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Managing Water in the West

Small Embankment Dam Safety Guide

U.S. Department of the Interior
Bureau of Reclamation

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Small Embankment Dam Safety Guide

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Abbreviations

BIA	Bureau of Indian Affairs
CDR	Comprehensive dam review
CFR	Comprehensive facility review
cfs	Cubic feet per second
CMP	Corrugated metal pipe
DOI	Department of the Interior
EAP	Emergency action plan
g	equal to a given acceleration divided by the standard gravitational acceleration (32.17 feet per second squared).
IDF	Inflow design flood
MCE	Maximum credible earthquake
NAICS	North American Industry Classification System code for manufacturing
NPSHA	Net Positive Suction Head Available
NPSHR	Net Positive Suction Head Required
NPS	National Park Service
O&M	Operation and maintenance
PAR	Population at risk
PMF	Probable maximum flood
PMP	Probable maximum precipitation
PMT	Project management team
Reclamation	Bureau of Reclamation
SBC	Small business concern
SOP	Standing operating procedures
TSC	Technical Service Center

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Preamble

This document does not address emergency management (such as Emergency Action Plans (EAPs) and early warning systems) at small dams.

Low-hazard dams (i.e., dams whose failure would result in no population at risk downstream) are also not covered by this document. It should be noted, however, that many low-hazard dams have the potential to cause damage downstream. Low-hazard dams should be properly operated and maintained to avoid dam failure.

It is expected that this *Small Embankment Dam Safety Guide* will need to be revised as it is used in the dam safety programs of Department of the Interior agencies. Please provide any comments/changes to:

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Part 1: General

The U.S. Department of the Interior (DOI) has an inventory of approximately 480 dams that pose a risk to downstream populations. Of these, about one-fourth are considered small. About one-half of non-Reclamation DOI dams are small dams.

The purpose of this document to provide dam safety professionals working on small DOI dams (those less than 30 feet high) with guidance based on the lessons learned from successful past small dam safety projects. Because of the specific nature of individual projects, this guide does not include case histories. This guide is intended to help agencies safely evaluate, design, and construct repairs to small dams at minimum cost. Sound operation and maintenance (O&M), public safety, and security issues for small dams are also included.

This guide supplements but does not change existing Federal, DOI, and DOI agency authorities. The reader must be familiar with the Federal Guidelines for Dam Safety (United States, 1979), DOI Manual Part 753, and specific agency manuals and guidelines. Similarly, the reader should consult the necessary current technical standards for dam safety evaluation and remediation, including *Design of Small Dams* (Reclamation, 1987). This guide builds on the *Guidelines for National Park Service (NPS) Dam Evaluation and Remediation Process* drafted in May of 1993.

Key points of this guide include:

- Successful small dam safety projects result in safe dams (no unacceptable risks), maintain project benefits, and keep costs to a necessary minimum.

- Particular dams may have outlived their usefulness and permanently breaching (deactivating) such structures should be considered.

- Inexpensive methods are available to collect data about small dams. Extensive data collection and analysis used for large dams sometimes can exceed the cost of fixing a small dam.

- Practices that result in the lowest cost for large dam projects may not result in the lowest cost for small dam safety projects. It may be better to design and construct a conservative small dam safety modification without the cost of extensive data collection and analysis.

- Effective and frequent project team communication is a key to successful small dam projects.

Dam safety is an important public safety concern. Each dam is unique and must be evaluated and repaired based on its own structure, condition, and geology. What worked at one dam may not work at another. The use of experienced and qualified dam safety technical organizations and professionals is critical for successful management and mitigation of risks posed by small dams. Designer involvement during construction and first filling is critical to ensuring the modified structure will not pose an unacceptable risk to the public.

This document focuses on existing small dams; however, it is critically important to design and construct new dams in accordance with current dam safety, Federal, DOI, and agency dam safety practices.

General Characteristics of Small Dams

For the purposes of this document, small dams are generally those dams that are up to 30 feet high and have a reservoir capacity of 10 to 400 acre-feet. This document addresses dams with a High or Significant downstream hazard potential classification from the ACER TM 11 criteria or High hazard potential by FEMA 333 Guidelines. These dams have a population at risk (PAR) downstream should the dam fail. Low-hazard dams do not have people at risk downstream and are generally subject to less regulatory oversight.

Most of these small dams are earthen embankments, usually homogeneous, and constructed without current state-of-practice dam safety defenses. Most of the dams are 30 to 75 years old with few or no records of design or construction.

The spillways are typically ungated and uncontrolled. While most of the dams have water at or near the spillway crest most of the time, some dams are normally dry to provide flood protection. The outlet works (gated low-level conduit) are often inoperable and are not normally exercised.

Small DOI dams provide the following benefits: recreation, stock water, flood control, irrigation water supply, and fish/wildlife habitat. Although the reservoirs behind these dams are often small, they often comprise important surface water resources—especially in the arid Western U.S.

The PAR downstream from small dams is usually small: between 1 and 50 persons. The PAR is usually in homes downstream or motorists who travel roads on the crest or on stream crossings downstream that would be flooded during dam failure. Heavily used campgrounds, trails, or recreation sites can also be located downstream of these small dams. Small dams with higher PAR should be more conservatively evaluated and repaired.

An agency faces many challenges to operate and maintain small dams:

- Typically, local agency or tribal staffs have many other responsibilities in addition to the operation and maintenance of dams.
- Turnover in operations and maintenance staff is common.
- Little or no instrumentation exists at the dams.
- Vegetation and animal burrowing are common problems.
- The public often has full access to small dams; therefore, the safety of the public and vandalism are a concern.

Most of the dams are located in remote areas far from agency offices. It is often very difficult to develop, plan, fund, and construct a dam modification project; thus, it is usually preferable to construct a conservative dam safety modification so it will not be necessary to return to the site later for an additional modification. The costs of initiating and coordinating a small dam project are significant compared to total project costs; therefore, conservative designs are usually justified to avoid additional modifications.

Potential Failure Modes

A relatively recent advance in the dam safety industry is the formal potential failure modes analyses to evaluate dams. Potential failure modes are defined as the specific ways a given dam can fail. Very remote failure modes are disregarded (such as the dam failing due to a large earthquake simultaneously with the probable maximum flood). Unique failure modes are developed for each dam. Potential failure mode analyses consider the geology of the foundation and abutments, knowledge about the design and construction of the dam, the dam’s condition, the dam’s performance, and the static/hydrologic/seismic loadings to which the dam is subjected.

By developing site-specific potential failure modes, the dam agency owner can be more assured that the evaluation and modification will comprehensively address the most likely ways a particular dam can fail. In this way, the technical specialists can present the dam’s vulnerabilities more quantifiably and can better assess the risks posed by the dams.

To quantify risks, the Bureau of Reclamation performs more formal risk analyses for its large dam inventory by numerically combining probability of failure with downstream loss of life. The Bureau of Indian Affairs also develops failure modes and probability of failure for its dams. Examples of potential failure modes include:

Static

- Internal erosion (seepage) through the dam or foundation.
- Internal erosion along the outside of the outlet works pipe.
- Internal erosion into the outlet works pipe.

Hydrologic

- Inadequate spillway capacity leading to dam overtopping in a flood.
- Spillway intakes clogs with debris, leading to premature overtopping and failure.
- An unlined spillway experiences lateral erosion, which progresses to the dam embankment and leads to dam failure.

Seismic

- An earthquake causes transverse cracking of the core. Seepage through the crack erodes a hole through the dam, leading to dam failure.
- An earthquake causes wet/loose foundation materials to liquefy, resulting in dam collapse, loss of freeboard, and overtopping.

The failure modes should be very specific to each dam under consideration.

Note that for flood control structures with little normal reservoir storage, seismic analyses are not typically required.

Consequences

Evaluation of potential consequences of dam failure is an important aspect of dam safety. Consequences of dam failure could include loss of life (the primary factor in determination of hazard classification), destruction of riparian ecosystems, loss of transportation systems (roads/trains), loss of utilities, destruction of buildings and homes, loss of historical structures, and loss of cultural resources. While failures of small dams generally have correspondingly fewer losses than failures of large dams, a small dam failure can devastate a small, local community.

Evaluation of small dams should determine the consequences of dam failure. Inundation maps are usually prepared both for hydrologic and sunny-day failure scenarios. The depth, velocity, and time to flood-wave arrival are usually determined for key locations of population at risk or key structures, such as bridges. It can be helpful to describe the consequences of dam failure for each stretch of channel downstream (total loss concept).

While no dam should present an unacceptably high risk of failure to any one person downstream, dams with high populations at risk downstream should be even more conservatively evaluated and subsequently modified to present very little likelihood of failure.

Project Team and Process

One common element of almost all successful DOI small dam modification projects to date is the cohesive makeup of a project team. The team typically consists of the agency dam safety program engineer, a local project or agency representative, and a technical lead from the Bureau of Reclamation (Reclamation) design and construction groups or another well qualified technical organization.

Appropriate coordination with local, county, State, tribal, Federal, or engineering organizations helps to ensure a successful project. The team should plan for how they are going to communicate with the public. State dam safety offices, local Corps of Engineers Districts, the Natural Resources Conservation Service (formerly Soil Conservation Service), and Reclamation may have considerable insight for small dam evaluation and corrective action.

Effective and frequent communication between team members is perhaps the greatest factor in the success of a small dam safety project. At the beginning of the project, the team needs to determine team membership, communication methods, decisionmaking process, and meeting frequency. Strong communication results in confronting problems early and uses the combined strength of the team to efficiently work through these problems. While side one-on-one meetings are fine, once-per-month meetings (sometimes called project management team meetings or PMTs) usually are sufficient to identify and address issues without being burdensome. Many meetings are conducted via conference call.

While one might be inclined to think small dams could utilize less experienced technical staff, the opposite is actually true. The experience of seasoned dam safety technical staff allows them to make good judgments, often without extensive data and analysis. Effective application of this guide generally requires assignment of senior dam safety technical staff to the project. If only junior (i.e., less experienced) staff members are available, consider teaming them with senior-level dam engineers who will provide thorough review and oversight. In addition, formal peer reviews or independent reviews are usually required. A construction team member should be added to the team early in the process.

The project usually proceeds in stages:

- problem(s) awareness
- data search and review

- development of failure modes
- site visit
- determination of the need for and collection of additional data
- evaluation of data
- selection of deficiencies and design loads
- development and selection of modification alternatives
- permitting
- modification design
- procurement
- construction
- first filling

It is advisable to invite the team and other stakeholders to visit the dam site early in the project.

The project team typically meets in person or via conference call at the end of each stage to plan for the next stage. Each team member shares his or her concerns and ideas. Options begin to emerge, through brainstorming, and creative solutions often arise to efficiently address dam safety issues for small dams. The technical staffs are often requested to flesh out options and to make recommendations to the agency owner. The team consults with local project staff and other entities, selects the alternative, and presents the selection in writing.

At each stage, consider the project budget in terms of funding the subsequent design/exploration budgets, as well as the construction budget. It is typical to revise the construction estimate several times as the project moves from conception through final design. Budgets should include a contingency and estimates for the many aspects of a small dam safety project (grand total estimate).

Federal technical reviews will be performed if the designer of record is a non-Federal entity.

In addition to cost, the length of time until the dam is repaired is also very important. The longer a dam with problems is operated, the more likely it is to fail and expose the population at risk to hazardous flooding. Sometimes, problem dams are temporarily breached or a reservoir restriction is imposed. Because loss of a reservoir for an extended period can create hardship for project beneficiaries, the team may determine very early in the process to proceed expeditiously to dam modification.

In summary, the team needs to consist of both technical staff and dam agency owner staff that meet and discuss how to proceed at critical points in the process. The team considers a variety of options and validates that the selected direction fully meets dam safety and maintenance requirements at minimum cost. This approach leads to timely solutions that limit the loss of benefits and exposure of the PAR to the risks posed by a dam. Effective communication among the team members helps to keep everyone informed, to bring up problems early, and to increase coordination.

Comprehensive Dam Reviews

For small dams, the comprehensive dam review can serve as a solid basis for designing and constructing major dam modifications.

Reclamation performs Comprehensive Facility Reviews (CFR) of its dams every 6 years. The Bureau of Indian Affairs (BIA) completes Comprehensive Dam Reviews (CDR) of its dams every 6, 9, or 12 years, depending on the condition of the facility. CDRs and CFR's go beyond a typical dam examination and include:

- Formation of a multi-disciplinary team
- Existing data search and review
- Initial team meeting to develop failure modes
- Site visit by Senior Engineer and Examination Specialist
- Report preparation, including the following sections for CDR
    - Executive Summary
    - Report of Findings
    - Description of Dam
    - Evaluation of Design and Construction
    - Examination
    - Failure Modes
    - Performance Monitoring
- Review of report and a meeting of senior technical staff
- Involvement of the agency owner, local dam safety, and/or O&M staff

Both Reclamation and BIA use comprehensive reviews to effectively and efficiently evaluate dams and to highlight dam safety concerns. Because all significant and high-hazard dams periodically undergo similar reviews, there is less chance that a problem will go undetected or unresolved. These comprehensive dam reviews are very helpful for ranking an agency’s dams for dam safety modifications.

Co-Located Dams

When dams are located in the same general area, efficiency can be gained by grouping the dams. For example, site visits can include several dams, and construction contracts can be larger and more attractive to bidders by including more than one dam. Environmental compliance can be accomplished for several dams concurrently, as well. A single borrow area can be used for several dams.

Response to Dam Safety Concerns and Alternatives to Full Remediation

Due to the poor condition of a dam or results of formal evaluation, it may be determined that a dam has an unacceptably high probability of failure during the period until the dam receives funding for major remediation. In these cases, an agency should take action to reduce the risk of dam failure. The following options can be considered:

Emergency or interim repair
Even small dam rehabilitation projects can be expensive and require many years of agency budget planning. Dams that present a relatively high short-term risk of failure for a particular failure mode can receive an emergency or interim fix for much less cost than for a full dam safety modification.

Permanently breach the dam (deactivation)
The dam may have outlived its usefulness. Permanently breaching a dam (also called dam removal or deactivation) saves all future dam operation and maintenance costs. However, considerable environmental studies may be required, which may require mitigation costs. The breach should be adequately sized. For more information, see *Dam Removal: A New Option for a New Century* by The Aspen Institute and ASCE. Web site: http://www.aspeninstitute.org/AspenInstitute/files/CCLIBRARYFILES/FILENAME/0000000074/damremovaloption.pdf

The value engineering study is a very good process for considering permanently breaching (deactivating) a dam. Cost savings can be shared in accordance with DOI and agency value engineering policies.

Temporarily breach
Funding may not be currently available to pay for complete dam rehabilitation. By temporarily breaching the dam, the hazard is removed and the public safety issues are addressed. If dams with a flood control benefit are temporarily breached, consideration should be given to damages from increased natural flooding downstream.

Partial breach
Sometimes total breaching is not necessary. An armored drop spillway can be constructed through the embankment. A partial breach should be sized so that the resulting structure is low hazard. Retention of a small pond can partially remediate the loss of the full reservoir.

Reservoir restriction
Reservoir restrictions are often not feasible at small dams because the dams are not operated regularly or they have no operable outlet works. However, some

small dams are filled by diversion from another stream. In this case, reservoir restrictions are more easily implemented.

Remove the population at risk or restrict access to potentially inundated area
It may be feasible to reclassify a dam as low hazard by removing the population at risk, which can be accomplished by relocating people from homes downstream and/or by closing recreation or public use areas downstream. Legal agreements are required with the land regulator so that new residents do not move back into or otherwise occupy the area.

Decide to monitor
At some dams, failure modes may take a long time to develop. If a dam is frequently inspected by operations staff, it may make sense to periodically inspect and document a concern, rather than immediately pursue an expensive modification. This strategy may not be practical at remote dams.

Targeted modification
Sometimes a dam may have one critical dam safety deficiency and it may be best to correct only that problem. However, as many of the dams are remote, and it takes much coordination and effort to take an action at a dam, it is usually preferable to correct many problems at once.

Rely on emergency management systems
If an agency has high confidence in its ability to detect events that threaten dam failure and to warn and evacuate the people at risk, the agency may decide to continue to operate a dam which has a borderline unacceptable high probability of failure. However, the agency should carefully consider this option, as early warning systems and Emergency Action Plans (EAPs) do not always function as planned (and evacuation of people during an event can be problematic).

Part 2: Evaluation and Remediation Rationale for Geotechnical Deficiencies

Introduction

Geotechnical-related issues must be considered in the evaluation and remediation of small embankment dams. Historically, a majority of the failure modes for embankment dams have involved geotechnical issues.

This part of the guideline addresses geotechnical issues associated with sources of data and failure mode evaluation/remediation. Also included are other considerations, including the dam’s general condition, slope protection, and instrumentation.

One of the key points of this part is that the need for subsurface exploration, laboratory testing, seismotectonic studies, and geotechnical analyses should be carefully considered in advance. These field data collection activities can be very expensive and there may be other ways to technically and conservatively address small dam embankment safety issues. Experience, judgment, and common sense often can provide a reasonable solution. It should not be the goal to perform investigations and studies just for the purpose of following the normal dam safety processes and documentation that were developed for large, high-hazard dams.

Geotechnical issues must be considered in conjunction with all other disciplines that combine to form a balanced dam safety approach. For example, if a small embankment dam has an overtopping concern (the number one cause of small embankment dam failures), one needs to consider if improvements to the embankment also would decrease the likelihood of one or more of the geotechnical related failure modes from developing. As an example, the materials excavated to facilitate construction of an auxiliary spillway could easily be used to construct a berm to address both static and seismic failure modes.

Data Sources

Geology

The geotechnical engineer should obtain and evaluate available geologic information from several sources. Regional and local geologic information is of value, but site specific geologic information is more important for evaluating most small embankment dams. Geologic characteristics, such as fracturing, solubility, stratification, etc., of the soil or rock foundation are sometimes needed. The agency owner or, if known, the previous designer(s) or constructor, may have geologic or other information about the dam in its files; this would likely be the most site-specific information. Other sources are Federal, State, and local government agencies that specialize in geologic information; for example, U.S. Geological Survey, U.S. Department of Agriculture Natural Resources Conservation Service, State, City and County Engineering Offices, State Geological Surveys, and State Dam Safety Offices. In Reclamation, the geology staff in the Technical Service Center (TSC) and Region should be contacted for any information available for the area or particular project being evaluated. In many cases, no documentation will be found, and a reconnaissance of the area may be required. Cut slopes along roads or highways near the dam can sometimes yield valuable information.

Photographs of the site, especially those taken during construction, may also contain valuable geologic information. A review of aerial photographs should be completed, if they are readily available, because they can provide evidence of general geologic site conditions. The Web site http://www.terraserver.microsoft.com provides detailed aerial photography for many areas.

Past performance data can also give clues to geologic conditions; for example:

- Excessive foundation seepage can be an indication of pervious strata beneath the dam that is not cut off.
- A distressed outlet works pipe can be an indication of a weak or soft foundation.
- A distressed spillway can be an indication that the structure is founded on soils.

All possible causes should be considered when evaluating past performance data.

Dam Foundation

Information on an existing dam's materials, such as strength, deformability, permeability, erodibility, etc., are sometimes needed. This information can be obtained from the same sources discussed for geology, with the most pertinent information obtained from on-site reconnaissance. Information can usually be enhanced economically by examining soil or rock near or at the site in existing excavations, erosional features, or by hand excavated holes using an auger or shovel. See the *Guidance for Geotechnical Hand-Sampling Methods for Small Embankment Dams* by Jeffrey Farrar of Reclamation's Earth Sciences and Research Laboratory, drafted on April 8, 2005. Caution should be exercised when excavating or drilling holes downstream of the dam to ensure they do not harm the foundation or embankment. Hand exploration should be avoided in areas of possible artesian pressures.

All explorations should be properly backfilled to ensure they do not create a weakness. Visual observation and simple field identification tests can yield much information. Small hand-excavated samples can be obtained and then classified in the laboratory by inexpensive index tests. Many correlations exist between index tests and engineering properties of soils that can be used, along with engineering judgment, to evaluate a foundation. In some cases, this information will be all that is economically feasible to assess the failure modes and to form the basis for the design. Prior dam performance should be reviewed for evidence relating qualitatively to these parameters. For example, evidence of weak seams in the foundations of existing embankments can be obtained from observations of distress, such as open joints in outlet works conduits.

Embankment Zoning and Material Types

This information would be obtained from the same sources and using the same methodology described for the dam foundation. The team should also review the borrow area(s) for the dam, if known, and sample as appropriate. Information about a dam’s past performance can give indications of potential zoning. For example, sinkholes can be an indication of internally unstable materials or incompatible materials or zones. Seepage exiting from the lower third of the downstream slope can indicate the dam is a homogenous dam on an impervious foundation.

Performance History

The geotechnical engineer should obtain and study all records of past performance and inspections. Operations and maintenance records should also be studied if they exist. Lastly, the operations and maintenance personnel should be interviewed because they frequently have useful information related to the dam. This information should be used in developing potential failure modes and determining which ones can be discounted. This information should be used when developing designs to ensure the design also addresses O&M issues and thus reduces future O&M costs.

Design and Construction Records

Many times, records of design and construction on small dams do not exist. The geotechnical engineer should thoroughly study any design and construction records that are available. The records should be reviewed to ensure that they reflect “as-built” conditions because it is not unusual for the construction of small dams to deviate from the plans. Whether or not the soils in a small dam were well conditioned and compacted can have such a profound effect on the outcome of an evaluation of a small existing dam that every effort should be made to learn about the construction methods. The use of heavy equipment to compact soils in small embankments can result in an embankment with more than adequate shear strength and, in fact, can result in overconsolidation of fine grained soils. Overconsolidated soils are much more resistant to shear failures, including those caused by earthquake loadings. Compaction and moisture conditioning also have a profound effect on the permeability of soils and their resistance to erosion. Such information adds much value to an evaluation.

Photographs

Construction photographs can provide important information on the construction methods of a small embankment dam. They can help to identify the type of embankment compaction, as well as the methods used for compaction around appurtenant structures, such as outlet works. Photographs can also provide information on embankment materials, as well as zoning, and foundation clean up and preparation. As mentioned in the Geology Section, photographs of the foundation, especially those taken immediately after final clean up, can reveal the actual condition of the foundation. High quality photographs can provide information on the amount of jointing, as well as openness of joints in rock foundations, information on the coarseness of soil foundations, and the foundation treatment methods used. Every effort should be made to obtain any high quality photographs if they are thought to exist because they can provide information that can be obtained by no other practical means.

Inspections

Inspection reports can provide important information. Locate all such reports and thoroughly review the text, as well as all photographs, to determine if conditions at the dam (i.e. seepage, sliding, and cracking) are changing with time by comparing reports and photographs from different inspections.

Instrumentation

It is not unusual to have information on seepage at small dams, but it is unusual to have elaborate instrumentation, such as piezometers. The geotechnical engineer should obtain and study all instrumentation data and use the data in evaluating the dam. Repeated visual observations made while the reservoir is at normal (or preferably higher) pool can give insights into the effectiveness of a dam in controlling seepage, as well as insights into the potential water levels within the body of the dam.

Geotechnical-Related Failure Modes Evaluation and Remediation Rationale and Considerations

Failure modes are defined as the specific ways a given dam can fail. Very rare failure modes are documented and disregarded (such as the dam failing due to a large earthquake occurring simultaneously with a large flood event). Failure modes are unique for each dam. Failure modes take into account the geology of the foundation and abutments, the design and construction of the dam, the dam’s condition and the loadings the dam may be subject to. Site-specific failure modes should be developed to ensure the evaluation, remediation design, and constructed modification will comprehensively address the most likely ways a particular dam can fail. The following sections present key potential failure modes and some remediation considerations that should be considered in evaluating most small embankment dams.

Hydrologic

In general, failure related to hydrologic events is the most common failure mode for small embankment dams. Small embankment dams frequently have small spillways and, as a result, are unable to safely pass floods with relatively frequent return periods, and are more easily blocked by debris than larger spillways. Many small dams fail from overtopping by flood waters. Another frequent issue is that spillways are frequently unlined and the potential for erosion and failure of the spillway must be evaluated. Because these are not common issues for large dams, it is recommended that the geotechnical engineer devote more design time to these issues than is done for most large dam modifications. Guidance on hydrology and design flood selection is provided in Part 3.

Overtopping Erosion — The impacts of overtopping a small embankment often need to be evaluated, because the return periods for spillway design floods are frequently small enough that overtopping of the embankment could occur during the life of the project. The performance of small dams during overtopping varies considerably and requires a substantial amount of engineering judgment to evaluate for a specific dam. The flow conditions (velocity, depth, and duration), as well as the erosion resistance of the soils in the embankment and soils and/or rock at the downstream toe, potentially subject to overtopping flows, should be evaluated. The positive effect of having a uniform grass cover has been demonstrated time and again, as well as the negative effect of having features on the embankment that concentrate flow (such as low areas, outlet structures, bushes, or trees).

Because of uncertainties in the critical parameters used to predict performance during overtopping, large embankment dams are typically assumed to breach if overtopping occurs. Moreover, most large dams that have been overtopped have failed. While the same uncertainties exist for small dams, a breach and failure should not be assumed to occur when the dam is overtopped, as confirmed by the fact that a breach did not form in many overtopping events of small dams. Each small dam should be evaluated on a case-by-case basis to determine if overtopping protection should be provided. The value of the reservoir must be weighed against the cost of the solution. Often, the likelihood of overtopping can be reduced to acceptable levels with fairly low-cost modifications and overtopping protection is, therefore, not warranted.

As mentioned in Part 3, the decision may be made to accept the risks of dam failure for larger, infrequent floods. In any case, the designer should consider how a small dam might overtop and possibly fail should a flood beyond the design flood (even a probable maximum flood [PMF]) occur, and what design details could lessen the impacts of such a failure. The crests of large embankment dams are typically cambered (crest is constructed to a higher elevation at maximum section than at the ends), and overtopping would initiate at both ends of the dam simultaneously. On a small dam, it should be considered whether it would be better to have only one end of the dam crest constructed lower to facilitate overtopping and breach formation in this area. This may be preferable to allowing the possibility of a much larger breach formation, possibly through the center of the dam. A wide breach is characteristic of overtopping failures (Sowers, 1976), likely because the crests on most small dams are relatively level and erosion from overtopping begins across much of the crest at nearly the same time. Because erosion proceeds in both directions from a breach that forms within the dam, as opposed to only one direction if it initiates on the end, a breach in the middle might be wider than a breach at one end on a small embankment.

If a dike exists, the benefits of leaving the dike crest lower should be evaluated. A lower dike crest would ensure the first overtopping occurs at this structure rather than the dam. This may result in less threatening conditions downstream and can be less costly to repair.

A breach initiating at one end of a dam may result in a lower peak breach discharge that takes longer to increase to the peak discharge than a breach that initiates at the maximum section. This type of breach may reduce the consequences, especially the loss of life, because the slower increase of flows may provide some warning of a failure in progress. The designer should predict the breach that may form from an overtopping failure, using available techniques (Wahls, 1998), and compare that to a breach initiating on one abutment. For many small dams, with abutment slopes of roughly 4H:1V or steeper, it is likely that a breach initiating at one abutment will be less threatening to downstream populations than one that forms elsewhere. A tradeoff exists between controlling where the overtopping initiates; i.e., near one end of the dam, and allowing the overtopping to occur across the entire crest. If one end of the embankment is left lower, it may seem as if the design allows for overtopping to initiate sooner. However, it is recommended that this issue be addressed similarly to crest details for camber, but rather than building the crest higher in only the middle, it is built higher across the whole crest, except one end.

An evaluation of the foundation erosion potential and the soils in the embankment should be factored into the evaluation and design for overtopping. If the abutment or foundation is highly erodible, or if a small dam is constructed of highly erodible soils, such as loose un-cemented sands, a conservative design should be adopted to avoid overtopping, or erosion protection should be provided.

Spillway Erosion —The original value of many small projects and/or the downstream consequences may be such that the expense of a concrete lined spillway was not justified. As a result, many small dams have unlined spillways that need to be evaluated for erosion. Unlined spillways for small dams, as well as for large dams, have performed as designed under huge flows in some cases.

An unlined rock spillway has successfully passed flows as high as 60,000 cubic feet per second (cfs) for days. However, flows less than 1,000 cfs have eroded and failed an unlined spillway constructed in soil. Flow conditions (velocity, depth, duration) and the erosion resistance of the materials in the bottom and sides of the spillway under these conditions must be evaluated.

The ultimate consequences of spillway erosion and failure should be considered. Fewer consequences of failure during floods above the design flood may occur if the spillway erodes rather than having the reservoir overtop and fail the dam. This option may result in a lower peak breach discharge, a slower increase of the breach discharge (similar to a fuse plug), and lower repair expenses.

Low-cost, easy-to-construct alternatives should be considered when evaluating spillway erosion issues. Due to the relatively low head associated with small dams, grass cover, riprap, grouted riprap, and/or gabions should be evaluated. If a concrete-lined spillway is the lowest cost alternative, the cost of the structure versus the cost of design and analysis should be considered. Previous designs and analyses should be used where possible for cost savings.

Freeboard — Freeboard is the vertical distance between the crest of the embankment (without camber) and the reservoir water surface. “Minimum freeboard” is defined as the difference in elevation between the crest of the dam and the maximum water surface that would result should the inflow design flood occur and the outlet works and spillway perform as planned. The desired minimum freeboard for a small embankment dam is typically 3 feet. Determining the freeboard to provide is dependent upon the fetch, (the maximum distance that wind could travel along the reservoir to the upstream dam face), design wind velocity, slope protection type, and the slope of the upstream face of the embankment. If the fetch is more than 1 mile, *Design of Small Dams* should be used to evaluate freeboard requirements (Reclamation, 1987).

The amount of freeboard provided should also take into account the potential for the crest to have been loosened by frost or cracked by drying out; in addition, zoning must be provided to control and defend against this condition. This is particularly important for a dam whose core classifies as ML (silt) or SM (silty sand) in areas with a very cold climate and for a dam whose core is a CL (lean clay) or CH (fat clay) located in a very hot, dry climate. The use of internal fillers located well within the body of the dam are strongly encouraged if these conditions exist or are anticipated.

At small embankment dams with beaver activity, both the design of the spillway and the freeboard provided should be considered to address the problems caused by beavers. One solution is to remove debris as the beavers construct it. If this solution is not feasible, a wide spillway(s) should be constructed and/or more than normal freeboard provided. In any case, regular maintenance should occur at a frequency that ensures the dam will not be overtopped as a result of beavers plugging the spillway.

Static (Normal Loading)

Seepage — Some seepage occurs at almost all dams. In most cases, it is not a problem, but when uncontrolled, it is the single dam safety deficiency that leads to more incidents and failures of large embankment dams than any other. It is the second leading cause of small embankment dam failures. If seepage is clear, low volume, and of consistent flow rate, it is probably not a threat to the safety of the dam. If the seepage volume increases with time, is sporadic or episodic, or moves material from the embankment or foundation (piping material), it probably is a current or potential threat. If large quantities of material are being moved, material deposits will usually be evident where seepage exits. The formation of sand boils is typically associated with foundation seepage. If seepage has been monitored, its potential threat can be evaluated by reviewing the records. If records are not available and seepage is significant, the problem should be repaired or a monitoring program established. If seepage is causing piping of a significant amount of material or causing instability, then dam deactivation, a reservoir restriction, other restriction, or repairs should be initiated promptly.

For small embankment dams, a very detailed investigation or analyses usually are not needed to determine an adequate solution to a seepage and/or piping problem. The solution usually is a matter of cutting off the seepage upstream of the centerline of the dam or providing filtering and drainage at the seepage exit area, combined with some counterbalancing weight, such as a berm or flattened slope. Both cutoffs and filtered drainage are often used together. However, the need for repair usually requires careful consideration.

As an example, small volume reservoirs may not contain enough water to cause a full breach that engulfs the dam’s crest, resulting from a seepage-related failure mode. As a result, the severity of downstream flooding would likely be low and not hazardous. If the embankment and foundation materials are cohesive, piping may occur slowly. As a result, flood severity may start extremely low at the beginning of breach formation and remain low throughout the failure. Many small embankment dams have failed and resulted in low severity flooding as the reservoir was released through a relatively small breach alongside an outlet works pipe. These possibilities and the value of the dam and reservoir must be weighed against the cost of investigation, analyses, and repair. Deactivation may be more cost effective for dams of low value to the agency or owner. Most of the time, these decisions can be made without in-depth, time-consuming, and costly technical studies, although environmental studies are frequently required.

Also, the dam’s value should be considered if the seepage is relatively large and/or concentrated and a filtered drainage system lacks the capacity to collect and drain the seepage, and hinders it instead. This type of problem can and has resulted in unsuccessful modifications because the concentrated seepage may begin to emanate from a new area with little difference in the amount of seepage. In these cases, the seepage should be reduced by the use of an upstream "cutoff," and the need for a filtered drainage system should be evaluated. Such difficult situations frequently call for multiple defenses. Another consideration for a small dam with such problems is that it may be more cost effective to add the second defense to the original contract rather than using a phased approach in which the decision to add a second defense is made after performance of the first defense is verified. In some cases, the cost of establishing a second contract, including a second mobilization, can be excessive.

Remediation for seepage related failure modes should be designed to minimize future maintenance. The evaluation and design should also address the potential for the embankment to crack or loosen and the potential for future animal, insect, or vegetation infestations. Recommendations related to cracking or loosening are also addressed in the previous section, "Freeboard."

Cracking is a serious issue with embankment dams and has likely been responsible for the seepage failure of many embankment dams. Cracks through embankments have also resulted from settlements and deformation. If cracks are discovered to exist in a small dam, they should be carefully evaluated with respect to seepage and the potential for future issues developing. Treatment of the cracks in tandem with the use of weighted filters, preferably well within the body of the dam, is a common solution.

Plant and animal infestations of small embankment dams have been the root cause of the failure of numerous small dams. This problem is not new, as the following was documented in a 1963 textbook, *Earth and Earth-Rock Dams,* written about the design of primarily large dams: "Burrowing animals have been responsible for piping failures in a number of small earth dams and dikes but have not caused trouble in major dams because animal holes do not penetrate to a great depth. In the United States the worst pests have been muskrats and ground squirrels" (Sherard, et al, 1963). The issue of plant and animal penetrations has been the subject of numerous recent workshops put on by dam safety officials; the latest is the Southeast Regional Conference of the Association of State Dam Safety Officials, April 23-26, 2006. Infestation of an existing small embankment dam, from either plant or animals, is a serious matter and should be investigated and evaluated with respect to the impacts on seepage related failure modes. At a minimum, the damage caused by plants and animals should be repaired and a control/repair program should be implemented to address the potential for further damage. More information on potential repairs is provided under "Other Considerations, General Conditions of the Dam." If the issue of plant and animal infestations is judged to be a serious threat to the dam that requires remediation, than special design measures, such as a metal core wall located in the central portion of the embankment (Sherard, et al, 1963), central cutoffs constructed of concrete or sheet pile (steel or composite), or fencing material buried in the slopes to prevent intrusion, should also be considered. For other remedial dam design considerations for plant and animal penetrations, see the various workshop results and proceedings: ASDSO/FEMA Workshop in 1999 (ASDSO/FEMA Workshop, 1999) and ASDSO Special Workshop in 2006 at the Southeast Regional Conference in Myrtle Beach, South Carolina (ASDSO Special Workshop, 2006).

Condition of Appurtenances — The location of any structure through an embankment, such as the outlet works, utility lines (water, gas, petroleum, sewer, communication), or spillway, is a critical decision. During construction, different placement and compaction procedures are used; where placement and compaction are more difficult, deficiencies often exist. Additionally, the materials often used in older dams deteriorate relatively quickly, such as corrugated metal pipe (CMP) culverts or metal pipes. As a result, seepage and piping often begin around structures and can result in failure. For this reason, every effort should be made to inspect and evaluate these structures. Closed circuit TV inspections can help to evaluate the internal condition of such pipes.

For smaller dams, the appurtenant structures are also small, and solutions are straight forward. For example, an outlet pipe can be lined, the annular space between the lining and the original pipe grouted, and a filter placed around the outside of the outlet pipe, near its downstream end. The filter should be covered and weighted with enough fill to prevent further piping of the filter itself. Designs and cost estimates can be developed without detailed investigation and analysis for these types of solutions. However, care must be taken to develop and implement an outlet works slip lining and grouting plan to ensure an adequate grouting job and to ensure no harm is done to the embankment. Personnel with expertise in grouting associated with embankment dams should review the plan and oversee the grouting operations.

Most small dam failures caused by seepage occur along a structure, such as an outlet works pipe or spillway that penetrates through the embankment. When designing repairs to small embankment dams, filter zones around and adjacent to these structures should be considered, because this is where a failure due to seepage is most likely to develop. To address the increased chance of having an internal erosion problem as a result of an outlet works penetrating the embankment, many small dams have a filter and drain around outlet works pipes, but not elsewhere in the dam. The filter should be "weighted" to ensure the filter materials are stable should pressures build up at the filter/core interface. The impact of a filtered drainage system on the project cost must be considered, because the filter and drain materials are almost always the most expensive embankment materials. A unit price for processed filter materials can be as high as $120 per cubic yard (in 2006) when the material must be hauled a great distance. A much lower unit price can sometimes be obtained if materials are readily available and the haul distance is short. However, due to the relatively small quantity typically needed, the price is much higher than is typical for large dams. These factors need to be considered when making cost estimates for small embankments.

If an outlet works/spillway pipe is removed and replaced, do not use a “cutoff or anti-seep collar.” Use a filter zone instead, as discussed above.

Slope Stability — If a dam shows no signs of instability at the time it is examined, it is obviously stable for the existing loading conditions. If it has been subjected to greater loading conditions in the past, it is very likely that it will be safe for those same loading conditions if they recur unless physical conditions have changed, such as materials loosened by frost or softened by swelling. Embankment dams with competent foundation conditions that are well constructed without signs of excessive seepage, piping, or erosion will usually have adequate static slope stability if they have slopes of 2H:1V or flatter. For small embankment dams, the slopes may be stable even when steeper. A homogeneous embankment dam that is not well compacted is probably not stable at a 2H:1V slope or steeper if the seepage exits high on the slope of the dam. An experienced investigator can judge whether the dam will remain safe under expected future loading conditions, or they can use some simple quick stability analysis techniques. An expensive investigation and analysis are usually not justified on small embankment dams. It may be better to use the money for conservative repairs instead of an expensive investigation and analyses, especially if seepage issues also exist that require remediation. Many modifications related to seepage have a significant benefit on stability at no additional cost.

Signs of distress in an embankment (cracks or slumps) and signs of distress in appurtenant structures (distressed joints and circumferential cracking) can indicate static slope stability issues. Topsoil movement frequently results in shallow cracks at the edges of the crest and on the slopes, but it is not an indication of a serious stability issue. If the cracks appear to be deep seated, shear related, and envelop the crest, then modifications in the form of a berm and filter are typically justified for a small embankment dam. More judgment is required if the cracking indicates more shallow movements just beneath the topsoil. Consideration needs to be given to the cost of fixing it now, versus the potential increase in future cost. If a small dam requires modifications, using excess excavated materials to construct a berm at the downstream toe of the dam should be considered.

Erosion Potential — Erosion can be caused by seepage, overtopping, wave action, or surface runoff. Seepage and overtopping related erosion have already been discussed. Erosion associated with wave action is discussed later in the section titled “Slope Protection.” Surface runoff erosion can become a dam safety concern, but the solution is very straight forward. The erosion should be repaired, and the source eliminated. Typically, the crest of an embankment is sloped slightly toward the upstream slope because this is the most protected slope.

Abutment Stability — The discussions presented for seepage, static stability, and dynamic stability also apply to abutment stability. It is unusual to have abutment stability issues on small embankment dams.

Reservoir Rim Stability — Reservoir rim stability is usually not a problem in smaller reservoirs. The surrounding terrain often has mild slopes with significant vegetation that reduces the possibility of sliding. The reservoir is generally small and shallow and does not significantly reduce available effective shear strength by saturating large zones within the reservoir slopes. If rim instability concerns are encountered, then remediation rationale presented under “Slope Stability” should be applied.

Seismicity and Seismic

Seismic related failures of embankment dams are rare. Seismic related failures are by far the least frequent cause of small embankment dam failures in the U.S.; the number of failures is near zero, although the number of small embankment dams is likely in the tens of thousands. For completeness, guidance is provided for seismic-related failure modes to assist in evaluating and remediating small embankment dams. In general, the lessons learned from the few failures of embankments (of all sizes) caused by seismic shaking should be considered. These failures have revealed that extremely loose materials are susceptible to sudden strength loss due to ground shaking. Some of the failures were attributed to loose materials in the foundations, some had loose materials in the embankment, and a few had both. These failures have occurred suddenly with little-to-no warning other than the ground itself shaking. Experienced embankment dam engineers with experience in earthquake engineering should perform the evaluation and remediation design of seismic-related failure modes.

Two types of stability concerns are related to embankment dams during earthquake shaking. The first is associated with excessive subsidence of the crest of the embankment and subsequent loss of the reservoir due to overtopping and erosion. Crest subsidence can be caused by the combination of induced cycles of shear stresses and existing static shear stress exceeding the available resisting shear strength for a short period during the earthquake. The second concern is for liquefaction of the foundation or embankment materials. Liquefaction generally only occurs in soils with low to no plasticity and if the density is sufficiently low that dynamic loading causes contraction of the soil. Liquefaction occurs due to a drastic increase in excess pore pressures and sudden reduction of the effective soil shear strength nearly to zero during or shortly after earthquake shaking. Low density, saturated fine grained soils (sensitive) can also undergo large strength loss during shaking, depending on their density, plasticity, and the intensity of the shaking. If this occurs in large zones of the embankment or foundation, large continuous deformations can result in sudden failure of the embankment and potentially a sudden release of the reservoir.

Deformations Potentially Resulting in Overtopping — Small dam embankments that have been compacted using at least modest control have an inherent resistance to earthquake loadings, because the soils tend to be overconsolidated and provide ample shear resistance to earthquake-induced shear stresses, even if liquefaction of the foundation occurs. This is especially true of cohesive soils. In addition, the amount of shear resistance required to maintain stability for small dams is such that only the loosest soils have the potential to fall below this shear resistance if they liquefy. For these reasons, dynamic stability should typically not be a concern for dams of a small height that have ample freeboard and are located in low seismic regions. The potential for seismic deformations becomes even more remote if a modest berm can be constructed over a key trench excavated to rock, effectively "cutting off" the potential liquefied layer. Even where berms cannot be excavated to rock, they can have a profound effect on the stability of a small dam even if liquefaction does occur. Small embankment dams constructed without compaction (such as hydraulic fill) and located in even a low-to-moderate seismic region could experience considerable strength loss during shaking. More thorough investigations are warranted or conservative modifications should be considered if the cost of investigations would be significant compared to construction costs of conservative modifications. Small dams of this nature constructed in high seismic regions are very susceptible to failure and total replacement of such structures should be considered. All dams located in high seismic regions should be thoroughly evaluated to determine the likelihood of failure during a large earthquake.

Where embankment and foundation soils have high density or high plasticity and at least moderate density, deformations will likely be relatively small. Experience has shown that vertical deformation for dams less than 30 feet high will generally be less than 6 inches when subjected to moderate-to-high earthquake loading. Since the probability is remote that a large flood and large earthquake will occur at the same time, only normal reservoir conditions are considered during earthquake loading. For small dams that do not have a significant liquefiable zone in the embankment or foundation and 3 feet or more of freeboard above the normal water surface, there is usually no concern related to seismic failure modes.

If liquefaction is possible, the problem must be addressed and the lowest cost solution that adequately addresses the dam safety concerns identified. A full-scale seismotectonic study and dynamic analyses are usually not justified for small dams. The value of the dam and reservoir can easily be exceeded with the exploration, testing, and analyses needed for these in-depth studies. One approach that can be used for small embankment dams is as follows:

> The peak acceleration is determined by using USGS National Seismic Hazard Maps with a 2 percent probability of exceedance in 50 years (2,500 year return period). This method of selecting an acceleration to be used in the evaluation and remediation designs is similar to methods and the level of

protection required by most municipalities, as discussed in building codes for structures representing a hazard to more people than with most small embankment dams.

A judgment on potential for liquefaction can then be made using the peak acceleration determined from this map. It is reasonable to assume a small embankment dam with a peak acceleration of 0.1g or less (for a 2,500 year earthquake) has a very unlikely chance of failure in its service life due to an earthquake. In most cases, this peak acceleration is associated with small magnitude earthquakes that are not expected to have more than a few cycles of strong loading. For dams in regions that have a peak acceleration above 0.1g, it is recommended that the evaluation be done using more rigorous techniques. See Bureau of Reclamation, *Design Standard No. 13 - Embankment Dams*, Chapter 13: Seismic Design and Analysis, for example (Reclamation, 2001). Based on this standard, a soil would have to be very loose to have a significant chance of liquefaction if the site was located in a region on the map with a peak acceleration between 0.1 and 0.2g. If a judgment is made that liquefaction is a concern, a simple stability analysis should be made to size a berm to achieve an adequate factor of safety. On a small embankment dam in which a berm can be founded on dense materials, it is appropriate to size the berm so that the resisting force provided by the berm provides a force equal to the driving force. This eliminates the need to determine the exact resistance provided by the "liquefied" soils. If the berm cannot be founded on dense materials; i.e., bedrock, a more elaborate analysis is appropriate.

If a small embankment dam has an unusually high potential for consequences (i.e., PAR greater than 50) or is located in a region with a peak acceleration above 0.2 g. on the USGS National Seismic Hazard Maps with a 2 percent probability of exceedance in 50 years (2,500 year return period), then a better definition of potential earthquakes and a study of effects of such an earthquake may be justified, but cost of the studies for investigation should be kept in mind. If the costs exceed a justifiable amount, a more expedient approach may be necessary, which may mean that investigations and analyses are minimized and conservative measures to mitigate the problem are designed and constructed. This approach should always be considered for small embankment dams. If a seismotectonic study and analyses are judged to be necessary, the philosophy should be to use common sense relative to their extent, use expedient methods as much as possible, and end the study or analyses when information is adequate to draw a reasonable conclusion. For efficiency, seismotectonic studies for co-located dams should be combined.

Translational Movements Resulting in Reservoir Release — This is a case in which deformation occurs but rather than slumping type deformations that result in overtopping, the dam translates downstream by sliding on its base. This behavior has been observed in some liquefaction related failures, generally described as “the dam swinging downstream similar to a gate on a hinge.” The lack of a positive cutoff trench, common with small embankment dams, increases the chance of such a failure. The information contained in the above section is applicable here, as well, in determining whether liquefaction is an issue that requires remediation. This failure mode should be evaluated for all small embankment dams with concerns related to seismic loading. If the embankment has and is modeled with high shear strengths, it is extremely important to evaluate a shallow translational type failure rooted in the foundation.

Cracking —Embankment dams commonly develop cracks when subject to earthquake shaking. These cracks form as a result of minor overstressing caused by the shaking and/or differential settlement of materials caused by shaking. Most times, these cracks have been harmless and only required minor repairs. Frequently they do not traverse the crest but parallel the alignment of the embankment. Nonetheless, the cracking potential should be evaluated and, if an issue exists, it should be addressed by remediation. Weighted filters against the core materials, preferably well within the body of the dam, are a common solution. Such a filter would also offer protection against other failure modes related to internal erosion through a dam, including those associated with damage to the core by frost or desiccation.

Other Considerations

General Condition of the Dam

A well maintained dam is easier to examine and draw conclusions about because it is easier to walk over and visually observe. If potential defects are observed, they do not have to be separated from poor maintenance practices. For example, if trees have not been allowed to grow on or near an embankment, and seepage is emerging on the slope, it is clear it is not related to tree growth. All high and significant hazard dams should either be properly maintained or deactivated.

Trees can cause a dam to fail and, certainly, good maintenance practice dictates that a dam and immediately adjacent areas be maintained free of trees. However, there is controversy about what to do when significant tree growth occurs on an existing dam. The biggest controversy occurs when proper maintenance has not occurred and trees and other vegetation have been allowed to grow. If the dam presents significant hazard to life or significant economic loss to the public, the trees, vegetation, and their roots should be removed and the dam properly repaired with oversight from an experienced dam engineer.

Simply removing the trees and woody growth is not enough. If the roots are left and allowed to decay, seepage paths may develop and lead to problems or failure of the dam. A proper job would entail cutting all trees and other woody vegetation and grubbing out all stumps, root clusters, and roots from the embankment and adjacent abutments. Trees should be removed and grubbed from the abutments for a 25-foot strip immediately adjacent to the embankment, if this space is appropriate for the specific dam site. On small dams, the removal of heavy tree growth will usually cause damage to or removal of significant portions of the embankment. If this occurs, it may be more expedient to lower the reservoir, remove the entire embankment to a steepened slope, provide an internal filter, and replace the embankment over the filter.

As discussed earlier, rodents can also cause failure of small embankment dams: “Ground squirrels normally dig only in dry soil and will stop when they encounter seeping water or moist soil but they can be dangerous during periods when the reservoir is low for a number of years. Under such conditions, ground squirrels have been known to enter the upstream slope below the high water level and dig completely through a small earth dam”(Sherard, et al, 1963). Good maintenance practices dictates that a dam and immediately adjacent areas be maintained free of rodents and other animal activities. Simply controlling the animals once they have infested a dam is not enough. Repair of the damage is frequently needed to ensure damage to a small embankment by animals does not lead to a seepage related failure of the dam. All earth dams in regions with many muskrats should be carefully inspected at frequent intervals (Sherard, et al, 1963), as the damage they cause can become a threat to the safety of a dam quite suddenly.

Controlling vegetation and animal populations on or near dams can be an expensive and time time-consuming activity, but the cost of control methods pales in comparison to the potential cost of repairing neglected dams that have been damaged by plant and animal penetrations (ASDSO/FEMA Workshop, 1999). The costs can be even greater if the damage to the dam from infestation of plants or animals is allowed to progress to failure.

Slope Protection

Slope protection provides protection from wind, wave action, and surface runoff. Protection against wind is automatically provided by protection against water. If the slope protection is inadequate, it should be repaired. On smaller dams, the agency owner can be given a preliminary design and cost estimate by using simple design techniques and common sense to determine what is needed. *Design of Small Dams* provides a very good discussion on slope protection in chapter six (Reclamation, 1987). The recommended requirements for upstream slope protection in this reference are conservative, so judgment must be applied. The potential for animal and vegetation infestation should be considered when designing slope protection. Consideration should be made to provide flat slopes which allow for mower operations if grass cover is used for slope protection.

Instrumentation

New instrumentation for small embankment dams that have been modified should typically consist of weirs at all potential and known seepage exit points. Weirs should be designed to accurately measure flow, as well as effectively trap sediments should they be transported by the seepage. Seepage measurements must be correlated with reservoir elevation. Seepage monitoring is very important as seepage related failures are the second most likely failure mode for small dams, in general. New instruments, such as surface measurement points or piezometers, are usually important only if they will provide information relevant to the development of a failure mode that could be used to intervene and prevent the failure from fully developing. In most cases, routine visual monitoring and quantified seepage monitoring that are well planned and thorough are all that is needed to effectively monitor a small embankment dam. Monitoring is especially important during refilling of a reservoir to allow for intervention should it be necessary to ensure satisfactory performance of the design. The designer should develop a first filling performance monitoring plan, which should be implemented. All dams should have staff gauges from below normal water surface to the dam crest.

Embankment Drains (Toe Drains)

Existing embankment drains should be carefully evaluated. Problems have occurred where drains were covered by repairs and then later collapsed. If possible, inspect all drains with closed circuit television cameras. The inspection and evaluation can be done using the *2005 Guidelines for Embankment Drain Inspections, Evaluation and Follow-Up Activities* (Reclamation, 2005). This guideline was written for large dams but most parts are applicable to small dams, as well.

Embankment drains should be considered when concentrated seepage has been observed either in the dam or foundation that cannot effectively be controlled by a single stage filter blanket due to the lack of capacity. Problems have arisen when the capacity of the drainage system for small dams was insufficient for the amount of seepage. If the expected seepage quantity exceeds the predicted capacity of the drainage system and the design cannot be modified to accommodate the expected seepage, a “cutoff” should be considered to reduce the seepage. New drains should be designed using the latest guidance for drain designs. Care should be taken to ensure excavation at the downstream toe for a drain installation does not compromise the dam or foundation during construction.

Summary of Geotechnical Evaluation and Design

To summarize, subsurface exploration, laboratory testing, seismotectonic studies, and geotechnical analyses can be very expensive. If dutifully applied, without a constant awareness of cost, they may easily exceed the value of a small dam’s reservoir and the agency owner’s budget. This is especially true for smaller dams with only recreational or historical value. Moreover, it is usually possible to arrive at cost-effective solutions that satisfy the dam safety and maintenance requirements without an overly expensive geotechnical exploration program. Experience, judgment, and common sense often can provide a reasonable solution. It should not be the goal to perform investigations and studies just for the purpose of following the normal dam safety processes and documentation that were developed for large, high-hazard dams.

On small embankment dams where the cost of exploration, testing and analysis is significant compared to the construction costs for corrective actions, the engineer should inform the decisionmakers that making straightforward corrective actions to decrease the likelihood of failure can add more value than high cost investigations and studies that, at best, reduce uncertainty but do not have any impact on reducing the actual likelihood of failure. Documentation should be adequate, but not excessive. Unnecessary steps in the process should be omitted. The foremost goal should be to evaluate and implement economical remediation to small embankment dams that result in safe dams for the least total cost in a timely manner.

Part 3: Evaluation and Remediation for Spillways and Outlet Works

Spillway Sizing and Flood Protection

As mentioned in the failure modes discussion in Part 2 (page 13), one of the leading causes of the failure of small embankment dams in the United States is the erosion of the embankment or foundation materials from overtopping flows during large flood events. The ultimate cause of most of these failures is an inadequate spillway capacity, usually because the spillway was originally designed for too small a design flood or because of improper maintenance, which affects its ability to pass the necessary discharge. This illustrates the criticality of performing regular evaluations and site inspections of the spillways at small dams. However, the evaluation of any hydrologic deficiencies and the resulting remediation designs for high and significant hazard dams of small size should not be restricted to only the safe passage of the Probable Maximum Flood (PMF). The costs to do this at many dams would be prohibitive and would not be justified based on the risks posed by extreme floods. The relatively small risks posed by the failure of many typical small dams during flood events may justify the decision to ensure the safety of the dam for smaller, more frequent flood events, but to accept the risks of dam failure for larger, infrequent floods. The key parameters that can influence the decisionmaking on the appropriate hydrologic loadings to use at a small dam are discussed in this section.

If a potential loss of life is associated with an overtopping dam failure mode, an incremental loss of life study may be necessary to determine the appropriate hydrologic loading condition. Incremental loss of life (sometimes also referred to as incremental hazardous flooding) is the difference between the estimated loss of life that may occur due to a natural flood of a certain frequency with no dam failure, and the estimated loss of life due to the flood resulting from the failure of the dam during the same flood event. Figure 1 provides an illustration of the concepts of incremental flood discharges used to estimate the incremental loss of life.

The appropriate inflow design flood (IDF) to consider for sizing a spillway is the flood that results in a discharge from the dam such that no additional incremental loss of life, hazard, or risks to the downstream public will occur due to the dam failure flood wave.

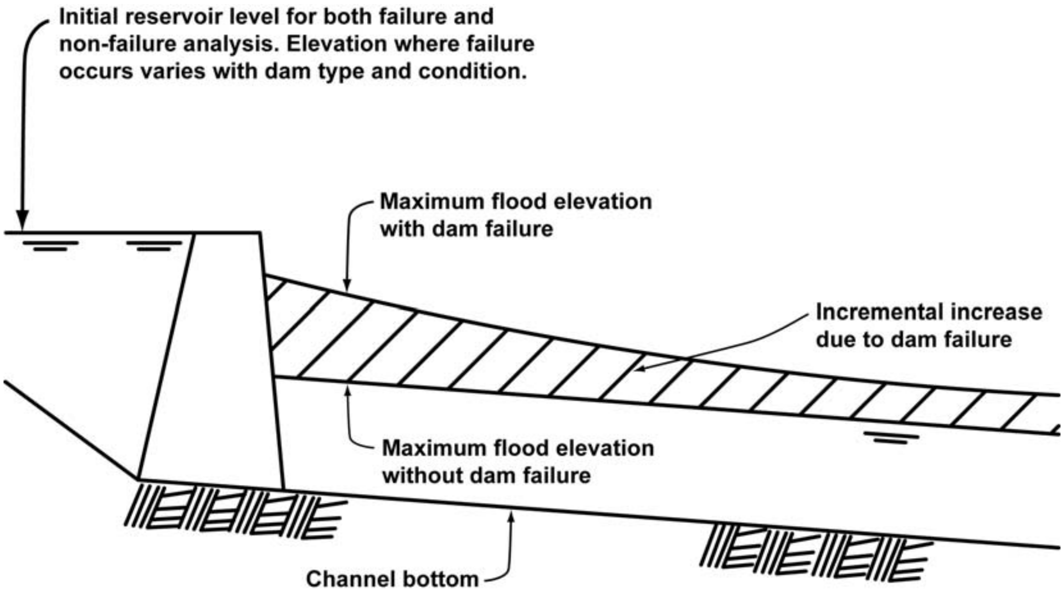

Figure 1. Incremental flood depth.

For many small dams, the only potential downstream lives at risk due to a dam failure are the people in a small number of inhabited structures, temporary visitors, recreationists along or on the downstream river channel, or passengers in vehicles on the dam or highway bridges that cross over the river or stream downstream of the dam. An evaluation of the spillway adequacy should determine if it is reasonable to assume that people will be in the dam failure flood plain during storms that can cause an overtopping dam failure. Outdoor activities, such as swimming, boating, and fishing are not as likely to occur during major storm events. However, homes in the flood plain are likely to be occupied and permanent recreational facilities, such as campgrounds and visitor centers, will probably have visitors present.

The peak breach discharge can be an important parameter in determining the appropriate hydrologic loading condition. Because many small dams have very small reservoir capacities compared to the natural flood volumes, the breach discharge from dam failure is often less than the larger more remote flood events, such as the PMF, associated with the basin. For these dams, the IDF generally should not exceed the peak breach discharge because any additional consequences resulting from larger flood events are attributed to the natural flood. By this approach, the IDF peak inflow is essentially equivalent to the maximum downstream channel discharge that causes life-threatening inundation levels that are at or below the dam breach inundation levels. An appropriate freeboard value based on the potential for waves, wave run-up, future dam settlement, and future maintenance activities should be included to ensure the dam safely survives the selected IDF.

The channel configuration and gradients taken from USGS topographic maps (in lieu of better available data) can be used to make initial estimates of downstream inundation levels for the various critical loading conditions described above. The results, in many cases, will either be of sufficient accuracy or will help determine what refinements may benefit the decisionmaking process. To help approximate the reservoir volume, any available depth surveys can be used, or estimates can be made by using the surface area of the reservoir from topographic maps and extrapolating the adjacent topography to the area beneath the reservoir.

Many small high-hazard dams present no downstream loss of life potential from flood overtopping failure modes because the flood plain is vacated by all occupants during the storm creating the flood. For these low-risk flood situations, the minimum level of flood protection usually provided is for the dam to safely pass at least the 100-year flood with an appropriate amount of freeboard (usually 3 feet or more). This typically provides an appropriate minimal level of economic protection against the lost benefits because of the dam failure and the costs associated with the replacement of the dam. The maximum spillway discharge (without dam overtopping) can be compared to the 100-year flood inflow. If the maximum spillway discharge is greater than the 100-year inflow with adequate freeboard, additional studies or dam hydrologic modifications generally are not needed. If the maximum spillway discharge capacity is less than the 100-year inflow, modifications to obtain the 100-year level of protection will either be apparent, or the need to develop and route the 100-year hydrograph to determine the best modification will be more apparent. If the downstream economic damages are potentially high, then an IDF based on an economic risk cost analysis may need to be considered and discussed with the dam agency owner. This analysis should not only include costs, but include other non-economic factors, such as cultural and environmental damages and loss of project benefits.

Spillway Remediation Considerations

Often for small dams, modification alternatives that will increase the threshold flood to the required levels of the IDF will be obvious and usually inexpensive relative to the cost of refinement studies. In such cases, the agency may decide to proceed to designing and constructing hydraulic improvements to the dam rather than conducting detailed hydrologic/hydraulic analyses. Some options to improve the ability of the dam to safely pass the IDF includes excavating a wider or deeper spillway crest, raising the effective dam crest elevation with earth materials or a secured parapet constructed of cast-in-place or precast concrete (Jersey barriers), providing overtopping protection, using available saddles in the reservoir rim as an auxiliary spillway, directing the flood discharges to the portions of the dam abutments that are more erosion resistant, or lowering the normal reservoir pool. Therefore, the scope and accuracy of additional studies should be limited to that necessary to properly facilitate the decisionmaking process. The cost of such studies should always have a good potential to be recovered by any anticipated reduction in modification costs. If this is not the case, the necessity of the study and its value to the decisionmaking process should be seriously reconsidered.

For many small dams, the use of nonstructural alternatives, such as early warning systems or reservoir restrictions, should not be used by themselves to resolve dam safety deficiencies because the necessary funding or personnel needed for maintenance of the system and monitoring of the events may not typically be available. However, effective and routinely exercised Emergency Action Plans are a prudent safeguard to ensure the dam agency owner is prepared for any emergency event.

Other failure modes associated with spillway operations to consider in the remediation include the erosion of the spillway chute or stilling basin materials resulting in a breach of the abutment or spillway foundation. This is of greatest concern for spillways on soil materials, those using grasses to resist the erosion of spillway discharges, or spillway with inadequate energy dissipation structures at the downstream end. The failure or lack of spillway and stilling basin underdrains may accelerate this failure mode. Additional details and guidelines on the layouts and design of spillway chutes and stilling basins and for other specific design requirements on spillways can be found in the *Design of Small Dams* prepared by Reclamation.

Outlet Works Remediation

Having an operable low-level outlet works on any dam, large or small, facilitates reservoir evacuation and it greatly increases the operational flexibility of the dam. However, many existing small dams do not have low-level outlet works, or if low-level outlets are present, they often are silted closed, have inoperable gates, and/or are corroded such that they have the potential to become a dam safety deficiency instead of a dam safety enhancement.

Outlet works at small embankment dams are often steel, metal, or concrete conduits placed within the embankment. Special methods of compaction for the embankment materials adjacent to the conduit are required during construction to prevent any structural damage to the conduit. This is often done by hand-compaction methods, which can result in lower density materials, and presents the potential for the outlet conduit to become a path for seepage along or into the conduit. The continuation of seepage can result in the internal erosion or piping of the surrounding embankment materials and ultimately lead to the failure of the dam.

Any holes or defects in the outlet conduit lining, resulting from corrosion or structural failure, provides a shorter path for any seepage along the conduit and increases the likelihood of internal erosion of the embankment materials because of the higher hydraulic gradients. These processes of seepage and piping along or into outlet works conduits are some of the leading causes of failure for small dams.

Corrosion is especially a problem with corrugated metal pipe (CMP) outlets. Whenever CMPs are present, corrosion should be suspected. Closed-circuit video equipment inserted into the outlet conduit provides an excellent, cost-effective method to determine the condition of the outlet works conduit downstream of the control valve. If corrosion already exists and appears to have penetrated the conduit, consider installing a new liner within the existing conduit or replacing the outlet works. The new lining or new conduit should be a more dependable and corrosion-resistant material, such as reinforced concrete or heavy-gauge plastic pipe. If an inspection reveals that corrosion is not yet a concern, processes should be established to regularly and closely monitor the condition of the lining.

The failure modes and remediation for embankment dams associated with the seepage and piping of dam materials along or into the outlet works are further described in Part 2: “Evaluation and Remediation Rationale for Geotechnical Deficiencies.”

A significant number of small dams do not have operable low-level outlet works, and all releases pass through the spillway. If a dam deficiency develops that could lead to dam failure, a method of reservoir evacuation could be instrumental in avoiding failure. However, if conservative improvements are made to the dam to remedy dam deficiencies, the need for emergency evacuation becomes more remote as long as the minimum dam maintenance requirements for continued safe dam operations are performed. The merits of installing low-level outlet works should be seriously considered, but the dam agency owner needs to make the decision between installing a new low-level outlet works, rehabilitating the existing inoperable outlet, installing siphons, or relying on pumps, as long as each alternative is technically acceptable for the specific dam. The benefits of a new low-level outlet works should always be balanced against the increased risk of failure of the embankment along the new conduit.

Constructing low level outlet works where none previously existed may be a relatively expensive undertaking, depending on the size of dam, depth to the outlet works, foundation conditions, reservoir operational restrictions, etc. Guidance on the design and layout of a new outlet works is provided in the *Design of Small Dams,* previously referenced. Excavating and replacing most of the dam cross-section is often required. In addition to this direct field cost, draining the reservoir or building a cofferdam at the intake is usually required. Locally removing reservoir sediments to set the intake or providing an intake channel is also likely. Draining the reservoir and removing reservoir sediments presents environmental and permit implications that will add both cost and time to complete the job.

To minimize the potential for the new outlet works from becoming inoperable or a dam safety deficiency (from siltation, corrosion, inoperable gates, etc.), a regular maintenance, exercise, and inspection program is required. The agency owner must be aware of the costs for this O&M requirement. Because of the relatively expensive replacement and O&M costs associated with a safe low-level outlet works, alternative outlet capabilities for small reservoir impoundments may also be considered.

Alternative methods can provide adequate evacuation capacity and can also regulate the reservoir to meet project purposes other than evacuation, but may not be as convenient as a permanently installed low-level outlet works. Self-contained, trailer-mounted, diesel-powered pumps can usually be readily rented where communities are located nearby. State or local flood control agencies may be another readily available source for high-capacity pumps. Large pumps with a capacity of 3 cfs or greater can be rented and can drain reservoirs with fewer than 30 acre-feet within a few days. Renting pumps is a low-cost, viable alternative that requires no maintenance cost and implementation cost is expended only if needed. Purchasing pumps has a greater one-time expense compared to renting and will require continuing maintenance on the pump, but may be justified for remote locations or to fulfill other needs for a high capacity pump by the dam agency owner, especially if one pump can service multiple dams.

A disadvantage of pumps is they are not as readily available as a permanently installed low level outlet works. If pumps are to be used in an emergency to evacuate the reservoir, the necessary information on pump suppliers and the means of obtaining and transporting the pump should be documented in the Emergency Action Plan (EAP), Standing Operating Procedures (SOP), Operations and Maintenance Manual, or similar document.

Another consideration with pumps is the limited Net Positive Suction Head Available (NPSHA) which essentially is the atmospheric pressure less any suction line friction losses and the height of the lift. To avoid cavitation, all pumps are rated with a Net Positive Suction Head Required (NPSHR). If the NPSHA does not exceed the NPSHR, the pump will not operate. Also, as the NPSHA approaches the NPSHR, the pump capacity decreases. Placing the pump as close to the reservoir water surface as possible and using large diameter suction lines to minimize friction loss will maximize pump capacity. For reservoirs deeper than about 15 to 20 feet, pumps located on the dam crest or spillway crest may not be able to totally drain the reservoir because the height of the lift from the water surface to the pump will by itself exceed the NPSHA when reservoir levels are down, unless the pump can be moved along with the receding reservoir water surface. Because of the potential for complications caused by terrain and reservoir sediments, the frequent movement of trailer-mounted pumps may not be practical. Floating pumps are available for these situations but are usually more expensive and probably not as available for rent as trailer-mounted units.

Totally draining the reservoir is usually not necessary to successfully evacuate the reservoir to levels that mitigate dam failure. Usually, only a portion of the total reservoir requires evacuation to stop or control piping, or to unclog spillway inlets. If the water surface needs to be maintained at lower levels to mitigate dam failure, a temporary excavation into the overflow spillway channel or a temporary breach in the dam can usually allow pumping to be discontinued and water levels to remain drawn down. Temporary breaches usually will not be detrimental to most small dams because of the small normal inflows as long as the breach opening is excavated at a slow, controlled rate. However, appropriate erosion protection or breach height should be used to prevent a catastrophic erosion failure of the dam through the temporary breach. To minimize the chance of catastrophic erosion, the breach should be developed while the water surface is pumped down.

Even where permanent low level outlet works are installed, consider including plans and procedures to evacuate the reservoir with pumps in the EAP or SOP as a backup measure. A backup evacuation measure is especially prudent where a lack of past O&M practices has allowed outlet works to become inoperable.

A permanently installed siphon can also be used as an alternative for a low-level outlet works. A siphon can be installed without significant excavation into the dam, but the reservoir will still need to be partially or completely drained, or a cofferdam installed to permit the intake of the siphon to be set at low reservoir levels. Local removal of reservoir sediments may be required. Siphons can discharge more than 10 cfs, depending on the size of the siphon pipe and the head differential between the reservoir level and the outlet elevation of the siphon pipe. The dam agency owner must be aware that the siphon requires a continuous O&M program just like a permanently-installed low-level outlet works to ensure the siphon remains operable when needed. If the siphon is embedded within the embankment, the design should also consider protection against seepage along the siphon conduit by using filtering materials. Burying the siphon crest pipe in the crest of the dam will facilitate wheeled vehicle traffic across the dam crest.

Additional guidelines on layouts and details for specific design requirements on outlet works can be found in *Design of Small Dams*, prepared by Reclamation. A new document, *Technical Manual: Conduits Through Embankment Dams: Best Practices for Design, Construction, Problem Identification and Evaluation, Inspection, Maintenance, Renovation, and Repair,* provides additional detailed information and guidance on the various issues of outlets works within embankment dams (Federal Emergency Management Agency, Bureau of Reclamation, Federal Energy Regulatory Commission, Natural Resources Conservation Service, Colorado Division of Water Resources, and Maryland Department of the Environment, 2005).

Part 4: Public Safety, Security and Operation/Maintenance

Public Safety Considerations

Small dams and their reservoirs can frequently present hazards to the visiting public. Hazards, such as drop inlet structures, overflow spillways, stilling basins, steep slopes, and high walls present potential dangers to visitors. Often, the potential for injury or death to the public by falls, drowning, or other accidents at small dams and reservoirs far outweighs the risks and threat to life associated with potential dam safety deficiencies.

Agency dam safety personnel should coordinate closely with any agency safety, parks/recreation, or operations staff that manages the safety and recreation at a small reservoir.

Many small dams and reservoirs are used frequently for recreational activities and may be major attractions for visitors. These facilities are usually not subjected to full-time supervision by dam operations personnel, and visitors often consist of children and teenagers who are not under direct adult supervision. Therefore, at a minimum, public safety inspections of areas around dams and reservoirs should be performed regularly as part of the operation and maintenance programs at dams. These inspections should focus on possible hazards at a site and safety features used to mitigate the hazards. If safety features are missing or vandalized or are not adequate to mitigate the hazard, then actions should be taken to correct the deficiency. Safety features should comply with current building code requirements and standard industry practices. The typical public safety issues to consider at small dams include:

- Installation of adequate fencing, guardrails, parapet walls, or other barriers to mitigate potential fall hazards

- Installation of the appropriate signs or barriers to warn or keep visitors away from potential hazards and dangerous or restricted areas

- Installation of barriers or locked gates on outlet works intakes, discharge structures, gate structures, or bridges to intake structures to prevent visitors from entering confined spaces or other potentially dangerous areas. These barriers should not impede flow or be subject to clogging by debris

- Installation of floats, buoys, log booms, or other appropriate floating barriers with signs to warn and keep swimmers and boaters away from intake structures or overflow spillways

- Isolation of mechanical or electrical operating equipment, such as housing in adequate lockable structures with the appropriate signs warning the public to stay out

- Maintenance of the public areas, such as providing trash receptacles and regularly removing litter, obtrusive vegetation, snow, and ice from the ground to prevent tripping/slipping

- Agency maps/guides/brochures can be updated to warn of public/personnel safety issues.

Additional information and guidance concerning public safety at dams can be found in the document titled *Public Safety Around Dams and Reservoirs – An Interim Working Guideline* (Reclamation, 1992).

Security Considerations

Some small dams can also pose significant risks to the downstream public if deliberately attacked, damaged, or mis-operated by aggressors, intruders, or vandals. The dams with the greatest security concerns are those situated upstream from permanent populations with low freeboard distances from the dam crest to the normal reservoir level or those with gates or valves that have a discharge capacity greater than the estimated safe downstream channel capacity. Dams with these characteristics should be evaluated by the dam operators or security specialists and modified as needed to appropriately address the security guidelines described below.

Review of the proposed remediation design in advance by local staff and dam security specialists is valuable to ensure security considerations are incorporated in the constructed dam remediation.

- Wherever possible, prevent the public from driving vehicles on the crest of an embankment dam by installing locked gates or barriers at each end of the dam crest or at other convenient locations on the access roads leading to the dam crest.

- For any discharge structure (such as outlet works, gated spillway, etc.) with the capacity to make releases exceeding downstream safe channel capacity, restrict access to that discharge structure using barriers and/or structural hardening as appropriate.

- The operating controls for any gates or valves should be within a locked and secure structure and the power supply to the operating equipment should generally be de-energized until operation by authorized personnel is required.

- The instructions on operating any gates, valves, or other critical equipment should not be accessible or in view of the public and should be locked within secure structures or containers.

- The exterior doors on structures containing operating equipment should be steel, have interior hinges or protected exterior hinges, and have deadbolt locks. Exterior windows at these structures should be protected with bars placed over the interior of the window. In any event, the security measures installed should not hinder the rapid exit of the structure by operating personnel if an emergency situation arises.

- Appropriate signs should be posted where the public is not allowed, such as “No Trespassing” and “Government Property — Authorized Personnel Only.” Crime Witness signs should be posted on the perimeter, accesses, and/or near critical assets, providing the public a phone number to call to report any suspicious activity.

- Use chain-link fencing with locked gates to delineate the areas where the public is to be excluded.

- Track and document the keys to all locks at the dam to ensure only authorized personnel have keys. A key control plan should be in place to change the locks if keys to critical facilities are lost.

- The Emergency Action Plan or similar document should include the appropriate communications information should a security incident occur and a rapid response by law enforcement or emergency management officials is required.

O&M Considerations

Any dam and its appurtenant structures requires regular periodic maintenance to ensure the dam will operate as required. Any future modifications to the dam or appurtenant structures should routinely include features that minimize the effort required to maintain the dam. Two examples are provided: first, a dam modification that is made to correct a potential seepage or stability issue should consider providing flattened downstream slopes that facilitate regular mowing and the control of vegetation on embankment dams using a grass cover for erosion protection. Second, the repair or replacement of outlet works gates should include the provisions for easier lubrication of moving parts and regular testing of the operating equipment.

In general, the remediation design should minimize the amount of future dam O&M. These dams are typically remote and are visited relatively infrequently. It is difficult to accomplish frequent maintenance activities at small dams due to lack of full-time dedicated maintenance staff.

The agency will need to determine dam access needs both for dam rehabilitation and for long-term operation and maintenance. Remoteness of the project and its location within a park or wilderness area may make the dam accessible only by pack animal or helicopter.

Review of the proposed remediation design in advance by local staff and dam O&M specialists is valuable to ensure O&M considerations are incorporated in the constructed dam remediation.

For small dams, the following maintenance practices should be considered a minimum. This list does not include specific maintenance tracking and implementation programs used within DOI, but those should be considered, depending on the policies of the individual agencies.

- Regularly mow and maintain embankment dams, abutments, and downstream areas to control vegetation, prevent the growth of trees, and to allow the observation of any new or changing seepage conditions.

- Implement a program of rodent removal, control, and repair of the damage at any indication of burrows or rodent holes.

- Repair with suitable erosion-resistant materials any indications of erosion or disturbance of the embankment materials on the upstream face, crest, or downstream face of the dam.

- Repair any spalls or damaged concrete, using the appropriate repair procedures. If the proper procedure is unknown, Reclamation can provide a guide for the required repair process. The early inexpensive repair of small areas of concrete damage will greatly reduce the likelihood of requiring expensive repairs to larger areas at a later date.

- Regularly maintain and operate the mechanical and electrical equipment for the outlet works and any other water conveyance features. This includes lubricating handwheels, operating stems, stem guides, and other exposed structural components; applying a suitable lubricant at all fittings and sliding surfaces; and cleaning any foreign material that may have collected on threaded stems. Check the oil in gear cases for dirt, water, and proper level. Replace, filter, or add oil as necessary.

- Regularly remove all trash, debris, brush, and other obstructions for outlet works intakes and conduits and spillway inlets and channels.

- Document all maintenance work and repairs in a log book.

- Inspect the dam and appurtenant structures frequently and take photos to document the conditions observed and to help detect subtle long-term changes.

- In some areas, riprap is valuable and has the potential to be stolen. In such cases, the riprap should be oversized or grouted to prevent theft.

- Cattle can cause significant long-term damage to an embankment dam. Include fencing in remediation designs to prevent cattle from walking on dams.

- Document the regular O&M procedures, schedules, and responsibilities in the Standing Operating Procedures, Operation and Maintenance Manual, or similar document. Review and update this on a regular basis.

Part 5: Construction

Introduction

Like large dams, small dams require just as much inspection during construction. The only difference would the amount of manpower needed to perform the necessary inspections. The manpower requirements can be minimized if construction personnel maintain an active role during the design and procurement process.

In a total design process, construction personnel need to be part of the team to ensure constructability of the project. This usually occurs at the concept level and at the 60-percent and 90-percent design. With these reviews, the construction personnel can recommend changes to the design that can make construction simpler and more cost effective while achieving the same results as the intended design. Some of these changes can be as simple as suggesting a different sequence of work, to the widening of the filter to accommodate the most likely equipment the contractor will have on site.

The involvement of construction personnel in the decision of what type of procurement option is to be used in the selection of the contractor will, generally, help determine the number of construction inspectors needed and the experience level required. These procurement options are explained below.

Procurement Options

Several procurement options are available for construction of modifications to dams. These are described in more detail below, and include Full and Open Competition, Small Business Administration, and Force Account (using Government labor forces).

The most appropriate procurement option for a given dam can depend on several considerations, such as the extent of the modifications, the availability and/or capability of staff to provide labor forces, the amount of money available to implement the modification, and the desires of the agency owner. Decisions about the type of contract should always include the Contracting Officer, the agency representative, and the project leader because several new pieces of legislation require the use of Small Business Administration contractors, particularly HUBZone contractors.

Option 1 — Full and Open Competition

Sealed Bid (Competitive) or Firm-Fixed-Price

This is the most common type of construction contract. The sealed bid contract helps to ensure, but does not ensure, that the least field cost contract is obtained. The specifications must provide a clear definition of construction intent and field conditions to allow the contractor to properly bid.

A very solid specification consists of well prepared drawings that clearly communicate the design, accompanied by complete specification paragraphs that accurately communicate design intent, construction procedures, and performance parameters. Preparing these documents represents a significant design cost and design time.

Without solid specifications, claims will often significantly increase the contract cost and can significantly affect the performance time to complete the work. Many times, the low bidder plans “going in” to assert claims, based on his/her perceived idea that the specifications are not solid, and cut performance to the bone.

Two-Step Bidding (Invitation for Bid)

Two-step sealed bidding is a combination of competitive bidding procedures designed to obtain the benefits of sealed bidding when adequate specifications are not available. An objective is to permit the development of a sufficiently descriptive and not unduly restrictive statement of the Government's requirements, including an adequate technical data package, so that the subsequent acquisition may be made by conventional sealed bidding. This method is especially useful in acquisitions requiring technical proposals, particularly those for complex items.

It is conducted in two steps:

- Step one consists of the request for, submission, evaluation, and (if necessary) discussion of technical proposals. No pricing is involved. The objective is to determine the acceptability of the services offered. As used in this context, the word “technical” has a broad connotation and includes, among other things, the engineering approach, special manufacturing processes, special testing techniques, and performance schedule. It is the proper step for clarification of questions relating to technical requirements. Conformity to the technical requirements is resolved in this step.

- Step two involves the submission of sealed priced bids by those who submitted acceptable technical proposals in step one.

Negotiated Bid (Request for Proposals or RFP)

Negotiated Contracting is used when price is not the determining factor in the contract award, or when factors other than price (i.e., technical expertise) must be considered.

Negotiated Contracting uses two methods:

- Tradeoff — when the contract is awarded to the offeror whose proposal represents the best value, considering technical ability and price.
- Lowest-Priced, Technically-Acceptable — when the contract award is made to the lowest-price offered among those that meet specified minimum technical requirements.

When using the negotiated method, a Request for Proposals (RFP) will be issued. Once a proposal is received, it will be evaluated by a panel of technical experts using only the evaluation factors specified in the RFP.

Contract award may sometimes be made without discussions. Normally, however, a competitive range is determined on the technical evaluation results. Discussions are then held with the offerors in the competitive range, and each offeror is given an opportunity to submit final proposal revisions.

Offers submitted in response to an RFP are confidential and are not released outside the evaluation panel.

Option 2—Small Business Administration (SBA)

8A Contracting

An 8A contract can usually be awarded in less time and with less design cost than competitive contracts. The SBA will select a qualified contractor. Since competition is not a factor, the selected contractor can be approached before the design documents are complete. Draft specifications and a site review often begin the negotiation process. All aspects of the modification can be thoroughly discussed with the contractor to ensure intent and uncertainties are understood and represented in the final negotiated price. This discussion allows the negotiation process to be entered into with a few more unknowns and options than with a competitive contract.

Because construction and design intent can be openly discussed with the contractor before award, drawings and specifications may not need to be as thorough as is required with a competitive contract. However, a specification is still required to document scope of work, intent, and performance. If the best negotiated price is not acceptable, another 8A contractor can be appointed.

HUBZone Contracting

A “HUBZone” is an area that is located in one or more of the following:

- A qualified census tract (as defined in section 42(d)(5)(C)(i)(I) of the Internal Revenue Code of 1986)
- A qualified “non-metropolitan county” (as defined in section 143(k)(2)(B) of the Internal Revenue Code of 1986) with a median household income of less than 80 percent of the State median household income or with an

unemployment rate of not less than 140 percent of the statewide average, based on U.S. Department of Labor recent data

- Lands within the boundaries of federally recognized Indian reservations

There are four types of contracting methods available for HUBZone use.

Competitive

Contracts can be set-aside for HUBZone competition when the contracting officer has a reasonable expectation that at least two qualified HUBZone small business concerns (SBCs) will submit offers and that the contract will be awarded at a fair market price.

Sole-Source

HUBZone contracts can be sole-source awarded if the contracting officer determines that:

- •Only one qualified HUBZone SBC is available to perform the contract,
- Two or more qualified HUBZone SBCs are not likely to submit offers and
- The anticipated award price of the proposed contract, including options, will not exceed:
  - $5 million for a requirement within North American Industry Classification System (NAICS) code for manufacturing
  - $3 million for a requirement within all other NAICS codes (Constrution)

Full and Open

Competitive contracts can be awarded with a price evaluation preference. The offer of the HUBZone small business must not be 10 percent higher than the offer of a non-small business.

Small Business Set Aside

The last type of SBA contracting method is Small Business Set Aside. This type of contracting is usually reserved for projects under $500,000 but can be as high as $1,000,000 and the work is not in a HUBZone area. The designer, the agency representatives, the contracting officer, and their construction representative can make a determination that there are qualified small businesses in the area that are capable of doing the work based on the complexity of the design. These contracts are Open and Competitive.

Option 3 — Force Account (Government Labor Forces)

This option can potentially permit the quickest, least costly implementation. Only minimal drawings or sketches are prepared to ensure features and technical content are understood and acceptable. The modification is implemented using field direction provided by Reclamation or qualified A/E design engineers and field engineers. Final configuration and intent will be provided by as-built drawings or sketches.

Labor forces and equipment operators can be provided by the agency owner's staff, temporary employees, or staff from other agencies. Heavy equipment and tools can also be rented. However, labor resources cannot be provided from local labor halls or other private sources. This would be considered a violation of rules against government personal services contracts. However, agencies can hire temporary employees to provide needed labor staff.

Other Considerations

Permitting

- The agency owner for whom the work is being done should obtain all required permits, both Federal and State, prior to final design.
- Any local permits, if needed, should be obtained by the group doing the Construction Management and not the contractor.

Design Support during Construction

- The designer needs to be kept abreast of the construction work daily to be able to respond quickly to any required changes.
- The designer also needs to make frequent visits, with his team, during construction to better understand the site conditions.

Construction Management and Inspection

- The Construction Management group needs to be identified during the initial phase of the work and included in any site visits for their input on constructability and possible shortcuts that can be taken during the design phases.

Sediment Control

- This issue needs to be resolved in the early stages of the design.
- If possible, the agency owner should drain the reservoir at least 4 months prior to onsite work to allow the sediments to dry out sufficiently for removal.

Testing

- Testing for the agency owner should be conducted independently of the testing the contractor may be required to perform; e.g., verification testing and record testing.
- The Construction Management group needs to arrange with a lab for any required testing.

Construction Close-out Package

- A Record of Construction Report should be completed for all projects. This report should be included in all Inter-Agency Agreements, if Reclamation performs the construction management. The report must be provided to the agency owner for future record of what has been done to the structure.
- Design Technical Memorandums (TMs)
- As-Built drawings
- Updated Standing Operating Procedures or Operation and Maintenance documents.
- Updated Emergency Action Plan
- Designer’s Verification Report
- Revised Technical Priority Rating sheet

First Filling

- The design team must be aware that, on small structures, normal first fill requirements may be difficult to achieve.
- Small reservoirs can fill overnight with a thunderstorm event or fill at a higher rate than anticipated.
- A decision needs to be made up front in the design process to allow for rapid filling.
- The designer should prepare a first filling plan.
- An Emergency Action Plan should be in place and exercised before first filling.

Safety

- Construction safety is the first priority. The construction contract should contain requirements for safety standards such as Reclamation’s *Construction Safety Standards*.

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Glossary

(Adapted from FEMA 148, Glossary of Terms)

Abutment. That part of the valley side against which the dam is constructed. An artificial abutment is sometimes constructed, as a concrete gravity section, to take the thrust of an arch dam where there is no suitable natural abutment. The left and right abutments of dams are defined with the observer viewing the dam looking in the downstream direction, unless otherwise indicated.

Acre-foot. A unit of volumetric measure that would cover 1 acre to a depth of 1 foot. It is equal to 43,560 cubic feet.

Adverse consequences. Negative impacts that may result from the failure of a dam. The primary concerns are loss of human life, economic loss (including property damage), lifeline disruption, and environmental impact. In addition, project benefits are lost.

Appurtenant structure. Ancillary features of a dam, such as outlets, spillways, powerplants, tunnels, etc.

Attenuation. A decrease in amplitude of the seismic waves with distance due to geometric spreading, energy absorption, and scattering, or decrease in the amplitude of a flood wave due to channel geometry and energy loss.

Axis of dam. The vertical plane or curved surface, chosen by a designer, appearing as a line, in plan or in cross-section, to which the horizontal dimensions of the dam are referenced.

Baffle block. A block, usually of concrete, constructed in a channel or stilling basin to dissipate the energy of water flowing at high velocity.

Base thickness. Also referred to as base width. The maximum thickness or width of the dam measured horizontally between upstream and downstream faces and normal to the axis of the dam, but excluding projections for outlets or other appurtenant structures.

Bedrock. Any sedimentary, igneous, or metamorphic material represented as a unit in geology; being a sound and solid mass, layer, or ledge of mineral matter; and with shear wave threshold velocities greater than 2,500 feet/second.

Berm. A nearly horizontal step in the sloping profile of an embankment dam. Also a step in a rock or earth cut.

Borrow area. The area from which natural materials, such as rock, gravel or soil, used for construction purposes is excavated.

Breach. An opening through a dam that allows the uncontrolled draining of a reservoir. A controlled breach is a constructed opening. An uncontrolled breach is an unintentional opening caused by discharge from the reservoir. A breach is generally associated with the partial or total failure of the dam.

Camber. Camber is ordinarily provided along the crest of earthfill dams to ensure that the freeboard will not be diminished by foundation settlement or embankment consolidation. Camber results in the dam being constructed higher at the maximum section(s), where more settlement is anticipated, than at the abutments.

Cofferdam. A temporary structure enclosing all or part of the construction area so that construction can proceed in the dry. A diversion cofferdam diverts a stream into a pipe, channel, tunnel, or other watercourse.

Compaction. Mechanical action that increases the density by reducing the voids in a material.

Concurrent floods. Flood flows expected at a point on the river system below a dam at the same time a flood inflow occurs above the dam.

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

Consequences. Potential loss of life or property damage downstream of a dam caused by floodwaters released at the dam or by waters released by partial or complete failure of dam. Also effects of landslides upstream of the dam on property located around the reservoir.

Construction joint. The interface between two successive placements or pours of concrete where bond, and not permanent separation, is intended.

Contact grouting. Filling, with cement grout, any voids existing at the contact of two zones of different materials; i.e., between a concrete tunnel lining and the surrounding rock.

Core. A zone of low permeability material in an embankment dam. The core is sometimes referred to as central core, inclined core, puddle clay core, rolled clay core, or impervious zone.

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

Crest length. The measured length of the dam along the crest or top of dam.

Crest of dam. See top of dam.

Cross section. An elevation view of a dam formed by passing a plane through the dam perpendicular to the axis.

Cutoff trench. A foundation excavation later to be filled with impervious material to limit seepage beneath a dam.

Cutoff wall. A wall of impervious material usually of concrete, asphaltic concrete, or steel sheet piling constructed in the foundation and abutments to reduce seepage beneath and adjacent to the dam.

Dam. An artificial barrier with the ability to impound water, wastewater, or any liquid-borne material, to store or control water.

Afterbay dam. See regulating dam.

Ambursen dam. A buttress dam in which the upstream part is a relatively thin flat slab usually made of reinforced concrete.

Arch dam. A concrete, masonry, or timber dam with the alignment curved upstream to transmit the major part of the water load to the abutments.

Buttress dam. A dam consisting of a watertight part supported at intervals on the downstream side by a series of buttresses. Buttress dam can take many forms, such as a flat slab or massive head buttress.

Crib dam. A gravity dam built up of boxes, crossed timbers or gabions, filled with earth or rock.

Diversion dam. A dam built to divert water from a waterway or stream into a different watercourse.

Double curvature arch dam. An arch dam that is curved both vertically and horizontally.

Earth dam. An embankment dam in which more than 50 percent of the total volume is formed of compacted earth layers that are generally smaller than 3-inch size.

Embankment dam. Any dam constructed of excavated natural materials, such as both earthfill and rockfill dams, or of industrial waste materials, such as a tailings dam.

Gravity dam. A dam constructed of concrete and/or masonry, which relies on its weight and internal strength for stability.

Hydraulic fill dam. An earth dam constructed of materials, often dredged, which are conveyed and placed by suspension in flowing water.

Industrial waste dam. An embankment dam, usually built in stages, to create storage for the disposal of waste products from an industrial process. The waste products are conveyed as fine material suspended in water to the reservoir impounded by the embankment. The embankment may be built of conventional materials but sometimes incorporates suitable waste products.

Mine tailings dam. An industrial waste dam in which the waste materials come from mining operations or mineral processing.

Overflow dam. A dam designed to be overtopped.

Regulating dam. A dam impounding a reservoir from which water is released to regulate the flow downstream.

Rock-fill dam. An embankment dam in which more than 50 percent of the total volume is comprised of compacted or dumped cobbles, boulders, rock fragments, or quarried rock generally larger than 3-inch size.

Roller compacted concrete dam. A concrete gravity dam constructed by the use of a dry mix concrete transported by conventional construction equipment and compacted by rolling, usually with vibratory rollers.

Dam failure. Catastrophic type of failure characterized by the sudden, rapid, and uncontrolled release of impounded water or the likelihood of such an uncontrolled release. It is recognized that there are lesser degrees of failure and that any malfunction or abnormality outside the design assumptions and parameters that adversely affect a dam's primary function of impounding water is properly considered a failure. These lesser degrees of failure can progressively lead to or heighten the risk of a catastrophic failure. They are, however, normally amenable to corrective action.

Dam safety. Dam safety is the art and science of ensuring the integrity and viability of dams so that they do not present unacceptable risks to the public, property, and the environment. It requires the collective application of engineering principles and experience, and a philosophy of risk management that recognizes that a dam is a structure whose safe function is not explicitly determined by its original design and construction. It also includes all actions taken to identify or predict deficiencies and consequences related to failure, and to document, publicize, and reduce, eliminate, or remediate to the extent reasonably possible, any unacceptable risks.

Dam safety program purposes. The purposes of a dam safety program are to protect life, property, and the environment by ensuring that all dams are designed, constructed, operated, and maintained as safely and as effectively as is reasonably possible. Accomplishing these purposes requires commitments to continually inspect, evaluate, and document the design, construction, operation, maintenance, rehabilitation, and emergency preparedness of each dam and the associated public. It also requires the archiving of documents on the inspections and histories of dams and the training of personnel who inspect, evaluate, operate, and maintain them. Programs must instill an awareness of dams and the hazards that they may present in the owners, the users, the public, and the local and national decisionmakers. On both local and national scales, program purposes also include periodic reporting on the degree of program implementation. Key to accomplishing these purposes is to attract, train, and retain a staff proficient in the art and science of dam design.

Dike. See saddle dam.

Diversion channel, canal, or tunnel. A waterway used to divert water from its natural course. The term is generally applied to a temporary arrangement; e.g., to bypass water around a dam site during construction. “Channel” is normally used instead of “canal” when the waterway is short.

Drain, blanket. A layer of pervious material placed to facilitate drainage of the foundation and/or embankment.

Drain, chimney. A vertical or inclined layer of pervious material in an embankment to facilitate and control drainage of the embankment fill.

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

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

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

Drainage wells or relief wells. Vertical wells downstream of or in the downstream shell of an embankment dam to collect and control seepage through and under the dam. A line of such wells forms a drainage curtain.

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

Earthquake, Maximum Credible (MCE). The earthquake(s) associated with specific seismotectonic structures, source areas, or provinces that would cause the most severe vibratory ground motion or foundation dislocation capable of being produced at the site under the currently known tectonic framework. It is determined by judgment based on all known regional and local geological and seismological data.

Emergency gate. A standby or reserve gate used only when the normal means of water control is not available for use.

Energy dissipater. A device constructed in a waterway to reduce the kinetic energy of fast flowing water.

Erosion. The wearing away of a surface (bank, streambed, embankment, or other surface) by floods, waves, wind, or any other natural process.

Failure. See Dam, Failure.

Failure mode. A potential failure mode is a physically plausible process for dam failure resulting from an existing inadequacy or defect related to a natural foundation condition, the dam or appurtenant structures design, the construction, the materials incorporated, the operations and maintenance, or aging process, which can lead to an uncontrolled release of the reservoir.

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

Flashboards. Structural members of timber, concrete, or steel placed in channels or on the crest of a spillway to raise the reservoir water level but intended to be quickly removed, tripped, or fail in the event of a flood.

Flood. A temporary rise in water surface elevation, resulting in inundation of areas not normally covered by water. Hypothetical floods may be expressed in terms of average probability of exceedance per year, such as 1-percent-chance-flood, or expressed as a fraction of the probable maximum flood or other reference flood.

Flood, Inflow Design (IDF). The flood flow above which the incremental increase in downstream water surface elevation due to failure of a dam or other water impounding structure is no longer considered to present an unacceptable threat to downstream life or property. The flood hydrograph used in the design of a dam and its appurtenant works particularly for sizing the spillway and outlet works and for determining maximum storage, height of dam, and freeboard requirements.

Flood, Probable Maximum (PMF). The flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the drainage basin under study.

Flood plain. An area adjoining a body of water or natural stream that may be covered by floodwater. Also, the downstream area that would be inundated or otherwise affected by the failure of a dam or by large flood flows. The area of the flood plain is generally delineated by a frequency (or size) of flood.

Flood routing. A process of determining progressively, over time, the amplitude of a flood wave as it moves past a dam or downstream to successive points along a river or stream.

Flood storage. The retention of water or delay of runoff either by planned operation, as in a reservoir, or by temporary filling of overflow areas, as in the progression of a flood wave through a natural stream channel.

Foundation. The portion of the valley floor that underlies and supports the dam structure.

Freeboard. Vertical distance between a specified stillwater (or other) reservoir surface elevation and the top of the dam, without camber.

Gate. A movable water barrier for the control of water.

Geotextiles. Any fabric or textile (natural or synthetic) when used as an engineering material in conjunction with soil, foundations, or rock. Geotextiles have the following uses: drainage, filtration, separation of materials, reinforcement, moisture barriers, and erosion protection.

Groin. The area along the contact (or intersection) of the face of a dam with the abutments.

Grout. A fluidized material that is injected into soil, rock, concrete, or other construction material to seal openings and to lower the permeability and/or provide additional structural strength. There are four major types of grouting materials: chemical; cement; clay; and bitumen.

Hazard. A situation that creates the potential for adverse consequences, such as loss of life, property damage, or other adverse impacts.

Hazard potential. The possible adverse incremental consequences that result from the release of water or stored contents due to failure of the dam or misoperation of the dam or appurtenances. Impacts from flood waters released through spillways and outlet works of the dam or waters released by partial or complete failure of the dam may be for a defined area downstream of a dam. There may also be impacts for an area upstream of the dam from effects of backwater flooding or landslides around the reservoir perimeter.

Hazard potential classification. A system that categorizes dams according to the degree of adverse incremental consequences of a failure or misoperation of a dam. The hazard potential classification does not reflect in any way on the current condition of the dam (i.e., safety, structural integrity, flood routing capacity).

Height. The maximum height from natural ground surface to the top of a dam.

Height, hydraulic. The vertical difference between the maximum design water level and the lowest point in the original streambed.

Height, structural. The vertical distance between the lowest point of the excavated foundation to the top of the dam.

Hydrology. One of the earth sciences that encompasses the natural occurrence, distribution, movement, and properties of the waters of the earth and their environmental relationships.

Inflow Design Flood (IDF). See Flood.

Instrumentation. An arrangement of devices installed into or near dams that provide for measurements that can be used to evaluate the structural behavior and performance parameters of the structure.

Inundation map. A map showing areas that would be affected by flooding from releases from a dam’s reservoir. The flooding may be from either controlled or uncontrolled releases or as a result of a dam failure. A series of maps for a dam could show the incremental areas flooded by larger flood releases.

Landslide. The unplanned descent (movement) of a mass of earth or rock down a slope.

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

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

Liquefaction. A condition whereby soil undergoes continued deformation at a constant low residual stress or with low residual resistance, due to the buildup and maintenance of high pore water pressures, which reduces the effective confining pressure to a very low value. Pore pressure buildup leading to liquefaction may be due to either static or cyclic stress applications and the possibility of its occurrence will depend on the void ratio or relative density of a cohesionless soil and the confining pressure.

Logboom. A chain of logs, drums, or pontoons secured end-to-end and floating on the surface of a reservoir to divert floating debris, trash, and logs.

Low level outlet (bottom outlet). An opening at a low level from a reservoir generally used for emptying or for scouring sediment and sometimes for irrigation releases.

Normal reservoir level. For a reservoir with a fixed overflow sill, the lowest crest level of that sill. For a reservoir whose outflow is controlled wholly or partly by moveable gates, siphons or other means, it is the maximum level to which water may rise under normal operating conditions, exclusive of any provision for flood surcharge.

Outlet works. A dam appurtenance that provides release of water (generally controlled) from a reservoir.

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

Peak flow. The maximum instantaneous discharge that occurs during a flood. It is coincident with the peak of a flood hydrograph.

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

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

Piezometer. An instrument used for measuring water levels or pore water pressures in embankments, foundations, abutments, soil, rock, or concrete. (See instrumentation.)

Piping. The progressive development of internal erosion by seepage.

Probable Maximum Flood (PMF). See Flood.

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

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

Reservoir capacity. The sum of the dead and live storage of the reservoir.

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

Riprap. A layer of large uncoursed stone, precast blocks, bags of cement, or other suitable material, generally placed on the slope of an embankment or along a watercourse as protection against wave action, erosion, or scour. Riprap is usually placed by dumping or other mechanical methods, and in some cases is hand placed. It consists of pieces of relatively large size, as distinguished from a gravel blanket.

Risk. A measure of the likelihood and severity of adverse consequences (National Research Council 1983). Risk is estimated by the mathematical expectation of the consequences of an adverse event occurring; i.e., the product of the probability of occurrence and the consequence, or alternatively, by the triplet of scenario, probability of occurrence, and the consequence.

Risk analysis. A procedure to identify and quantify risks by establishing potential failure modes, providing numerical estimates of the likelihood of an event in a specified time period, and estimating the magnitude of the consequences. The risk analysis should include all potential events that would cause unintentional release of stored water from the reservoir.

Risk assessment. The process of deciding whether existing risks are tolerable and present risk control measures are adequate and, if not, whether alternative risk control measures are justified. Risk assessment incorporates the risk analysis and risk evaluation phases.

River basin. The drainage area for a river above a particular point.

Seepage. The internal movement of water that may take place through the dam, the foundation, or the abutments.

Seismotectonic source area(s). An area or areas of known or potential seismic activity that may lack a specific identifiable seismotectonic structure.

Settlement. The vertical downward movement of a structure or its foundation.

Slope. Inclination from the horizontal. Sometimes referred to as batter when measured from vertical.

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

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

Spillway, auxiliary. Any secondary spillway that is designed to be operated infrequently, possibly in anticipation of some degree of structural damage or erosion to the spillway that would occur during operation.

Spillway, emergency. See Spillway, auxiliary.

Spillway, service. A spillway that is designed to provide continuous or frequent regulated or unregulated releases from a reservoir, without significant damage to either the dam or its appurtenant structures. This is also referred to as principal spillway.

Spillway capacity. The maximum spillway outflow that a dam can safely pass with the reservoir at its maximum level.

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

Spillway chute. A steeply sloping spillway channel that conveys discharges at super-critical velocities.

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

Spillway, fuse plug. A form of auxiliary spillway consisting of a low embankment designed to be overtopped and washed away during an exceptionally large flood.

Stability. The condition of a structure or a mass of material when it is able to support the applied stress for a long time without suffering any significant deformation or movement that is not reversed by the release of the stress.

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

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

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

Storage, inactive. The storage volume of a reservoir between the crest of the invert of the lowest outlet and the minimum operating level.

Surcharge, flood. The storage volume between the top of the active storage and the design water level.

Toe of the dam. The junction of the downstream slope or face of a dam with the ground surface; also referred to as the downstream toe. The junction of the upstream slope with ground surface is called the heel or the upstream toe.

Upstream blanket. An impervious blanket placed on the reservoir floor and abutments upstream of a dam. For an embankment dam, the blanket may be connected to the core.

Wave runup. Vertical height above the stillwater level to which water from a specific wave will run up the face of a structure or embankment.

Weir. A notch of regular form through which water flows.