to form a team. The USACE, Bur Rec, and FERC provided members gratis. The team did not arrive on site until six weeks following the failure.

2017	Oroville Dam California	770	Not a release of reservoir	CA Dept of Water Res	0	Extensive damage to spillways and deposition of material in river	The DWR (with FERC concurrence) requested ASDSO and USSD to nominate experts to a forensic investigation team. DWR accepted the nominations. The team's work is ongoing as of July 2017
2019	Spencer	26	16,500	Nebraska Public Power District	1	The dam was destroyed. One home, saloon and RV camp were destroyed. Bridges were also destroyed, but may have been destroyed by the ice run whether the dam failed or not.	4-member panel. Members selected by an ASDSO team. Investigation funded by the dam owner. Investigation duration was 7 months. There were 12 lessons learned and 11 appendixes. The report can be found here .

* Height includes the combined height of the fuse plug embankment and the fuse plug foundation material eroded in the breach event.

APPENDIX B

List of Suggested Equipment for Responding in the Field

Many of the below items are from a paper presented at the Association of State Dam Safety Officials (ASDSO) conference by Jerry Oden at Montgomery County Maryland.

Maps showing alternative access and locations for outgoing communication on satellite phones, cell phones, or field radios	Bolt cutters (for locks when people forget their keys)
Clear jars for taking seepage samples and determining if piping is occurring	Proper identification
Flags and stakes for marking seepage areas	Hard hat, high-visibility vest
Tape measure	Rope, safety equipment/clothing
Five-gallon bucket and stopwatch	Tools: hammer, screwdrivers, pliers, vice grip
Digital camera, batteries, and USB cable	Staff rod, probe pole
Duct tape and knife	Life vest
Power inverter and battery cables	Whistle
Laptop for Web access (email, sharing photos, monitoring weather)	Chest waders
Good rain clothing (Tyvek suits work well), umbrella, waterproof boots	Foldable ladder
Cell/satellite phone	Amber rotating beacon for vehicle
Extra batteries/chargers for camera, phone, etc.	Leather gloves (two pair)
Paper (including waterproof paper), pencil, all weather writing pen, black Sharpie, lumber crayon, highlighter	Flashlight (with batteries)
Ruler, clipboard, sticky notes, clips	Mini-marker flags
Bubble level (for measuring wall tipping)	Orange surveyor's flagging
Calculator	Orange spray paint
	Personal first aid kit
	Traffic flares (three each)
	Orange traffic flag
	Folding pocket knife