Federal Guidelines for Dam Safety

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FEMA

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Preface

The Federal Emergency Management Agency (FEMA) coordinates the federal response to disasters and provides federal guidance to state, tribal, and local emergency management authorities for all foreseeable disasters and emergencies in the United States and U.S. territories. To reduce dam-related risks to the Nation, FEMA believes that formal guidelines are needed to review procedures and criteria used by federal agencies in the design, construction, operation, management, and regulation of dams.

The Federal Guidelines for Dam Safety encourage strict safety standards in the practices and procedures employed by federal agencies or required of dam owners regulated by federal agencies. The Federal Guidelines for Dam Safety provide the most complete and authoritative statement available on the desired management practices for promoting dam safety in the United States and U.S. territories. The Federal Guidelines apply to federal practices for dams with a direct federal interest; the Federal Guidelines do not attempt to establish technical standards and are not intended to supplant or conflict with state, tribal, or local government responsibilities for the safety of dams under their jurisdiction.

Since 1979, the Federal Guidelines for Dam Safety have provided guidance and structure for the continued improvement and coordination of dam safety activities among federal agencies. Changes in dam safety practices have occurred over the last four decades, based on science and best practices, and this document has been updated to reflect those changes. The 2019 version of the Federal Guidelines for Dam Safety contains most of the original content of the 1979 version, with minor updates to reflect changes in dam safety practices over the last four decades. The authors of the 2019 version sought to balance the need to update the 1979 version to reflect the current state of the dam safety practice while maintaining the intent of the original Federal Guidelines for Dam Safety.

Dam Safety is a shared responsibility. Many entities have a role to play in creating a future where all dams are safer – including dam owners, engineers, emergency managers, community planners/leaders, regulators, and all levels of government. Dams are unique infrastructure components that can be affected by:

- Natural hazards (earthquakes, flooding, hurricanes, etc.).
- Human-made threats (human error, terrorism); and
- An imbalance between resources invested and a dam's age.

Risk is the result of the interaction between a hazard, how the infrastructure will perform in the event of a hazard, and the consequences of the hazard. To properly communicate risk to communities, it is important to share and present information in such a way that allows the whole community to be prepared.

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I. Introduction

These guidelines apply to dam safety management practices for all federal agencies responsible for the planning, emergency preparedness, design, construction, operation, regulation of dams, and response to dam incidents. They are not intended as guidelines or standards for the technology of dams. The basic principles presented apply to all dams. However, reasonable application of these principles should be made in recognition of a dam's size, complexity, and hazard potential.

The federal agencies have a good implementation record of sound practices for dam safety. These guidelines are intended to promote management control and a common approach to dam safety practices. Although these guidelines are applicable to all agencies, the methods and degree of application depend on agency missions and functions.

A. Background

On May 31, 1889, the South Fork Dam in Johnstown, Pennsylvania, failed after days of unusually heavy rainfall, sending torrents of water downstream, killing 2,200 people, and leaving thousands homeless. The Johnstown disaster was the worst dam failure in the United States in terms of the number of lives lost and injuries.

On February 26, 1972, a tailings dam in Buffalo Creek, West Virginia, failed, devastating a 16-mile valley with 6,000 inhabitants. In minutes, 125 people were killed, 1,100 people were injured, and more than 3,000 were left homeless. On June 5, 1976, the Teton Dam in Idaho failed, leaving 11 people dead and causing $1 billion in damage. In November 1977, the Kelly Barnes Dam in Georgia failed, killing 39 people, most of them college students. These catastrophic dam failures collectively led to a series of national actions designed to ensure the safety of America's dams.

In response to the Buffalo Creek flood disaster in 1972, Congress enacted Public Law 92-367, the National Dam Inspection Act, which authorized the U.S. Army Corps of Engineers (USACE) to inventory and inspect non-federal dams.

On April 23, 1977, a Presidential memorandum was issued (reproduced in Appendix A) directing federal agencies to review their dam safety practices, addressing critical elements of dam safety. Major elements included internal and external review processes and standards, qualifications of personnel, integration of new technology, emergency action plans, and review of existing dams. The Agencies' reviews and the assessment of the reviews by a federal ad hoc Interagency committee and an Independent Review Panel showed that sound practices were generally used. Still, they concluded that improvements were needed in management practices for increased dam safety.

This led to the development of the Federal Guidelines for Dam Safety (Guidelines) in 1979 by the ad hoc Interagency Committee on Dam Safety (ICODS) of the Federal Coordinating Council for Science, Engineering, and Technology. In 1979, a Presidential Memorandum was issued requiring the head of each federal dam safety agency to implement these Guidelines.

In 1979, Executive Order (EO) 12148 established FEMA. It provided the authority to coordinate all national efforts in dam safety and to "reduce the risk of life and property from dam failure in the United States through the establishment and maintenance of an effective National Dam Safety Program to bring together the expertise and resources of the federal and non-federal communities in achieving national dam safety hazard reduction." FEMA has continued to act as the lead federal agency on dam safety in the United States and to support the safety of the Nation's dam infrastructure through state assistance funds, emergency action planning, training, public outreach, research, and creating new guidance regarding the maintenance and construction of dams.

In 1986, federal legislation was enacted through the Water Resources Development Act of 1986 to further address dam safety. Title XII of this legislation authorized the state assistance program, the establishment of a National Dam Safety Review Board (NDSRB), research and training programs, and funds to maintain and update the National Inventory of Dams (NID).

The National Dam Safety Program (NDSP) was legislatively mandated by Congress in 1996 when they enacted the National Dam Safety Program Act as part of the Water Resources Development Act (Public Law 104-303). This act formally established the roles and membership of the NDSRB, financial assistance in the form of grants to the state dam safety programs, and funding for maintaining the NID, research, and training related to dam safety. The act also directed FEMA to educate on the importance of strong dam safety programs nationally and locally. FEMA was also given the federal responsibility for coordinating and facilitating partnerships among all stakeholders to enhance dam safety.

The NDSP was reauthorized in 2002 under the National Dam Safety and Security Act, in 2006 under the Dam Safety Act, and again in 2014 under the Water Resource Reform and Development Act.

The President signed the "Water Infrastructure Improvements for the Nation Act," or the "WIIN Act," on December 16, 2016, which adds a new grant program under FEMA's National Dam Safety Program (33 United States Code [U.S.C.] § 467f). Section 5006 of the Act, Rehabilitation of High Hazard Potential Dams, provides technical, planning, design, and construction assistance in the form of grants for the rehabilitation of eligible high hazard potential dams.

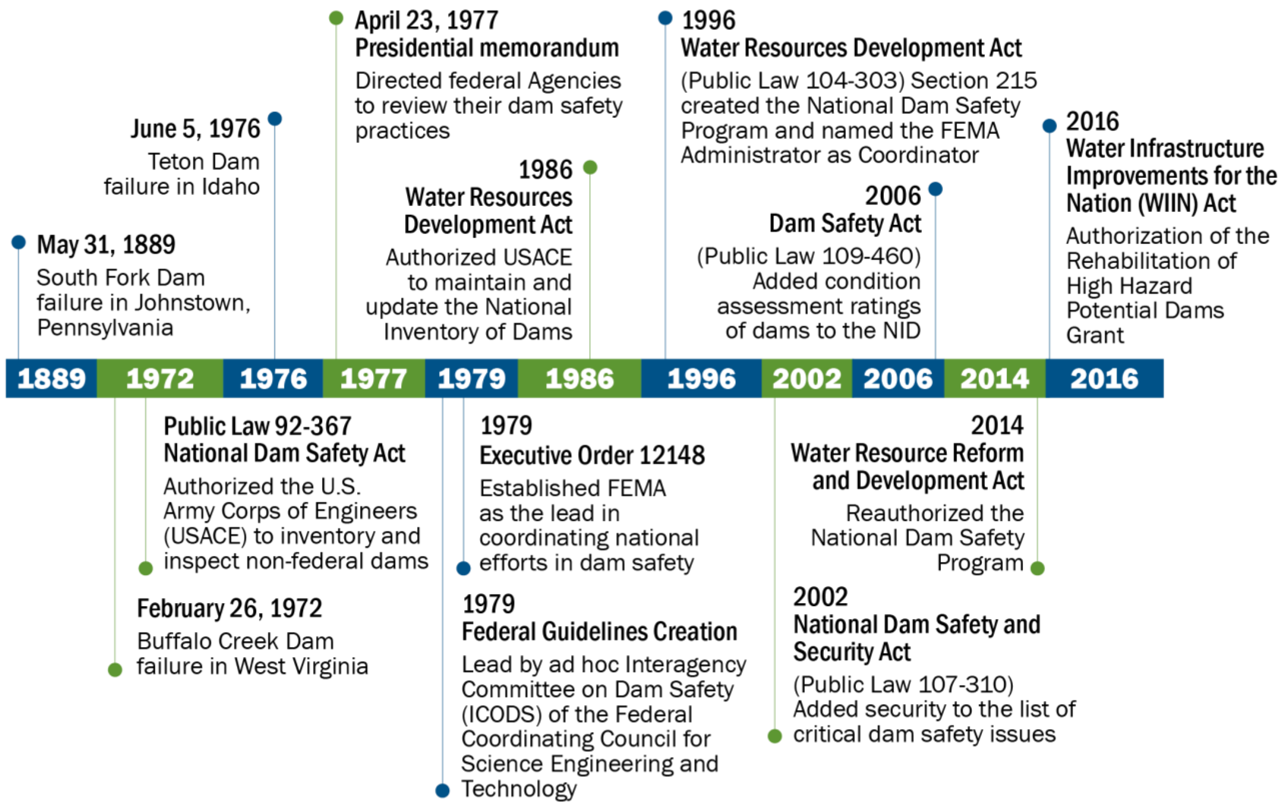

Figure 1. Dam incident and legislative timeline

B. Definitions

The following definitions apply to these guidelines.

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

Consequences: Potential loss of life or property damage downstream of a dam caused by floodwaters released at the dam, or by water, liquid-borne solids, or industrial wastes released by partial or complete failure of the dam. Also, the effects of landslides upstream of the dam on property located around the reservoir.

Cooperating Agency: Any federal agency (and a State, Tribal, or local agency with agreement of the lead agency) other than a lead agency that has jurisdiction by law or special expertise concerning any environmental impact. 40 CFR § 1508.1(e), 2020

Dam or Project: Any artificial barrier, including appurtenant works, that impounds or diverts water, liquid-borne solids, or industrial wastes, and (1) is twenty-five feet or more in height from the natural bed of the stream or watercourse measured at the downstream toe of the barrier, or from the lowest elevation of the outside limit of the barrier if it is not across a stream channel or watercourse, to the maximum water storage elevation or (2) has an impounding capacity at maximum water storage elevation of fifty acre-feet or more. These guidelines do not apply to any barrier that is not more than six feet in height, regardless of storage capacity, or has a storage capacity at maximum water storage elevation not over fifteen acre-feet, irrespective of height. This lower-size limitation should be waived for dams or projects with a high or significant hazard potential classification.

These guidelines apply with equal force whether the dam has a permanent reservoir or is a detention dam for temporarily storing floodwaters, liquid borne solids, or industrial wastes. The impounding capacity at maximum storage elevation includes storage of floodwaters above the normal full storage elevation.

Liquid-borne solids: Materials that are or have been transported (e.g., slurry) via liquid and exhibit mobility or material behavior consistent with a fluid.

Dam Failure: Catastrophic type of failure characterized by the sudden, rapid, and uncontrolled release of impounded water, liquid-borne solids, industrial wastes, or any combination of these. There are lesser degrees of failure in which any malfunction or abnormality outside the design assumptions or parameters that adversely affect a dam's primary function of impounding. Such 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 Incident: An emergency situation that threatens the integrity of the dam, or its components, that could result in an increased risk to the population or environment but does not result in the catastrophic failure of the dam. An incident may also include operational releases from the dam (e.g., principal spillway, emergency spillway) that may result in flooding major roads, homes, or businesses.

Dam Safety: Dam safety is the art and science of ensuring the integrity and viability of dams such 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.

Emergency Action Plan (EAP): A formal document that identifies potential emergency conditions at a dam and specifies actions to be taken to minimize loss of life and property damage.

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%-chance flood or expressed as a fraction of the probable maximum flood or other reference flood.

Floodplain: 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.

Hazard: A situation that creates the potential for adverse consequences such as loss of life, property damage, or other adverse effects. Hazards can be caused downstream of a dam by the release of floodwaters at the dam, waters released by operational releases, partial or complete failure of the dam, or release of liquid-borne solids or industrial wastes. Hazards can be caused upstream of the dam from the effects of rim slides. The Federal Guidelines for Dam Safety: Hazard Potential Classification "sets forth a hazard potential classification system for dams" (p. 1) [2].

Industrial Waste: Waste produced by an industrial activity, which includes material rendered useless during a manufacturing process such as that of factories, mills, and mining operations. For the purpose of these guidelines, specifically industrial waste in the form of a liquid or semi-solid that is stored or disposed of in a surface impoundment behind a dam.

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.

Maintenance: Maintaining structures and equipment in intended operating condition; equipment repair and minor structure repair.

National Environmental Policy Act (NEPA): The NEPA process is required by law. It can be a critical component to selecting the preferred modification alternative, and the project schedule and budget must account for this activity. Staff specialized in NEPA processes will generally have the lead to analyze the needs and make recommendations of what type of environmental study (categorical exclusion (CE), Environmental Assessment (EA), or Environmental Impact Statement (EIS)) will be required.

Cultural resources must be considered, and the impacts on cultural resources should be identified. Many older structures are historically significant or are constructed on and around culturally sensitive areas. Surveys for prehistorical and historical evidence must be provided, and the State Historic Preservation Office (SHPO) review and concurrence are required. Native American concerns must also be addressed through consultations with affected Tribes.

Notification: To inform appropriate individuals about an emergency condition so they can take appropriate action.

Piping: The progressive development of internal erosion by seepage.

Principal Spillway: 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 structure is also referred to as a service spillway.

Rehabilitation or Improvement: Repair of structure deterioration to restore original condition; alteration of structures to improve dam stability, enlarge reservoir capacity, increase spillway and outlet works capacity, improve containment systems, or replacement of equipment.

Reservoir: A body of water or liquid-borne solids impounded by a dam.

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

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.

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.

The Federal Guidelines for Dam Safety: Glossary of Terms (2004) provides “common terminology for dam safety for use within and among Federal Agencies” (p. 1) [3].

Whole Community: Preparedness is a shared responsibility; it calls for the involvement of everyone – not just the government – in preparedness efforts. By working together, everyone can help keep the nation safe from harm and help keep it resilient when struck by hazards, such as natural disasters, acts of terrorism, and pandemics.

Whole Community includes:

- Individuals and families, including those with access and functional needs
- Businesses
- Faith-based and community organizations
- Nonprofit groups
- Schools and academia
- Media outlets
- All levels of government, including state, local, tribal, territorial, and federal partners

II. Objectives and Scope

The overall purpose of these guidelines is to enhance national dam safety. The objective is to encourage high safety standards in the practices and procedures federal agencies use or require of those they regulate for dam site investigation, design, construction, operation, and maintenance, as well as activities and programs supporting emergency preparedness and response. As these guidelines are applied to make federal dams as safe as practical, it is the intent that they will also influence state dam safety agencies and public and private dam owners to be more safety conscious. Safety is not just limited to the dam's structural integrity but also includes reducing the risk to people, property, and the environment downstream of the dam.

These guidelines outline federal agency management procedures and actions that will continually revise technical methods in dam planning, design, construction, operation, and maintenance to minimize the risk of failure. These guidelines acknowledge, plan, and prepare for dam incidents that require a response. Those charged with administering these guidelines must recognize that dam safety is achieved through a continuous, coordinated, and dynamic process in which guidelines, practices, and procedures are examined and periodically updated with the assistance of the emergency management community. Coordination between personnel in planning, design, construction, operations and maintenance, and emergency planning and response are crucial to create a common understanding of the information needed for the design of a dam, periodic safety inspections, and response to dam incidents.

Technical procedures need to evolve with technological advancement, and management should ensure that observed deficient practices are corrected, and successful practices are documented, shared, and duplicated. Risk is the result of the interaction between a hazard, how the infrastructure will perform in the event of a hazard, and the consequences of the hazard. Proper communication, sharing materials, and presenting information clearly are all crucial to preparing community officials. Emergency managers, floodplain managers, community planners, and other state and local officials can use dam risk information to understand the potential dam-related flood hazards a population faces.

Local emergency managers should be given a dam breach inundation map, which shows properties at risk and can be used to establish evacuation routes to coordinate with dam owners to understand the roles, responsibilities, and actions described in the owner's Emergency Action and Emergency Preparedness Plans. Likewise, communication and coordination between stakeholders (which may include multiple jurisdictions) should happen on a frequent, regular basis, well in advance of any dam safety emergencies. It is essential all parties have a plan of communication before, during, and after a dam safety emergency and know what to expect from each other. This includes municipalities that must understand the areas at risk and take measures to minimize the impacts. The public should also know whether they could be impacted by a dam safety emergency and understand what to do during a dam safety emergency.

No dam can ever be completely “fail-safe” because of an incomplete understanding of uncertainties associated with natural (earthquakes and floods) and human-made (sabotage) destructive forces, with dam materials’ response to these forces and the construction process. It is critical for those responsible for the design, construction, operation, maintenance, and regulation of dams and the emergency management community to share the responsibility of dam risk management. Management must ensure that uncertainties are properly balanced with competent technical judgment. Decisions must be collaborative and based on technical and emergency management, focusing on emergency preparedness.

Dam engineering draws heavily upon mathematical principles and physical laws, but every stage of the planning and execution of a dam project also requires the exercise of experienced judgment. This is true in designing and constructing new dams and especially true in evaluating or improving existing dams. For many of these “older dams,” little information is available to document original site exploration, design, construction, and past operation. These dams must be carefully inspected and observed for indicators of distress.

It is also important to recognize that dam failure is not the only threat to communities downstream. “Normal” operational releases can cause damaging flooding. Additionally, spillway releases, while operating as designed and ensuring the dam’s integrity, can have devastating consequences for those downstream. Finally, unseen conditions, such as seepage or release of pollutants or constituents that can cause adverse environmental reactions, can threaten ground and surface waters. Impoundments must comply with applicable state and federal statutes and regulations that govern ecological impacts to groundwater and surface water and operations and closure requirements instead of complying with additional or conflicting guidelines set forth herein.

Construction is a critical phase in achieving a safe dam. Any project must be continuously evaluated and “re-engineered” to ensure that the final design is compatible with conditions encountered during construction. Quality of construction is also critical to safety. Deficiencies in materials or construction practices can occur during all stages of construction. Sampling and testing at a completed project cannot be relied on as an effective substitute for inspection and quality control during construction. Construction of industrial waste and tailings dams often occurs over decades. Development of long-term plans and continual assessment of site conditions is crucial.

Monitoring existing dams and responding quickly to inadequate performance or danger signals is critical for dam safety. Careful monitoring and quick response can prevent failures or minimize their effect.

Coordination with the emergency management community and public safety agencies is vital to protecting the public. The threat of a dam incident cannot be eliminated. While emergency management is responsible for preparing for the worst, they must also be ready for events less severe than the dam or spillway failure, such as spillway releases. It is paramount that emergency management agencies work together with personnel responsible for the operation and maintenance of the dams.

These guidelines are intended to reduce failure risk in constructing new dams and to prioritize the need to improve existing dams according to hazard potential as estimated by technical analysis to ensure maximum benefit when financial and personnel resources are constrained.

In consideration of the differing agency missions, these guidelines were designed to be free of specific agency policies and unnecessary details. The level of detail in these guidelines represents an attempt to achieve a balance between general management goals for assuring dam safety and meaningful principles that can survive technological changes and be useful to the non-federal community.

For the sake of life safety issues, it is important to clearly understand a dam's multiple owners to coordinate with everyone and implement strategies to lessen the impacts on life and property. A special situation exists regarding the application of these guidelines to dams of international nature. Several dams of concern to the U.S. are located in the United States and Mexico or Canada. Those dams located at the U.S.-Mexican border are only partly subject to the jurisdiction of a U.S. federal agency, the U.S. Section of the International Boundary and Water Commission. In this case, the U.S. should seek an agreement with the Mexican Section of the Commission to adopt applicable sections of these guidelines to ensure dam safety. For dams located on the U.S.-Canadian border, these guidelines should be referred to the U.S. Section of the International Joint Commission to seek agreement with the Canadian Section of the Commission on means by which these guidelines could be implemented through the entities that are responsible for construction, operation, maintenance, and regulation of the projects.

Section III.A., Organization Management, outlines the elements of agency management responsibilities for dam safety. Sections III.B, III.C, and III.D, Management of Technical Activities, contain additional guidance on technical activities for Site Investigation and Design, Construction, and Operation and Maintenance (includes Periodic Inspection Program and Emergency Action Planning). Appendix H is a bibliography of references to related guidelines and practices developed by federal dam building Agencies and other scientific and technical organizations. The body of knowledge represented by the bibliography is intended to be representative of dam technology but not inclusive of all available literature that may be helpful.

III. Guidelines

A. Organizational Management

1. General

Each federal agency is responsible for developing and implementing policies, resources, and procedures for the safe design, construction, operation, inspection, and regulation of each dam under its jurisdiction, as applicable to the agency's mission and priorities. These responsibilities may also extend to non-federal dams on federal lands.

Each agency's management structure is responsible for obtaining compliance with the intent of these management and technical activities guidelines and ensuring that procedures are evaluated and updated periodically.

A. ADMINISTRATION

The head of each federal agency responsible for the design, construction, operation, or regulation of dams, as well as emergency planning, preparedness, and environmental compliance efforts, should establish a dam safety office and include a dam safety officer. The dam safety officer should be a registered professional engineer. The dam safety officer should report to the head of the agency or the agency's designated representative. The dam safety office should be responsible for ensuring that the agency makes every reasonable and prudent effort to enhance the safety of the dams and the safety of the people and property downstream of dams under its jurisdiction. Duties of the office should include surveillance and evaluation of the agency's administrative and technical practices related to dam safety concerning design, construction, and regulation of new dams; operation, maintenance, rehabilitation, and regulation of existing dams; recommending improvements in the practices when evaluation reveals safety-related deficiencies; and maintaining an inventory of agency dams.

The dam safety office should be an advisor to the agency head and, through the agency head, to the agency administrative and technical units. The staffing and detailed duties of the office should be commensurate with the agency's mission. The heads of the dam safety offices in the respective agencies should serve in an advisory role in FEMA's Interagency coordinating functions.

The agency responsible for the design, construction, operation, or regulation of a dam project should have a single, identifiable, technically qualified administrative head who has the responsibility for assuring that all management and technical safety aspects of dam engineering are adequately considered throughout the development and operation of the project. The position must have continuity of guidance and direction and the authority and resources to ensure these responsibilities can be carried out. This can be achieved through standard continuity of operations processes.

Management should ensure that organization staffing is sufficient and qualified for the projected workload and that all programs necessary for the safety of dams are established, continued, and realistically funded. Allocation of workforce and funds should give priority to safety-related functions. Safety-related functions and features must not be sacrificed to reduce costs, improve project justification, or expedite time schedules.

B. ENVIRONMENTAL PLANNING AND HISTORIC PRESERVATION (EHP) COMPLIANCE CONSIDERATIONS

Early integration of Environmental Planning and Historic Preservation (EHP) compliance considerations helps federal programs and federal programs and stakeholders make fully informed decisions before deciding on a course of action. Early scoping is a federal agency's opportunity to become familiar with project-specific conditions and identify circumstances that may cause a project to require a higher-level review under commonly encountered EHP laws or Executive Orders (E.O.s), including the potential for required interagency coordination or consultation. When EHP is considered early in the process, identifying EHP issues and potential mitigation measures can help avoid or minimize impacts on EHP resources. Early consideration also ensures EHP compliance milestones and timelines are accurately constructed and integrated at the beginning of each project. This enables federal agencies to engage in any required consultations with regulatory agency partners early to streamline coordination, consultation, and permit approval or issuance.

The requirements mentioned above relate to multiple EHP laws and E.O.s, specifically the National Environmental Policy Act (NEPA; 42 U.S.C. §§ 4332-4347, 2000) and the Council of Environmental Quality's (CEQ) NEPA Implementing Regulations (40 Code of Federal Regulations (CFR) §§ 1500-1508, 2020), and other laws including the:

- Section 106 of National Historic Preservation Act (NHPA; 36 CFR Part 800.1(c), 2004);
- Endangered Species Act (ESA; 50 CFR § 402.11, 2011);
- E.O. 13690 and 11988, Floodplain Management, 44 CFR § 9.2(a), 2022;
- E.O. 11990, Protection of Wetlands, 44 CFR § 9.17(a), 2019;
- E.O. 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations, 32 CFR § 651.17, 1994;
- Coastal Zone Management Act (CZMA; 15 CFR § 930.96, 2020); and
- Coastal Barrier Resources Act (CBRA; 44 CFR § 206.349(d), 2019).

C. DESIGN RESPONSIBILITY

The design office should establish specific programs for onsite construction and operational inspection for review by appropriate design personnel and technical specialists. Federal design responsibilities include planning for and incorporating national environmental and historic preservation laws and regulations as early as possible in the process. The programs should include frequent and mandatory inspections during construction to confirm that site conditions conform to those assumed for design or to determine if design changes may be required to suit the actual conditions. A major requirement is the inspection and approval of the dam foundation and foundation treatment before placing dam materials. Final design inspection of the construction should include complete project surveillance and testing of operating equipment. In the case of many industrial or tailings dams where construction continues over the life of the dam, continual construction monitoring and inspection is warranted. Operational design inspections should continue throughout the life of the project in accordance with a formal inspection program covering all project features. Management must provide adequate funds to ensure dam safety is not compromised by failure to conduct regular and thorough inspections and reviews.

The design function includes planning any dam instrumentation to be installed during construction or operation to monitor conditions that could threaten dam safety or the safety of groundwater or downstream surface waters. The design should identify the purpose of the instrumentation and include plans for timely reading, collecting, reducing, and interpreting the data. It should include an advance determination of critical instrument observations or rates of data change and a plan of action if observations indicate a critical condition may or is occurring.

D. CONSTRUCTION RESPONSIBILITY

The responsibility for administering construction and supply contracts, including understanding the design and contract intent, maintaining technical coordination between design and construction engineers, and managing the construction staff to assure compliance with specifications, should be vested in an identified engineer at the construction project. They should have the administrative and technical control of all resources necessary to construct the dam safely. Construction personnel should understand the conditions upon which the design is based and the relationship between these conditions and the design features. Design personnel should be involved in determining their effect on dam construction when unanticipated conditions are encountered.

E. OPERATION AND MAINTENANCE RESPONSIBILITY

The project operation and maintenance responsibility should be assigned to a single staff member of the operating organization. The position should also manage the operating organization requirements for coordination with the design organization, including reporting changed conditions discovered by operators and participation of the operating organization personnel with design personnel in the periodic inspection program.

F. TECHNICAL COORDINATION

All technical specialties required to plan, design, construct, operate, and regulate dams to achieve dam safety should be staffed, and their efforts should be coordinated to ensure technical adequacy. A project design engineer should be assigned a technical coordination responsibility for each dam. The position should manage technical coordination within the agency and with private and public organizations.

Continuous communication should be maintained among the personnel concerned with the various stages of project development and operation so that each concerned discipline and organizational unit knows and understands the relevant activities of the others. This coordination must be given constant attention to be sure proper action is taken.

G. EMERGENCY PLANNING

An emergency plan should be formulated for each dam. The plan should be warranted in detail by the size and location of the dam and reservoir and the chemical nature of the impounded material. It should evaluate downstream inundation hazards resulting from floods or dam failure, upstream conditions that might result from major land displacements or increased flood flows, including the effects from the failure of upstream dams, and downstream environmental impacts in the case of industrial/tailings dams.

The plan should include inundation maps for the flows resulting from design floods and possible failure of the dam. The emergency plan should be transmitted to appropriate local, state, tribal, and federal governmental entities and other relevant public safety agencies in the affected jurisdictions. The plan should be periodically reviewed and, kept up to date and regularly publicized to maintain awareness of its existence.

In addition to the emergency plan for the completed dam, a similar plan should be prepared for the construction period, including area facilities that may remain during the period and floods that may be anticipated.

H. RISK MANAGEMENT

Federal agencies have implemented numerous techniques and methodologies to better understand and manage dam risks. The Federal Guidelines for Dam Safety Risk Management (2015) describes risk management as “action implemented to communicate the risks and either accept, avoid, transfer, or control the risks to an acceptable level considering associated cost and benefits of any action taken” (p.5) [4]. Agencies should continue to improve techniques for evaluating potential failure modes and estimating the consequences of such failures; consider risk management when studying project alternatives, incorporating safety into dam facilities, establishing priorities for examining and rehabilitating dam; include evaluation of the potential consequences of failure of the dams under agency jurisdiction and consider opportunities to manage the consequences; and incorporate risk communication as an integral part of the risk management process.

2. Staffing

A. TECHNICAL SUPPORT

Management should ensure adequate and competent technical staffing to perform the essential functions in planning, design, construction, operation and maintenance, inspection, regulation, and emergency preparedness. Technical staff should be supported by administrative, clerical, and other personnel to ensure staff is not diverted from technical work. In the planning and design function, emphasis should be given to adequate staffing in hydrology, hydraulics, geology, engineering seismology, field investigation, geotechnical and structural design. Construction and operation staff should have sufficient expertise to understand design decisions related to the various design specialties and related industry advancements.

Construction inspection staffing should assure quality and quantity inspection coverage. A higher authority than the local construction office should review staffing. Construction staff should be well trained and experienced if the design is to be implemented and a safe structure is to be constructed. They must not only recognize the need for adherence to the design but also recognize when the design is at odds with the conditions being encountered. The responsibility and importance of the construction staff to dam safety must be given appropriate consideration in organizational and position classification decisions.

Operating personnel must be qualified to perform many functions, including recognizing conditions possibly detrimental to dam safety. Operation and maintenance staffing requires careful attention to personnel responsible for operating inspections and personnel participating in the periodic inspection program. It is essential that support personnel and equipment are provided to accomplish maintenance activities.

Agencies solely responsible for regulating dams should ensure their engineering staff is trained in multiple disciplines and, if necessary, is qualified to conduct technical reviews of design plans. In addition, agencies must ensure inspection staff are trained and qualified to perform the inspections. Personnel must understand the design and operating parameters, be familiar with construction techniques, and be able to recognize conditions possibly detrimental to dam safety.

B. COMPETENCE

All positions should be staffed by competent engineers or specialists in the related disciplines. Job-related experience, professional aptitudes, and educational background should be major factors in evaluating the competence of individuals for the requirements of each responsible position concerned with the safe design, construction, operation of dams, and emergency action planning for dam incidents.

C. CONTINUITY

Staffing policies should recognize that the continuity of technical positions is essential to maintain consistently high standards of practice. This applies to all elements of project development, from design, operation, and incident response. This is especially critical in those positions with supervisory responsibility for dam safety.

D. PROFESSIONAL ADVANCEMENT

Agencies should maintain a program to advance technical personnel in recognition of acquired experience, training and education, and increased competence. It is essential that agencies maintain the technical and managerial expertise required for safe, effective dam design, construction, and operating programs. Organizational structure, position classification, and career incentives must recognize technical and managerial responsibility and compensate equitably.

3. Training

A. INTERNAL

To supplement technical staffing, agency management should provide internal personnel training. A rotational training program should be established to familiarize new personnel with all major aspects of the agency's functions. Provisions should be made for technical personnel to observe and participate in decision-making meetings and site visits. Staff members should be allowed to attend consultant meetings to gain experience.

A rotational training program that would place construction engineers in the design organization during design and design engineers in the field during construction on temporary assignments should be considered. Preconstruction training should be provided for inspection personnel, covering the design engineering considerations and the requirements and importance of thorough field inspection. The training should be given by embankment or structural engineers and geologists assigned from design or by the construction engineer who had received preconstruction orientation by the designers, geologists, and embankment and structural engineers (section III.A.3.a). This training should ensure that all inspectors know the expected requirements in detail. Onsite instruction sessions for inspection of new construction features should be developed and given by supervisors or lead inspectors before initiation of the work.

Operation and maintenance personnel should be trained by staff experienced in the operation of similar projects, covering all facilities operation and inspection features. Thorough training should be provided for the personnel who observe and monitor any installed dam instrumentation. The training should be conducted by the engineers responsible for analyzing the structural effects revealed by the instrumentation data.

Operating personnel should be trained in problem detection and evaluation and appropriate remedial (emergency and non-emergency) measures. These skills are essential at all levels of responsibility for proper evaluation of developing situations, which must be based, initially, on observations made by trained operating personnel at the project. The training should cover the problems that are most likely to occur with the type of dam and facilities and include the kinds of monitoring best suited to early detection of those problems. Such training will permit prompt action when time is a critical factor. Enough personnel should be trained to ensure adequate coverage of all tasks. If a dam is operated by remote control, training must include procedures for dispatching trained personnel to the site at any reported indication of distress.

Personnel involved in inspections should be trained in the requirements of these duties. The training should cover the types of information needed to prepare for the inspections, critical features that should be observed, inspection techniques, and preparation of inspection reports.

Regulatory agencies should ensure their engineering and inspection staff are properly trained and receive periodic training updates. Training should be commensurate with the agency's mission.

B. ACADEMIC

Agency management should establish and maintain a program for continuing formal education and training to increase and broaden the agency's base of professional expertise in areas related to the safe design and construction of dams and emergency response to dam incidents. Such training should be provided for part or full-time attendance at universities and at special courses prepared by technical and professional organizations. Programs should be designed to further the development or provide refresher training.

Supervisory construction, inspection, and operation and maintenance staff should learn the latest modern methods and techniques by attending technical courses. Agency emergency planners should also continue their education by attending discipline-related courses and dam seminars to learn best practices from others in the dam safety community. Pertinent courses are available from private sources and educational institutions. Also, agencies that develop internal educational programs should make them available to other agencies, permitting them to gain mutual benefit in exchanging information on new methods and practices.

C. PROFESSIONAL

Professional growth should be encouraged to ensure adequate training, support participation in technical and professional societies, and establish attractive career and promotional ladders for technical specialists. Professional registration and active membership in professional and technical organizations should be considered in assessing qualifications for higher technical positions.

D. NEW TECHNOLOGY

Provisions should be made to establish procedures to screen and disseminate information on technical advances relating to dam design, construction, operation, and emergency planning and response. Programs for continuing professional training should be oriented toward keeping the technical staff abreast of new or improved technology. Interagency coordination on training in new technology should be established in areas of mutual interest.

4. Communication

Agencies should maintain effective methods of communication that function properly at all times. Communication practices should be periodically reviewed and updated. Procedures for communications on safety-related matters among federal, tribal, state, territory, and local agencies and the public should be established. Specific areas of suggested communication are discussed below.

A. INTERDISCIPLINARY

Direct communication between personnel in planning, design, construction, operations, maintenance, and emergency planning and response should be established. Coordination is necessary for preparing the site investigation plan and for a common understanding of the information needed for design. Before site investigations, the design staff should arrange for meetings between geologists, geotechnical engineers, and designers to review known site conditions and project functional requirements and review preliminary design concepts. A site visit should be included in the review of existing information. Communication between the engineers and emergency managers is essential to maintaining up-to-date plans and procedures.

A document referred to by some agencies as “Design Considerations” should be prepared by the design staff to transmit site-specific design considerations to the construction staff. This document should cover, but not be limited to, hydrologic and hydraulic considerations, geologic and geotechnical data, foundation conditions, foundation treatment details, control of liquid-borne solids and industrial waste, and anticipated foundation problems. It should specify points at which inspection and approval are required by the design staff. Copies of the document should be furnished to those responsible for dam operation and inspection.

Additionally, the design staff should arrange a preconstruction orientation for the construction engineers, geologists, and embankment and structural engineers so that the construction engineer and their staff fully understand the design concepts and the significance of the results of the exploratory work. Before advertising the construction contract, the construction engineers need to provide the designers comments on the constructability and the ease of contract administration for the plans and specifications.

During construction, the engineers should be alert for conditions that need to be reported to the design engineers. Field personnel should notify design personnel of any critical construction sequence or of a suspected change in conditions that could affect the design of the structure. Design engineers with relevant expertise must be available to visit the construction site. Changes in construction or materials should be made only after plans for changes are approved by design personnel.

The design staff should furnish the operation staff and emergency planning staff documents with any manuals containing pertinent design and construction information on structures and equipment required for effective and safe operation of the dam. A conference of design, operating, and emergency planning and response personnel should be held to ensure the operators understand the operating and inspection procedures required for safe and reliable operation. The operators and the designers should have copies of equipment operating and testing manuals and procedures. The operators should notify the designers, emergency planners, and responders of any safety-related operating malfunctions and the actions taken to correct them. There should be continuing communication between operating, design staff, and emergency planning regarding plans and schedules for periodic safety inspections of the dam. Copies of operation and maintenance manuals should be furnished to the dam inspection staff.

The emergency planning and response staff should disseminate plans to operations and inspection staff to ensure proper information is reflected in the plans. Effective emergency and response plans need the subject matter expertise that these other divisions have. Additionally, the staff responsible for the operations and inspections should be aware of the emergency activities that will take place, to ensure the consistency of all planning and response actions.

B. INTERAGENCY

Interagency communications should be maintained on safety matters related to design, construction, and operation of dams, related research, and regulation. This should include the exchange of materials such as design standards, construction specifications, significant research reports, final design and construction reports on major structures, incidents, and failures. The agencies should establish communications to periodically review investigation methods, construction materials testing standards, analytical methods, design philosophies, and management procedures.

In 1996, the National Dam Safety Program Act P.L. 104-303 established the Interagency Committee on Dam Safety (ICODS) and the National Dam Safety Review Board (NDSRB) [5]. The ICODS and the NDSRB work to encourage communication among federal and non-federal agencies and groups interested in dam safety, including state agencies, tribes, territories, local governments, professional organizations, private industry, and the public. In addition, 33 U.S.C. § 467a requires federal agencies to cooperate with state dam safety officials [6].

C. PUBLIC

Agencies should communicate the importance of dam safety to the public. Agencies should proactively communicate with the public potentially impacted by a dam failure or actions that will modify the operation at the dam. Communication should consider the benefits of information sharing versus security concerns, keeping in mind that the public has a right to know the risks related to dam failure in the communities where they live.

The Federal Guidelines for Dam Safety Risk Management (2015) provides guidance for risk communication. According to these guidelines, “Risk communication and stakeholder participation should ensure that (1) responsible and affected stakeholders will be partners and be afforded the opportunity to participate in decisions that affect them and (2) communications regarding potential inundation hazard, consequences, and shared solutions will be open, transparent, and understandable [4]. There may be multiple levels of stakeholders that will be impacted by risks at a given dam or that could be impacted by the risk at another dam upstream or downstream of the given dam. Effective communication of dam risks with emergency management authorities responsible for responses and evacuation actions is essential. Effective risk communication should provide timely and best available information to facilitate the development of response plans and risk mitigation strategies.”

5. Documentation

Decisions should be documented throughout the project development lifecycle including planning, site investigation, design, construction, initial reservoir filling, operation and emergency preparedness and response, all data, computations, and engineering and management. Documentation should also cover investigation and design, construction plans and construction history, operation and maintenance instructions and history, damage, repairs and improvements, and periodic inspections during construction and operation. It should include, but not be limited to, memoranda, engineering reports, criteria, computations, drawings, emergency plans, incident response reports, and records of all major decisions pertaining to the safety of the dam.

Regulatory agencies should ensure entities under their jurisdiction establish and maintain practices similar to those expected of federal agencies.

A. DESIGN RECORD

Written documentation should be maintained in a standardized format on all design-related information for the project. Planning design documentation should cover the project objectives and the studies made to site size, classify as to potential hazard and select the type of dam and auxiliary facilities. Site investigation documentation should cover geologic mapping and studies made of the geologic and geotechnical explorations and conditions for the various other dam sites considered and the detailed investigations for the chosen site. Geological, seismological, and geotechnical features and considerations, whether specifically identified during the investigation, interpretations from the data and experience at other sites, or suspected by experienced personnel, should be fully documented. Design documentation should include all design criteria, data and qualitative information, assumptions, analyses and computations, studies on discarded alternatives, and derived judgments and decisions.

As-built drawings should be prepared as facilities are completed and should be made available to both operation and maintenance personnel and the dam inspection staff.

B. CONSTRUCTION RECORD

All phases of the construction should be documented, including reporting of routine and special activities. Changes in construction plans and departures from expected site conditions should be documented and include any design changes. The record should include information on materials and construction processes, field exploration and test results, geologic mapping of foundations and excavations, inspection records, as-built drawings, and decisions to adapt the design to actual field conditions.

A formal plan for a construction inspection system should be developed, including inspection procedures and types and forms of reports. The system should identify and record the status of inspection of approved and rejected materials. Survey notes, sketches, and records of all materials tests made for the control of construction quality should be maintained for the life of the project. A job diary should be maintained for each construction contract to provide a complete history of the work, listing in chronological order the events having a bearing on performance of the work, and analysis of cause and effects of special events. Photographic documentation of significant events, findings, and safety problems should be provided. The inspection program and record should give special attention to factors that may affect dam safety.

A special case is industrial waste and tailings dams, where construction is ongoing and typically continues over the life of the industrial or mining operation, which may be several decades. Because dam construction is often tied to waste production at the operation, changes to the design may occur frequently. There may be changes to the volumes of material produced or changes to the engineering properties of the materials. Careful record keeping is required to document design changes and when/where these changes were incorporated into the site.

Documentation must also be provided, as required, by applicable procurement, safety and health personnel, and financial regulations.

C. INITIAL RESERVOIR FILLING AND SURVEILLANCE RECORD

An initial reservoir filling and surveillance plan should be prepared by the design staff. Initial filling should be well documented, including a record of reservoir elevations and controlled water releases during the filling. The record should include complete written justification and design approval of any deviations from the plan. The surveillance record should include all information obtained from inspection of the dam, appurtenant structures, abutments, and reservoir rim during the initial filling.

D. OPERATION AND MAINTENANCE RECORD

Operation and maintenance should be fully documented, including the routine activities and systematic inspection processes, and complete information on project maintenance, rehabilitation, and improvements. In addition to records on the actual operations, the operating record should include data on reservoir levels, inflow and outflow, drainage system discharge, and structural behavior.

If there are maintenance problems that require remedial work, a thorough record should be maintained, and a final report made after complete remedy of the problem.

E. EMERGENCY PREPAREDNESS AND RESPONSE RECORDS

All emergency preparedness and response activities should be fully documented, including the outreach to all stakeholders, their contributions to the planning efforts, situation/incident reports, after-action reports, improvement plans, etc.

F. PERMANENT FILES

One copy of all project-related documents should be assembled in a single project file. The file should be kept up to date and maintained as a permanent archival reference. A second file of the materials should always be easily accessible to responsible personnel for reference in future reviews and inspections, and in dealing with problems, repairs, etc. Both files should be continuously updated with records on problems, repairs, operation, instrumentation, inspection, safety/emergency plans, and response efforts for the life of the project. Information such as foundation reports, as-built drawings, and maps should be permanently retained at the project and at the agency's engineering design office.

6. Reviews

A. EXTENT

All factors affecting the safety of a dam during planning, design, construction, operation, maintenance, modification, rehabilitation, and emergency preparedness and response efforts should be reviewed on a systematic basis at the appropriate authority level. Reviews include those internal to the agency, and those external to the agency, by individuals or boards (consultants) with recognized expertise in dam planning, design, and construction. Agencies should consider risk when prioritizing and determining the level of detail for reviews.

B. INTERNAL

Provisions should be made for an internal review of all decisions, methods, and procedures related to dam safety. Uniformity of criteria and design technique related to the internal review process should be maintained and include information that ensures that specific experience is exchanged and used to advance the agency's ability to design, construct, operate safe dams, emergency plan and respond.

Management technical personnel should review the construction periodically. Reviewing personnel should include geologists, geotechnical engineers, and embankment and/or structural engineers who have had experience in responsible positions relating to similar structures. When appropriate, the reviewers should include mechanical and/or electrical equipment engineers. A preconstruction inspection should be made after geologic mapping is completed but before ground surface disturbance. On large projects, construction reviews would normally be at critical construction periods such as the start and completion of foundation preparation and grouting, dam construction at several stages, and completion of the dam. On large projects regular visits by appropriate personnel are recommended at a minimum of every six months and must accompany the consultants during scheduled reviews. The final construction inspection must cover inspection of completed structures and equipment, the adjacent valley floor and abutments, and the reservoir rim. On smaller projects, the frequency of the construction review and the disciplines represented in the review would vary with the size and complexity of the project. However, management should make certain that the construction reviews are sufficient to meet requirements for dam safety.

Reviews should be made of the agency's procedures for post-construction operation and periodic inspections. These would include the responsibilities for collection and evaluation of data from any dam instrumentation. Reviews should be made to ensure that the project emergency action plan is periodically updated. Formal documentation should be made of all significant findings from reviews and inspections.

C. EXTERNAL

Agencies should perform an independent review of dam safety programs consistent with these guidelines. These reviews should occur on a minimum 10-year frequency.

The need to review a dam safety program by independent experts (consultant board or firm) from outside the agency should be determined on a case-by-case basis, depending on the degree of hazard, size of the dam, complexity of the site geology and geo-technology, complexity of the design, or a specific need perceived by the public. Consultant reviews should provide appropriate overview evaluations of site investigation, design, construction, emergency planning, and response efforts.

Consultant reviews of operation and maintenance practices, and of alterations and improvements, should be conducted when the agency considers such reviews advisable.

The following text deals first with design and construction reviews. Applicable portions apply also to post-construction reviews; specifics for post-construction reviews are in the last paragraph of the section.

The agency should be represented at each consultant meeting by appropriate design and construction staff. Meetings should include a site visit, when appropriate. At each meeting, the agency should document all aspects of the continued development of the project for presentation in a meeting-opening briefing to the consultants. The consultants should document findings and recommendations and present them to agency staff at a closing conference.

The consultant board members should be chosen to assure coverage of all areas of expertise needed to assess the dam design, construction, and safety. The board should contain at least three, but no more than five, permanent members. For conventional water storage dams, the board should contain a general civil engineer, a geologist and/or geotechnical engineer, as appropriate, a concrete and/or embankment dam engineer, and usually a member for the electrical and mechanical features, especially if a power plant is part of the project. For industrial waste and tailings dams, the board should include specialists on the materials being used, environmental specialists, and water balance specialists. Additional specialists covering specific aspects such as structural integrity, earthquake response, or three-dimensional analysis should be assigned for short intervals as recommended by the board. The board should be formed during the design stage and consulted (if possible) on site selection, on type of structure, and for input to the feasibility study. The board should be kept active throughout design and construction, to keep the board completely familiar with all aspects of the project so they are able to respond rapidly if problems arise.

During design and construction of large projects, the board should meet every 6 to 12 months, depending upon activities and duration of the work. Meetings should be scheduled to review specific phases of construction. These phases might include, but are not limited to, review during the early stages of foundation cleanup and treatment, on completion of foundation cleanup, and during the early stages of embankment and/or concrete placement. For industrial waste and tailings dams, the board should review construction and operation reports generated since the last review and assess the performance of the dam. All board members should plan to attend every meeting. This ensures that the entire board is fully aware of the completed work status before being asked for their input on specific points.

The briefing to the board by agency personnel at the start of the meeting should include exploration data, structural adequacy and seepage characteristics of the foundation, proposed foundation treatment, grouting programs, quarry test data, test fill data, embankment requirements for zones and material for those zones, sources of materials, compaction requirements, inspection requirements, instrumentation program, type of spillway (gated or ungated), proposed water release control systems, diversion requirements and care and diversion of water, power generation anticipated, and surge tank design. For concrete dams, the review would include concrete design and placement requirements in lieu of the embankment information.

On a smaller project, the use of consultants should be commensurate with the dam size and complexity and with the degree of associated hazard potential. For smaller projects with high or significant hazard potential, the agency should obtain consultant reviews adequate to assure an independent assessment of the dam's safety.

Consultants should be engaged during agency evaluations of existing dams if considered necessary to provide independent support for agency assessment of dam safety. This may be in connection with studies for alterations or improvements for potential criticality of dam stability resulting from structure deterioration, or from increased reservoir levels due to possible flood inflows larger than design floods and consequent inadequate spillway capacity. It might involve consultation on seismic design; and in the case of old dams, especially embankment dams with inadequate records of materials properties, it might include consultation on the advisability and procedures for new materials investigations. Consultants on features of existing dams may be individuals rather than formal boards.

7. Research and Development

Research and development efforts are necessary to reduce the uncertainties still present in dam design, hydrology and hydraulics, materials behavior, construction, and emergency preparedness and response techniques, equipment, and practices. As part of their dam safety programs, agency management should identify opportunities and needs for research and programs both internally and through other Agencies, including the National Science Foundation and the U.S. Geological Survey. This would include staying current on emergency management principles and innovations, including research and development and best practices in the dam sector.

A. METHODS AND MATERIALS

Management should ensure that a continuing review is made of state-of-the-art methods, experience, research, etc., and that improvements are incorporated into agency criteria and methods of analysis, exploration, construction, testing, and instrumentation. The process should build on experience from past projects relating to constructability, observed behavior, problems encountered, and problem solutions tried and their results, as well as lessons learned/best practices from past projects' emergency preparedness and response efforts. Experience histories should be reviewed, summarized, and disseminated to evaluate current practice to advance agency practices. Research and development needed on materials and their use as revealed by dam observation and monitoring and new developments and best practices should be conducted on a continuing basis. Establishing a schedule of research priorities is necessary for defining overall research and development goals and for achieving outcomes that support the orderly and consistent progress in advancing dam technology and safety of critical infrastructure and the public near dams.

B. RISK ANALYSIS

The agencies should individually and cooperatively support research and development of risk analysis and methodologies related to the safety of dams. This research should be directed towards hydrologic, static, and seismic loading, consequence estimation, flow modeling (tailings), and potential for dam failure and linked capabilities, including the cascading effects and lifelines. The research should also study past dam incidents and learn from the planning efforts and responses to implement the best practices into their own policies and procedures. Existing agencies work in these fields should be continued and expanded into developing risk concepts useful in evaluating safety issues. The Dams Sector-Specific Plan is a great resource for understanding more about risk management and national preparedness. All these analyses should be shared with the local public safety agencies, as they could meaningfully impact those local planning and preparedness efforts.

C. INTERAGENCY COORDINATION

Existing Interagency research coordination activities should be continued, with attention to minimizing unnecessary duplication. It is imperative to engage all disciplines/dam stakeholders in the coordination of dam safety, including dam safety officials, engineers, emergency managers, floodplain managers, etc. Dam safety cannot be effective in a silo/vacuum – it takes a Whole Community approach to both planning and preparedness and response activities. Coordinated efforts amongst all affected parties are essential to keeping the dam, people, and the environment as protected as possible.

A key partner must be the local public safety agencies. All emergencies, even those concerning federal dams, will be responded to and recovered from by local personnel. Local governments are the first line of defense against emergencies and disasters and are primarily responsible for managing the response to and recovery from those events. It is only once local resources are exhausted that regional, state, and national partners are asked for assistance. These local agencies are critical to dam safety and need to be a part of the program from the beginning and then throughout the life cycle of a dam and all associated activities therein.

8. Contracts

A. DOCUMENTS

Agency procedures should ensure that all contracts for dam design, construction, operation and emergency preparedness and response plans are written to accomplish the design intent and to require that contractors provide complete documentation of their work.

B. MODIFICATIONS

During the construction period, any modifications in the design or construction which result from significant departures from expected field conditions, design reviews, or other studies should be promptly included in revisions to appropriate contracts. Such modifications, and any discovered later, that affect operation should be included in operation contracts (and in agency operation, monitoring, and maintenance policy). The basis and justification for any change should be documented.

9. Constraints

Many constraints, which are outside agency authority, can directly or indirectly affect dam safety. Managers at all levels must maintain awareness of their fundamental responsibilities for dam safety and exercise vigilance in identifying constraints on fulfilling those responsibilities. Every manager has a duty to seek resolution or mitigation of such constraints through their own agency channels, through the Interagency, or other intergovernmental channels as appropriate.

A. FUNDING FOR ORGANIZATIONAL MANAGEMENT

Continuity of operations and adequate funding are essential to ensure safe dams and the safety of the downstream communities: people, environment, property, etc. Agencies should cooperatively develop common budgetary terms and consistent processes to provide the necessary visibility of dam safety funding essentials at all levels and within all branches of the government. Long-term programming objectives should be established and followed, to meet the requirements of organization management, personnel staffing and training, research and development, quality construction and operation, a complete program of inspection and evaluation of the safety of existing dams, and a planned program for the rehabilitation and/or improvement of existing dams.

B. PUBLIC CONCERNS

The public should have the opportunity to voice their concerns in the development of public works projects, during construction, operation, and decommissioning removal. These concerns often represent constraints in the form of local or regional political interests, legislation, perceptions of risk and hazard, environmental factors, social conflicts, etc., which can influence technical decisions and operational procedures. Agencies should develop and organize their procedures for early assimilation of those public views, which affect possible design, construction, or operating parameters, emergency preparedness and response efforts, and, in turn, influence dam safety.

Resolution of public issue, conflicts, and problems, including use of executive and legislative government decisions, should be made prior to the start of construction. This ensures that dam safety is not compromised.

B. Management of Technical Activities – Site Investigation and Design

This section of these guidelines outlines the site investigation and design technical activities that agency management should ensure are undertaken to obtain safe design of dams. It is recognized that the extent of application of these guidelines will vary depending on the size and function of the dam.

1. Hydrology

A. HAZARD EVALUATION

Areas impacted by dam construction and existing dams should be examined for potential hazards to present and future developments in the event of major flooding by controlled flood discharges or flooding induced by dam failure, operation, or the accidental release of liquid-borne solids or industrial waste. This hazard evaluation is the basis for selection of the performance standards to be used in dam design or in evaluation of existing dams.

B. FLOOD DEVELOPMENT

Hypothetical floods, generally of severe magnitude, should be used in the design or evaluation of major dam and reservoir features, including the development of appropriate floods for the construction period.

C. FLOOD SELECTION FOR DESIGN (OR EVALUATION)

Select design floods based on an evaluation of the relative risks and consequences of flooding under both present and future conditions. Some existing structures may have to accept higher risks because of irreconcilable conditions. The *Federal Guidelines for Dam Safety – Selecting and Accommodating Inflow Design Floods for Dams* (2013) provides guidance on selecting appropriate design floods [7].

When flooding could cause loss of life or major property damage, the floods selected for design should have low exceedance probabilities. If lesser hazards are involved, smaller floods may be selected for design. However, all dams should be designed to withstand relatively large floods without failure, even when there is no downstream hazard involved under present development conditions.

D. HYDROLOGIC DESIGN OF RESERVOIR

In addition to the selection of a design flood, the hydrologic design of a new reservoir or the evaluation of an existing project involves consideration of discharge and storage capacities, reservoir regulation plans including constraints, land requirements, and wind/wave effects. Evaluating existing projects should also include observed performance capabilities and whether improvements are necessary to ensure safety.

Reservoir regulation plans should be developed in the planning of projects so that realistic release rates are used in routing the design flood. Regulation plans should include the construction period. When gate operations are involved, a water control management plan should be established to direct reservoir regulation effectively and efficiently. An emergency regulation plan is also required for use by the dam tender in the event of loss of communication with the water control management staff. A data information system should be designed to collect and process pertinent hydrometeorological data in a timely and reliable manner.

The reservoir regulation plans, water control management plan, and data information systems should be periodically reviewed for safety deficiencies and potential for misoperation during severe flood events and normal conditions. Necessary corrections should be made as soon as practicable.

Storm discharges may not be allowed or advisable in industrial waste and tailings dams. The impoundment should be designed to store the appropriate design flood with freeboard until it can be decanted safely.

E. DOWNSTREAM EFFECTS

Safety design should include studies of areas that would be flooded during the occurrence of the design flood, operational releases, and in the event of dam failure. The areas downstream from the project should be evaluated to determine the need for land acquisition, floodplain management, or other methods to prevent major damage. Suitable information should be developed and documented to release downstream interests regarding the remaining flood risk.

F. WARNING SYSTEMS

Safety design should include an emergency flood or environmental monitoring/warning system, backup systems, and an action plan that would notify all concerned in ample time for appropriate action. This should be coordinated with the local public safety agencies to ensure all the relevant parties are notified.

2. Earthquake Investigation and Design

The Federal Guidelines for Dam Safety: Earthquake Analysis and Design of Dams (2005) provides a “basic framework for the earthquake design and evaluation of dams” (p. 1) [8]. The following provides general guidance for earthquake investigation and design.

A. INVESTIGATION FACTORS

The following factors should be considered in the selection of design earthquakes.

(1) Geologic and tectonic setting of the site area by analysis of the lithology, stratigraphy, structural geology, and tectonic history.

(2) Historical earthquake records to include the size, location, and other seismological characteristics as available and the relationship, if possible, with the tectonic siting of the area in which the earthquakes have occurred.

(3) Influence of the properties of the surficial materials on the determination of the size of historical earthquakes.

(4) Influence of faulting or other tectonic features on the estimate of the occurrence, size, and location of possible future earthquakes.

B. SELECTION OF DESIGN EARTHQUAKES

From the above factors, select earthquakes should have sufficient potential of occurring to require consideration in the dam design. Earthquake description should include estimates of the size, location, depth, focal mechanism, and frequency of occurrence.

C. ENGINEERING SEISMOLOGY

Determination should be made of the characteristics of ground motion that would be expected from the design earthquakes to the extent possible, including amplitude (displacement, velocity, and acceleration), frequency content, and duration.

D. NEED FOR EARTHQUAKE ANALYSIS

The effects of earthquakes on the dam and its appurtenant structures should be evaluated to determine the need to include earthquake forces in the structures analyses. Evaluation includes consideration of factors such as the project stage, hazard and risk factors, the size of the dam and reservoir, the potential ground motion at the site, site geology, and type of structure. Where a determination is made that no earthquake forces are required in analysis, the document is the basis of that decision.

E. SEISMIC AND GEOLOGIC STUDIES

(1) Earthquake Sources. The essential first step is determining the design of seismic events (usually the maximum credible earthquakes) and estimating the ground motion at the site due to these events. From a study of the regional tectonics and seismicity, and both regional and local geology, potential sources for seismic events should be identified, and the maximum credible earthquake magnitudes should be postulated.

(2) Design Events. A maximum credible earthquake (MCE) is the hypothetical earthquake from a given source that could produce the severest vibratory ground motion at the dam. Time histories of the estimated rock motion (accelerograms) at the dam for the various seismic events are selected to characterize the severity of the strong motions by their peak accelerations, frequency content, and duration.

F. DESIGN FOR EARTHQUAKE FORCES

(1) Safety Concerns. All earthquake-related safety concerns should be identified. Potential safety concerns include, but should not be limited to, dam foundation integrity, stability, unacceptable stress levels, fault displacements, abutments stability, effects of dam overtopping, dam stability, susceptibility of embankment dams to embankment or foundation liquefaction, cracking, or excessive deformation.

A survey of component and accessory structures and equipment should be made to identify those that have functions essential for earthquake-related safety.

(2) Analysis Method. Determination of appropriate earthquake analysis methods for evaluating safety concerns may be as appropriate, qualitative evaluations, pseudo-static analysis, and dynamic analysis. The methods selected should be appropriate to the identified safety concerns, in accordance with good engineering practice and currently available technology.

(3) Structural Adequacy. Structural adequacy assessments should be made of all safety-related components and concerns identified. These assessments should incorporate all applicable data and analysis.

3. Geotechnics

A. GENERAL

(1) Site Specifics: After a site is selected, a program for the geotechnical exploration, design, and analysis of that specific site is required. No checklist can be made that would cover all eventualities at all sites or at any one site and attempts to formulate such a list would be counterproductive to the intent to ensure dam safety. The best insurance for adequate geotechnical work is a well-trained and experienced staff actively involved in field inspections throughout all phases of site development.

(2) Documentation: Many evaluations are possible for a given set of geotechnical conditions. It is important that full documentation of the reasoning process involved in geotechnical decisions be made. General guidelines for documentation are given in section III.A.5.

(3) Management of Diverse Technical Expertise: Geotechnical work encompasses the expertise of geologists, geophysicists, and engineers—all with diverse experience, training, interests, and technical terminology. The administrative and technical supervision of these experts should be structured to optimize coordination and cooperation. Management should encourage intellectual curiosity and an inquisitive approach to all geotechnical work. Since the field of geo-techniques is

rapidly expanding, management should ensure that those associated with site exploration and development maintain currency with the state of the art.

B. EXPLORATION AND IDENTIFICATION OF GEOTECHNICAL PROBLEMS

The exploration program needs to be site-specific, flexible, and executed to obtain the maximum data from each part of the program. Agency management should ensure sufficient funding for the orderly development of the exploration program. This will reduce uncertainties and make adequate provisions for corrective measures.

Prior to the initial onsite exploration, a review of all available information pertinent to the development of the site (literature, maps, photographs, well and spring information, seismic data, area construction records, etc.) should occur. This includes preparing a detailed geological map of the site using all available data. Geotechnical explorations generally proceed from wide-spaced borings and geophysical surveys to determine the general geological conditions. They may include additional explorations assigned in an ongoing sequence to develop the geologic correlations and to determine the type of dams suitable for the site. The extent, depth, and type of exploration depend on the complexity of the geology and the size and type of dam.

Generally, explorations are not complete at the end of the planning phase but continue during the preparation of plans and specifications and into the construction phase. Conditions encountered during construction often require additional explorations to evaluate the need for design changes.

All potential geological problems, inferred from onsite data and experience at similar sites, should be explored and described. This information should cover the adverse features and geologic processes associated with a geological environment similar to the site. It should also cover the expected short- and long-term behavior of the foundation and reservoir rim materials at the site when subjected to the changed geological environment associated with the construction and operation of the dam and to geologic processes operating during the life of the project.

During the design and continued exploration of the project, all potential problems should be investigated and corrected with appropriate treatment, or where uncertainty remains, design defenses should be provided to control or monitor the problems. Types of problems that might require consideration include reservoir-induced seismicity, solubility, internal erosion, liquefaction potential of materials, foundation heave or deterioration during excavation, reservoir rim leakage and stability, past and future mining, and differential consolidation associated with petroleum or water extraction.

C. GEOTECHNICAL DESIGN

Geotechnical design considerations for the dam foundation and reservoir area are essentially defined after the geologic conditions of the site, the type of dam, and the magnitude of the stresses imposed on the foundation by the dam and reservoir have been determined.

Foundation design typically consists of four distinct elements. These are (1) the definition of the geometry of the foundations and areas of potential instability in the foundations, abutments, and slopes; (2) determination of the properties of foundation materials using judgment, past experience, laboratory testing, and in situ testing; (3) an analytical procedure that predicts the behavior of the foundation in terms of stability, permeability, and deformation; and (4) a reevaluation of parts (1) through (3) as construction progresses so that a comparison can be made of preconstruction assumptions and conditions with the actual conditions revealed by the foundation excavation and treatment. Additional exploratory work may be required.

D. FOUNDATION TREATMENT

(1) General: The preparation of the foundation, including the abutments, is an important construction phase. The primary purposes of foundation treatment are to provide stability, obtain positive control of seepage, and minimum adverse deformation. The geology, foundation conditions, foundation treatment, and proposed structure should be considered together.

(2) Stability: Surfaces should be prepared to provide a satisfactory contact between the foundation and the overlying structure by removal of unsuitable materials. Deficiencies in the foundation that are not removed should either be treated by modification of the structure or by appropriate foundation treatment tailored to handle the conditions encountered.

(3) Positive Control of Seepage: Highly permeable foundations should be treated by cutting off the pervious material, grouting, increasing the seepage path by upstream blankets, or controlling the seepage with drainage systems. Where appropriate, surficial cavities should be traced, cleaned out, and backfilled with material satisfying the design requirements. When cavities exist at depth, measures should be taken to ensure against the migration of cavity filling material.

In industrial waste and tailings dams, where constituents that cause adverse reactions in the environment, such as acid rock drainage/metal leaching contamination, may be impounded, additional measures to control seepage, such as containment systems consisting of liners and collection systems or other special considerations such as permanent water covers, may be necessary unless the impoundment is closing, or has closed, pursuant to the requirements of applicable state and federal regulations.

(4) Control of Piping: Silts and fine sands in the foundation, which are susceptible to piping, should be removed if practical, cut off near the downstream limits of the dam, covered with impervious material, or provided with filtered drainage systems. If pipeable material is used in the dam, the foundation surface treatment should prevent the migration of dam material into the foundation.

(5) Deformation: Foundations subject to differential settlement or foundations having highly compressible anomalies can cause stress concentrations or cracking in dams. The foundation excavation should be shaped to remove abrupt changes in elevation to preclude excessive differential settlement or stress concentrations. Low shear strength material in a foundation can

cause shear failure. Excavation and replacement of low-strength material is a positive method for treating a foundation with one or both unfavorable conditions.

E. INSTRUMENTATION

A well-conceived foundation instrumentation program serves to monitor the foundation and indicates distress, but it cannot of itself certify the foundation's safety. The expertise of the engineer/geologist to analyze, design, and prepare a foundation that will safely carry the loads and water pressure imposed by the dam and the reservoir is fundamental to the design adequacy of the foundation. The purposes of foundation instrumentation include (1) providing data to validate design assumptions, (2) providing information on the continuing behavior of the foundation, (3) observing the performance of critical known features, and (4) advancing the state of the art of foundation engineering.

The general requirements for foundation instrumentation should be determined early in the project's design, and the instrumentation's rationale should be thoroughly documented. Factors that influence the need for and the type of instrumentation include the geology of the foundation, the size and type of the dam and reservoir, and the location of the project. The program must provide flexibility to allow for changes from anticipated foundation conditions encountered during construction or operations.

Intrinsic to an instrumentation program is the schedule for reading the instruments before and during construction, during initial reservoir filling, and through the service life of the project. No less important is the need for clear instructions for the prompt evaluation of data and prompt notification to responsible personnel when observations are atypical or diverge markedly from the design assumptions.

F. INSPECTION AND CONTINUING EVALUATION DURING CONSTRUCTION

Those responsible for the investigation and design of the foundation should make onsite evaluations to confirm that actual conditions conform to those assumed in the design and to review documentation of site conditions.

A qualified project geologist should examine and map the geologic details of the foundation as it is being exposed during construction. Investigation and testing at this point provide details useful in controlling grouting and other improvements and in confirming the competency of the foundation. Even though extensive exploration and testing may have been conducted prior to construction, most foundations can be expected to reveal unanticipated conditions that may require redesign or changes in the type or extent of foundation treatment.

Approval should be obtained from the geotechnical and design staff before the placement of dam materials on the foundation. This approval should be documented and indicate that all unanticipated conditions encountered were addressed and that the foundation and its treatment meet the design requirements.

G. REEVALUATION AT EXISTING STRUCTURES

Older dams may not have been designed to current design standards. Also, a substantial portion of safety-related dam incidents are associated with foundation problems, which develop in a time-dependent fashion after construction. For these reasons, a systematic reevaluation of existing dams should be made.

Reevaluations should go beyond the analysis of problems that are observed visually or from instrumentation data. A review should be made of all existing exploratory information, design information, construction records, and operation records, to determine the adequacy of the foundation with respect to the present site of the dam. Where available information is insufficient or where deficiencies are found or suspected, modern criteria for analysis, instrumentation, exploration, and testing should be used to gather the necessary data to show that no problem exists or to furnish information to modify the structure or foundation.

4. Hydraulic Appurtenances

A. GENERAL

(1) Protective Measures. All hydraulic appurtenances used for releasing water should be designed to preclude jeopardy to the damming provisions.

(2) Blockage. Allowances for or preclusion of blockage of hydraulic facilities should be incorporated in the design.

(3) Reliability. When operational failure of a gated passage would jeopardize the damming provisions, alternate capacity should be provided. When the operation of a gated passage is essential to safety, reliable staffing, communications, and accessibility should be assured.

(4) Hydraulics and Hydrology. Hydraulic and hydrologic design considerations should be correlated with section III.B.1.

B. DESIGN FLOOD RELEASES

(1) Spillway and Outlets. Gated spillways are the usual hydraulic appurtenances for control of all or the major portion of the design flood and major emergency releases at conventional water storage dams. Outlets (sluiceways, conduits, and tunnels) may be used alone or in conjunction with spillways to control flood discharges. Industrial waste and tailings dams may have no outlet or may only have a decant system to control the normal pool elevation.

(a) Selection of type. Spillways and outlets should be selected to meet the site-specific purposes of the project. For a drainage area with short concentration time combined with reservoir storage capacity that is small relative to the flood volume, especially for embankment dams, (1) the spillway should usually be uncontrolled, and (2) outlets should not normally be used for sole or part control of the design flood except in special cases where the outlets can be uncontrolled.

(b) Capacity. Spillway and outlet capacity should be sufficient to satisfy the discharge requirements of the reservoir regulation plan and other design considerations.

(2) Power Facilities. A portion of installed turbine flow capacity may be considered to assist in the control of the design flood if it is demonstrated that possible power load interruptions during the design flood would not preclude the operation of the power facilities.

C. OTHER WATER RELEASES

Other water release hydraulic appurtenances such as navigation facilities, locks, fish facilities, ice sluices, trash sluices, and water quality facilities should conform to the requirements of section 4. a.

D. RESERVOIR EVACUATION

Wherever practicable, reservoir release facilities should be provided to lower the pool to a safe level adequate to correct conditions that might threaten the integrity of the dam.

E. CONTROL OF FLOWS DURING CONSTRUCTION

The provisions of section 4a also apply generally to the design of hydraulic appurtenances used during construction. The capacity of these appurtenances should be sufficient to satisfy the discharge requirements of the regulation plan for the control of water during construction.

F. DESIGN CRITERIA AND GUIDANCE

(1) General. Their sufficiency should be documented if existing design criteria and guidance from past projects and experience are used to design the hydraulic appurtenances.

(2) Hydraulic Model Tests. When sufficient criteria and guidance are unavailable for the analytical design of the hydraulic appurtenances, physical hydraulic model studies should be performed.

(3) Prototype Testing. Features of safety-related hydraulic appurtenances that are beyond state of the art or for which model-to-prototype relationships have not been verified should be tested in the prototype.

G. REANALYSIS BECAUSE OF CHANGES

Changes in project purpose, new purposes, operational requirements, limitations of environmental factors, construction material, other constraints, design criteria, legal requirements, etc., may require a reanalysis of the hydraulic appurtenances.

H. HYDRAULIC DESIGN INVOLVEMENT DURING LIFE OF STRUCTURE

Hydraulic design engineers should participate in the project's periodic inspection program to evaluate the operational adequacy of all hydraulic appurtenances essential to dam safety throughout the life of the structure, including final disposition.

5. Concrete Dams and Concrete Elements of Embankment Dams

A. SITE SPECIFIC DESIGN

Because all dam sites are unique, the type of dam and its appurtenances should be matched explicitly to site conditions and project requirements. When reviewing the safety of existing dams, it is essential to consider conditions that may have changed physically and new concepts resulting from new technology or because of additional project information since construction, such as foundation deterioration, increased flood hydrographs, environmental hazards, larger design earthquakes.

B. MATERIALS

Concrete for the structures requires competent investigation of materials sources, adequacy of supply testing of materials' properties in accordance with accepted standards, and proper proportioning of concrete mixes (including additives) for strength, durability, control of thermal properties, and economy.

C. DESIGN OF STRUCTURES

There are three components of a dam that must be considered for safety: the foundation, the dam, and its appurtenant structures.

(1) Foundation. The proper design of a concrete dam requires information on the foundation's geological conditions and material properties to ensure its capability to support the loads of the dam and reservoir in its natural state or as improved by foundation treatment.

(2) Dam. Concrete dams should be designed to be safe against overturning and sliding without exceeding the allowable stresses of the foundation and the concrete for all loading conditions imposed on the dam. The shape or curvature of a dam and its contact with the foundation is extremely important in providing stability and favorable stress conditions. Proper consideration should be given to ensure the dam’s safety in the event of overtopping.

Joints in the dam should be properly designed to control cracking due to thermal, shrinkage, and structural effects. Temperature control measures such as proper concrete mix design, pre-cooling of the concrete mix, and post-cooling of the concrete blocks can also be used to control cracking. Openings in the dam, such as waterways, galleries, chambers, and shafts, should be designed with consideration for their effects on the behavior of the structure.

(3) Appurtenances. Safety-related appurtenances, such as outlet works structures, spillways, and navigation locks, should be designed with the same degree of safety as the main dam. If the project has a powerhouse as an integral part of the dam, it should be designed with the same safety requirements as the dam.

D. DEFINITION OF LOADS

The dam and appurtenances should be designed for all static and dynamic loads to which they will be subjected. Dynamic loadings should include inertial, hydrodynamic, and earth pressures from earthquake ground motions and structural response and dynamic loads resulting from flowing water.

E. DESIGN METHODS

The methods required to design the several types of concrete dams and their appurtenances vary from simple to complex, depending on the type and size of the structure, the hazard potential of the site, the kinds of loading, and foundation conditions. The design process involves judgment and analytical expertise to select appropriate methods to analyze a structure, whether it requires a simple or complex analysis, and to determine design input data that is representative of the range and variation of foundation and structural material properties. The selection of input parameters is just as important as the mechanics of the analysis used.

F. DESIGN EVALUATION

Technically qualified supervisory personnel should ensure that structures are designed to meet safety requirements. This includes confirmation of design input parameters, design methods, and utilization of allowable safety factors against overturning, sliding, and stressing appropriate to the probability of the loading conditions.

G. INSTRUMENTATION

Knowledge of the behavior of structures and their foundations may be gained by studying the service action of the structures using observations on embedded instruments, other internal instrumentation, and external measurements. Information from which a continuing assurance of the structural safety of the dam can be assessed is of primary importance. Still, information on structure behavior and the properties of the dam and foundation materials serve to verify the design and provide information for the improvement of the design. Observations may be made in the dam and foundation in terms of strain, deflection, pressure, temperature, stress, deformation, and drainage flows. External measurements for deflection and settlements may be made by precise surveys on targets set on the dam, in galleries, in vertical wells in the dam, in tunnels, and on the foundation. Status reports on the condition of structures should be issued regularly. Examinations of existing structures should include assessments of whether additional instrumentation is required.

H. CONSTRUCTION AND OPERATIONAL FOLLOW-UP

Designers should be involved in the construction and operation processes to confirm that the design intent is carried out and to allow changes and modifications resulting from redesign necessitated by differences between design assumptions and actual field or operating conditions.

6. Embankment Dams

Section 5 contains general dam considerations; the following additional considerations are applicable to embankment dams.

A. SITE SPECIFIC DESIGN

Embankment design should be developed for specific site conditions and based on adequate exploration and testing to determine all pertinent geologic and material factors with emphasis on shear strength and stability, permeability and control of seepage, and consolidation and settlement.

Embankment dams are particularly vulnerable to damage and possible failure from internal erosion when founded on rock having large cavities, open joints, discontinuities, or other geologic defects. The sites should be carefully explored, with special attention given to the design of cutoffs, foundation treatment, and other defensive measures. Special problems related to embankment integrity may include soft rock such as clay shales, areal subsidence, old mining activity, solution-susceptible rock, and collapsing soils.

B. MATERIALS

Embankments can generally be designed to utilize locally available construction material; investigation of material characteristics is required, and problem materials should be discarded or protected by defensive design. Industrial waste and tailings dams are typically constructed of the waste material produced by industry or mines. There is often a need for importing special materials for slope protection, filters, and drainage systems. Any embankment zoning should consider the properties and quantities of available materials and the effect of their characteristics on the construction process.

C. DESIGN CONSTRUCTABILITY

Embankment designs should be constructible regarding the location of borrow areas with respect to flooding, in-situ moisture conditions, climatic effects on construction schedules, width of zoning, and needs for special material processing. Design should include protection of critical features from overtopping by floods during construction.

D. EMBANKMENT DESIGN

The safety of an embankment is dependent on its continued stability without excessive deformation under all conditions of environment and operation and on control of seepage to preclude adverse effects on stability and prevent migration of soil materials. Design considerations given below are specific to embankment dams.

(1) Seismic. Where earthquake design is necessary, consideration should be given to earthquake-related concerns of soil liquefaction and cracking potential, stability and excessive deformation, abutment stability, overtopping effects, and required defensive measures.

(2) Stability. Embankment stability should be analyzed for all pertinent static and dynamic loading conditions without exceeding allowable shearing stresses in the embankment or foundation. Factors of safety should be appropriate to the probability of the loading conditions. They should consider the effects of loading and time on shear strength, particularly if limited placement volume can result in rapid construction. In most cases, embankments should be designed for unrestricted rates of reservoir filling and drawdown.

(3) Settlement and cracking. The potential for transverse cracking of the embankment caused by differential settlement, tension zones, and possible hydraulic fracturing should be minimized by careful consideration of abutments, foundation and cutoff trenches, and their geometry and treatment. Filter zones of adequate size should be positioned upstream and downstream of the impervious zone at all locations where there is a possibility of transverse cracking, regardless of cause. Potential problems of differential settlement should be considered in establishing the construction sequence.

(4) Seepage. The design should attempt to prevent or minimize seepage through the embankment and its foundation and abutments; however, the designer should recognize that seepage usually occurs and that protective control measures must be provided. Filtering transition zones and foundation and abutment treatment to seal openings should be provided wherever necessary to preclude the migration of soil materials into or out of all embankment element contacts upstream and downstream. Filters, drainage blankets, and transitions should be of a quality and size to conservatively control and safely discharge seepage for all conditions for the life of the project. Attention should be given to contacts with the foundation, abutments, embedded structures, and the end slope of closure sections to ensure adequate compaction and bonding to control seepage.

(5) Zoning. When used, Embankment zoning should ensure adequate stability for all pertinent conditions, control seepage through the embankment, and provide filter action to prevent material migration.

(6) Erosion. Upstream and downstream slopes and foundation and abutment contacts should be protected against erosion from surface runoff, wave action, and impinging currents. Spillways and outlet work should be located and designed so discharges do not erode the embankment or its foundation.

E. INSTRUMENTATION

Due to the myriad variables associated with embankment design and performance during construction and operation, the site should be monitored by a designed system of external measurements or installed instrumentation.

When appropriate, a well-planned system of instruments should be installed to provide data on internal and external movements and water pressures at critical locations in the embankment and foundation during construction and operation. In the case of industrial waste and tailings dams, an instrumentation system should be designed and implemented to monitor for materials that may seep through the embankment or foundation, pursuant to the requirements of applicable state and federal regulations.

F. CONSTRUCTION AND OPERATIONAL FOLLOW-UP

In addition to the need for designers to be involved in the construction and operation of dams, in general, to confirm the design intent and assess the need for possible design changes, certain other requirements should be observed at embankment dams. Stability should be evaluated during and after construction using strength parameters from as-placed materials and observations of pore pressure and seepage if conditions warrant. Designers should inspect and review the performance of embankments during and after reservoir impoundment to detect and provide prompt remedial treatment for problems. While major emphasis is placed on initial impoundment, the surveillance should continue for the life of the project. As the state-of-the-art advances in analysis, material behavior, and methods of observation, deficiencies in embankments should be investigated and corrected. Collected experience information should be summarized and used to advance the state of the art further.

C. Management of Technical Activities – Construction

1. Introduction

This section of these guidelines outlines the construction technical activities that agency management should ensure are undertaken to obtain safe construction of dams. The principles and guidelines are prepared in a broad sense to ensure that the construction of a safe structure is the prime requisite.

A. CONSTRUCTION CONTRACTS

Construction contracts should be based on site conditions as interpreted at the time of contract award. All anticipated work on foundation cleanup, preparation, and treatment should be included as specified items. Contract provisions should require the contractor to submit advance notice of significant shift change to the construction engineer, to enable adequate inspection coverage of multishift operations.

B. CONSTRUCTION/DESIGN INTERFACE

Many aspects of construction directly overlap in design considerations. Reference is made below to numbered paragraphs in Section III.B. Management of Technical Activities-Site Investigation and Design, which concern such common interests:

3. Geotechnics
a. General
(1) Site Specifics
b. Exploration and Identification of Geotechnical Problems

c. Geotechnical Design
d. Foundation Treatment
e. Instrumentation
f. Inspection and Continuing Evaluation during Construction

4. Hydraulic Appurtenances
e. Control of Flows during Construction
5. Concrete Dams and Concrete Elements of Embankment Dams
a. Site Specific Design
b. Materials
c. Design of Structures

(1) Foundation
g. Instrumentation
h. Construction and Operational Follow-up

6. Embankment Dams
a. Site Specific Design
b. Materials
c. Design Constructability
d. Embankment Design

(3) Settlement and Cracking
(4) Seepage
e. Instrumentation
f. Construction and Operational Follow-up

2. Evaluation during Construction

Field personnel must be highly trained and experienced if the design principles and site conditions are to be understood, and a safe structure is to be constructed.

When differing site conditions (different from those anticipated) are encountered, construction supervisory forces must have the authority to suspend any or all portions of the work affected until the design engineers, with assistance as needed, can evaluate the condition and determine if design modification is required.

Construction milestones should be identified when the design engineers inspect the work and concur with the construction progress.

3. Orientation of Construction Engineers and Field Inspectors

Construction engineers need to be aware of design philosophies and assumptions as to site conditions and function of project structures. They must understand the designers' intent concerning special technical provisions in the specifications. Identified preconstruction activities should include the orientation of construction engineers to the site specificity of the design and the close communication requirements with all concerned engineering disciplines during the construction process. There should be periodic meetings between design and construction engineers to discuss upcoming construction activities for major projects. Also, during the initial stages of important construction activities, the construction engineers should request site inspections by the design engineers to ensure construction procedures are in accordance with design requirements.

Construction specifications, supplemental reports, and conferences to orient field personnel to the particular site, the features of the dam, and the designers' intent for construction should, as applicable, include the following:

A. DESIGN RELATED

(1) Design concepts. Explanation of philosophies and assumptions and the reasons for special requirements in the specifications to assure accomplishment of design intent.

(2) Construction sequence. Identification and explanation of the dates to which construction progress must conform to satisfy project requirements and the special sequences for construction activities required by design.

(3) Instrumentation systems. Description of the instrument types, their purpose, the procedures for installation of each instrument type, the method and time interval for reading each instrument, and the importance of prompt data transmission for analysis and feedback.

(4) Care and diversion of water. Description of the design features included to prevent and control flooding and turbidity and accomplish diversion and closure of the dam. This should also contain the design requirements for controlling normal flows through the work area to ensure that construction is always accomplished under dry conditions. Critical aspects of the construction schedule related to flood problems should be emphasized.

B. FOUNDATION

(1) Description. Discussion of the type of foundation conditions expected to exist, i.e., overburden, general rock description, formation weaknesses such as joints, shears, and faults, and acceptable foundation conditions.

(2) Excavation. Discussion of the depth and nature of materials expected to be encountered, the controls for dewatering and blasting, identification of critical areas, quantity estimates, and an acceptable foundation.

(3) Preparation. Review of the methods of rock foundation preparations such as cleaning; the use of wire mesh, mortar, shotcrete, or rock bolts; grouting and treatment of faults, shears, and joints; and subsequent exploration to ensure desired results. Review of methods of earth foundation preparation.

C. MATERIALS

(1) Materials from required excavation. Definition of acceptable and unacceptable properties of materials, the usage and the processing requirements if used, and identification of waste area locations.

(2) Other excavated materials. Identification of the location and amount of usable material, "based on current test data," available from all designated areas, including borrow pits. Review of the blasting methods that are expected to produce the desired rock quality and sizes. Discussion of the expected amounts of waste and the areas where borderline material may be used in lieu of waste, such as in berms or certain zones of the downstream shell of an earth fill dam.

(3) Embankment. Description of acceptable and unacceptable material properties, placement, and compaction procedures for each zone. Review of the required procedures for areas adjacent to abutments, around instruments, and at interfaces between zones or structures.

(4) Concrete and concrete materials. Identification of acceptable aggregate sources and review of mix designs, joint and surface treatment, finish requirements, form tolerances, and placement procedures. Cooling, as well as hot and cold weather protection requirements, should be defined.

D. CONSTRUCTION GENERAL

(1) Field control. Discussion of the quality assurance procedures required to control all phases of construction. Acceptable placement standards should be established for concrete, earth and rock materials, and embankments.

(2) Structural. Discussion of structural steel installation, reinforcing steel placement, anticipated problem areas, and specified treatment for such areas.

(3) Mechanical-electrical. Description of equipment installation requirements, special procedures, performance tests, protective coatings, and protection devices such as ground fault indicators.

(4) Environmental-Identification of those construction controls required to minimize environmental damage, comply with environmental and historic preservation regulations, and assure public involvement.

4. Construction Assurance

A. CONSTRUCTION PROCEDURES

Agency criteria must ensure that acceptable methods and procedures are specified and utilized to accomplish design requirements. At the same time, the design and construction organizations must maintain the flexibility necessary to modify the design, material requirements, and construction specifications as conditions dictate without altering the basic design intent.

B. CONSTRUCTION MATERIALS TESTING

A materials laboratory that is adequately staffed and equipped at the field construction office must be established to accomplish the on-site testing requirements set forth in the engineering considerations and instructions to field inspection personnel. Provisions should be made for a thorough and periodic review "above project level" of the construction materials testing procedures to assure their continued suitability. Periodic companion test samples of embankment material should be checked by a higher echelon for uniform test assurance.

C. QUALITY ASSURANCE

Adequate construction quality assurance systems and procedures must be established to ensure safe dam construction. By direct inspection and testing, the quality assurance system must guarantee that construction is accomplished in compliance with the contract plans and specifications. The quality assurance system must identify when site conditions require modification of the design to ensure the construction of a safe dam and must document the construction activities and test results. Daily inspector's reports, laboratory test data records, and photographs are the minimum mandatory documentation methods. General guidelines for documentation are given in section III.A.5.

As a part of the quality assurance program, the contractor should normally be required to submit various plans for approval not limited to but including, the following:

- Construction Schedule, Safety Program, Care and Diversion of Water (including pollution control)
- Fire Protection, Plant Layout (including haul roads)
- Environmental Measures, Equipment Inventory, Dewatering, Foundations and Borrow Areas, Excavation Sequence of Foundations and Borrow Areas, Drilling and Blasting Procedures, Concrete Placement, Restoration of Construction Area

D. Management of Technical Activities-Operation and Maintenance

This section of these guidelines outlines the technical activities for operation and maintenance, periodic inspection program, and emergency action planning that agency management should ensure are undertaken to obtain safe operation of dams.

1. Operation and Maintenance

A. GENERAL

The intent is to define practices that will ensure the safe operation of dams and reservoirs and to require a maintenance program that will provide timely repair of facilities. It is assumed that each federal agency is responsible for the proper operation and maintenance of dams owned by the agency or under its jurisdiction.

Operation and maintenance personnel should be selected based on their capability to acquire the knowledge needed to perform the many operation and maintenance functions. They should be trained for the associated duties at each specific project.

All operation and maintenance manuals should be up-to-date, and records of instructions, inspections, and equipment testing should be maintained, with copies given to those responsible for design and dam safety inspections. General guidelines for documentation are given in section III.A.5.

In the following sections, outlets or outlet gates refer to gates or valves on any outlets, such as sluices, conduits or tunnels, pumps, generating units, and infrequently operated plant intake and discharge gates. If the project has a navigation lock, emergency closure, and other infrequently operated equipment are also included.

B. OPERATING PROCEDURES

Written operating instructions should be prepared for the dam and its associated structures and equipment. The instructions should cover the functions of the dam and reservoir and describe procedures to follow during flood conditions to ensure dam safety – both the integrity of the dam and the safety of the people and environment downstream.

Reservoir operating rule curves should be available for each normal mode of operation and emergency conditions, including communication of these effects to the local public safety agencies.

An auxiliary power system, such as a gasoline or diesel-operated generator, is essential if the outlet and spillway gates and other dam facilities are electrically operated.

All spillway and outlet gates should include regularly scheduled testing. The tests should include the use of both the primary and the auxiliary power systems.

Project security is a matter of concern at all major dams. This includes preventing structural damage by vandals or saboteurs and unauthorized operation of outlet or spillway gates. In most cases, restricting public access is essential, and in some instances, armed guards may be necessary.

Public safety is of paramount importance at all dams and reservoirs. Specifically, public safety on the reservoir, in areas adjacent to the reservoir, and below the dam should be considered, particularly in recreational areas. Safety measures should include the identification of high watermarks to indicate past or probable reservoir levels and stream flows, posting safety instructions at highly visible and key locations, and providing audible safety warnings upstream of and below outlets as appropriate. It is crucial to inform the public of their risk and the actions to take (which direction to evacuate towards) to stay safe during a dam incident.

Communication should be maintained among affected governmental bodies and with the public to enhance the safety aspects of the operation of the dam and the safety of the people and environment downstream. Communication alternatives include written communications, radio, telephone, cell phone, television, newspapers, email, and the Internet.

C. MAINTENANCE PROCEDURES

Written instructions should provide information needed for proper maintenance of all water control facilities.

Specialists should prepare maintenance checklists indicating the maintenance procedures and protective measures for each structure and each piece of operating, communications, and power equipment, including existing monitoring systems. Special attention should be given to known problem areas.

Special instructions should be provided for checking operating facilities following floods, earthquakes, tornados, and other natural phenomena.

Maintenance procedures include preventive measures such as painting and lubrication and repairs to keep equipment in intended operating condition, and minor structural repairs such as maintaining drainage systems and correcting minor deterioration of concrete and embankment surfaces. The design staff should be apprised of any significant maintenance work.

2. Periodic Inspection Program

A. GENERAL

The purpose of a periodic inspection program is to verify the structural integrity of the dam and appurtenant structures, assuring the protection of human life and property. Periodic inspections disclose conditions that might disrupt the operation or threaten dam safety in time for them to be corrected. When such conditions are encountered, it is necessary to determine the adequacy of structures and facilities to continue serving the purposes for which they were designed and to identify the extent of deterioration as a basis for planning maintenance, repair, or rehabilitation.

The following general principles and guidelines for a periodic inspection program should be used by federal agencies responsible for the operation or regulation of dams.

All existing dams meeting agency hazard potential or risk criteria should have a safety evaluation based on current technical guidelines and criteria. New dams added to the inspection program should be planned, designed, and constructed in accordance with current technical criteria. Improvements in dam technology require that dams and appurtenant structures be reassessed to assure dam safety for more stringent design and materials criteria.

Periodic inspection of dams, reservoirs, and appurtenant structures involves important aspects other than dam safety; however, these guidelines encompass only dam safety issues. Each agency is responsible for assuring that the existing dams for which it is responsible are periodically inspected and that new dams are re-inspected initially upon completion of construction and periodically thereafter.

B. TYPES AND FREQUENCIES OF INSPECTIONS

The inspection types and intervals herein recommended are for general guidance in developing inspection programs for all federal dams. These guidelines do not preclude other inspections or more frequent inspections if deemed necessary, depending on the project history and the importance of the facility. For some projects, less frequent inspections may be permissible where hazard potential and structural integrity warrant such relaxation.

A formal inspection schedule should be maintained, which lists each feature to be inspected, frequency of inspection, date last inspected, date of last inspection report, maintenance record, description of repairs made, and date of next inspection. The schedule should also have a note on major alterations that are made.

Inspection personnel should be selected carefully, have qualifications commensurate with their assigned levels of responsibility, and receive training in the inspection procedures. Qualifications and training required for inspection personnel may vary with the complexity of the facility and the type of inspection.

Regulatory agencies should ensure that owners of dams under their jurisdiction establish inspection, monitoring, and periodic review programs similar to those of federal agencies.

(1) Informal Inspections. The purpose of informal inspections is to have practicable continuous surveillance of the dam. Employees at the project are to make frequent observations of the dam and appurtenances and operation and maintenance. They are to identify and report abnormal conditions in accordance with adequate instructions and guidance. A detailed checklist of items to be inspected may be provided. The instructions or checklists should be prepared specifically for the project by engineering and operating specialists. The personnel performing these inspections should be properly trained and made aware of the heavy reliance placed upon them and the great importance and absolute necessity of their careful inspection and reporting. Any unusual conditions that seem critical or dangerous should be reported immediately to the agency's inspection organization or those assigned inspection responsibility.

Particular attention should be given to detecting evidence of (or changes in) leakage, erosion, sinkholes, boils, seepage, slope instability, undue settlement, displacement, tilting, cracking, deterioration, and improper functioning of drains and relief wells.

(a) Frequency of informal inspections. Informal inspections should be scheduled by experienced, trained engineers as needed according to the dam’s size, importance, and potential for loss of life and damage to property or the environment. The schedule for inspection should be changed by the engineers as required to be responsive to observed changing conditions. Operating personnel should inspect the dam immediately after any unusual event, such as large floods, earthquakes, suspected sabotage, or vandalism.

(b) Qualifications of personnel for informal inspections. In most instances, informal inspections can be performed satisfactorily by dam tenders or operation and maintenance personnel not formally educated in the field of engineering or geology. Persons selected to make informal inspections must have sufficient training and experience to allow them to recognize abnormal conditions, must have demonstrated their ability to perform operation and maintenance functions, and must have an appreciation for the importance of their responsibilities. They must be provided with adequate written instructions on the performance of responsibilities and evaluated periodically to ensure that they understand and can perform the requirements. In addition, procedures for monitoring structural performance, observing the structure, its foundation, abutments, and appurtenances, and reporting abnormal conditions must be clearly defined and understood by these personnel.

(2) Intermediate Inspections. Intermediate inspections should include a thorough field inspection of the dam and appurtenant structures and a review of the records of inspections made at and following the last formal inspection. If unusual conditions are observed that are outside the expertise of these inspectors, arrangements should be made for inspections to be conducted by specialists.

(a) Frequency of intermediate inspections. Intermediate inspections should be performed preferably on an annual basis, but at least biennially, where there is a high probability that dam failure could result in loss of life or significant environmental damage. For other dams, intermediate inspections should be scheduled by responsible engineers based on the dam’s size, importance, and potential for damage to property or the environment.

(b) Qualifications of personnel for intermediate inspections. Intermediate inspections should be performed by technically qualified engineers experienced in the operation and maintenance of dams, and trained to recognize abnormal conditions. The inspectors should have access to and be familiar with all permanent documentation, especially the operation and maintenance histories for the dam, and should be directly responsible for and intimately familiar with the operating characteristics of the dam. The dam tender or operator should be a participant in these inspections.

(3) Formal and Special Inspections. A formal inspection is required periodically to verify the safety and integrity of the dam and appurtenant structures. Formal inspections should include a review to determine if the structures meet current accepted design criteria and practices. The inspection should include a review of all pertinent documents, including instrumentation, operation, and maintenance, and to the degree necessary, documentation on investigation, design, and construction. In making the detailed inspection of the dam's appurtenant structures and equipment, diving inspections of underwater structures affecting the integrity of the dam should be included. All formal inspections should be conducted by a team of highly trained specialists. To ensure that a dam and its appurtenant facilities are thoroughly inspected, checklists should be prepared to cover the condition of structural, electrical, and mechanical features. This inspection should also verify that operating instructions are available and understood, instrumentation is adequate, and data is

assessed to ensure structures are performing as designed, and there are emergency provisions for access to and communication with all project operating facilities.

(a) Frequency of formal inspections. Formal inspections should be made periodically at intervals not to exceed five years. Depending on past experience or the project history, some dams may require more frequent formal inspections.

(b) Frequency of special inspections. Special inspections should be performed immediately after the dam has passed unusually large floods and after the occurrence of significant earthquakes, sabotage, or other unusual events reported by operating personnel.

(c) Qualifications of personnel for formal and special inspections. Formal and special inspections should be conducted under the direction of licensed professional engineers experienced in the investigation, design, construction, and operation of dams. The inspection team should be chosen on a site-specific basis considering the nature and type of the dam. The inspection team should be comprised of individuals with specialized knowledge in structural, mechanical, electrical, hydraulic, embankment design, geology, concrete materials, and construction procedures. They must be capable of interpreting structural performance and relating conditions to current criteria and safety aspects. It is imperative that the inspection team adequately prepare for the inspections by reviewing and discussing all documents relative to the safety of the dam.

C. INSTRUMENTATION

Instrumentation or performance observation devices are used to supplement visual inspections in evaluating the performance and safety of dams. Careful examination of instrumentation data on a continuing basis may reveal a possible critical condition. Conversely, instrumentation may ensure that an observed condition is not serious and does not require immediate remedial measures.

(1) Adequacy of Instrumentation. Instrumentation to monitor structural and functional performance should be installed in dams where complex or unusual site conditions have been encountered or where there is a high probability that failure could result in loss of life or significant property/environmental damage. Instruments should be examined periodically for proper functioning. The adequacy of the installed instrumentation should be assessed from time to time by specialists to determine if it is sufficient to help evaluate the performance of the dam. When required, additional instrumentation should be installed to confirm suspicious trends or to explore an indicated potential adverse trend.

(2) Observation of Monitoring Devices. The instrumentation data should be collected by personnel trained specifically for the purpose, including training to recognize and immediately report to those responsible for inspections any anomalies in the readings or measurements. Performance observation data should be properly tabulated for recording purposes.

(a) Frequency of observations. The frequency of instrument readings should be established when the instrumentation system is designed to give a timely warning of possible adverse conditions. Whenever necessary, more frequent readings, sometimes as often as hourly, should be taken to monitor a suspected rapidly changing adverse condition. The frequency or number of readings may be reduced after the project has been in operation for an extended time, and performance observation data indicates that readings have stabilized.

(3) Data Analysis. Instrumentation data must be processed, reviewed, and assessed in a timely manner by specialists familiar with the design, construction, and operation of the project. Operation manuals and design information should be referred to in the evaluation of possible adverse trends. The performance observation data should be periodically analyzed to determine whether project structures are reacting as assumed in the design and to detect behavior conditions that may indicate the need for corrective action.

D. CORRECTION OF DEFICIENCIES

The inspection program could reveal those deficiencies or potential deficiencies which, if uncorrected, could eventually lead to failure of the dam or release of liquid-borne solids and industrial waste. Deficiencies may vary from emergency-type items, where immediate action is required, to non-emergency-type items, which must be corrected in a timely manner but do not present an immediate danger to the safety of the structure. In all cases corrective action should be made under the supervision of qualified personnel. Emergency action plans to be implemented when failure has occurred or is imminent are discussed in Section III.D.3. Emergency Action Planning.

(1) High Priority Corrective Action. High-priority corrective action is required for deficiencies that could result in the failure of the dam or the release of liquid-borne solids and industrial waste within a short period of time. Heads of agencies should have authorities, procedures, and levels of delegation for the transfer of funds and other emergency funding provisions to ensure they are adequate for accomplishing corrective actions in cases where time constraints will not permit allocation through the normal budget process. Procedures for seeking transfer authority beyond that delegated to the agency or requests for supplemental appropriations should also be reviewed to ensure such requests can be forwarded quickly and with all necessary supporting documentation to enable expeditious action by the President or the Congress.

(2) Non-emergency Corrective Action. Non-emergency corrective action is taken when there is no immediate threat to the safety or operation of the dam, nor any threat to life, property downstream, or the environment. Corrective action should be scheduled in advance of the fiscal year in which the work is to be done to allow time for planning, funding through the normal budgeting process, and arranging for special reservoir operations when required. Some of these deficiencies may be corrected through the regular operation and maintenance program discussed in Section III.D.1., Operation and Maintenance.

(3) Follow-up Action. Periodic inspection reports should continue to list previously identified deficiencies and any newly discovered deficiencies and show the status of corrective action. Appropriate inspection personnel should make frequent field examinations as long as the problem exists to see that all corrective measures are being completed. When deficiencies are not corrected

within a reasonable time, an investigation should be made to determine the reason for the delay, and appropriate management personnel should be notified of the findings.

E. DOCUMENTATION

Proper documentation of the dam's current condition and past performance is necessary to assess the adequacy of operation, maintenance, surveillance and proposed corrective actions. A complete record or history of the investigation, design, construction, operation, maintenance, surveillance, periodic inspections, modifications, repairs, and remedial work should be established and maintained so that relevant data relating to the dam is preserved and readily available for reference. This documentation should commence with the initial site investigation for the dam and continue through the life of the dam.

(1) Instrumentation. All instrumentation observation data and evaluations should be properly tabulated and documented for record purposes. Maintenance of instrumentation systems requires that details of the installation be available for a clear understanding of its functioning. A complete history of past repairs, testing, readings, and analyses should be available as pertinent reference data in the evaluation of current instrumentation data.

(2) Inspections. All inspection observations, especially as related to the safety of the dam and its containment system, should be documented. The extent and nature of inspection reports required for the informal, intermediate, formal, and special inspections will vary in proportion to the intensity of the inspection and the nature of the findings. Informal inspection reports may range from memoranda to supervisors which describe conditions and corrective actions to detailed accounts of an event or occurrence. Intermediate inspection reports may vary from similar memoranda or trip reports to more formal reports containing substantial records, details, and recommendations. Formal and special inspections require complete formal technical reports of all findings, corrective actions, and recommendations for permanent record and reference purposes to form a basis for major remedial work when required.

All reports should be in a self-explanatory form that permits their retention as permanent records and should carefully document times of inspections, inspection personnel, and findings of the inspection.

(3) Correction of Deficiencies. All deficiencies corrected due to the recommendations contained in periodic inspection reports should be fully documented in report form and made a part of the permanent project record. Alterations made to the facility due to changes in criteria to meet current practices or changes in dam technology should be fully documented, including as-built drawings.

3. Emergency Preparedness and Response Planning

A. GENERAL

It is intended that these guidelines for the design, construction, operation and maintenance, and inspection of dams will minimize the risk of future dam failures. Nevertheless, it is recognized that despite the adequacy of those guidelines and their implementation, the possibility of dam failures still exists. Even though the probability of such failures is small, preplanning is required to identify conditions that could lead to failure in order to initiate emergency measures to prevent such failures as a first priority and, if this is not possible, to minimize the extent and effects of such failure. The Federal Guidelines for Dam Safety: Emergency Action Planning for Dams (2013) provides guidance for “consistent emergency action planning to help save lives and reduce property damage in the areas that would be affected by dam failure or operation” (p. 3) [9]. The Emergency Operation Planning: Dam Incident Planning Guide (2019) [10] provides guidance for dam owners and operators on how to engage with emergency managers prior to an incident to ensure a well-coordinated response. An emergency action plan should include the following components:

- Actions the dam owner will take to moderate or alleviate a problem at the dam.
- Actions the dam owner will take, in coordination with emergency management authorities, to respond to incidents or emergencies related to the dam.
- Procedures dam owners will follow to issue early warning and notification messages to responsible downstream emergency management authorities.
- Inundation maps to help dam owners and emergency management authorities identify critical infrastructure and population-at-risk sites that may require protective measures, warning, and evacuation planning.
- Delineation of the responsibilities of all those involved in managing an incident or emergency and how the responsibilities should be coordinated.

Each federal agency that owns or is responsible for dams and each public or private owner of a federally regulated dam should evaluate the possible modes of failure of each dam, indicators or precursors of failure for each mode, possible emergency actions appropriate for each mode, and the effects on downstream areas of failure by each mode. In every case, the evaluation should recognize the possibility of sudden failure. It should provide a basis for such "worst case" emergency planning actions in terms of notification and evacuation procedures where failure would pose a significant danger to human life, property, and the environment. Plans should be prepared in a degree of detail commensurate with the hazard, and instructions should be provided to operators and attendants regarding the actions to be taken in an emergency. Planning should be coordinated with relevant state, local, and tribal officials who have a role or responsibility in safeguarding the population at risk. The owner should communicate risks associated with the operation and failure of the dam to enable those officials to develop jurisdictional plans, such as emergency operation plans, evacuation plans, recovery plans, and hazard mitigation plans.

Dam safety efforts must also include coordination with emergency managers in the four phases of emergency management: mitigation, preparedness, response, and recovery. Mitigation involves reducing the impacts of hazards or future emergencies by engaging in activities that prevent, reduce the chance of, or reduce damages from emergencies. Preparedness includes planning and preparation for response during emergencies. Response mobilizes actions in preparedness plans to save lives and minimize damage during emergencies. Recovery includes actions taken to restore an area to a normal or even safer situation following an emergency. The Department of Homeland Security, Dam Sector Crisis Management Handbook (2015) [11] and the Department of Homeland Security, National Response Framework (2016) [12] provide guidelines and best practices for assisting the dam owners and the dam safety community align with the emergency management community and the community at large.

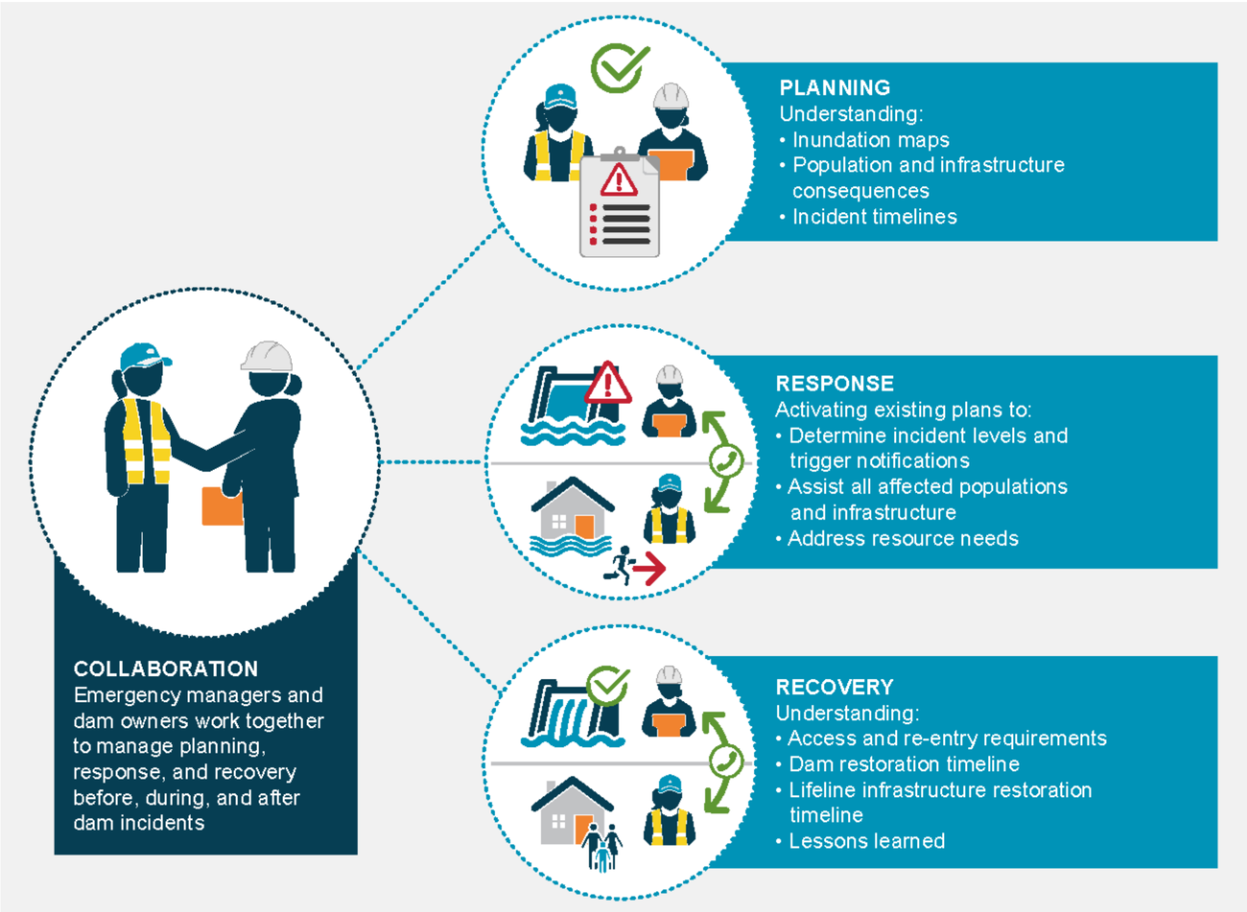

Figure 2. Collaboration between dam owners and emergency managers, federal, state, local, and tribal governments.

Coordination between all levels of government is important to help ensure consistency in guidance and response actions. For dam incidents, dam owners and operators must coordinate with state, local, tribal, and territory government agencies to ensure ongoing mutual understanding. During an incident, stakeholders should have a shared understanding of the situation at the dam, immediate and long-term impacts, and the incident timeline.

For additional guidance on developing EAPs, reference the Federal Guidelines for Emergency Action Planning for Dams (FEMA Publication No. P-64) and Emergency Operations Planning: Dam Incident Planning Guide.

E. Management of Technical Activities – Decommissioning

Decommissioning is the full or partial removal of an existing dam and its associated facilities or significant changes to the operations thereof. Reasons for decommissioning include dam safety issues, environmental issues, economic considerations, and requirements of lifecycle planning. It is imperative that dam safety is integrated throughout planning, design, removal, or other phases of the decommissioning process. Important factors include staging of dam removal, managing sediment within the reservoir, environmental impacts, and downstream impacts. This includes a detailed evaluation of any residual effects from partial dam removal.

In the case of industrial waste and tailings dams, full or partial removal of the dam may not be possible due to the nature of the materials stored. Additional waste or tailings will not be added to raise the level of the impounded solids. In most instances, the impounded waste will be covered with soil or other materials and graded to ensure surface runoff does not impound on the site. Containment of impounded materials, seepage control, and long-term stability are critical factors to be addressed during the reclamation of an industrial waste and tailings dam.

Appendix A. Federal Guidelines 1977 Memorandum (Original Text)

The authority for preparation of these guidelines is contained in a memorandum from President Carter dated April 23, 1977, which read as follows:

“MEMORANDUM FOR:

The Secretary of the Interior

The Secretary of Agriculture

The Secretary of the Army

The Director, Office of Management and Budget

The President’s Adviser on Science and Technology

The Chairman, Federal Power Commission

The Chairman, Tennessee Valley Authority

The Commissioner, U.S. Section, International Boundary and Water Commission

The safety of dams has been a principal concern of federal agencies that are involved with the various aspects of their planning, construction, operation and ultimate disposal. Events of the past several years have highlighted the need to review procedures and criteria that are being employed by these Agencies with the objective of ensuring that the most effective mechanisms are established to give the best assurance of dam safety possible within the limitations of the current state of knowledge available to the scientific and engineering communities. The safety of such projects should continue to be accorded the highest consideration, and it is the responsibility of the head of each Agency concerned to ensure the adequacy of their Agency's dam safety program.

1. Agency Dam Safety Reviews

The head of each federal agency responsible for, or involved with site selection, design, construction, certification or regulation, inspection, maintenance and operation, repair and ultimate disposition of dams shall immediately undertake a thorough review of practices which could affect the safety and integrity of these structures. This review will encompass all activities which can be controlled or regulated by the Agency.

Several aspects of the problem require special attention. In particular, the following items should be investigated: the means of inclusion of new technological methods into existing structures and procedures; the degree to which probabilistic or risk-based analysis is incorporated into the process of site selection, design, construction, and operation; the degree of reliance on in-house, Interagency, and outside expert interpretation of geologic data in site selection and design development; the effect on dam safety of earthquake or other earth movement hazards; the effects of cost-saving incentives on decisions both prior to and during construction; the procedures by which dam safety problems are identified, analyzed, and solved; the involvement of local communities in identifying, analyzing, and solving dam safety questions; and the major outstanding dam safety problems of the Agency.

2. Interagency Report and Proposed Guidelines

The Chairman of the Federal Coordinating Council for Science, Engineering and Technology (FCCSET) shall convene an ad hoc Interagency committee to coordinate dam safety programs, seeking consistency and commonality as appropriate, and providing recommendations as to the means of improving the effectiveness of the Government-wide dam safety effort. The Agency reviews described above should be provided to the FCCSET as a basis for the Interagency analysis on a timetable established by the FCCSET group as reasonable and consistent with the October 1, 1977 deadline for a final report. Representation on the FCCSET for this activity should be expanded to include other appropriate federal agencies or departments including, but not limited to, the Tennessee Valley Authority, the United States Section-International Boundary and Water Commission and the Federal Power Commission. The FCCSET effort will include preparation of proposed Federal dam safety guidelines for management procedures to ensure dam safety. FCCSET should report on all these items.

3. Independent Review Panel

In addition, the Director of the Office of Science and Technology Policy will arrange for review of Agency regulations, procedures and practices, and of the proposed federal dam safety guidelines, by a panel of recognized experts to be established immediately. The panel will obtain the views and advice of established organizations, professional societies, and others concerned with the safety of dams which are in any way affected by a federal role.

The review report thereon should be completed no later than October 1, 1978."

(signed) Jimmy Carter

The ad hoc Interagency committee called for in paragraph II of the memorandum was established by FCCSET, under the direction of the Office of Science and Technology Policy. The committee was represented by:

Office of Science and Technology Policy (Chairman)

Department of the Army

Department of Agriculture

Department of the Interior Nuclear Regulatory Commission (NRC)

U.S. Section, International Boundary and Water Commission (IBWC)

Federal Energy Regulatory Commission (FERC) (Formerly Federal Power Commission)

Tennessee Valley Authority (TVA)

The Nuclear Regulatory Commission was added to the dam Agencies addressed in the memorandum. Members of the ad hoc committee are listed in Appendix C.

Subcommittees were also established for the preparation of the proposed federal dam safety guidelines called for in paragraph II of the memorandum. These subcommittees and their task groups had representatives from all the Agencies with responsibilities for dams. Appendix D lists the members of the subcommittees and task groups and their Agencies.

In accordance with the Presidential memorandum, the participating Agencies submitted their reports on review of Agency management practices involving dam safety; the subcommittees submitted the proposed federal dam safety guidelines; and the ad hoc committee prepared the FCCSET report, Improving Federal Dam Safety, dated November 15, 1977. The report contains summaries of the Agency reports, and the subcommittee proposed guidelines and summary thereof; assesses the Agency reports; and makes recommendations for improvement of management practices for dam safety.

Pursuant to paragraph III of the President's memorandum, the Independent Review Panel was formed with specialists from the academic and private sectors concerned with dams. Members of the panel are listed in Appendix E. The panel reviewed the FCCSET and associated reports and proposed guidelines, and submitted a report, Federal Dam Safety, Report of the OSTP Independent Review Panel, December 6, 1978.

These guidelines were developed from the FCCSET report and its proposed guidelines, from Independent Review Panel recommendations, and with the cooperation of the panel.”

Appendix B. FCCSET ADHOC Interagency Committee Members

(Members List from Federal Guidelines for Dam Safety, 2004)

Phillip M. Smith (Chairman)
Assistant Director for Natural Resources and Commercial Services
Office of Science and Technology Policy
Washington, D.C.

William S. Bivins
Hydrology and Meteorology Branch Director of Site Safety and Environmental Analysis
Nuclear Regulatory Commission
Washington, D.C.

Neil F. Bogner
Director, Engineering Division Soil Conservation Service
Department of Agriculture
Washington, D.C.

George L. Buchanan
Chief, Civil Engineering and Design Branch
Division of Engineering Design
Office of Engineering Design and Construction
Tennessee Valley Authority Knoxville, Tennessee

Donald Dillon
Deputy for Policy Planning and Legislative Analysis
Department of the Army
Washington, D.C.

Joseph Friedkin
Commissioner, U.S. Section International Boundary and Water Commission
Washington, D.C.

Gary Wicks
Deputy Assistant Secretary for Land and Water Resources
Department of the Interior
Washington, D.C.

Gerald R. Wilson, Jr.
Chief, Project Analysis Branch Licensed Projects Division
Federal Energy Regulatory Commission
Washington, D.C.
Consultant to OSTP

Bruce A. Tschantz
Department of Civil Engineering
University of Tennessee
Knoxville, Tennessee

Appendix C. Federal Guidelines Historical Background

Throughout history, dams built to store water have occasionally failed and discharged stored waters to inflict incalculable damage in the loss of lives and great damage to property. Failures have involved dams built without application of engineering principles but have also involved dams built to accepted engineering standards of design and construction. Aging infrastructure and increase in extreme weather events have also increased the number of dam incidents. The technology of dams has improved with the increased knowledge of design principles and of the characteristics of foundation and dam materials. It is generally agreed that safe dams can be built with the proper application of current technology and only as long as the dams are properly maintained and inspected. It is the intent of these guidelines to outline management practices that will help to ensure the use of the best current technology in the design, construction, and operation of new dams, in the safety evaluation of existing dams, and in emergency management.

In 1929, following the failure of the St. Francis Dam, California enacted a dam safety program. Subsequently, other dam failures causing loss of life and property have prompted additional legislation on state and national levels.

In 1972, Congress enacted Public Law 92-367, known as the “National Dam Inspection Act” [1]. The Secretary of the Army was authorized to inspect non-federal dams in the nation meeting the size and storage limitations of the Act to evaluate their safety; report inspection results to the states and advise the states on actions needed to ensure dam safety; report to the Congress the information given to the states; prepare a national inventory of dams; and make recommendations to the Congress “for a comprehensive national program for the inspection and regulation for safety purposes of dams of the nation.” Responsibilities under the law were delegated to the U.S. Army Corps of Engineers. The activities performed under the program consisted of an inventory of dams; a survey of each state and federal agency's capabilities, practices, and regulations regarding the design, construction, operation and maintenance of dams; development of guidelines for inspection and evaluation of dam safety; and formulation of recommendations for a comprehensive national program. In November 1976, a report on these activities and proposed legislation to implement a federal dam safety program were transmitted to Congress, but a lack of funding prevented the execution of the detailed dam inspections.

The failure (during initial filling in 1976) of the Teton Dam in Idaho, a federal earth embankment dam over 300 feet high, reactivated intense public and Governmental concern for dam safety. Congressional and federal agency investigations were made into this disaster and the entire question of dam safety, and new federal legislation for dam safety was initiated in the Congress.

Appendix D. Interagency Guidelines Subcommittee Members

(Members List from Federal Guidelines for Dam Safety, 2004)

Site Investigation and Design (SID) Subcommittee Members

George L. Buchanan, TVA, Chairman David C. Ralston, SCS Ernest L. Dodson, Army-Corps Robert A. Wilson, BLM William D. Woodbury, BOM Geotechnical James H. Coulson, TVA, Chairman Jake Redlinger, Army-Corps James Legas, BoR Robert Peterson, MESA Henry W. Coulter, USGS Harry Thomas, FERC E.T. Scherich, BoR Walter L. West, FWS Robert Fujimoto, MESA Henry W. Coulter, USGS Gerald R. Wilson, Jr., FERC William S. Bivins, NRC Hydraulics Svein Vigander, TVA, Chairman Sam Powell, Army-Corps Edwin C. Rossilon, BoR Robert F. McVain, FWS Gus Center, MESA SID Task Group Members Concrete Dams Hydrology Vernon Hagan, Army-Corps, Chairman Norman Miller, SCS Fred A. Bartle, BoR Dennis Tarmay, FERC Ed Hawkins, NRC Donald W. Newton, TVA Seismology Jim Divine, USGS, Chairman Al Geiger, SCS Ellis Krimitzsky, Army-Corps Andy Vikone, BoR John Kellerher, NRC Donald J. Reinhold, TVA Glenn Tarbox, BoR, Chairman Keith O'Donnell, Army-Corps Billy F. Horton, FWS Kuo-Hua Yang, FERC Earl L. Spearman, TVA Embankment Dams Robert L. James, Army-Corps, Chairman David C. Ralston, SCS Edwin W. Gray, BoR Dan Kealy, BOM Constantine Tjoumas, FERC Samuel D. Stone, TVA Construction (CON) Subcommittee Members Seismic Engineering Richard W. Kramer, BoR, Chairman Donald A. Giampaoli, BoR, Chairman A.G. Franklin, Army-Corps Jim Talbot, SCS Richard McMullen, NRC Thomas J. Abraham, TVA Neil F. Bogner, SCS Joseph M. Nelson, Army-Corps William R. Groseclose, BoR Walter L. West, FWS Herman E. Smalling, TVA CON Task Group Members Inspection Joseph M. Nelson, Army-Corps, Chairman William R. Groseclose, BoR Herman E. Smalling, TVA Contractor Quality Control Neil F. Bogner, SCS, Chairman Joseph M. Nelson, Army-Corps Walter L. West, FWS Staffing Walter L. West, FWS, Chairman Joseph M. Nelson, Army-Corps Herman E. Smalling, TVA Standardization of Materials Testing William R. Groseclose, BoR, Chairman Neil F. Bogner, SCS Dess L. Chapelear, BoR Identification of Acceptable Construction Methods Herman E. Smalling, TVA, Chairman Joseph M. Nelson, Army-Corps Dess L. Chapelear, BoR Construction Documentation Neil F. Bogner, SCS, Chairman Dess L. Chapelear, BoR Herman E. Smalling, TVA Operation and Maintenance (O&M) Subcommittee Members Gerald R. Wilson, Jr., FERC, Chairman James A. Wolfe, FS William F. Britnell, Army-Corps Philip Corke, BIA Roy H. Boyd, BoR S. Anthony Stanin, MESA Sears Y. Coker, FERC Desloge Brown, Initial Chairman (ret'd) T.R. Martin, IBWC Harold C. Buttrey, TVA O&M Task Group Members O&M Procedures Roy H. Boyd, BoR, Chairman Paul E. Nylander, SCS William F. Britnell, Army-Corps Philip Corke, BIA S. Anthony Stanin, MESA Ronald A. Lesniak, FERC T.R. Martin, IBWC Meigs Brewer, Jr., TVA Periodic Inspection Program Harold C. Buttrey, TVA, Chairman James A. Wolfe, FS Ralph H. Fike, Army-Corps S.J. Occhipiati, FERC B.A. Pritchard, BoR Emergency Action Planning Sears Y. Coker, FERC, Chairman James E. Shanks, Army-Corps Edgar C. Roper, BoR Robert A. Shelton, TVA Legend Army-Department of the Army BIA-

Bureau of Indian Affairs BLM-Bureau of Land Management BOM-Bureau of Mines BoR-Bureau of Reclamation Corps-Corps of Engineers DOI-Department of the Interior FERC-Federal Energy Regulatory Commission FS-Forest Service FWS-Fish and Wildlife Service IBWC-International Boundary and Water Commission MESA-Mining Enforcement and Safety Administration NRC-Nuclear Regulatory Commission SCS-Soil Conservation Service TVA-Tennessee Valley Authority USDA-Department of Agriculture USGS-United States Geological Survey

Appendix E. Office of Science and Technology Policy (OSTP) Independent Review Panel Members

(Members List from Federal Guidelines for Dam Safety, 2004)

Professor Frank E. Perkins, Chairman Department of Civil Engineering Massachusetts Institute of Technology Cambridge, Massachusetts Mr. Gordon W. Prescott Department of Geosciences Purdue University W. Lafayette, Indiana Professor Clarence R. Allen Department of Geology California Institute of Technology Pasadena, California Professor H. Bolton Seed Department of Civil Engineering University of California, Berkeley Berkeley, California Dr. Elio D'Appalonia Professor Erik H. Vanmarcke D'Appalonia Consulting Engineers, Inc. Department of Civil Engineering Pittsburgh, Pennsylvania Massachusetts Institute of Technology Cambridge, Massachusetts Mr. Gerald W. Farquhar, Attorney Ford, Farquhar, Kornblat & O'Neill Consultant to OSTP Washington, D.C. Professor Bruce A. Tschantz Mr. H. Keith Honeker Department of Civil Engineering Kentucky Department of Natural University of Tennessee Resources and Environmental Protection Knoxville, Tennessee Frankfort, Kentucky Professor L. Douglas James, Director Utah Water Research Laboratory Utah State University Logan, Utah Mr. Eric B. Kollguard International Engineering Company San Francisco, California Mr. Ray E. Lineley Hydrocomp, Inc. Palo Alto, California

Appendix F. Acknowledgements

The authority for preparation of these guidelines is given in the memorandum reproduced in Appendix A. They were prepared by an Interagency guidelines task group composed of the Chairmen of the subcommittees identified in Appendix C. Specific sections preparation assignments were:

Section I. SID Chairman, George L. Buchanan, TVA

Section II, CON Chairman, Donald A. Giampaoli, BoR, and O&M Chairman, Gerald R. Wilson, FERC, with the cooperation of L. Douglas James, representative of the Independent Review Panel (Appendix E) to the guidelines task group, and Bruce A. Tschantz, consultant to OSTP and advisor to the task group.

Section III A. and III.B. SID Chairman

Section III.C. CON Chairman

Section III.D. O&M Chairman

The Chairmen were assisted by their subcommittee and task groups members (listed in Appendix D).

Reviews were made by subcommittee members and by representatives of the Agencies other than the preparing Agency and by L. Douglas James of the Independent Review Panel. Major contributory reviews were made by representatives of the major dam building Agencies, BoR, Corps, SCS, and TVA, and the Independent Review Panel member.

Editing and assembly of the final working draft for submittal to FCCSET were handled by the SID Chairman (TVA). Oliver H. Raine of the SID Chairman’s engineering staff assisted in the preparation and review of various portions of these guidelines and in the editing and assembly of the working draft.

Appendix G. Federal Guidelines 2019 Update Members

James Demby, FEMA
Bill Allerton, FERC, Retired
Doug Boyer, FERC
Erin Williams, FERC
Steve Durgin, NRCS, Retired
Laura Groce, TVA
George Kelley, TVA, Retired
David Paul, USACE, Retired
Barb Schuelke, USACE, Retired
Travis Tutka, USACE
Randy Behm, USACE
Steven Matheny, USACE
Brian Becker, USBR
Betty Dinneen, USBR
Beth Boaz, USBR, Retired
Cliff Denning, USFS, Retired
Mark Baker, NPS, Retired
Patrick Kelly, EPA
Stanley Michalek, DOL
John Wolfhope, USSD
Jose Lara, State of California

Appendix H. References

[1] National Dam Inspection Act of 1972 (P.L. 92-367, 33 U.S.C. § 467), 8 August 1972.

[2] Federal Emergency Management Agency. 2005. Federal Guidelines for Dam Safety: Hazard Potential Classification.

[3] Federal Emergency Management Agency. 2005. Federal Guidelines for Dam Safety: Glossary of Terms (2004).

[4] Federal Emergency Management Agency. 2015. Federal Guidelines for Dam Safety Risk Management.

[5] Water Resources Development Act of 1996 (P.L. 104-303, Section 215).

[6] National Dam Inspection Act of 1972 (P.L. 92-367, 33 U.S.C. § 467), 8 August 1972.

[7] Federal Emergency Management Agency. 2013. Federal Guidelines for Dam Safety - Selecting and Accommodating Inflow Design Floods for Dams.

[8] Federal Emergency Management Agency. 2005. Federal Guidelines for Dam Safety: Earthquake Analysis and Design of Dams.

[9] Federal Emergency Management Agency. 2013. Federal Guidelines for Dam Safety: Emergency Action Planning for Dams.

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