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Best Practices to Prevent Releases from Impoundments at Abandoned Mine Sites while Conducting CERCLA Response Actions

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NOTICE AND DISCLAIMER

This document presents best practices and approaches to reduce the threat of, or prevent, a proposed Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) activity from causing a breach or failure of impoundments at abandoned mine sites. These best practices are based predominantly on current U.S. federal and state practices and standards for management of operating impoundments but have been adapted to the conditions found at abandoned mine impoundments.

This document is not intended to provide approaches on how to remediate and close abandoned mine impoundments nor does it provide information on the design, construction, and inspection of active impoundments. This document does not address how to respond to natural events that could cause abandoned mine impoundment failure; it only addresses field activities associated with U.S. Environmental Protection Agency (EPA) CERCLA response actions.

This document provides considerations and recommendations and does not impose legally binding requirements, nor does it confer legal rights, impose legal obligations, implement any statutory or regulatory provisions, or change or substitute for any statutory or regulatory provisions. It is important that users of this document also refer to applicable regulations, policies, and guidance documents.

The best practices presented in this document and in other documents referenced are intended to serve as technical resources for EPA working on CERCLA sites with abandoned mine impoundments. Mention of specific products does not constitute endorsement or promotion of those products.

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ACRONYMS AND ABBREVIATIONS

§	Section
AML	Abandoned mine land
ASDSO	Association of State Dam Safety Officials
ASTM	American Society for Testing and Materials
BOR	Bureau of Reclamation
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
CNEAP	Contingency, notification, and emergency action plan
CPT	Cone penetrometer testing
CSM	Conceptual site model
DHS	U.S. Department of Homeland Security
DPT	Direct push technology
EC	Engineering control
EPA	U.S. Environmental Protection Agency
EPRP	Emergency preparedness and response plan
ETA	Event tree analysis
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FHWA	Federal Highways Administration
FMEA	Failure modes and effects analysis
FOS	Factors of safety
GBC	Government of British Columbia
GPR	Ground penetrating radar
H&H	Hydraulic and hydrologic
HSA	Hollow stem auger
ICMM	International Council on Mining and Metals
IDF	Inflow design flood
InSAR	Interferometric synthetic-aperture radar
LEA	Limit equilibrium analysis
LIDAR	Light detection and ranging

ACRONYMS AND ABBREVIATIONS (CONTINUED)

MAC	Mining Association of Canada
MCE	Maximum credible earthquake
MDE	Maximum design earthquake
MSHA	Mine Safety and Health Administration
NCP	National Contingency Plan
NID	National Inventory of Dams
NOAA	National Oceanic and Atmospheric Administration
OSC	On-Scene Coordinator
OSMRE	Office of Surface Mining, Reclamation, and Enforcement
PE	Professional Engineer
PFM	Potential failure mode
PG	Professional Geologist
PGA	Peak ground acceleration
PH	Professional Hydrologist
PMF	Probable maximum flood
QA/QC	Quality assurance/quality control
RPM	Remedial project manager
SEE	Safety evaluation earthquake
SPT	Standard penetration test
START	Superfund Technical Assessment and Response Team
Tetra Tech	Tetra Tech, Inc.
TSF	Tailings storage facility
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
USACE	U.S. Army Corps of Engineers
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
USSD	U.S. Society on Dams
WISE	World Information Service on Energy

1.0 INTRODUCTION

Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the U.S. Environmental Protection Agency (EPA) performs a range of activities at abandoned mine land (AML) sites. CERCLA authorities may be used to respond to releases or threatened releases of hazardous substances, as well as pollutants or contaminants, into the environment, "which may present an imminent and substantial danger to the public health or welfare" (40 *Code of Federal Regulations* [CFR] Section [§] 300.130). The National Oil and Hazardous Substances Pollution Contingency Plan, more commonly called the National Contingency Plan (NCP), is EPA's blueprint for carrying out CERCLA response actions. The adoption of any of the best practices noted in this document cannot be inconsistent with the NCP. While this best practices document was prepared for use by EPA, federal land management agencies such as the U.S. Department of the Interior and the U.S. Forest Service, also have authority to implement CERCLA actions on federal lands. EPA regions and their site support partners and contractors should follow the best practices laid out in this document when carrying out CERCLA removal, remedial, and site investigation activities at Superfund sites with abandoned mine impoundments.

This best practices document presents approaches to prevent a failure[1] at abandoned[2] mine impoundments[3] that result in a sudden release of fluid and liquefiable mine waste[4] from a proposed CERCLA activity. The application of these best practices depends on site-specific conditions that, in limited cases, may warrant the use of alternative technologies and approaches to those described in this document. The key activities for assessing and mitigating the potential impacts of such releases from a proposed CERCLA action at an abandoned mine impoundment include:

- Conducting an initial impoundment condition assessment, including development of a conceptual site model (CSM), of whether the proposed CERCLA action has the potential to cause a failure or breach at an abandoned mine impoundment;
- Determining the need to collect additional geotechnical data;
- Developing a drilling and excavation plan;
- Performing a failure modes and effects analysis (FMEA) of the proposed invasive activity;
- Developing or revising contingency, notification, and emergency action plans (CNEAP);

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[1] "Failure" as used in this document refers to situations where impoundments or impoundment structures fail, releasing contained waste. Failure modes include overtopping, slope instability, earthquakes, seepage, structural inadequacies (such as pipe leaks or collapses), and foundation conditions.

[2] "Abandoned" as used in this document refers to situations where impoundments are no longer actively managed, maintained, or regulated as waste management units. In some cases, abandoned mine impoundments may be located on property with owners, operators, or claimants.

[3] "Impoundment" as used in this document refers collectively to the whole impoundment structure, including any impounded waste and associated impoundment structures, such as dams, berms, liners, and spillways. Impoundments in this document are limited to abandoned above-ground tailings, storm water, and process water impoundments at former mine sites.

[4] "Fluid and liquefiable mine waste" as used in this document includes impounded water, impounded process waste and waters, process solutions, high moisture content tailings, and other mine wastes disposed of in an abandoned impoundment. It should be noted that there may be varying degrees of saturation of wastes within an abandoned impoundment.

- Collecting data by minimally invasive and invasive (drilling and pit excavation) methods[5];
- Determining impoundment hazard potential, factors of safety (FOS) and condition ratings; and
- Mitigating identified impoundment failure risks that do not meet FOS prior to conducting a proposed activity.

Use of the approaches described in this document may not be necessary if an abandoned mine impoundment no longer holds liquids or saturated wastes and poses no known risk of failure based on existing records, site evaluations, and monitoring data. However, investigating and remediating wastes present within such abandoned mine impoundments may be appropriate under existing CERCLA authorities since wastes may remain in a saturated state even after an impoundment has been breached or dewatered and can suddenly flow downgradient under hydraulic or seismic conditions.

Abandoned mine impoundments are typically constructed of concrete, tailings, or other earthen material, such as rock, waste rock or unconsolidated overburden. The fine grain size of mill tailings compared to the coarse, heterogeneous grain size of waste rock means that tailings impoundments may tend to be saturated and anoxic whereas waste rock piles tend to be unsaturated and oxic. Abandoned tailings impoundments themselves may have been used to dispose of other materials in addition to tailings, such as waste rock, processing and water treatment sludge, process waste waters and sewage treatment wastes.

This document does not address the prevention of breaches or failures at abandoned man-made infrastructure that store fluids below ground. This document also does not address the potential for failure of concrete tailings impoundments and dams. Concrete tailings impoundments and dams are rare and should be evaluated for potential failure on a case-by-case basis, referring to appropriate concrete dam structural stability evaluation guidelines (USACE 1995, 2005, 2007; BOR and USACE 2015; and FERC 2016b).

This document does not provide best practices for conducting abandoned mine impoundment remediation activities. Such actions are highly diverse and site-specific, and they are addressed through existing EPA, state, and other agency guidance. Remediation activities require detailed planning and execution, the best practices for which are beyond the scope and intent of this document.

When investigating and mitigating the threat of sudden releases at abandoned mine impoundments with complex structural, geotechnical, and geochemical issues, some degree of uncertainty will remain. Application of the best practices described in this document will reduce both risk and uncertainty but will never eliminate them.

The bibliography at the end of this best practices document (Section 5.0) includes documents cited in the text and relevant to abandoned mine impoundment failure prevention. General information about wastes found at abandoned mines can be found in EPA's *Abandoned Mine Site Characterization and Cleanup Handbook* (EPA 2000).

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[5] "Minimally invasive methods" refers to work that does not disturb the impoundment or that minimally disturbs the impoundment, such as measuring or sampling using existing wells, boreholes, or other safely accessible surface openings, and water elevation measuring and sampling. "Invasive methods" refers to work that disturbs the impoundment or its structures, such as drilling, using heavy equipment, excavating, blasting, grading, and dewatering.

1.1 Background

Mining produces waste rock, ore and protore containing the valued commodity or commodities. Overburden and waste rock (rock that contains lower levels of mineralization) are removed during mining to gain access to the ore. Mine tailings are the waste materials that remain after processing the ore to remove the valuable metals, minerals, or other material. Water and chemicals are generally added during ore processing, which results in tailings that are in a slurry form. The physical and chemical attributes of the tailings are directly dependent on the mineralogical composition of the ore, the process of size reduction and extraction and to what extent the tailings have been dewatered. Impoundments and tailings storage facilities (TSF) were historically constructed by using natural basins and by building dams of tailings, waste rock or other earthen materials behind which tailings slurries were impounded (Richmond 1991; Taggart 1944).

When mining operations ceased, impoundments holding tailings or other mining wastes were often not adequately closed or maintained and no longer inspected. Even after operations cease, these abandoned mine impoundments commonly continue to capture and retain precipitation and runoff. As a result, abandoned mine impoundments and associated dams may be in a deteriorated condition and have decreased structural integrity, compromising their ability to impound wastes safely. In addition, abandoned mine impoundments and associated dams may not have been designed, constructed, and operated to meet modern engineering design and construction standards.

There is limited information about impoundment failures at abandoned mines. However, the Lava Cap Mine Superfund site dam failure in 1996 is one illustrative example of the effects of such a possible failure (EPA 2008). Downstream impacts from breached or failed impoundments at operating mines can also provide insight into the types of environmental, infrastructure, and human health risks should abandoned mine impoundments be breached or fail. Notable tailings dam failures at operating mines occurred at the Córrego do Feijão iron ore mine near Brumadinho, Minas Gerais, Brazil in 2019; the Cieneguita Mine in Chihuahua, Mexico, in 2018; the Hpakant Mine in Myanmar and Germano Mine in Minas Gerais, Brazil, in 2015; the Mount Polley Mine in British Columbia, Canada, and Buenavista del Cobre Mine in Cananea, Sonora, Mexico, in 2014; and the Church Rock uranium mill tailings pond failure near Gallup, New Mexico, in 1979. Additional notable impoundment failures are listed in the U.S. Department of Interior, Bureau of Reclamation's (BOR) *Reclamation Consequence Estimating Methodology: Dam Failure and Flood Event Case History Compilation* (BOR 2015a) and on the World Information Service on Energy (WISE) Uranium Project website.[6]

Reviews of past tailings impoundment failures have identified numerous causes of failure, the majority of which can be attributed to a few common factors for which data exist. The United Nations Environment Programme (UNEP) reported that of over 200 tailings dam failures between 1915 and 2015, the most commonly known and documented failure modes were overtopping, slope instability, earthquakes, seepage, structural inadequacies, and foundation conditions (UNEP 2017). Often, the underlying cause was a failure to construct or operate to the design intent. The associated deficiencies can remain long into the post-operation period. Following the Mount Polley Mine impoundment failure in 2014 in British Columbia, Canada, the Mining Association of Canada (MAC) prepared updated guidance documents on the design, operation, and maintenance of tailings impoundments and evaluated the causes of failure of such impoundments. These documents provide excellent information on how tailings

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[6] http://www.wise-uranium.org/mdaf.html

impoundments are designed, constructed, and maintained and include sound technical background useful for evaluating risks at abandoned mine impoundments (see MAC 2017).

Both federal and state guidance and regulations exist for evaluating the structural integrity of operating earthen and rock dams and their impoundments. These guides and regulations contain well established engineering methods to assess the stability of these units. These regulations and guidance materials are, for the most part, intended for the inspection and evaluation of operating dams, but may also be used for the inspection and evaluation of impoundments at reclaimed, closed, or abandoned mines. The regulatory status of an impoundment at an abandoned mine is important and should be verified with the appropriate state or federal agency. In addition, relevant engineering design information or inspection reports for older dams and impoundments provide useful information for engineering stability evaluations. In cases where little or no data about the foundation and design of an impoundment and dam are available, significant time has passed since existing data were collected, or site conditions have changed since initial data were collected, it may be necessary to perform geotechnical investigations to collect data that support updated risk and stability assessments of the facilities.

This document compiles the technical resources and approaches that are the best practices for conducting stability and safety evaluations of abandoned mine impoundments and their associated dams. These best practices should be used to evaluate whether an abandoned mine impoundment has sufficient structural integrity to withstand invasive CERCLA activities without causing a sudden, uncontrolled release.

1.2 Primary Resources

This best practices document includes information drawn from published standards of practice and guidelines for stability assessments and hazard potential evaluations of operating impoundments. While the conditions at abandoned mine impoundments may differ from operating impoundments, the best practices for assessing their safety, stability, and hazards are similar.

Published sources and experts were consulted to compile the best approaches in this document, including (1) national and international technical resources and publications; (2) lessons learned from tailings dam failures; and (3) technical contributions from expert professionals with relevant dam safety experience. Individual experts from the following entities were consulted during the development of this report:

- U.S. Army Corp of Engineers (USACE)
- U.S. Department of the Interior:
  - Office of Surface Mining, Reclamation, and Enforcement (OSMRE)
  - U.S. Geological Survey (USGS)
  - Bureau of Reclamation (BOR)
- U.S. Environmental Protection Agency (EPA)
- U.S. Department of Labor, Mine Safety and Health Administration (MSHA)
- Federal Energy Regulatory Commission (FERC)
- U.S. Department of Homeland Security, Federal Emergency Management Agency (FEMA).
- U.S. Department of Agriculture, U.S. Forest Service (USFS)

- Association of State Dam Safety Officials (ASDSO)
- Mining Association of Canada (MAC)
- International Commission on Large Dams

1.3 Document Organization

This document is organized into five sections and an appendix.

- **Section 1.0** introduces the document and provides an overview of the best practices and approaches presented in this document.
- **Section 2.0** describes the elements of conducting an initial impoundment condition assessment.
- **Section 3.0** describes the process for performing or overseeing an impoundment structural stability analysis and preparing a structural stability and safety report.
- **Section 4.0** discusses interim mitigation actions, such as dewatering the impoundment, prior to conducting CERCLA activities.
- **Section 5.0** provides a bibliography with references for material used in the development of this document, as well as additional resources. Where available, website addresses are provided for additional informative materials.
- **Appendix A** provides checklists for the best practices described in this document and for conducting impoundment safety assessments.

2.0 CONDUCT INITIAL IMPOUNDMENT CONDITION ASSESSMENT

When EPA proposes a CERCLA activity that has the potential to adversely affect impoundment stability, an initial impoundment condition assessment is performed to identify if the abandoned mine impoundment shows signs of imminent failure. There are a range of CERCLA activities that have the potential to adversely affect abandoned mine impoundments. Such activities include well installation, removal of wastes at or adjacent to an impoundment, placement of heavy construction equipment near or on an impoundment, heavy trucks causing vibrations, and reclamation or closure of adjacent waste units. The initial assessment is not a formal structural stability determination; rather, it is used to determine if further studies are necessary. The initial assessment is not necessary if it is known that fluids or liquefiable wastes are not currently impounded.

The initial impoundment condition assessment begins with creating a CSM of the impoundment to understand the characteristics of the dam and impounded materials by (1) reviewing available documents and data; (2) conducting a site visit to gather data to update the CSM; and (3) making an initial imminent or unacceptable failure risk determination and deciding if further invasive geotechnical analyses should be conducted.

2.1 Develop an Impoundment Conceptual Site Model

Creating or updating an abandoned mine impoundment CSM with data and information specific to the impoundment will better integrate and improve the evaluation of impoundment information, as well as identify key data gaps, to assess impoundment conditions and resolve uncertainties regarding the potential for impoundment failure. It is important that the abandoned mine impoundment CSM includes (1) information on the physical structure of the impoundment; (2) the physical properties of wastes or other impounded materials; and (3) the regional and local geology, seismicity, meteorology, and hydrology. Use of graphical CSM depictions (for example, cross-sections of the dam and impoundment structures and three-dimensional visualizations) is considered a best practice for understanding and communicating information related to impoundment physical structures, drainage features, surface areas, cross-sectional areas, and the condition of related features. The impoundment CSM is distinct for mining site features, but it can also be informed and supplemented by the environmentally focused site CSM prepared for CERCLA site cleanup efforts.

The CSM integrates information on dam and impoundment structure and waste characteristics with geotechnical, hydrogeologic, hydrologic, hydraulic, seismic, and geochemical data to assess the potential risk of a sudden, uncontrolled impoundment failure as a result of proposed CERCLA activities. Given the specialized focus on the geotechnical, hydrogeologic, hydrologic, hydraulic, seismic, and geochemical conditions, the impoundment condition assessment is not intended to equate with any traditional site assessment, remedial investigation, or other characterization stage in the CERCLA site cleanup process.

The problem statement developed as the basis for creating the impoundment CSM is:

What is the stability condition of the impoundment and dam and what are its potential failure modes?

Data gaps identified during the evaluation of the impoundment CSM are used to focus data/information collection, which leads to a greater understanding of structural stability and helps facilitate site decision-making. A decision logic is useful in helping to prioritize data collection for the CSM. Exhibit 1 represents a decision logic for determining whether there is an imminent risk of failure and whether it is necessary to conduct an impoundment structural stability and safety analysis.

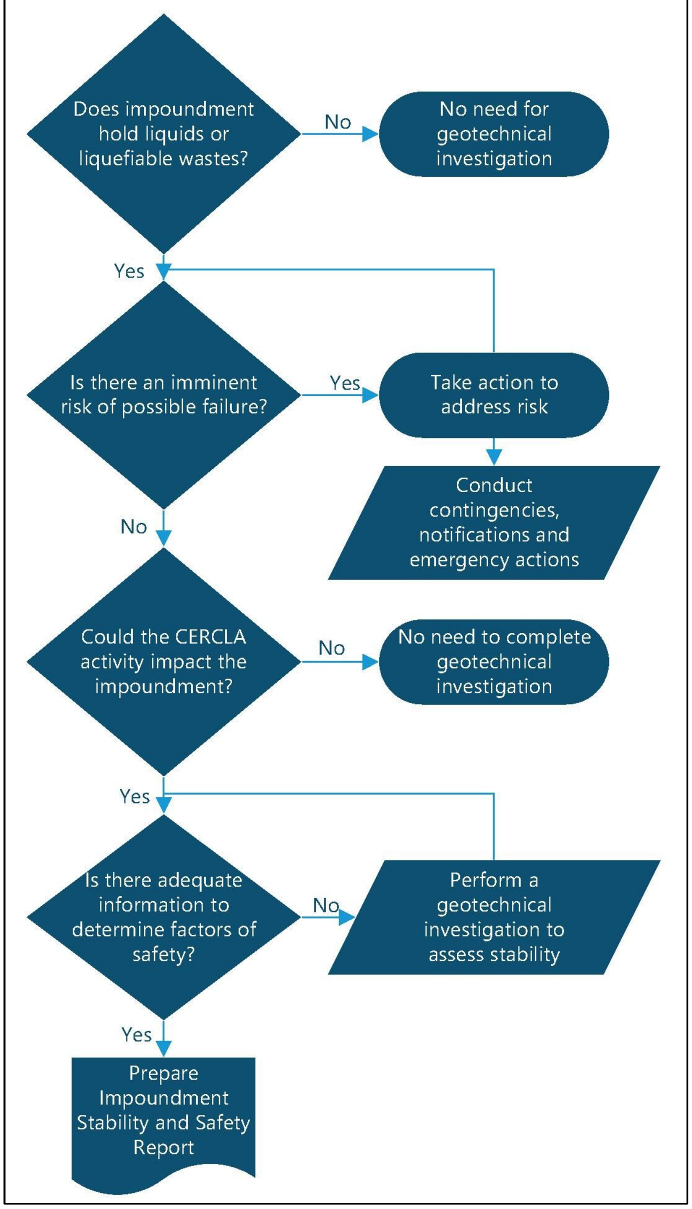
The following subsections present key elements of an abandoned mine impoundment condition assessment that are conducted to develop a comprehensive impoundment CSM, thereby reducing uncertainties in determining whether an imminent or unacceptable risk of failure exists.

2.1.1 Review Available Documents and Data

In some design cases, abandoned mine impoundment monitoring and prior structural integrity investigations may have been performed. A comprehensive review of existing impoundment structure-related documents should be conducted to confirm the physical status of the impoundment of concern. In particular, review of state agency documents, which may include assessments of the structural condition of the impoundment or rating of its condition, would be highly beneficial to development of the impoundment CSM.

At this stage of the condition assessment, it is important to confirm whether geotechnical information is available relative to the design, construction, and operational performance of the impoundment. For example, is there documentation of the characteristics of the material underlying the dam foundation, is the base of an impoundment dam keyed into bedrock, and is there information on dam construction material and design, construction quality assurance/quality control (QA/QC), and operational and closure monitoring? It is a best practice to compare design information to as-built diagrams (if they exist) to identify design deviations. If such information is available, the investigation team may use it as an important element in assessing impoundment conditions.

Exhibit 1. Condition Assessment Decision Logic



Structures identified as dams by states are listed in the National Inventory of

Dams (NID) and assigned a NID number. Each NID dam is given a hazard classification (high, significant, or low) that is based on the size of the dam and the potential for life loss and economic damage should it fail. It is best practice to consult with state dam safety officials to determine whether an impoundment dam is listed in the NID.

Visual assessment of the impoundment alone will not provide enough information to assess a unit's structural stability. Documents and data to consider for review include:

- Documentation of the general history of the mine and impoundments.
- Regulatory status of the impoundment, including the NID hazard classification, if available.
- Historical site layout and topographic maps.
- Records of past releases, breaches, or failures.
- Engineering specifications packages and construction QA/QC data (impoundment design and as-built drawings).
- Historical site investigation reports:
  - State dam inspection and studies of structural stability, hazards, or condition ratings;
  - Archived state, U.S. Bureau of Mines, and MSHA reports;
  - Geotechnical and laboratory studies of the impoundment dam and impounded waste;
  - Structural ratings during impoundment operation;
  - Hydrology and hydraulic studies;
  - Past environmental studies by federal, state, or local authorities;
  - Geological or geochemical studies; and
  - Historical operations, maintenance, and closure performance reports (including tailings deposition records from the operating phase).
- Historical instrumentation records (including inflow and suspended solids deposition rates, deformation, pore water pressure, piezometer data, inclinometer reports, and surface monument survey data, if available).
- Aerial photos and satellite imagery.
- Topographic, seismic hazard, and flood maps.
- Soil boring and sampling results, laboratory test results, and cone penetration (or penetrometer) testing (CPT) data (particularly lithologic logs of borings).
- Maps showing nearby residences, businesses, agriculture, water supply wells, wetlands, streams, rivers, ponds, and lakes;
- Available structural or geotechnical modeling of the abandoned mine impoundments.
- National Oceanic and Atmospheric Administration (NOAA) historical precipitation records.
- Published journal articles, published master's or doctoral theses or other academic publications evaluating dams or impoundments at the site.
- Interviews with past operators.

Review of historical data and analysis of prior site studies will typically help determine the composition of surface impoundment liquids and wastes, provide information on impoundment design, and confirm whether there had been impoundment failures. In cases where historical data from instrumentation do not exist, are incomplete, or cannot be located, consultation with local, state, tribal, or federal officials and state mining associations is paramount to ensure that relevant studies and prior actions at the site have been identified and that conditions at the site are understood. Consultation with state agencies (for example, the state dam safety division and the state mine land reclamation department) are also valuable for obtaining information on any previously identified safety issue. Federal land management agencies may also possess prior studies on the uses and conditions of impoundments at sites located on federal or tribal lands or at mixed-ownership sites (sites located on both public and private lands). Consultations with local government agency officials, as well as with nearby community residents, retired miners, mine historians, and landowners, often yield relevant information about the site.

2.1.2 Conduct a Site Visit and Visual Assessment

The next step in an initial condition assessment is to conduct a site visit and visual assessment of the abandoned mine impoundment. The visual assessment is performed during a site visit to gather information to update the impoundment CSM. The visual assessment is key to confirming the conditions of the impoundment and evaluating whether the proposed CERCLA actions could have an adverse impact on the impoundment. A site visit has multiple purposes, including to (1) determine whether the impoundment shows visual signs of imminent failure and, if so, recommend any appropriate mitigation actions; (2) orient the investigation team to current conditions at the site and surrounding environment; (3) estimate the type and nature of materials contained (or suspected to be contained) in the impoundment; (4) assess the general condition of the impoundment structures; (5) assess whether the impoundment is likely to be adversely affected by a proposed CERCLA activity; (6) determine whether invasive geotechnical studies would be helpful to assess the structural stability of the impoundment; (7) evaluate whether any immediate mitigation actions might improve surface impoundment and dam stability; and (8) determine, if possible, why the impoundment no longer retains liquids or wastes. To support these findings, a site visit identifies any obvious locations of distress, malfunctions of the impoundment and appurtenant structures (such as outlet structures), and evidence of hydraulic management structures passing through the impoundment (MAC 2011). Exhibit 2 provides a discussion of using UAS for conducting initial impoundment condition assessments.[7]

Exhibit 2. Unmanned Aerial Systems Use in Initial Impoundment Condition Assessments

A best practice is to use Unmanned Aerial Systems (UAS) to gather baseline information about an abandoned mine impoundment and the surrounding area. UAS can be effectively used to visually survey site conditions to document potential seepages, mine drainage, slope stability issues, and impoundments structures. They can also provide imagery for base maps, baseline conditions, potential safety hazards, and field work planning. Information or data from UAS may also be used as input into three-dimensional models and the conceptual site model. Advantages of drone use includes:

- Rapid deployment and data collection.
- Ability to survey large areas.
- Lower cost than other aerial imagery.
- Finer scale aerial imagery than conventional aircraft.
- Access to areas that are unsafe or unhealthy to people.
- Documents current conditions from vantages unavailable at ground level.

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[7] UAS use will be consistent with Agency Policy and Office of Land and Emergency Management UAS procedures.

Initial condition assessment and site visit documentation on each impoundment should include (see FEMA 2015b):

1. A description of the impoundment, including location, type of construction, size, shape, infrastructure, and age.
2. An assessment of the type and condition of impounded wastes; for example, slurry tailings, paste tailings, dry tailings, tailings mixed with waste rock, or other wastes.
3. An estimate of the volume of impounded wastes (liquid, solid, and fluid-saturated) and the remaining volume capacity of the impoundment, including consideration of freeboard for flood management.
4. The status and condition of hydrologic structures; for example, spillways, drains, overflow structures, outlet conduits, pumps, and relief wells.
5. Visual evidence of former hydrologic conditions and features, including water levels, inflow/run-on locations, and outflow/runoff features.
6. The location, type, and condition of any monitoring instrumentation.
7. The weather conditions at the time of the site visit, including recent precipitation or storm water inflow.
8. An estimate of the volume of sedimentation (for example, soils, silts, and sands from run-on) if present.
9. Measurements of the impoundment slopes and geometry; for example, approximate grade, height, length, crest width, and bench widths (particularly when as-built designs are absent).
10. Observations and evidence of the following impoundment conditions:
    a. Settlement or slumping
    b. Recent or frequent standing water (as visually indicated on embankment crests)
    c. Visual evidence of movement
    d. Overtopping
    e. Erosion
    f. Seepage or leakage (sometimes indicated by wetland vegetation)
    g. Cracking
    h. Rutting of surface soils
    i. Deterioration
    j. Presence of woody vegetation on embankments
    k. Rodent burrows or activity on embankments
    l. Unauthorized use (industrial or recreational) or vandalism
    m. Upstream and downstream slopes and embankment crest condition
11. An assessment of the spillway and outfall structures to evaluate the adequacy of the hazard potential rating design flow and whether there is sufficient storage within the impoundment to avoid overtopping during a major storm event.

12. Documentation or other evidence of adjacent or nearby underground mine workings.
13. A description of the watershed, including the location of the impoundment within the watershed, topography, size of the catchment basin, and confirmation of reviewed runoff and infiltration characteristics and downstream fluvial systems (for example, wetlands, streams, rivers, ponds, and lakes).
14. A description of the impact of seasonal weather events; for example, estimated snow melt loading, freeze-thaw events, and severe storm events.
15. The condition of upstream and downstream slopes, as well as the embankment crest.
16. The location of downstream areas of potential impact in the event of a release; for example, water intake structures, residences, farms, schools, hospitals, daycare centers, businesses, and any other at-risk infrastructure, and sensitive ecological features located along the flow path of a release within at least 5 miles downstream of the impoundment.
17. Descriptions of each photo or video taken, including subject, date, time, direction of view, photo number, geo-referencing, and photographer name.

Based on the information collected, the investigation team should evaluate whether the impoundment is subject to imminent risk of failure. The following section further describes the steps in making such a determination and the actions that should follow.

2.1.3 Make an Imminent Risk Determination and Decide if a Geotechnical Analysis Is Needed

The goal of the site visit and visual assessment is to make an initial determination of whether an imminent risk of failure exists or whether additional geotechnical data are needed to assess the risk of failure. The key findings of the initial impoundment condition assessment (both the information/data review and the site visit/visual assessment) should present answers to the following questions:

1. Are conditions such that there is a plausible risk of imminent dam failure or is there evidence of deteriorating conditions that might, without intervention, lead to dam or impoundment failure?
2. Is the dam currently impounding liquids or liquefiable wastes?
3. Do the proposed CERCLA actions have the potential to cause a sudden, uncontrolled release?
4. Are the natural and physical attributes of the impoundment and its wastes adequately known to assess whether an impoundment failure may occur as a result of CERCLA actions?

The answer to the first question should include an estimated failure risk category of immediate, urgent, moderate-to-high, low-to-moderate, or low priority (BOR 2011). Immediate or urgent failure risk categories should be supported by evidence of imminent failure or rapidly deteriorating conditions. If the initial conditions assessment reveals evidence of imminent failure or rapidly deteriorating conditions that, without intervention, would likely lead to failure, then the project manager should immediately notify the appropriate management, local, state, tribal, and federal officials and implement necessary emergency actions to mitigate the potential failure. No further actions at the site should be implemented until a structural stability and safety analysis is performed by a qualified team or immediate action is taken to reduce the risk of failure. During preparation of responses to a potential imminent failure, communication with all interested parties should be maintained on a regular basis. Implementation of a CERCLA response to reduce the threat of an imminent failure should not be inconsistent with the NCP. FEMA's *Federal Guidelines for Dam Safety: Emergency Action Planning for Dams* (FEMA 2013a) and the U.S. Department of Homeland Security's (DHS) *Dam Sector Crisis Management Handbook* (DHS 2008) should also be consulted prior to taking action.

If the initial conditions assessment does not identify an immediate or urgent failure risk category, then it is necessary to determine whether additional data are needed. It is unlikely that geotechnical data will be available to support a reliable estimate of an abandoned mine impoundment's structural stability. Under such circumstances, performance of intrusive geotechnical investigations should be considered to collect additional data as part of a structural stability and safety analysis (see Section 3.0).

A geotechnical investigation may not be recommended if (1) the document review and visual assessment find that the impoundment is no longer capable of impounding liquids; (2) saturated wastes no longer exist in the impoundment; or (3) the proposed CERCLA activities would not adversely affect the impoundment's structural stability. However, if a geotechnical investigation is found to be unnecessary, do not assume that the site no longer poses other human health and environmental concerns from the contaminated waste materials. Abandoned mine impoundments not retaining fluids may still have the potential to fail. Such a failure may not cause a sudden release but may still cause a release of wastes and potentially hazardous substances.

3.0 PERFORM STRUCTURAL STABILITY AND SAFETY ANALYSIS

When the initial impoundment condition assessment finds that the proposed CERCLA activities could adversely affect an abandoned mine impoundment that is impounding fluids or potentially liquefiable wastes, it is a best practice to evaluate whether the impoundment and dam are structurally sound enough to withstand the effects of proposed invasive geotechnical studies. Abandoned mine impoundment stability is determined under static, seismic, and liquefaction conditions. In the absence of existing data and information, geotechnical investigations are the primary means of gathering data to support a structural stability and safety analysis. While various terms are used to describe these geotechnical investigations and analyses, this document refers to them as an impoundment structural stability and safety analysis.

Structural stability and safety analyses are performed using best practices based on established methods. FEMA, MSHA, and USACE have guidelines on how to conduct structural stability analyses of existing earth and rock-fill dams (FEMA 2004; MSHA 2009; USACE 2002, 2003, 2004, 2014a, 2014b, 2014c). ASDSO also has guidelines on how to conduct a dam safety inspection (ASDSO 2005; FEMA 2004).

This section includes the following subsections:

- **Section 3.1:** Assemble a Qualified Investigation Team
- **Section 3.2:** Plan and Conduct an Impoundment Geotechnical Investigation
- **Section 3.3:** Determine the Hazard Potential Classification
- **Section 3.4:** Evaluate the Hydraulic and Hydrologic Capacity
- **Section 3.5:** Estimate the Factors of Safety
- **Section 3.6:** Assign a Condition Rating
- **Section 3.7:** Develop an Impoundment Structural Stability and Safety Report

3.1 Assemble a Qualified Investigation Team

Specialized knowledge, training, and experience are required to perform structural stability and safety analyses of abandoned mine impoundments. Therefore, it is important that the qualifications of the impoundment investigation team be confirmed before a structural stability and safety analysis is undertaken. The specific makeup of the team is dependent on site conditions and state-specific professional qualifications for conducting structural stability determinations of earth or rock-fill dams and impoundments. Leading roles and common expertise requirements of investigation team members may include the following.

Lead Geotechnical Engineer with a Professional Engineer (PE) license in the state of study and 10 or more years of experience in dam structural stability studies (static, seismic, and liquefaction analyses) of earth and rock-fill embankments. The lead geotechnical engineer typically signs the final geotechnical investigation report and stamps it with a PE seal. A second geotechnical engineer with PE license may be included on the investigation team, depending on the level of involvement of the lead geotechnical engineer.

Hydrologist with a Professional Hydrologist (PH) license in the state of study and 10 or more years of experience in assessing site hydrology and hydrogeology.

Mining Geologist with a Professional Geologist (PG) license in the state of study and 10 or more years of experience in the evaluation of impoundments.

Hydrologic Engineer with a PE license in the state of study and 10 or more years of experience evaluating stream hydrographs and assessing precipitation impacts on catchment basins and generation.

Site visits should have no less than two professionals to assure that conditions can be cross verified in the field. It is a best practice that the team consult with state dam safety officials for guidance on state-specific planning for impoundment safety studies and to inform whether team personnel have the recommended and applicable requisite academic training, licensure, and qualifications to perform activities in that state.

When an agency or other responsible organization does not have the internal qualifications or expertise to form a qualified team or does not have the proper equipment to conduct investigation activities, outsourcing the structural stability and safety analysis may be appropriate. In this case, the information in this section can be used to support efforts to oversee the contractor(s) or other agency performing the investigation.

3.2 Plan and Conduct an Impoundment Geotechnical Investigation

The primary purpose of an impoundment geotechnical investigation is to collect samples and conduct in situ measurements of impoundment construction materials and impounded wastes for geotechnical analysis and to install instrumentation to monitor conditions before, during, and after CERCLA actions as required by an approved Sampling and Analysis Plan/Quality Assurance Project Plan (SAP/QAPP). The technologies and methods to be used in the geotechnical investigation should be selected based on site-specific data and conditions and only after analyzing the risks of performing invasive activities.

This section includes the following subsections:

- **Section 3.2.1:** Conduct a Data Gap Analysis and Second Site Visit
- **Section 3.2.2:** Develop a Geotechnical Investigation Plan
- **Section 3.2.3:** Analyze the Risks of the Proposed Geotechnical Investigations
- **Section 3.2.4:** Develop a Contingency, Notification, and Emergency Action Plan for the Proposed Intrusive Geotechnical Activity
- **Section 3.2.5:** Analyze the Geotechnical Data

3.2.1 Conduct a Data Gap Analysis and Additional Site Visits

The investigation team should conduct a data gap analysis of the CSM and additional site visits, as appropriate, to confirm the information noted in the initial condition assessment and to determine where and how geotechnical investigations will be performed. Abandoned mine impoundment site visit checklists guide information collection and observations for more thorough inspections and to support investigation planning (see Appendix A).

Investigation team personnel should also collect and document any other helpful information to better evaluate the structural stability of the surface impoundment. Exhibit 3 provides several sources of information for conducting site visits. In addition to the sources in Exhibit 3, ASDSO may have information sources and recommendations for conducting impoundment site visits.

Exhibit 3. Information Sources for Performing Impoundment Inspections

- USACE. 2014. "Chapter 13: Reporting Evidence of Distress in Civil Works Structures." Engineering and Design: Safety of Dams – Policy and Procedures. ER 1110-2-1156. March 31. www.publications.usace.army.mil/Portals/76/Publications/EngineerRegulations/ER_1110-2-1156.pdf.
- ASDSO. 2016. "Module: Documenting and Reporting Findings from a Dam Safety Inspection." Training Aids for Dam Safety. https://www.hsdl.org/?view&did=759064.
- ASDSO online dam inspection guidance and training seminars.
- Bureau of Reclamation. 1995. *Safety Evaluation of Existing Dams Manual*. Denver, Colorado: Bureau of Reclamation.

Results of the site visits and the data gap analysis may indicate a rationale to perform a geotechnical investigation to obtain data to support the structural stability and safety analysis. If the data support a determination to collect additional geotechnical data, a geotechnical investigation plan should be developed.

3.2.2 Develop a Geotechnical Investigation Plan

It is important to design a geotechnical investigation work plan that can be effectively and safely executed by the field personnel and contractor(s) performing the work. A first step in developing a plan is to determine if there are minimally invasive methods (such as geophysical methods) that could provide relevant information in evaluating the stability of an abandoned mine impoundment. If such approaches are not viable, then the use of invasive methods (such as drilling or excavation) may be appropriate.

Common geotechnical technologies and approaches include:

- **Geophysical Surveys.** Typically, minimally invasive, geophysical surveys include methods of collecting remote sensing-type data to detect and map subsurface features and conditions. Geophysical survey methods, such as ground penetrating radar (GPR), electromagnetometry, magnetometry, and resistivity, can be performed at the ground surface and are viewed as minimally invasive. Satellite-based remote sensing technologies (for example, interferometric synthetic-aperture radar [InSAR] and light detection and ranging [LIDAR]), which are also not invasive, can provide an assessment of past deformations if adequate historical data are available. Other surface geophysical methods, such as seismic reflection, may be deployed using vibratory or sonic technologies, which, while considered minimally invasive, may disrupt unstable unconsolidated materials. Geophysical surveys are often used to minimize invasive exploration methods, such as drilling and excavation, but some drilling is often required to confirm and calibrate geophysical survey results. Geophysical surveys can also identify critical locations for the placement of drill holes.

- **Drilling (Boring or Coring) and Sounding.** Considered to be the primary sample collection and in situ testing method for geotechnical analysis, drilling is performed to (1) confirm the presence, depth, and hydraulic head of impounded water or liquids; (2) obtain discrete or continuous in situ measurements of subsurface conditions for correlation with geotechnical parameters of interest; (3) collect samples to establish the physical and geochemical characteristics of impounded waste and dam materials of construction; (4) collect samples for analysis to determine the physical characteristics of the underlying geology; and (5) collect samples to determine groundwater geochemistry. There are a variety of drilling methods available that provide flexibility in investigation design and allow for the installation of instrumentation (such as piezometers and inclinometers) and in situ testing (such as standard penetration test [SPT] and permeability testing). Drilling tools and technologies can also accommodate variable site conditions. Drilling is typically considered an invasive activity because it has the potential to result in impoundment instability and failure.
- **Excavation.** Subsurface excavation is used to dig test pits and test trenches to provide access for obtaining visual confirmation, collecting samples, and conducting in situ field testing. Excavation may be an appropriate primary geotechnical investigation method in certain circumstances, such as confirming foundation materials and how or if a dam's foundation is keyed into bedrock. Excavation is considered an invasive activity; therefore, planned excavation activities should be evaluated for their potential to result in impoundment instability or failure.
- **Field Testing, Instrumentation, and Monitoring.** A variety of specialty instruments and methods are used for testing material, fluid, and physical properties. Field testing methods and instruments include groundwater monitoring wells; hydraulic pressure testing in boreholes; seepage measurement using weirs, flow meters, and flumes; thermistors for measuring groundwater temperature variations; and extensometers and inclinometers for measuring material displacement and deformation. Most of these methods are minimally invasive unless deployed by creating boreholes or excavations.

The geotechnical investigation work plan should assess the site conditions and risks to ensure that investigation activities can be safely performed. Low strength or saturated material may not be able to support personnel or equipment. Tailings can also lose strength because of the vibratory stress from drilling or excavating, resulting in a threat to equipment and personnel. If internal erosion is suspected, the work plan should also consider the potential for voids beneath the tailings surface. Environmental factors should also be taken into account during the planning for field analysis as exposure of reduced material can result in geochemical changes in mine drainage release. In addition, erosion of stockpiles created during excavation or exposure of buried decant structures could impact surface water and sediment quality. Health monitoring and safety planning and practices, along with environmental protection controls, should be part of any plan.

The selection of geotechnical investigation methods and instruments is a significant aspect of geotechnical investigation work planning. Typically, geotechnical investigations involve drilling and excavation, both of which are considered invasive activities. To complete the geotechnical investigation plan, the geotechnical team should select the drilling and excavation technologies most appropriate for the data requirements and amenable to site conditions, including site access, slope, and ground stability. A combination of techniques may be required to characterize abandoned dams and impoundments. Many small, lightweight drill rigs and excavators can be deployed on tracks and adjustable platforms to work on less stable ground and on steep slopes. However, significant care is required in selecting the appropriate drilling rig or excavator to safely accommodate site-specific conditions. It is important to acknowledge that drilling and excavation may have different types of risks associated with their use.

3.2.2.1 Drilling Methods and Instruments

The most common geotechnical drilling methods are traditional auger drilling, hydraulic rotary drilling, and the use of direct push technology (DPT). Specific instruments may be deployed with different drilling techniques. Common drilling and testing methods[8] for abandoned mine impoundment geotechnical investigations include:

- **Hollow Stem Auger (HSA) Drilling.** This method is generally fast, especially in shallow applications, in soft unconsolidated material, or in weak weathered bedrock. HSA drilling is effective for collecting samples to characterize soils, unconsolidated overburden, and tailings associated with earthen dams and impoundments. A conventional and cost-effective drilling method, HSA drilling uses a rotating HSA to convey cuttings to the surface via auger flights on the outside of the casing. Grab samples can be obtained from cuttings or sampling tools deployed inside the hollow auger flights. The large openings formed during HSA drilling allow access to the bottom of the borehole after the pilot bit is removed without withdrawing the auger drill string. The auger acts as a temporary casing during drilling to facilitate sampling soils and unconsolidated material and installing monitoring wells. HSA drilling produces coarse cuttings that can be readily observed and characterized; thus, HSA drilling is the most common method of drilling for geotechnical investigations. Advantages for this method are that HSA drilling does not use downhole liquids to facilitate drilling and does not grind rock or soil to fine particle sizes. A disadvantage is that HSA drilling cannot penetrate many types of hard rock. Continuous sampling for geotechnical investigations is described in American Society for Testing and Materials (ASTM) International Standard D6151 (ASTM 2008). FERC considers HSA drilling a preferred method for drilling in impoundments (FERC 2016a).
- **Continuous Flight Auger Drilling.** This method uses a spiral auger that is advanced into the ground via rotation and then lifted out. Soil is driven to the surface or the blades are removed and the soil remaining on the blades is collected for analysis. Soil removed by continuous flight augers is considered disturbed. If enough clay or binding material is present in the formation, the hole will remain open when the augers are removed. Dry or saturated sands and other caving formations may be problematic for this technique.
- **Fluid (Mud) Rotary Drilling.** This method is commonly used to drill through hard or comparably unweathered rock that cannot be drilled using augers. This drilling method is typically used for assessing the geotechnical characteristics of rock materials beneath impoundments. The technology can use a variety of drill bit types (for example, diamond-impregnated, carbide core barrel, or tri-cone roller) and uses a mud/bentonite-based fluid to cool and clean the bit, capture and carry cuttings up the annular space to the ground surface, and help prevent cave-in of open boreholes. Disadvantages of this method for impoundment drilling are that a mud pit or tank is necessary to capture, clean, and circulate drilling fluids, and pumping fluids into impoundment waste or dams may cause instability. Since drilling fluid is used, this method also has a potential for hydraulic fracturing. Drill bits used in

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[8] Additional information about the risks of drilling is noted in FERC's *Guidelines for Drilling in and near Embankment Dams and Their Foundations* 2016a.

this method grind up the subsurface materials, which then becomes coated with drilling fluid, making proper characterization of the materials difficult. USACE (2014c) notes that the use of fluid drilling should be limited only to locations where there is high confidence that it will not cause hydraulic fracturing. However, fluid rotary is the preferred method for SPTs for liquefaction (ASTM D6066), where it is recommended to keep the hole full of fluid during the test to stabilize sands. Drill bits, sampling tools, and drill rods should be raised and lowered slowly so as not to induce increased positive or negative fluid pressures.

- **Air Rotary Drilling.** This method utilizes compressed air to lift the cuttings up the borehole and to cool the bit. Air rotary drilling is used when possible for environmental monitoring because no drilling fluids are introduced into the formation. This method is feasible only in consolidated or semi-consolidated formations.
- **Sonic Drilling.** This method has the appearance of rotary drilling, but it uses a vibratory drill bit that physically vibrates up and down in addition to being pushed down and rotated. These three combined forces allow drilling to proceed rapidly through most geological formations, including most types of rock. The vibratory action causes the surrounding soil particles to liquify thereby allowing penetration. Sonic drilling and coring may be accomplished without the use of any drilling fluids.
- **Direct Push Technology.** DPT can provide valuable in situ data and information about tailings and unconsolidated earthen materials in an impoundment. Discrete soil sampling devices, such as Shelby tubes and continuous liner soil samplers, can be affixed to a DPT drilling rod to obtain samples for laboratory analysis. CPT, flat plate dilatometer test, and SPT (ASTM D1586-11) equipment can also be affixed to a DPT drilling rod and advanced into the subsurface to collect real-time, in situ geotechnical data. Advantages to DPT technologies include the use of lighter, more mobile drill rigs, less subsurface impact, and real-time, fast results. Disadvantages are that DPT tools cannot penetrate solid rock or very stiff and dense soils and can be difficult to advance in rocky substrates. ASTM International Standard D5778 outlines standard procedures for measuring the point resistance during penetration of subsurface soils (ASTM 2012a). Instruments used to monitor water pressure in soil or rock, such as vibrating wire piezometers or other piezometers, can be installed using DPT.
- **Cone Penetrating (or Penetrometer) Testing.** This test method consists of pushing (typically using DPT) an instrumented cone into the ground at a controlled rate (controlled between 1.5 to 2.5 centimeters per second). CPT piezocone, inclinometer, seismic geophone, resistivity, electrical conductivity, dielectric, and temperature sensors may be used to measure geotechnical properties of impoundments in real time as the cone is advanced through the material to be measured. CPT is useful in pore pressure measurements and is an essential tool to assess the potential for wastes to liquefy. Pile load tests can be conducted with CPT equipment measures to determine end bearing and side friction (ASTM Standard D3441) (ASTM 2016c).

Decisions about drilling methods and technologies should consider the goals of the drilling program, including safety, data requirements, access, strata type, surface slope stability, and other factors such as drill rig capability, cost per foot, and availability and experience of the drilling crew. Slope, ground stability, and physical accessibility commonly limit the size and type of the drill rig that can be deployed. These issues may also prevent vertical drilling from directly on top of the impoundment or dam. Under such circumstances, other drilling methods, such as horizontal or directional drilling, may be considered. In addition, some track-mounted, walking, and all-terrain “spider” rigs can drill on steeper slopes.

When planning a geotechnical investigation, it is valuable to select drilling locations and directional drilling azimuths and inclinations to adequately characterize impoundment materials of construction while avoiding buried impoundment infrastructure, such as drain pipes and liners. Instrumentation types and their installation requirements also inform the drilling plan. As noted earlier, geophysical surveys can also identify critical locations for the placement of drill holes.

Simple horizontal drilling (or drilling inclined from vertical) should not be confused with horizontal directional or angular drilling, which is a steerable, trenchless method of installing underground pipe, conduit, or cable in a shallow arc along a prescribed bore path through soils (not rock). Horizontal drilling may be an effective method for drilling from the sides of impoundments or to obtain a cross-sectional analysis of impounded waste.

If not properly designed, drilling and sampling may contribute to structural failures. The methods used to collect samples is a site-specific determination made by a qualified geotechnical engineer. Exhibit 4 provides two important resources for drilling programs in impoundments.

Exhibit 4. Resources for Impoundment Drilling

- U.S. Army Corps of Engineers. 2014. "Drilling in Earth Embankment Dams and Levees." ER-1110-1-1807. http://www.publications.usace.army.mil/Portals/76/Publications/EngineerRegulations/ER_1110-1-1807.pdf.
- Federal Energy Regulatory Commission. 2016. "Guidelines for Drilling in and near Embankment Dams and Their Foundations." Division of Dam Safety and Inspections. Version 3.1. June. https://www.ferc.gov/sites/default/files/2020-04/guidelines.pdf.

Borings should be advanced to depths adequate for defining impounded waste, impoundment materials of construction, and natural substrate. Borings should be advanced at the top and bottom of slopes if possible. The number of borings required depends on the continuity and homogeneity of the soil and waste conditions and the extent of the possible issues of concern. Accurate surveying and an understanding of the local structural geology, lithology, and impoundment design help support planning efforts so that drilling will not contribute to a failure or adversely affect infrastructure. Driller experience, including knowledge of local geology and drilling conditions, also increases the likelihood of a successful drilling program. Exhibit 5 provides a list of the contents for a FERC drilling program plan for drilling in or near embankment dams and foundations (FERC 2016a).

Exhibit 5. Federal Energy Regulatory Commission Drilling Program Plan Required Content

1. Provide the name and a description of project.
2. Describe the purpose of the site-disturbing activity.
3. Describe the proposed site-exploration activity (including coring locations, depths, in situ testing, and instrument installation).
4. Describe and show anticipated site conditions.
5. Describe the proposed equipment, methods, and processes.
6. Identify the project personnel and qualifications/experience.
7. Identify and describe the potential risks from invasive activities and a risk management plan.
8. Identify a communication plan with names and phone numbers.
9. Provide an overall schedule and duration of drilling activities.

Source: Federal Energy Regulatory Commission. 2016. "Guidelines for Drilling in and near Embankment Dams and Their Foundations." Division of Dam Safety and Inspections. Version 3.1. June. https://www.ferc.gov/sites/default/files/2020-04/guidelines.pdf.

While it is considered a best practice to use non-fluid drilling methods whenever possible, the choice of a specific drilling method at a site depends on that site's geotechnical characteristics. While drilling with fluids raises concerns, it should not be automatically rejected if drilling can be accomplished without causing structural stability issues. Therefore, prior to any drilling using fluids, the proposed drilling plan should be reviewed and approved by a licensed geotechnical engineer who has experience with fluid drilling into embankments to avoid the risk of hydrofracture or other failure modes.

USACE (2014c) recommends drilling be performed by drill rig operators with working knowledge of USACE and state drilling guidelines and with a minimum of 5 years of experience drilling with the equipment and following drilling program plan procedures. All drilling operations on abandoned mine impoundments should be conducted in the presence of a licensed PE or PG who will be responsible for monitoring the integrity of the impoundment during these invasive activities.

3.2.2.2 Excavation Methods

The excavation method used for geotechnical investigations will vary by site and strategic approaches to excavation, including the use of shoring, which may be required to assist in characterizing abandoned mine impoundments. Excavators vary significantly in size, weight, and length of excavation reach. Many excavators are deployed on all-terrain tires or tracks and adjustable platforms to enable work on the side of steep slopes.

Depending on the depth of excavation and worker access for sampling and testing activities, there may be potential health and safety risks associated with excavation efforts that should be addressed during geotechnical investigation planning and included in an approved Health and Safety Plan (HASP). Risks of cave-ins and slope failure may be mitigated using sloping, benching, shoring, and other techniques. Specialists familiar with the technical and regulatory requirements associated with excavation in unstable terrain and confined-space environments should be included in the planning efforts.

3.2.3 Analyze the Risks of the Proposed Geotechnical Investigations

Because drilling and excavation are invasive activities, it is recommended that a risk analysis (sometimes referred to as the drilling/excavation plan) for the geotechnical investigation be conducted. The risk analysis should identify the potential failure modes (PFM), the triggering events associated with the drilling or excavation plans, and the likelihood of a sudden, uncontrolled release of impounded liquids or wastes event, the severity of its consequences, and any potentially affected receptors.

Failure risk assessments and FMEAs are two risk analysis methods that can be used to evaluate whether a proposed geotechnical investigation could cause a failure of the abandoned mine impoundment (BOR and USACE 2015; FERC 2016b; USACE 2014b). Because PFMs vary for each proposed invasive method and for each abandoned mine impoundment, a risk analysis can involve different levels of detail when assessing how a proposed invasive method may impact an abandoned mine impoundment. A FMEA is generally more detailed and formal than a failure risk assessment and is used when the risks are likely to be high and when the risk analysis indicates more extensive examination may be warranted. The risk analysis can be either qualitative or quantitative. The determination of whether the risk analysis will be qualitative or quantitative should be based on the professional judgment of the planning team, considering potential consequences and available information. While the results of a FMEA are typically documented in a separate FMEA report, a failure risk assessment may be incorporated as a section or appendix in the drilling plan.

Exhibit 6. Examples of Drilling-Related Potential Failure Modes

- Drilling vibration liquefying soil or other material workings blockages.
- Failure of soil, rock, or waste material under drilling equipment.
- Piping of impounded water around drill steel/augers in unconsolidated material.
- Rapid changes in hydraulic head pressure.
- Rupture of drains causing liquefied waste to escape via drain pipes.
- Weight of drilling or construction equipment.

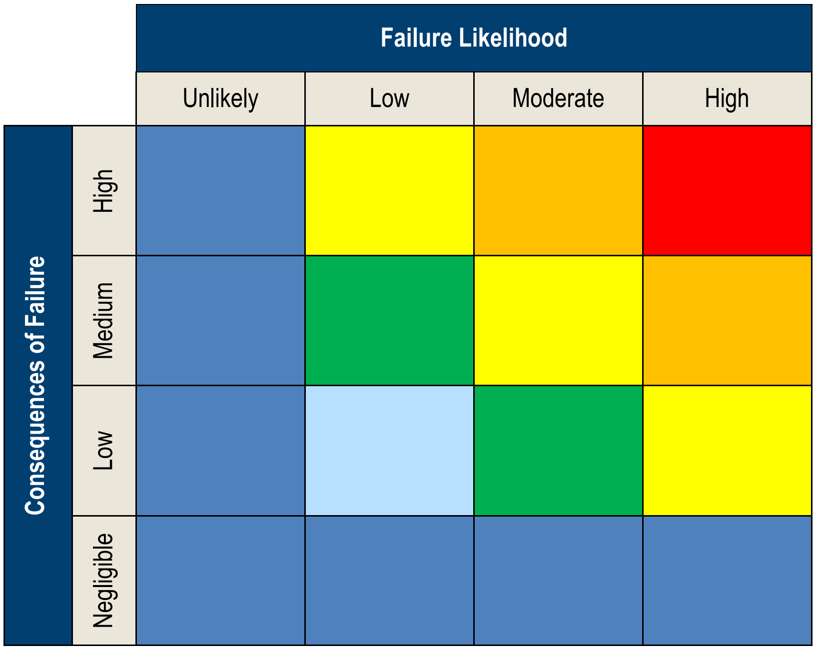
Risk analysis results should be provided to responsible personnel in each organization that will be involved in drilling or excavation to ensure that each organization is fully aware of the risks and consequences and that work proceeds collaboratively to mitigate and manage those risks. Suggested mitigation measures are identified to manage the risk of failure and impacts by reducing the likelihood of occurrence or the severity of the consequence or both. Exhibit 6 provides some examples of PFMs from drilling that may contribute to impoundment failure; similar PFMs exist for excavation. A FMEA typically requires participation of a multi-disciplinary team with diverse knowledge of mining and civil engineering; impoundment design and mechanics; environmental site investigation and remediation; geology and hydrogeology; emergency action planning and response; general mine site safety; and other expertise as relevant to the impoundment or site conditions. The scale of the FMEA effort should be proportional to the diversity and degree of potential drilling-related risks associated with the current conditions of the impoundment.

A worksheet may be used to guide and document the FMEA effort and typically contains the following elements:

- Identifying and numbering task and components.
- Identifying PFMs.
- Identifying triggering events.
- Identifying potential failure consequences and assigning a severity rating from negligible to high. Potential failure consequences range from no significant economic, environmental, or human impact at the low end of the spectrum to loss of life at the high end of the spectrum (BOR 2008).
- Assessing the confidence in the risk analysis as low, medium, or high. The confidence level of the failure risk analysis can indicate whether additional evaluation is necessary to predict both the risk and mitigation measures to reduce risk.
- Identifying worker and health safety risks.
- Identifying mitigation measures.

A FMEA provides a hierarchy of risks posed by each PFM. A risk matrix is typically used to present the likelihood of a failure occurring with the consequences of the failure to identify the highest priority tasks or components requiring mitigations. Exhibit 7 provides an example of a FMEA risk categorization matrix, which can be modified for project and stakeholder needs as warranted.

Exhibit 7. Example FMEA Risk Categorization Matrix



		Failure Likelihood			
		Unlikely	Low	Moderate	High
Consequences of Failure	High	🟦	🟨	🟧	🟥
	Medium	🟦	🟩	🟨	🟧
	Low	🟦	🟦	🟩	🟨
	Negligible	🟦	🟦	🟦	🟦

Note:

FMEA Failure modes and effects analysis

Source: Bureau of Reclamation. 2008. "Leadville Mine Drainage Tunnel Risk Assessment: Leadville Mine and Drainage Tunnel Project, Colorado, Great Plains Region." November. https://www.usbr.gov/gp/ecao/leadville/combined_risk_assessment.pdf.

The colors in Exhibit 7 indicate the hierarchy of risk as follows:

- Red – Extreme risk
- Orange – High risk
- Yellow – Moderate risk
- Green – Tolerable risk
- Blue – Well within tolerable limits

Activities that present a high or moderate failure likelihood of an uncontrolled release should not be undertaken unless there is certainty that the consequences are negligible or can be controlled through effective contingency measures. Recommended mitigation actions are developed based on the level of risk starting with high (red) and working down to unlikely (green or blue). Site-specific conditions are used to adjust the ranking of risk determinations because, in some cases, the severity of consequences may make even a negligible likelihood of consequences unacceptable.

While described in this document as best practices for drilling and excavation risk analysis, FMEAs and risk assessments are not the only methods of failure, reliability, or dependability risk analysis. Other risk analysis methods include (1) preliminary hazard analyses and functional failure analyses, which may be effective for identifying PFMs; (2) common cause analyses, which allow for the evaluation of risks posed by multiple, concurrent failure modes; and (3) event tree analyses (ETA), which can be used to identify all failure sequences, including assessing probabilities and consequences of outcomes that follow an initiating event. ETAs can also be used to test the PFMs for specific actions or events potentially affecting the impoundment system (Kaplan and others 1999). Additional information on how to assess risks at dams are noted by BOR and USACE (2015), USACE (2014b), and FERC (2016b).

Uncertainty will be associated with missing information, measurement inaccuracy, and human error used to assess PFM-related risks. An appropriate level of conservatism should generally be considered based on the level of uncertainty for each PFM analysis.

3.2.4 Develop a Contingency, Notification, and Emergency Action Plan for the Proposed Intrusive Geotechnical Activity

It is a best practice that a carefully developed Contingency, Notification, and Emergency Action Plan (CNEAP) be prepared or updated for all proposed invasive activities supporting a geotechnical investigation, particularly for drilling and excavation. The CNEAP is more commonly known as an Emergency Preparedness and Response Plan (EPRP) in the mining industry. The CNEAP (or similar documentation) serves as the key document for comprehensive contingency, notifications, and emergency action planning for planned site activities. The CNEAP has three elements: a contingency plan, a notification plan, and an emergency action plan.

The CNEAP is a high-level plan that coordinates site activities with local and regional response teams in the event of a potential failure. The CNEAP should be based on activity specific risk analysis, adaptive management processes related to the activity, and activity related risk mitigation procedures. The CNEAP should also assess how long it may take to reach receptors should a sudden release occur.

The CNEAP evaluates if there are risks from the geochemical nature of the impounded liquids and wastes. In some circumstances, these liquids or wastes may present specific risks if released and may require special worker health and safety training to address those risks. Another important element of the CNEAP is the hazard potential classification of the abandoned mine impoundment since such classification indicates the potential severity of the failure of the impoundment. The CNEAP should also consider how the placement of heavy equipment could adversely affect the bearing capacity of the impoundment surface and pose a threat to worker safety.

It is best practice to have all other site documents that address related topics defer to and reference the CNEAP, including site cleanup-related work plans, such as field sampling plans, quality assurance project plans, remedial designs, technical specifications for drilling and construction, monitoring plans, project management plans, and health and safety plans. Development or modifications to the CNEAP should be directly supported by the results of the risk analysis performed to identify and manage risks associated with the proposed geotechnical study. Conditions at the time of the risk analysis should be confirmed during contingency and emergency action planning and again when geotechnical studies are being initiated. All site personnel should be familiar with and be tested on the contents of the CNEAP before work is initiated to ensure that emergency action procedures are understood and followed.

Adaptive management planning principles are a best practice to apply when developing the CNEAP. Comprehensive monitoring and data collection help field managers adapt their knowledge of site conditions in an iterative learning process while enhancing their understanding of the risks. All site personnel should be familiar with the contents of the CNEAP before work is initiated to ensure that adaptive management principles are considered across the project.

3.2.4.1 Contingency Plan

Contingency plans typically focus on the types of emergencies that could occur, the potential impacts of such an emergency, and the existing engineering controls (EC) and other actions that should be implemented to mitigate or partially mitigate the consequences of such an emergency. ECs should be in place for proposed invasive geotechnical activities, but will also pertain to other site activities, such as abatement of water pollution, erosion protection, and sedimentation control. Contingency plans assess how the site will manage impacts from extreme events, such as high rainfall occurrences or earthquakes, and estimate how long it may take for a release to reach critical infrastructure or population centers depending on the type of release (saturated tailings or precipitation/impounded water enhanced mudflow), the likely impacts of a release, and the notification team response time.

While this document identifies some best practices for preventing impoundment failures, it does not provide an exhaustive treatment of this topic. Contingency plans for invasive activities to be conducted at abandoned mine impoundments include the following elements:

- Providing a list of training or qualifications required for personnel responsible for leading and supporting notifications and emergency action efforts.
- Planning and documenting contingencies to control and mitigate minor uncontrolled releases of liquids or liquefied impoundment waste that do not pose significant risk to human health or the environment.
- Developing or updating a breach or failure analysis completed to the level appropriate for the triggering event.
- Planning and documenting approaches to mitigate an impoundment failure, including
  - Calculating the maximum potential impoundment liquid and waste volumes;
  - Mapping inundation assuming various failure scenarios;
  - Calculating the time it would take to reach receptors assuming various failure scenarios;
  - Evaluating the site infrastructure’s ability to contain the maximum potential waste volume;
  - Characterizing, testing, and analyzing the abandoned mine impoundments;
  - Considering safeguards to implement should a failure occur (for example, buttressing, channelization, use of geotextiles to reduce erosion, or other stability safeguards);
  - Evaluating the suitability of the site’s footprint and topography for increasing containment capacity; and
  - Recommending solutions for containment capacity increases (for example, the expansion of existing containment ponds or downstream dams).
- Installing monuments or deflection sensors to monitor potential movement in the dam face or impoundment walls.
- Monitoring changes in impoundment discharge rates and water quality at discharge points or dam toe during and after invasive activities.
- Using the risk analysis to inform mitigation measures and as the basis for developing instructions related to contingencies and emergency response action requirements and procedures.

3.2.4.2 Notification Plan

It is a best practice to develop a comprehensive notification plan that addresses all future activities at a site with known or potential risks of an impoundment failure. Notifications may vary depending on the type of emergency at the site. It is important that notification plans for possible impoundment failures include notifications for responders and downstream receptors, such as names and contact information. Site personnel should be familiar with the site CNEAP (or similar documentation) and have reliable telecommunication capabilities to support immediate notifications (for example, satellite phones in remote areas without cell phone coverage).

3.2.4.3 Emergency Action Plan

Emergency action plans may include the following content (based partially on FEMA 2013a):

- A list of possible events that could cause an impoundment failure or breach. For each possible event, emergency actions are specified, including the responsible personnel, resources, and equipment required.
- A notification tree identifying what emergency response agencies will be called in the event of an impoundment failure.
- Site personnel mustering plan and designated locations to ensure protection of human health and safety in the event of a release or pending release.
- Updated maps that depict site roads, features, infrastructure, and areas of sensitive and hazardous or dangerous environments, including protected areas and steep or heavily forested topography. Maps should also indicate areas of likely inundation.
- An inventory of chemicals and fuels stored on site so that responders will know how to neutralize or clean up such chemicals or fuel in the event of a sudden release. It is recommended that all hazardous material storage, equipment storage, offices, and other important infrastructure be located out of the area of impact from any impoundment failure.
- How to address specific risks related to the geochemical nature of impounded liquids or wastes.
- Inspection forms, plan views, and associated details, including corrective and maintenance action procedures, for pertinent features such as detention ponds.
- Procedures to ensure that off-site first responders tour a site before high-risk work is started to increase their preparedness to respond in the event of a serious incident and to provide off-site responders notice of such high-risk work activities.
- Contact informational training for emergency responders.
- A list of experts or service vendors for specialty technologies to be used for high-risk activities, as well as notification procedures to ensure that such vendors are on call or on site (as applicable) to assist with their technologies during such high-risk activities.

To be effective, emergency action plans should be tested regularly (through exercises or drills) and updated, including the incorporation of lessons learned.

3.2.5 Analyze the Geotechnical Data

The results of the geotechnical field and laboratory tests listed in Exhibit 8 can be used to validate or modify the geotechnical parameters. Geotechnical parameters are used to provide the quantitative basis for evaluating the structural stability of an abandoned mine impoundment and their vulnerability to PFMs under applied loadings (for example, the undrained strength of the weakest soil layer of concern).

Laboratory results from invasive geotechnical activities, minimally invasive survey data, observations from site visits, and data from instrumentation can be used by the investigation team to complete structural stability and safety analysis, including determining the hazard potential classification, condition rating, and FOS.

Exhibit 8. Common Field and Laboratory Soil Test Methods[1]

Test Method Name	Method Number	Purpose
Field Tests		
Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils	ASTM D1586	Provides a disturbed soil sample for moisture content determination, identification and classification, and laboratory tests.
Standard Test Method for Mechanical Cone Penetration Test of Soil	ASTM 3441	Test method for determining end bearing and side friction, the components of penetration resistance.
Electronic Friction Cone and Piezocone Penetration Testing of Soils	ASTM D5778	Rapid evaluation of stratigraphy, including heterogeneity, to estimate soil classification and correlate with soil engineering properties.
Pocket Penetrometer	ASTM WK27337 (Under development)	Rapid quantification of soil compressive strength.
Field Vane Shear Test in Saturated Fine-Grained Soils	ASTM D2573	Evaluation of rapid loading strength for total stress analysis of saturated fine-grained clays and silts, mine tailings, and organic muck.
Laboratory Tests		
Particle-Size Analysis of Soils	ASTM D422 (Withdrawn in 2016, pending update)	Quantitative determination of the distribution of particle sizes in soils.
Liquid Limit, Plastic Limit, and Plasticity Index of Soils (Atterberg Limits)	ASTM D4318	Characterization of the fine-grained fractions of soils to specify the fine-grained fraction of construction materials.
Soil Density (Unit Weight)	ASTM D7263	Determination of dry or bulk density to evaluate the degree of materials compaction.
Direct Shear Test of Soils under Consolidated Drained Conditions	ASTM D3080	Determination of the consolidated drained shear strength of soil in direct shear.
Moisture Content of Soil and Rock by Mass	ASTM D2216	Determination of water content to correlate soil behavior and index properties, such as liquidity index, derived in conjunction with ASTM D4318.
Laboratory Compaction Characteristics of Soil Using Standard Effort	ASTM D698	Low-energy compaction test determination of soil moisture-density relationship; generally, at a higher optimum moisture content.

Exhibit 8. Common Field and Laboratory Soil Test Methods[1]

Test Method Name	Method Number	Purpose
Laboratory Compaction Characteristics of Soil Using Modified Effort	ASTM D1557	High-energy compaction test determination of soil moisture-density relationship; generally, at a lower optimum moisture content.
Unconfined Compressive Strength of Cohesive Soils	ASTM D2166	Determination of unconfined compressive strength of cohesive soil in undisturbed, remolded, or compacted conditions.
Unconfined Compressive Strength and Elastic Moduli of Intact Rock Core	ASTM D7012C (Replaces D2938-95)	Determination of unconfined compressive strength and elasticity of intact rock under varying states of stress and temperatures.
Consolidated Undrained Triaxial Compression Test for Cohesive Soils	ASTM D4767	Determination of the consolidated undrained shear strength of soil under changed conditions.
Consolidated Undrained Direct Simple Shear Testing of Fine Grain Soils	ASTM D6528	Determination of shear strength under constant volume conditions equivalent to undrained conditions for a saturated specimen.
Miniature Vane Shear Test for Saturated Fine-Grained Clayey Soil	ASTM D4648	Rapid estimation of undrained shear strength of undisturbed, remolded, or reconstituted fine-grained soils.
One-Dimensional Consolidation Properties of Soils Using Incremental Loading	ASTM D2435	Estimation of the magnitude and rate of both differential and total settlement of a structure or earthen fill.
One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading	ASTM D4186	Estimation of one-dimensional settlements, rates of settlement associated with the dissipation of excess pore-water pressure, and rates of fluid transport because of hydraulic gradients.

Notes:

[1] These “soil test methods” are recommend methods for impoundment geotechnical investigations. The lead geotechnical engineer will choose which of these tests are appropriate based on site-specific conditions.

ASTM American Society for Testing and Materials

3.3 Determine the Hazard Potential Classification

It is a best practice that the investigation team should determine the hazard potential classification for each abandoned mine impoundment under study. Hazard potential is an independent metric from the condition and risk probability of a breach or failure of an abandoned mine impoundment. Hazard potential classifications are not designed to evaluate the specific physical condition or structural stability of an impoundment; rather, they are a rating of potential for harm (that is, the inferred consequence) should the impoundment fail. Many states have developed and adopted their own hazard potential classification criteria, but for national consistency, this best practices document relies on FEMA hazard potential guidelines (FEMA 2004; USACE 2014b). If the dam is listed in the NID, it will have an assigned hazard classification based on the size of the dam and the potential for life loss and economic damage should it fail.

Three hazard potential classifications describe the potential risk of sudden fluid or liquefiable releases from abandoned mine impoundments:

- **High Hazard Potential** failure results in probable loss of human life. High hazard potential impoundments are typically located in areas with nearby populations.
- **Significant Hazard Potential** failure results in no probable loss of human life, but can cause economic loss, environment damage,[9] disruption of lifeline facilities, or affect other concerns. Significant hazard potential impoundments are often located in predominantly rural or agricultural areas, but could be located in areas with population and significant infrastructure.
- **Low Hazard Potential** failure results in no probable loss of human life and low economic or environmental losses. Losses are principally limited to the owner's property.

3.4 Evaluate the Hydraulic and Hydrologic Capacity

Hydraulic and hydrologic (H&H) evaluations provide important inputs into determining FOS and the condition rating. As part of the H&H evaluation, the impoundment, dam, impounded material, and spillways are evaluated to determine whether there is sufficient storage within the impoundment to avoid overtopping the dam during major storm events given outfall flow capabilities. This effort includes evaluating the ability of the impoundment to safely accommodate the inflow design flood (IDF) according to the appropriate IDF per the hazard potential classification of the impoundment (FEMA 2013b). To make such a determination, analysis should conclude that impoundment decant structures and other water conveyance features have not degraded over time. To accomplish this type of study, it may be helpful to calculate surface water flow rates as part of an abandoned mine site water balance and to assess what the estimated inflow to an impoundment may be. For additional information regarding threats of overtopping an impoundment, see FEMA's *Technical Manual: Overtopping Protection for Dams* (FEMA 2015a). If the tailings structure is categorized as a dam by the state, the structure may be required to safely pass the probable maximum flood (PMF).

3.5 Estimate the Factors of Safety

The FOS is the ratio of the forces tending to resist the failure of a structure or slope compared with the forces tending to cause a failure (as determined by accepted engineering practice). Federal agencies and many states have developed minimum FOS requirements for earth and rock-fill dams. This document is adopting USACE and FEMA FOS for use at abandoned mine impoundments and is based on USACE's *Engineering and Design: Slope Stability* (USACE 2003) and FEMA's *Federal Guidelines for Dam Safety: Earthquake Analyses and Design of Dams* (FEMA 2005). Impoundment FOS are the results of an H&H evaluation and a slope stability analysis of the material present in the abandoned mine impoundment.

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[9] In terms of environmental damage, knowledge of the geochemical characteristics of the tailings is important.

3.5.1 Determine Slope Stability

A slope stability analysis is a two-dimensional limit equilibrium analysis (LEA) and is performed to estimate the ratio of shear strength to the shear stress required for equilibrium. Slope stability analyses are commonly conducted using computer-based geotechnical software using limit equilibrium methods. Slope stability models are commonly used in conjunction with finite element seepage models to define pore water conditions. Evaluation of the dam or impoundment construction method can also provide input in the slope stability analysis if such information is available. The geotechnical software used to conduct two-dimensional LEA typically requires the following model inputs:

- Embankment construction method
- Slope geometry
- Soil shear strength
- Pore pressure conditions
- Soil properties
- Loading conditions

3.5.2 Determine the Factors of Safety

Using data and inputs from the slope stability analysis and the H&H evaluation, the investigation team or qualified contractor should determine three FOS for each impoundment: static, seismic, and liquefaction.

- **Static FOS.** Static refers to the FOS under static loading conditions that can reasonably be anticipated to occur during the lifetime of the tailings dam. Static loading conditions are those that occur when a slope is in equilibrium, meaning that the load is at rest or is applied with constant velocity (shear strength is a function of normal stress as governed by mass and gravity). The calculated static FOS for earthen dams, such as tailings impoundments under the long-term, maximum storage pool loading condition, should equal or exceed 1.50 (see Table 3-1 in USACE 2003). The rapid drawdown loading condition typically does not apply to abandoned waste impoundments unless active dewatering occurs because, to satisfy the conditions of the loading condition, a release of the impoundment has likely already occurred with subsequent loss of the reservoir and impounded material (USACE 2003).
- **Seismic FOS.** Seismic refers to the FOS determined using analysis under earthquake conditions for a seismic loading event, typically based on USGS seismic hazard maps[10] for the area where the abandoned mine impoundment is located. This seismic analysis is a pseudo-static analysis that approximates a seismic event by applying an additional static load; it is used to predict whether an impoundment would remain stable during an earthquake. While conducting seismic analyses, it is important to consider the appropriate loading conditions, such as maximum storage pool level and existing silt load. While pseudo-static analysis is considered appropriate for many applications, dynamic seismic analysis or deformation modeling may be appropriate for high-risk structures. In determining the appropriate peak ground acceleration (PGA), the maximum credible earthquake (MCE), the maximum design earthquake (MDE), or safety evaluation

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[10] https://earthquake.usgs.gov/hazards/hazmaps/

earthquake (SEE), refer to FEMA's *Federal Guidelines for Dam Safety Earthquake Analyses and Design for Dams* (FEMA 2005) and BOR's "Design Standards No. 13. Embankment Dams: Chapter 13: Seismic Analysis and Design" (BOR 2015b). For certain high-risk sites, more stringent probabilistic intervals may be appropriate. The calculated pseudo-static seismic FOS should equal or exceed 1.00 (FEMA 2005).

- **Liquefaction FOS.** Liquefaction refers to the FOS determined using analysis under liquefaction conditions. Liquefaction is a phenomenon that typically occurs in loose saturated or partially saturated soils where the effective stress of the soils reduces to zero, corresponding to a total loss of shear strength of the soil. The most common occurrence of liquefaction is in loose soils, typically sands. The liquefaction FOS determination is used to determine if a dam would remain stable if the soils of the embankment or its foundation were to experience liquefaction. The calculated liquefaction FOS should equal or exceed 1.20 (FEMA 2005). If results indicate that the FOS is greater than 1 but less than 1.2, it may be useful to conduct deformation modeling to determine if deformation under the maximum design earthquake case is tolerable. The mining industry often refers to this analysis as a post-seismic analysis.

There may be circumstances where analyses conclude that the tailings may not liquefy; however, this conclusion does not necessarily mean that wastes will not flow upon failure. It may be useful to conduct additional studies (using CPT or other methods) to determine if flow can occur even if the wastes may not liquefy. ASDSO has developed online webinars to educate users on how to conduct static and seismic stability studies.[11]

3.6 Assign a Condition Rating

After the FOS have been determined and a hazard potential classification is assigned, the investigation team should assign a condition rating of the abandoned mine impoundment. Condition ratings are a subjective rating based on the site visit findings, geotechnical investigation results, hazard potential classification, FOS analysis, and professional judgment. Based on NID database definitions, condition assessments include the following ratings (USACE 2016):

- **Satisfactory.** No existing or potential safety deficiencies are recognized. Acceptable performance is expected under all applicable loading conditions (static, seismic, and liquefaction) in accordance with the applicable criteria. Minor maintenance items may be required.
- **Fair.** Acceptable performance is expected under all required loading conditions (static, seismic, and liquefaction) in accordance with the applicable safety regulatory criteria. Deficiencies may exist that require additional action and secondary studies or investigations.
- **Poor.** The impoundment has a safety deficiency for any required loading condition (static, seismic, and liquefaction) in accordance with the applicable impoundment safety regulatory criteria. Additional action is necessary.
- **Unsatisfactory.** An impoundment safety deficiency considered unsafe is recognized that requires immediate or emergency actions for problem resolution. Remedial project managers (RPM), on-scene coordinators (OSC), or site managers should be immediately notified after a site visit if

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[11] https://learningcenter.damsafety.org/on-demand-webinars

impoundment conditions warrant corrective actions or when an impoundment is found to be rated unsatisfactory or poor so that corrective actions can be taken in a timely manner. In addition, short- or long-term corrective measures necessary to safeguard the structural stability of the impoundment should be identified and the appropriate local and state officials notified.

3.7 Develop an Impoundment Structural Stability and Safety Report

Based on the results of the stability and safety analysis, the site investigation team and qualified contractors should prepare an impoundment structural stability and safety report. The report contains findings, conclusions, and recommendations derived from:

- Document review;
- Initial impoundment condition and failure assessment and site visit;
- Instrumentation or monitoring results;
- Geotechnical investigations and laboratory testing as applicable; and
- Structural stability and safety analyses, including:
    - Hazard potential classification;
    - FOS estimation for static, seismic, and liquefaction conditions; and
    - Condition rating.

The report typically will include a discussion of the following topics:

- H&H capacity of the impoundment, including an evaluation of the surface water contributory area and IDF.
- Soil, groundwater, surface water, geology, geohydrology, and waste characteristics, including data on site climate, geology, geotechnical, seismicity, hydrogeology, and hydrology accumulated since the impoundment was constructed or last inspected.
- Determination of the degree of dam face erosion as a primary concern during overtopping, including analysis of surface cover, material properties, and depth and duration of overtopping.
- A history of the performance of the impoundment through analysis of data from monitoring instruments (if available) and review of available operating records.
- Location of areas of potential downstream impact, such as schools, hospitals, or other critical infrastructure within at least 5 miles downgradient of the impoundment.
- Location with respect to federally designated flood plains.
- Location of federal and tribal lands.
- Conditions at the time of the impoundment assessment and recent precipitation.
- Results and findings of the structural stability and safety analysis, including the data collected, reviewed, and analyzed. Does the impoundment meet minimum FOS?

Based on the impoundment investigation team's field observations and evaluation of other relevant data, the report will contain findings and recommendations, including:

- Overall determination of the hazard potential classification of each impoundment; and
- Overall condition rating based on structural adequacy and stability of the impoundment structures under all credible loading conditions through a review of static, seismic, and liquefaction FOS and an assessment of the H&H capacity of the impoundments.

If an impoundment is found to meet or exceed recommended minimum FOS and there are no other reasons to take any other actions to reduce risks associated with the impoundment, then it is appropriate to proceed with the proposed CERCLA activity. A PE's signature and state-specific certification engineering seal are typically required on the impoundment structural stability and safety report.

4.0 MITIGATION MEASURES TAKEN PRIOR TO PROCEEDING WITH THE PROPOSED ACTIVITY

When an impoundment's condition is rated as poor or unsatisfactory or the impoundment does not meet the required minimum FOS, the impoundment structural stability and safety report should recommend appropriate risk reduction measures. The timing of the mitigation will be a site-specific decision. Some mitigation measures may be appropriate as part of the investigation phase to allow for the safe implementation of the investigations. Many mitigation measures would be included in the alternatives developed for the response action or require an independent response action (either removal or remedial) depending upon whether the CERCLA threshold for action is triggered. If a determination is made that a CERCLA action is not warranted, those responsible for the impoundment from an ownership and regulatory oversight perspective, as well as local planning agencies, should be provided with the completed stability assessment.

Should an action be recommended, there are a variety of risk reduction approaches, including buttressing, adding height to the dam, compaction, use of alternative capacity, use of geotextiles, and reducing or eliminating inflow. Before implementing any of these approaches, it is a best practice to subject them to a risk analysis to ensure that they will not cause sudden releases. All these approaches will have site-specific capital and operating costs that should be considered in planning a risk reduction measure. This best practices document only mentions several common impoundment mitigation approaches, but the correct approach is a site-specific determination. The BOR (2011) and the Montana Department of Natural Resources and Conservation (MDNRC) and FEMA (2016) provide examples of mitigation measures at impoundments.

One of the more rapid mitigation measures is dewatering an impoundment to reduce risks of excess ponded water above the mine waste and to reduce the high moisture contents of the mine waste. The BOR (2011) approach to dewatering standing water in an impoundment includes:

1. Pumping out impounded water (which may incur maintenance and treatment costs);
2. Constructing diversion ditches to prevent surface run-on; and
3. Using sprinklers or evaporators to spray impounded water into the air to speed evaporation (where climatic conditions allow).

Dewatering may also include pore water management, such as installation or maintenance of wick drains or passive horizontal drains. Dewatering may require treatment of the impoundment liquids based on testing of those liquids. Reducing the water level in an abandoned tailings impoundment may cause a rapid drawdown condition that can become a structural threat to the dam or impoundment slopes. Structural failures may occur when the potentiometric surface of the impoundment pool is lowered at a rate significantly higher than the excess pore water pressure within the impoundment walls can dissipate. Other failure modes that may occur because of dewatering include internal dam erosion, significant dam face erosion with the potential to expose weak material, and saturation of foundation material.

An engineering evaluation should be conducted to identify a safe drawdown rate. Factors to consider include climatic conditions, the structural stability of the impoundment, and the receiving water flow and chemistry. Caution should be exercised during dewatering efforts to reduce impacts to the integrity of the impoundment and to decrease the risk of failure. A FMEA should be performed on selected dewatering approaches before implementation to identify any risks of mine waste release that might occur during dewatering efforts (BOR 2011; USACE 2004).

Another common mitigation method is to construct diversion ditches around the perimeter of a surface impoundment to intercept and manage surface run-on and, thus, reduce water infiltration reporting into the impoundment. USACE, BOR, and state regulations should be reviewed to determine if specific design standards have been issued for these types of diversions. Diversion construction near spillways may also include a PMF and precipitation analysis. For example, MSHA guidelines require that diversion ditches have an appropriate configuration and elevation around the impoundment, which is determined on a case-by-case basis. MSHA guidelines also dictate that the channels provide flow capacity for a 100-year, 24-hour storm event and include long-term protection against erosion and deterioration (BOR 2011; MSHA 2009; USACE 2004).

An additional mitigation method is buttressing or reinforcing. Reinforcement may include installing toe drains, improving or adding spillways, and regrading slopes. Buttressing uses rock armoring or a compacted earth buttress of slopes as an additional form of slope protection that has been relied on extensively in dam safety.

Consideration of the use of geosynthetic (geotextiles, geogrids, geonets, geomembranes, and geocomposites) and other materials for embankment reinforcement should also be considered although the limited understanding of their long-term performance should be recognized.

In some situations, a combination of these risk reduction measures could be useful, such as reinforcement with partial or full dewatering.

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APPENDIX A. BEST PRACTICES SITE VISIT CHECKLISTS

Sample Impoundment Condition, Stability, and Safety Checklist

Item	Activity Description	Completed* (Yes / No / NA)
1. CONDUCT INITIAL IMPOUNDMENT CONDITION ASSESSMENT AND		
2. DEVELOP IMPOUNDMENT CONCEPTUAL SITE MODEL		
2a	Identify, obtain and review available site documents and data	
2b	Conduct a site visit and visual assessment including use of UAS where appropriate	
2c	Make initial determination of risk of failure priority (Check One):** ☐Immediate ☐Urgent ☐moderate to high priority ☐ Low to moderate priority ☐ Low priority	
2d	If 2c is Imminent, recommend interim risk mitigation measures	
3. PERFORM STRUCTURAL STABILITY AND SAFETY ANALYSIS		
3a	Assemble qualified investigation team	
3b	Perform data gap analysis and impoundment inspection (Use separate Surface Impoundment Dam Inspection Checklist)	
3c	Develop geotechnical investigation plan	
3d	Analyze risks of investigation plans using Failure Mode and Effects Analysis (FMEA) or other risk assessment technique	
3e	Develop Contingency, Notifications and Emergency Action Plan (CNEAP)	
3f	Evaluate impoundment geotechnical characteristics	
3g	Review and analyze geotechnical investigation data	
4. DETERMINE HAZARD POTENTIAL CLASSIFICATION (CHECK ONE)		
4a	Impoundment Name: ☐High ☐Significant ☐Low	
5. CALCULATE FACTORS OF SAFETY (FOS) – ENTER FOS CALCULATED VALUE		
5a	Impoundment Name: Static__________ Seismic__________ Liquefaction__________	
6. DEVELOP CONDITION RATING (CHECK ONE)		
6a	Impoundment Name: ☐Satisfactory ☐Fair ☐Poor ☐Unsatisfactory	
7. DEVELOP SURFACE IMPOUNDMENT STRUCTURAL STABILITY AND SAFETY REPORT		
8. DETERMINE IF RISK REDUCTION MEASURES ARE NECESSARY		
8a	Identify risk reduction measures	
8b	Perform or modify FMEA on selected measures	
8c	Develop or modify CNEAP (where appropriate)	
9. ASSESS AND MITIGATE RISKS FROM PROPOSED MITIGATION **10. TAKE MITIGATION MEASURES BEFORE PROCEEDING WITH THE PROPOSED ACTIVITY**		

* Explain any No and NA answers; provide documentation and references for Yes answers.

** If the initial determination results in an imminent risk, conduct interim risk reduction/mitigation measures.

Sample Surface Impoundment Site Visit Form

Site Name:	Date:
Unit Name:	Operator's Name:
Unit I.D.:	Hazard Potential Classification:
Name:	☐High ☐Significant ☐Low

Check the appropriate box below. Provide comments when appropriate. If not applicable or not available, record 'N/A'. Any unusual conditions or construction practices that should be noted in the comments section. For large diked embankments, separate checklists may be used for different embankment areas. If separate forms are used, identify approximate area that the form applies to in comments.

	YES	NO		YES	NO
1. Tailings saturation depth (in ft. above MSL)?	_________Feet		18. Sloughing or bulging on slopes?		
2. Pool elevation (in ft. above MSL)?	_________Feet		19. Major erosion or slope deterioration?		
3. Decant inlet elevation (in ft. above MSL)?	_________Feet		20. Decant Pipes:		
4. Open channel spillway elevation (in ft. above MSL)?	_________Feet		Is water entering inlet, but not exiting outlet?		
5. Lowest dam crest elevation (in ft. above MSL)?	_________Feet		Is water exiting outlet, but not entering inlet?		
6. If instrumentation is present, are readings recorded?			Is water exiting outlet flowing clear?		
7. Overall, does the impoundment appear stable (if no, describe below)?			21. Seepage (specify location, if seepage carries fines, and approximate seepage rate below):		
8. Foundation characteristics adequate (visual evidence)?			From underdrain?		
9. Trees growing on, or rodent burrows in, embankment? (Indicate diameter below)			At isolated points on embankment slopes?		
10. Cracks or scarps on crest?			At natural hillside in the embankment area?		
11. Is there significant settlement along the crest?			Over widespread areas?		
12. Are decant trash racks clear and in place?			From downstream foundation area?		
13. Depressions or sinkholes in tailings surface or whirlpool in the pool area?			'Boils' beneath stream or ponded water?		
14. Clogged spillways, groin, or diversion ditches?			Around the outside of the decant pipe?		
15. Are spillway or ditch linings deteriorated?			22. Surface movements in valley bottom or on hillside?		
16. Are outlets of decant or underdrains blocked?			23. Water against downstream toe?		
17. Cracks or scarps on slopes?			24. Were photos taken during the dam inspection?		

Major adverse changes in these items could cause instability and should be reported for further evaluation. Adverse conditions noted in these items should normally be described (extent, location, volume, etc.) in the space below and on the back of this sheet.

Comments:

SAMPLE SURFACE IMPOUNDMENT SITE VISIT FORM

Impoundment # ______________________________________

Name of Site Visitor(s): ____________________

Date_______________________________

Impoundment Name____

Impoundment Company ____

EPA Region ______________________

State Agency (Field Office) Address____

Estimated volume of impoundment: ____

	Yes	No
Is impoundment currently being maintained?	________	________
Is water or liquid waste currently present?	________	________

IMPOUNDMENT TYPE OF CONSTRUCTION

Downstream _____

Upstream ________

Centerline________

IMPOUNDMENT FUNCTION: ____

Nearest Downstream Town: Name____

Distance of town from the impoundment ____

Impoundment Location:

Longitude___________Degrees__________ Minutes ________ Seconds

Latitude ___________ Degrees _________ Minutes ________ Seconds

State________________ County __________________

Who owns the impoundment? ____

Is this a PRP lead site? ____

EVALUATE HYDRAULIC AND HYDROLOGIC (H&H) CAPACITY

Are there data (or visual evidence) that the impoundment is able to safely accommodate the inflow design flood (IDF) according to the appropriate IDF per the Hazard Potential Classification of the impoundment (FEMA 2013b).

Yes: _________ No: _________

Is there evidence of prior overtopping? Yes: _________ No: _________

HAZARD POTENTIAL (In the event the impoundment should fail, the following would occur):

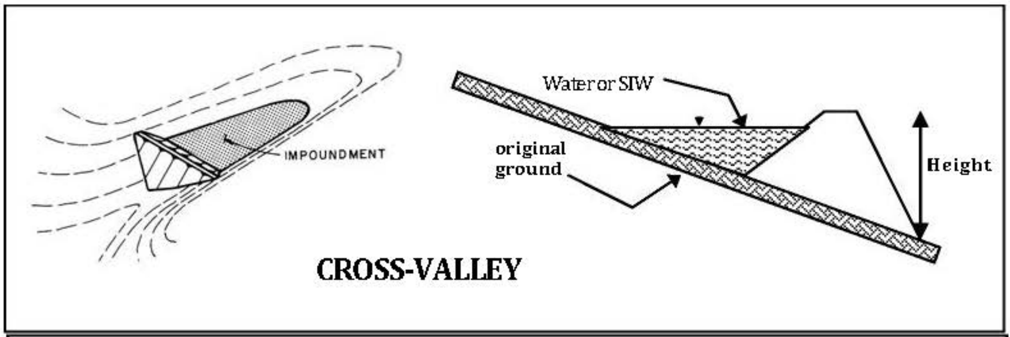
_______ **LOW HAZARD POTENTIAL**: Dams assigned the low hazard potential classification are those where failure results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the owner's property.

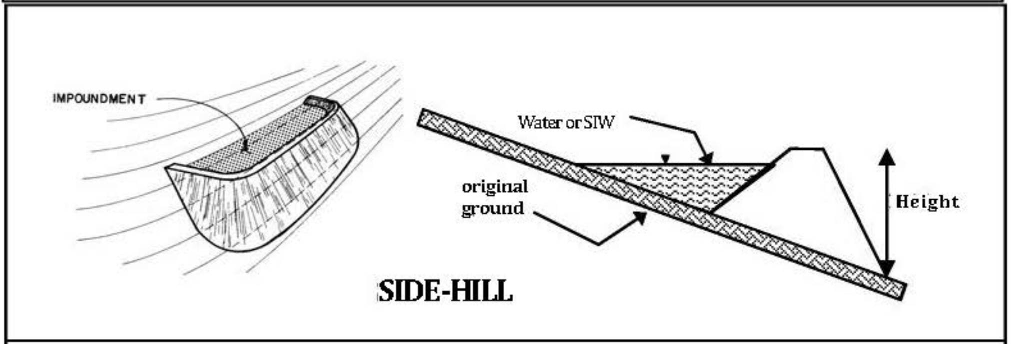
_______**SIGNIFICANT HAZARD POTENTIAL**: Dams assigned the significant hazard potential classification are those dams where failure results in no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns. Significant hazard potential classification dams are often located in predominantly rural or agricultural areas but could be located in areas with population and significant infrastructure.

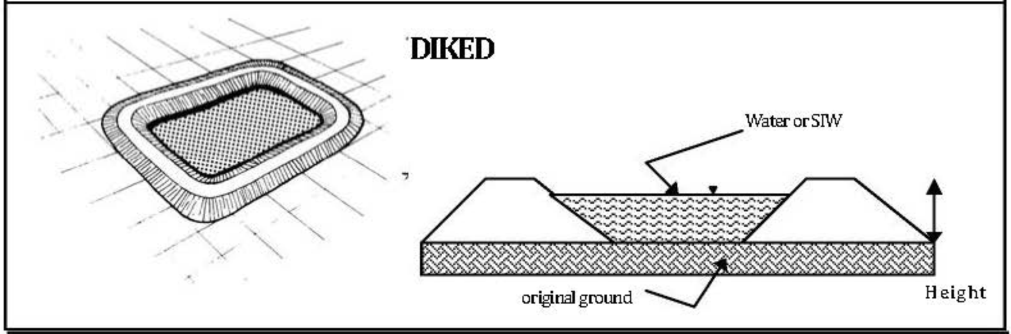
_______**HIGH HAZARD POTENTIAL**: Dams assigned the high hazard potential classification are those where failure will probably cause loss of human life.

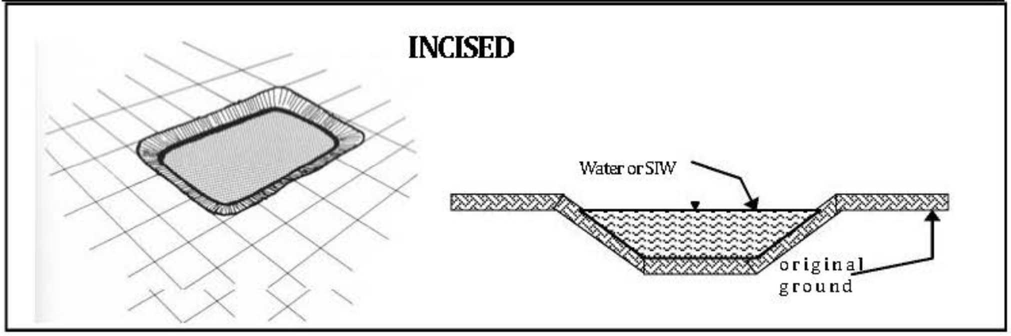
DESCRIBE REASONING FOR HAZARD RATING CHOSEN:

CONFIGURATION:









_____ Cross-Valley
_____ Side-Hill
_____ Diked
_____ Incised (form completion optional)
_____ Combination Incised/Diked

Embankment Height____________ feet Embankment Material____________________
Current Freeboard __________ feet Pool Area ________acres

TYPE OF OUTLET (Mark all that apply)

_____ Open Channel Spillway

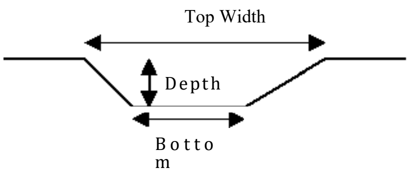
_____ Trapezoidal Spillway

_____ Rectangular Spillway

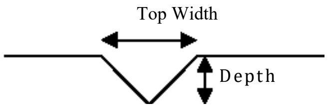
_____ Irregular Spillway

_____ Piped Outlet

TRAPEZOIDAL



TRIANGULAR

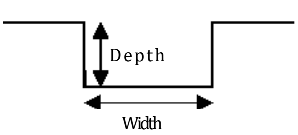


_____ Spillway depth

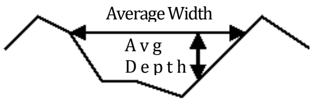
______ Spillway bottom width

______ Spillway top width

RECTANGULAR



IRREGULAR



________ Piped outlet inside diameter

Piped Outlet Material

_____ Corrugated metal

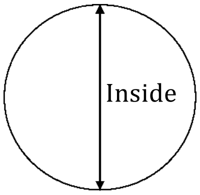
_____ Welded steel

_____ Concrete

_____ Plastic (HDPE, PVC, etc.)

_____ Other (specify)______________________

PIPED OUTLET



Is water flowing through the outlet? YES________________ NO ___________

_______ **No Outlet**

_____ **Other Type of Outlet** (specify) ___________________________________

Are there geotechnical soils data available to conduct FOS?

____

____

____

Has there ever been a failure at this site? YES ____________ NO ____________

If So, When? ________________________________

If So, Please Describe: ____

Has there ever been significant seepages at this site? YES __________________ NO ________

If So, When? ______________________________

If So, Please Describe:

Has there ever been any measures undertaken to monitor/lower phreatic water table levels based on past seepages or breaches at this site? YES __________ NO__________

If So, Which Method (e.g., piezometers, gw pumping)? ______________________

If So, Please Describe: ____